D.PHIL. THESIS IN ECONOMICS

An Analysis of the Relationship between Monetary Policy, Business Cycles and Financial Stability

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Introduction

The recent global financial crisis has once again urged policymakers to rethink macroeconomic policies.[1] The key lesson learnt is that price stability alone is not sufficient to achieve macroeconomic stability and sustainable growth. Policymakers are advocated to be vigilant on financial stability risks since they, if excessive, can precipitate into financial and economic crises. In this regard, two important policy questions follow. First, what policy instruments should policymakers employ to handle risks towards financial stability? The dominant view before the crisis is that financial stability is to be achieved by prudential regulation and supervision, while monetary policy focuses solely on price stability. This coincides with Tinbergen Principle, which suggests one policy instrument for each policy objective. Second, how should macroeconomic models be developed to address financial-stability issues? Macroeconomic models seldom incorporate the notion of risk, perhaps due to its elusive nature. However, recent advancements of macroeconomic modelling have focused more attention on introducing financial factors, particularly the banking sector, to study their role in economic fluctuations. These should provide a foundation for theoretical analysis on financial stability going forward. My thesis will try to shed light on these two issues by exploring the relationship between monetary policy, business cycles and financial stability. I hasten to add that the analysis of financial stability also includes prudential regulation which serves as its key policy instrument. The thesis will be organized into three chapters.

The first chapter explores the nexus between monetary policy and financial stability. More specifically, the aspect of financial stability I emphasise is "bank risk-

[1] Word count: 77,843 words (excluding references)

taking". Borio and Zhu (2012) describe their relationship as the missing link in the study of monetary policy transmission. However, it is widely believed that continuously loose monetary policy, following the dot-com crisis, incentivised banks to search for yield, and so to accumulate excessive risk on their portfolios. This view has received immense support from the theoretical literature. Borio and Zhu (2012) argue that monetary policy can affect banks' risk perception and tolerance, and hence on the degree of portfolio riskiness, and price and non-price terms of funding extensions. One potential channel is through the effects of monetary policy on valuation, income and cash flows, which in turn affect banks' appetite for risk. Rajan (2005), meanwhile, attributes higher bank risk-taking following monetary easing to a search-for-yield incentive. He claims that monetary easing induces low returns on risk-free assets and hence encourages investment managers to search for higher-yield risky investments in order to achieve the target rate of returns. Furthermore, Dell'Ariccia et al. (2010) argue that low interest rates induce banks to increase their leverage. As higher leverage implies lower skin-in-the-game, banks therefore assume more risk on their portfolio.

Despite vast theoretical support, whether "the bank risk-taking channel" exists is indeed an empirical question. The empirical literature also tends to support the notion that expansionary monetary policy results in higher bank risk-taking. However, the studies are mainly conducted in the case of developed countries, particularly the US and the EU. Jiménez et al. (2014), in the case of Spain, find that low interest rates induce banks to grant new loans to borrowers with worse credit histories. Meanwhile, Maddaloni and Peydro (2011) study the US and other 12 countries within the EU, and suggest that low monetary policy rates encourage banks to soften their lending standards. To make a contribution, in the first chapter, I explore evidence of the risk-taking channel in the case of Asia. Most countries in the sample that I will consider have a bank-based financial system, implying a less modern financial industry as compared with the US and the EU. During the sub-prime crisis, Asian banks have proven to be resilient, being one factor supporting the fast, solid recovery of the real sector. Therefore, it is interesting to investigate "whether" the risk-taking channel still exists in a more conservative (Asian) banking environment. Moreover, given several theoretical propositions, the existing literature has not made any attempt to shed light on "how" the risk-taking channel actually works. I also intend to fill the gap in this area.

The second chapter still focuses on bank risk-taking but takes a broader perspective by allowing banks' appetite for risk to be influenced by a wide range of factors. There is a consensus that prior to the crisis, banks and shadow banks increased considerably their risk-taking. Evidence shows that they took excessive leverage to expand their balance sheet. More importantly, they tended to grant loans to riskier borrowers who were once unsuccessful in their loans application. Therefore, the aim of this chapter is to construct a model suitable for analysing bank risk-taking and to assess macroeconomic policies in mitigating risk-taking. The findings should be beneficial in clarifying the issues outlined at the beginning.

Modelling bank risk-taking in the macroeconomic model poses a challenge. Standard dynamic stochastic general equilibrium (DSGE) macroeconomic models (as appeared in Christiano et al. (2005) and Smets and Wouters (2007)), which incorporate a number of frictions and shocks, assume away financial factors. Those models, therefore, cannot capture the interactions between the real and financial sectors, let alone financial-stability analysis. The seminal papers of Bernanke et al. (1999) and Kiyotaki and Moore (1997) attempt to introduce financial frictions into macroeconomic models. The former assumes asymmetric information between borrowers and lenders, which produces the external finance premium that is determined by borrowers balance sheet conditions. The latter postulates a borrowing constraint linked to the expected value of the collateral. However, a drawback of those two models is that there is no role for banks, since their focus is on borrowers' financial conditions.

The recent crisis has shown that the liquidity and insolvency problems in the banking sector can precipitate into an economic crisis. Therefore, there has been a renewed interest in incorporating banks into DSGE models. Gertler and Kiyotaki (2010), for example, introduce moral-hazard incentives for banks to abscond away with part of their assets. They show that negative capital quality shocks result in lower bank net worth, causing banks to extend less credit. Moreover, their model also includes the interbank market so as to capture the modern financial crisis, where liquidity problems in the wholesale funding market are important. Christiano et al. (2010) also reflect on the recent crisis by modelling liquidity (i.e., deposits) production functions and introducing funding technology shocks. In their model, bank funding condition is a major determinant of loans supply decisions.[2] However, their framework is not suitable for risk-taking analysis since their focus is on the quantity, rather than the quality of bank balance sheet. Therefore, risk cannot be measured.

After the crisis, there are a handful of articles that attempt to study bank risk-taking in the macroeconomic model. Gertler et al. (2012) attribute higher bank risk-taking to the improved risk perception and the moral hazard problem arising from the Central Bank's implicit role as lender of last resort. They show that whenever banks engage in high risk, the economy becomes more susceptible to negative shocks. Meanwhile, in Collard et al. (2017), it is limited liability and deposit insurance that cause excessive bank risk-taking. My second chapter deviates from standard practices, which usually rely on moral hazard incentives to motivate bank risk-taking, and proposes new arguments. However, I claim that my approach is more aligned with the aforementioned definition of the risk-taking channel which emphasises bank risk perception and tolerance. In particular, bank risk-taking will be attributed to

[2] See Gertler and Karadi (2011), Goodfriend and McCallum (2007) and Meh and Moran (2010) for more DSGE models that incorporate banks

time-varying default risk of the risky borrowers and capital adequacy ratios of the banks, which can in turn be influenced by standard macroeconomic shocks.

The second chapter also intends to assess the effectiveness of macroeconomic policies in preventing high bank risk-taking. These include monetary policy and macroprudential regulation. A long-standing debate over whether monetary policy should "lean against the wind" or "mop up after" has yet to reach the conclusion. The dominant view among academics and policymakers, before the recent crisis occurred, was that monetary policy should not respond to asset price bubbles and credit boom.[3] The supporting arguments range from the difficulty to identify bubbles in a timely manner to the fact that monetary policy is a blunt instrument. Also, the cost of financial crisis may be small. However, the recent crisis has proven that the last argument is incorrect and urged policymakers to step in to deal with risks towards financial stability before the crisis occurs.

While the debate over the role of monetary policy remains unsettled, there is an agreement that macroprudential regulation is used to address systemic risk. This in turn reduces the probability and magnitude of the financial crisis, while improving the resilience of the financial system. Examples of the regulation include counter-cyclical capital buffers, caps on loan-to-value (LTV) ratio, minimum requirement for the leverage ratio, or dynamic loss provisioning. They complement microprudential regulation which ensures the resilience of individual financial institutions but does not guarantee stability of the whole financial system. Over the past decade, a number of articles[4] assess the effectiveness of these macroprudential regulation measures. They tend to find that the measures can help achieve the optimal allocation, improve the welfare and reduce macroeconomic volatilities. However, evidence remains limited with respect to their effectiveness in leaning against risk-taking.

Finally, the third chapter focuses on post-crisis aspects, emphasising the spillover

[3] See, for example, Bernanke and Gertler (2001).

[4] See, for example, Roger and Vlček (2011), Lambertini et al. (2013) and Angelini et al. (2014).

effects of shocks originating in the housing and financial market on the real economy. A series of articles by Atif Mian and Amir Sufi study microeconomic data and highlight the problems of excessive household leverage and house price boom during the run-up to the crisis. Mian and Sufi (2009) and Mian and Sufi (2011) suggest that the presence of securitisation is a major cause of a more relaxed mortgage extension. This in turn boosted house prices, which then raised household leverage further through home equity-based borrowing. They also find that those who benefited the most from these circumstances are borrowers with low credit score and high credit card utilisation. Imbalances in the housing market then precipitated into an economic crisis. Mian and Sufi (2010) suggest that rising household leverage predicts subsequent increase in mortgage defaults and the fall in durable consumption during the US recession of 2007 to 2009. From an international perspective, Glick and Lansing (2010) also find that countries that experienced large increase in household leverage are those who faced large subsequent decline in consumption. All these arguments have motivated me to focus on developments within and shocks originating from the housing market.

My theoretical model in this chapter will therefore incorporate the possibility of mortgage default into the framework with housing and banks. As in Brunnermeier (2008), I consider that a rise in mortgage defaults is a key trigger of the subsequent financial turmoil and economic downturn. Increased defaults adversely affect bank profitability, which in turn results in a more constrained credit extension. A handful of articles precedes my paper in introducing mortgage default into the DSGE framework. They include Forlati and Lambertini (2011), Quint and Rabanal (2014), Clerc et al. (2015) and Ferrante (2015). I make a contribution to the literature by studying shock propagation within the banking sector while introducing macroprudential regulation measures to improve economic stability and agents welfare. The model with mortgages allows me to explore the effectiveness of certain prudential measures including LTV limits or state-contingent LTV ratio.

This chapter is related to articles that study shocks originating in the financial sector. Jermann and Quadrini (2012) show that their proposed financial shocks, which directly affect the tightness of the borrowing constraint, are significant in explaining business cycle fluctuations as compared with standard productivity shocks. Meanwhile, Gerali et al. (2010), using the model with monopolistically competitive banks, introduce a number of financial shocks. These include shocks to bank capital and to the elasticity of substitutions of loans and deposits–the latter directly matters for credit spreads. Using historical decomposition, they find that those shocks can explain the largest portion of the output decline during the recent recession in the euro area. I proceed, in this chapter, by introducing shocks that are potentially relevant in generating economic downturn during the recent crisis. At least, they should be able to capture a surge in mortgage default and loans risk premium that was a key symptom of the crisis.

Chapter 1

An Empirical Analysis of the Bank Risk-Taking Channel of the Monetary Policy Transmission Mechanism in Asia

Abstract

The study addresses what used to be called the "missing link" of the monetary policy transmission mechanism (Borio and Zhu, 2012): the bank risk-taking channel. In particular, I investigate whether and how expansionary monetary policy contributes to bank risk-taking, in the case of Asia. The Bankscope Database has allowed me to conduct a bank-year panel study covering 432 banks in 9 Asian countries. I achieve an identification of the risk-taking channel mainly by (1) controlling for the adjustments of bank balance sheets consistent with other traditional transmission channels, and (2) testing for cross-sectional differences in how banks respond to monetary easing. A number of strategies have also been employed to counter monetary policy endogeneity. Using the dataset for 2000-2011, my bank-panel model finds evidence supporting the existence of the bank risk-taking channel, which is more pronounced for banks listed on the stock market, where incentives for bank managers to take excessive risks should be more relevant. I also report a new finding: that banks increase risk on their portfolio mainly through origination of corporate loans. More importantly, I find no evidence that bank risk-taking is accompanied by an increase in leverage, as suggested by the theory. The

findings have important policy implications for both monetary-policy makers and financial regulators.

1.1 Introduction

The recent sub-prime crisis has focused attention on the relationship between monetary policy and bank risk-taking in both academic and policy debates. It is widely believed that continuously loose monetary policy, following the dot-com crisis, incentivised banks to search for yield, and so to accumulate excessive risk on their portfolios. Massive risk was revealed when banks suffered asset losses, triggering prolonged and widespread impacts on the global economy. However, in the view of monetary policymakers, Altunbas et al. (2010) argue that financial stability objective is of minor importance given a move towards strict inflation targeting and the belief that financial developments foster efficient risk-sharing. Indeed, the absence of solid study prior to the crisis may also explain the lack of attention to the effects of monetary policy on bank sector stability (Gambacorta, 2009). Therefore, my thesis aims to develop a better understanding of the bank risk-taking channel, or the conjecture that expansionary monetary policy contributes to incentives for banks to take more risk, with particular emphasis on the case of Asia. This, in turn, is crucial in creating a complete picture of the monetary policy transmission mechanism.

Until the mid-2000s, both the theoretical and empirical literature fail to explore a certain "monetary policy and bank risk-taking" nexus. Borio and Zhu (2012) describe the channel as a "missing link" in the study of monetary policy transmission. In particular, macroeconomic models seldom incorporate the notion of risk, assuming away time-varying risk appetite (Dell'Ariccia et al., 2010). The bank lending literature focuses on the quantity, rather than quality, of bank credit. Meanwhile, the study of the balance sheet channel focuses on borrowers' riskiness, rather than the risk appetite of financial intermediaries, which is at the heart of the risk-taking channel. Only after the crisis unfolded did literature begin to investigate the consequences of monetary policy on bank risk-taking. The dominant view among a handful of studies supports the existence of the channel (Rajan, 2005; Jiménez et al., 2014 among others). Supporting empirical evidence has already been found in the case of US and many developed countries.

Although Asia is not the focus of the recent crisis, an investigation of the risk-taking channel in this region remains of importance. Twenty years ago, a few countries in Asia experienced a twin currency and banking crisis. The Asian banking sector has undergone massive reform and restructuring over the past decade, as documented by Adams (2008). The health of the banking sector has substantially improved. Bank regulation and supervision have been upgraded, in line with international standards. During the sub-prime crisis, Asian banks have proven to be resilient, being one factor supporting the fast, solid recovery of the real sector. Nevertheless, there is no reason to invalidate the link between monetary policy and financial stability. In particular, Asian banking sector is not insulated from the force of financial innovations, globalization, and competition. Given that the banking sector is predominant source of finance for households and businesses in Asia, the failure to address uprising risk in it can contribute to significant real economic consequences. More importantly, as Asia has become increasingly important driving force of the global economy, its economic and financial stability is now a global concern.

My study complements the bank risk-taking literature by exploring the research question of **"whether" and "how" expansionary monetary policy contributes to bank risk-taking, in the case of Asia during the period 2000-2011**. To my knowledge, it is among the first studies of the bank risk-taking channel in this region. Limited availability of data, and the fact that Asian banks are not at the core of the recent crisis, could explain absence of empirical works for this region. I relied on the Bankscope database, which allows me to conduct an international study of 9 Asian countries, covering 432 banks. The dataset of individual banks' balance sheets enabled me to construct a simple measure of bank risk-taking. As usual in empirical works in the area of monetary transmission, my estimations are subject to misidentification problems. By observing that riskiness of bank portfolio goes up after monetary easing, this cannot be conveniently interpreted as the working of the bank risk-taking channel, since it also admits other interpretations based on traditional transmission channels.

The major contribution of this thesis to the literature is that I propose two new empirical strategies to counter the misidentification problems. Firstly, I use asset size as a control for banks' balance sheet adjustments consistent with the credit channel. I postulate that the bank risk-taking channel offers unique balance sheet adjustments which can be identified by holding asset size fixed. Secondly, I investigate cross-sectional differences in the risk-taking responses to monetary policy shocks across banks. To identify the risk-taking channel, I hypothesise that banks listed in the stock market, whose bank managers have more incentives for risk-taking, should be more responsive to a change in monetary policy. Apart from misidentification, I am also aware of the potential endogeneity of monetary policy since this may correlate with variables that are relevant to bank risk-taking behavior. I therefore employ a few steps to deal with the problem, ranging from using an instrumental-variable method to directly recovering exogenous monetary policy components.

I employ the ratio of risky assets to total assets as a risk-taking measure. The benchmark regression has variables entered the model in level form, where I find evidence supporting the existence of the bank risk-taking channel. In other words, low interest rates significantly contribute to bank risk-taking. This is found to be the case for only listed banks, while unlisted banks do not significantly respond to changes in monetary policy. The results are robust to the introduction of bank-level and macroeconomic controls. My GMM specification, which accounts for the dynamic nature of bank risk-taking and the potential endogeneity of monetary policy indicator, confirms the previous finding. Additionally, I find that "too low" interest rates, proxied by negative Taylor residuals, can be detrimental to financial stability. To ensure that the relationship between monetary policy and risk-taking is not driven by spurious common trends in those variables, I also conduct regressions in first differences. The results show weaker evidence of the risk-taking channel. Monetary policy has a significant effect on bank risk-taking with one-period lag. However, I still find that listed banks are more responsive in risk-taking as a result of monetary easing. The result that monetary policy that is too expansionary as compared to economic fundamentals induces banks to take excessive risk is also confirmed.

Apart from delving into the main question of "whether" monetary easing influences bank risk-taking, I empirically explore further "how" the risk-taking channel works, a question which the previous literature has not made any attempt to answer so far. To make a contribution, I investigate which types of risky assets banks actually invest in when they are searching for yield following monetary easing. I report that banks increase risk on their portfolios mainly through origination of corporate loans. In addition, I test the hypothesis of whether bank risk-taking is accompanied by an increase in leverage, as predicted by the theory. The results show no evidence of excessive leverage increasing banks' incentives to take risk. In other words, I reject the "leverage channel," which is proposed as one of the mechanisms that the risk-taking channel works through, at least in the Asian case. Both estimations above are new to the literature, and set the stage for further theoretical and empirical analysis. In addition, I find that, among listed banks, the risk-taking responses towards monetary easing differ across bank types and banking sectors.

Nevertheless, it is important to note that the findings above cannot be used to conclude whether the increase in bank risk-taking, following monetary easing, is socially excessive or not. It can be that such increase is welfare-improving since risk-taking may be initially constrained. Or, despite the fact that bank risk-taking may exceed the socially-desired level, it is difficult to judge whether it is excessive such that it will lead to adverse consequences going forward. What we can learn from the results above is that banks risk exposure rises in the event of low interest rates, where I interpret as an evidence of the bank risk-taking channel.

The thesis is organised as follows. In the next section, I review the existing literature in the area. Section 3 describes the dataset and identification strategies I employ, as well as the model specifications. I separate the estimation and results into two sections. Section 4 covers the main estimation and results on "whether" monetary policy matters for bank risk-taking, featuring both static and dynamic models. Then, in section 5, I additionally explore the question of "how" the risk-taking channel works. The thesis ends with a conclusion and potential extensions of future work. Policy recommendations for monetary authorities are also critically offered.

1.2 Literature Review

In this section, I give a brief overview of the conventional view of the monetary policy transmission and how bank risk-taking channel fits into it. To describe how the channel works, several proposed mechanisms in the theoretical literature are documented. Lastly, I review the empirical studies.

The traditional view of monetary policy transmission mechanism primarily focuses on the so-called **interest rate channel**, where expansionary monetary policy leads to a fall in real interest rates. This, in turn, causes intertemporal substitution towards current consumption and investment, prompting a rise in loan demand. **The credit channel**, meanwhile, emphasises loan supply and the role of credit market imperfection (Bernanke and Gertler, 1995). It consists of two subchannels. First, **the balance sheet channel** emphasises the role of asymmetric information and resulting agency problem between firms and their creditors in creating the "external finance premium". Monetary easing, by improving firms' net worth and cash flows, alleviates the information asymmetry problem. Creditors, therefore, lower the external finance premium, prompting firms to demand more credit (Bernanke and Gertler, 1989). Second, **the bank lending channel** gives a special role to "bank loans" (Bernanke and Blinder, 1988). In particular, monetary tightening shrinks reserved deposits in the banking system, which in turn affects banks' supply of loanable funds. Although banks may attempt to replace any shortfall in deposits with non-deposit source of funds, Stein (1998) argues that the uninsured non-deposit funding is subject to agency problems.

1.2.1 The Bank Risk-Taking Channel: The Theory

Borio and Zhu (2012) define the risk-taking channel as "the effects of monetary policy on banks' risk perception and tolerance, and hence on the degree of portfolio riskiness, and price and non-price terms of funding extensions". In particular, low interest rates encourage banks to relax lending standards, thereby taking more risk on their portfolio. The channel differs from the traditional transmission mechanism in two key aspects. First, it emphasises the quality, rather than the quantity, of bank assets. Secondly, it operates through the time-varying risk appetite of financial intermediaries. In this subsection, I document mechanisms proposed in the literature so far to give a rough idea of how the channel works.

A noteworthy mechanism appears in Rajan (2005), who explains **search-for-yield** incentives with institutional or contractual reasons. The author argues that, in the context of a currently competitive and deregulated financial landscape, managerial compensation is linked to nominal investment returns. In this environment, monetary easing, which induces low returns on risk-free assets, encourages investment managers to search for higher-yield risky investments in order to achieve the target rate of returns. Rajan's proposal comes close to asset substitution (or portfolio reallocation) channel, as discussed in De Nicoló et al. (2010). A lower yield on safe assets leads to a decrease in their weight in bank portfolio, until returns on risky and safe assets are equalised. A similar mechanism can be in place when financial intermediaries strive to match returns with fixed-rate long-term liabilities.

Alternatively, monetary policy may impact bank risk-taking through **valuation, income and cash flows**, which in turn affect banks' risk perception and tolerance (Borio and Zhu, 2012). Low interest rates, by boosting asset prices, income and profits, reduce the measured risk, such as probabilities of default, expected loss, etc. Banks thus perceive lower risk. In addition, as wealth improves, banks also become more risk-tolerant. All of these arguments support banks to take more risk. Adrian and Shin (2010a) work in the same spirit. In their model, as bank liabilities are mostly short term, expansionary monetary policy improves marginal lending profitability, thereby boosting the forward-looking measure of capital. This raises banks' risk-taking capacity, allowing them to leverage up and expand their balance sheet.

A distinct mechanism works through an improvement in **lending profitability**, since this provides incentives for banks to accept additional risk for higher expected profit. Valencia (2014) shows how a decrease in the risk-free interest rate improves intermediation margin by lowering the cost of deposit financing and enhancing the surplus that monopolistic banks can extract from their borrowers. Agur and Demertzis (2010), in contrast, attribute an increase in lending profitability to the business cycle effect. Low interest rates drives up the gap in returns between risky assets and safe investments, provided that returns of the former are more responsive to economic conditions.

Risk-taking incentives can also be influenced by banks' financial structure, under the so-called **leverage channel**. Leverage conditions inversely reflect banks' "skin in the game", and the extent to which they internalise the consequences of a bankruptcy. The less leverage banks take on, the higher their own funds and the more they are aware of taking on a risky position. In theory, monetary easing results in cheaper debt liabilities (Agur and Demertzis, 2010), while reduces the benefit of holding capital by improving banks' financial condition (Dell'Ariccia et al., 2010).[5] Banks, as a result, are inclined to increase their leverage and adopt a riskier profile.

The last main set of effects works through **expectations of the central bank's reaction function** (Borio and Zhu, 2012). If the public perceive that the central bank is aggressive in addressing large downside risks (also known as the Greenspan Put), there will be asymmetric bank behaviour towards a change in monetary policy. In particular, this insurance effect creates another moral-hazard incentive for banks to take excessive risk in the event of low interest rates.[6]

So far, several candidate driving forces for the risk-taking channel have been proposed. Their existence and relative importance are yet to be investigated to establish a firmer theory. In this paper, I make a contribution by testing whether the risk-taking channel works through the leverage channel.

[5]Banks, operating under limited liability and asymmetric information, usually take excessive risk. It is therefore beneficial for them to hold capital to abate agency problem, which in turn helps lower their cost of deposits and debts.

[6]Nevertheless, it is crucial to note that not all theories predict that monetary easing is associated with increased banks' risk appetite. Dell'Ariccia et al. (2010) argue that low risk-free interest rates cause a reduction in the cost of liabilities, resulting in an increase in the intermediation margin. Therefore, in the context of limited liability, banks will be induced to limit their risk-taking so as to reap higher profits (the so-called "risk-shifting effect"). They also find that the effect is greater for highly-leveraged banks, which can afford high limited-liability protection. In addition, as discussed in Jiménez et al. (2014), expansionary monetary policy decreases the opportunity cost for banks in holding cash, thus making risky investment less attractive (Smith, 2002); meanwhile, a high interest rate reduces banks' net worth, inducing banks to adopt gambling strategies to recoup their losses (Hellmann et al., 2000). Apart from these, Nicolo et al. (2010) postulate that high interest rates indeed should be conducive to increased risk-taking, since they imply larger room for the central bank to respond to negative shocks. As a result, banks take on high risk with the hope of receiving liquidity assistance during the bust period. In light of a few articles that disagree with the existence of the channel, the impact of monetary policy on bank risk-taking behaviour becomes a more interesting and non-trivial empirical question.

1.2.2 The Bank Risk-Taking Channel: The Empirical Evidence

Despite a limited number of empirical articles, they almost arrive at the same conclusion and support the existence of the channel. Basically, empirical literature differs with respect to the level of aggregation of the dataset employed.

Two studies so far have employed comprehensive, but confidential, **loan-level dataset** from the Credit Register, where information on default history of each borrower is available. Jiménez et al. (2014), in the case of Spain, find that low interest rates induce banks to grant new loans to borrowers with worse credit histories, and with a higher hazard rate (defined as per-period probability of default). Ioannidou et al. (2015) report similar results in the case of Bolivia. They also observe that there is a lower risk premium after monetary easing. In terms of **aggregate data**, some literature makes use of lending survey for each country. Maddaloni et al. (2009) and Maddaloni and Peydro (2011) study the US and other 12 countries within the EU, and report robust evidence for the softening impact of low monetary policy rates on lending standards. Peersman and Wagner (2014), meanwhile, use aggregate loans data within a vector autoregression (VAR) model with a combination of zero and sign restrictions. They find strong search-for-yield effects for US banks.

My thesis is among an intermediate case, which employs a **bank-level dataset**, mainly using information from bank balance sheets and financial conditions. Altunbas et al. (2010) and Gambacorta (2009), in the context of 16 developed countries, find similar results that "too low" monetary policy raises banks' estimated default frequency (EDF). More interesting is the finding that the extent of bank risk-taking increases with the amount of time monetary policy is left too expansionary, highlighting the danger of a "too low for too long" monetary policy. Other bank-level literature relies on "accounting-based" risk measures, such as the ratio of risk-weighted assets to total assets, the ratio of non-performance loans (NPL) to total loans, Z-score[7], etc. In the context of US banks alone, De Nicoló et al. (2010) and Delis et al. (2011) have supportive evidence for the risk-taking channel. Meanwhile, Delis and Kouretas (2011), using the ratio of risky assets to total assets as their main risk measure, report that low interest rates are conducive to increased risk-taking for European banks.

The presence of the risk-taking channel in Asia is supported by Ramayandi et al. (2014). They employ several risk-taking indicators including (1) a market measure of idiosyncratic bank risk, based on bank-specific residuals derived from CAPM[8], (2) the Z-score, (3) the ratio of NPL to total loans, and (4) the standard deviation of asset returns. However, I argue that those measures may not reflect changes in banks' risk appetite. They mostly are "ex post" risk measures which may not reflect risk that banks take at the times of loans origination. Also, the paper is not aware of a misidentification problem. In particular, the findings that too low interest rates lead to higher bank riskiness admit several interpretations other than the working of the risk-taking channel, which I will explain in detail later. My paper makes improvements along these two lines.

1.3 Data and Method

I form a bank-year panel dataset covering banks from 9 Asian countries including China, Indonesia, India, Korea, Malaysia, the Philippines, Singapore, Thailand and Taiwan. Altunbas et al. (2010) argue that quarterly data suits better the study of monetary policy transmission, which is mainly short-term. However, I believe that the implications of monetary policy on financial stability is of long-term horizon,

[7]The Z-score measures bank insolvency risk, calculated from the ratio of return on assets plus the equity-to-asset ratio to the standard deviation of return on assets.

[8]The first-stage regression exploits daily stock prices of each bank as a dependent variable.

supporting the use of annual data.

The panel includes various types of banks according to their legal status. There are commercial banks, cooperative banks, saving banks, Islamic banks, mortgage banks, bank holding companies and government-sponsored credit agencies. Commercial banks form a large part of the whole dataset, at approximately 80 percent of total number of banks. Investment banks are excluded due to limited data availability. However, I suspect that the risk-taking channel is even more pronounced for them. Hence, the estimation using current subset of banks should provide a lower bound for estimates of risk-taking incentives for the investment banks.

1.3.1 Measures of Bank Risk-Taking

Following Delis and Kouretas (2011) and Delis et al. (2011), I employ an accounting-based measure that can be conveniently computed from bank balance sheet information. The measure is **the ratio of risky assets to total assets**, where the risky assets are total assets, excluding two riskless components: cash and due from banks, and government securities. Risky assets, based on this categorisation, basically include (1) loans to individuals and businesses, (2) loans and advances to banks, and (3) private securities (including trading securities, derivatives and so on). The ratio is thus restricted to lie between zero and one, where a rise in the ratio implies an increase in bank's risk exposure. Each component of the risky assets listed above is subject to some form of risks, ranging from credit, liquidity to market risks.[9]

An immediate challenge to the measure would be on an implicit assumption that all components of risky assets are considered equivalent in terms of their riskiness.

[9] Loans to household and firms, for example, are subject predominantly to credit risk. Liquidity risk is also a concern since bank loans involve long-term commitments and cannot be liquidated easily unless a market for securitisation is adequately available. This is certainly not the case for Asian banking sector. Loans and advances to banks are also not free from counterparty risk; in particular, interbank lending is committed without collateral. Meanwhile, the recent Global Financial Crisis has shown that a decline in the market value of securities can trigger asset losses and writedowns.

One might be tempted to say that mortgage loans, which require collateral, are safer than corporate lending. Even within the same category of loans, the riskiness of each loan contract should differ. A superior measure within the same family would be the ratio of risk-weighted assets to total assets, utilised in De Nicoló et al. (2010), which gives unequal weight to each asset according to how risky it is. However, with limited availability of detailed information, calculating a risk-taking measure in the latter way risks losing significant number of the observations. Therefore, it is important to note that **this study aims to measure the impact of monetary policy on how banks rebalance their portfolio broadly across two categories of assets, as a way of inferring the risk-taking channel**.[10]

Despite some drawbacks, I view the measure as a good indicator as it matches the theoretical definition of bank risk under the risk-taking channel. In particular, it measures "ex ante" risk exposure that banks take at the times of loans origination. The "ex post" risk measures, such as the NPL or the Z-score, can be contaminated by other economic factors over the life of loans and may not reflect risks that banks decide to assume at first. Moreover, the market-based measures such as EDF, which rely on information from stock and bond market or other financial market data, may not well capture bank risk-taking. During pre-crisis, a rising market with low price volatility would signal a stable financial market and hide the true bank risk-taking. This argument also applies to the ratio of risk-weighted assets to total assets. In good times, the default probability declines, leading to a fall in risk weights for most or all types of risky assets. It is, therefore, possible that banks take excessive risk and expand their balance sheet but this risk-based measure still looks under control.

[10] Another fair criticism is that the measure is also affected by movements in the market prices of risky and safe assets, which are beyond the bank's control. A change in the risky-asset ratio, in this case, does not reflect any shift in banks' risk appetite. Nevertheless, the issue is alleviated by the fact that market price movements mainly affect the value of securities, which do not form a large part of banks' assets.

1.3.2 Monetary Policy Indicators

I choose the central bank's policy interest rate as a proxy for monetary policy. An ideal setting would be when the central bank uses a particular interest rate as an operational target, which would perfectly signal its policy intention. This is the case for Korea, Indonesia, Malaysia and Thailand. For the rest, I rely on information from one of the central bank's policy instruments.[11] I describe monetary policy indicator for each country in table 1.8 in the Appendix, where the data are compiled from Datastream and CEIC database. Most of the chosen indicators are overnight interest rates in the interbank or repurchase market, except for China, whose central bank uses a one-year retail deposit rate as a policy instrument (Geiger, 2008).[12]

Singapore's monetary policy poses a concern. Due to being a very open economy, Singapore uses an exchange rate as a target for policy conduct. The choice of interest rates to reflect monetary policy stance is thus arbitrary since they all are left to be determined by market forces. I therefore choose overnight repurchase rate to be a proxy, to ensure consistency with other countries.

Detailed data description and descriptive statistics of all variables in the regression are presented in table 1.9 and 1.11 in the Appendix.

1.3.3 The Identification Strategy

In the estimation, two major sources of identification problems were encountered. Firstly, by regressing the ratio of risky assets to total assets on monetary policy indicator, an immediate question is how we can be confident that the parameter es-

[11] The central bank may operate under monetary targeting or does not officially specify particular operational target, but instead employs broad range of indicators.

[12] One concern for the selection of monetary policy indicator is that a shift in monetary regime occurred during the period studied, making it difficult to find a single interest rate that summarises the policy stance for the whole period, contributing to a problem of monetary policy identification. Of all the countries in the sample, there exists a shift in monetary policy framework in Indonesia, with a move from Monetary Targeting to Inflation Targeting in 2005. However, the issue is alleviated by the fact that there tends to be a high correlation among various short-term market interest rates.

timate is really identifying the effect that is the focus here, that is, banks' risk-taking behaviour that boosts the supply of lending, rather than capturing other channels of transmission mechanism. That is, the finding that the ratio of risky assets to total assets increases following monetary easing admits several interpretation. A lowered monetary policy rate stimulates consumption and investment, prompting individuals and businesses to demand more credit (interest rate channel). It also increases the supply of loanable funds through an expansion of deposits (bank lending channel). Moreover, it triggers banks' willingness to lend as borrowers' creditworthiness improves (balance sheet channel). All of these lead to a rise in loan demand and supply, and hence an increase in the ratio of risky assets to total assets: this is exactly the same response predicted by the risk-taking channel. And, since new loans are likely to be riskier than average loans, a consequence is an increase in the riskiness of bank portfolios. Therefore, the challenge is to distinguish the risk-taking channel from other traditional transmission channels. A standard solution in the literature is to use real GDP growth to control for variation in loan demand across countries (Loutskina, 2005). However, this should only capture the interest rate channel; we are left with a task to distinguish risk-taking channel from credit channel. Whether monetary policy indicator is "exogenous" is the other identification issue. Monetary policy may be correlated with local macro-economic conditions or bank-level characteristics that are relevant in the risk-taking equation. For example, low interest rates may be a response to expected weakness in output growth, which also matters for bank risk-taking.

As a result, in this sub-section, I discuss three main identification strategies to establish the true causal effect of monetary policy on banks' risk taking behaviour.

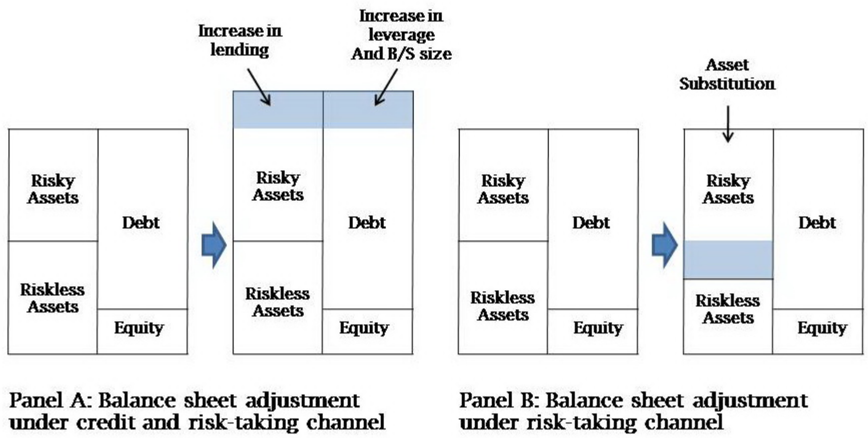
1.3.3.1 Balance sheet adjustments under the risk-taking and credit channel

The first strategy focuses on how bank balance sheet adjusts after monetary policy shocks under each transmission channel. The risk-taking channel may have a distinct adjustment pattern that we would like to identify. Assume a simple bank balance sheet where total assets comprise risky and riskless assets, and are made up from the sum of liabilities and equity. Firstly consider balance sheet adjustment under the credit channel. Owing to monetary easing, the theory predicts that banks will make more loans since they can obtain higher deposits and borrowers' creditworthiness improves. This results in an expansion of their balance sheets. This is illustrated in panel A of figure 1.1. In the figure, for simplicity, bank loans are financed by debt liabilities. This is particularly true for the bank lending channel, where monetary policy influences liabilities (either reserved deposits or non-deposit source of fund) and hence supply of loanable funds. The adjustment, which involves balance sheet expansion, is also compatible with the risk-taking channel, as shown in Adrian and Shin (2010a) (see also figure 2.4 in their paper). An increase in net worth, following an expansionary monetary policy, enables financial intermediaries to increase their leverage and purchase additional assets. Therefore, the risk-taking and credit channel can offer a common balance sheet adjustment, making identification difficult.

Nevertheless, I posit that the risk-taking channel can deliver another distinct pattern of adjustment. This involves portfolio reallocation or asset substitution from riskless towards risky assets, holding **balance sheet size fixed**. De Nicoló et al. (2010) are in favour, arguing that the asset substitution will take place until risk-adjusted returns of both assets are equivalent. The adjustment is exemplified in panel B. As a result, this provides me with a way to control for the credit channel by including banks' total assets in the regression model. Ideally, such an inclusion would block an operation of the credit channel as balance sheet size is held constant, and the monetary policy coefficient would only capture the latter force of the risk-taking channel, that is, the reallocation between the two types of assets.

A drawback immediately follows since the "Adrian-Shin" conjecture over how banks take risks, which requires an expansion of bank assets, is also being sterilised, while only asset-substitution mechanism is identified. If the former is economically important, it will not be possible to learn the true risk-taking effect. However, if our assumptions regarding balance sheet adjustments are correct, the estimated coefficient will at least give a lower bound for the true effect. In the event that low interest rates are found to significantly boost banks' risk appetite, one needs to be aware that the appetite can be larger once we allow banks to reoptimise their size.

Figure 1.1: Balance Sheet Adjustment



1.3.3.2 Exploring cross-sectional differences in risk-taking response across banks with different characteristics

The second strategy explores the cross-sectional implications of the risk-taking channel in the sense that banks of different characteristics should respond differently to monetary policy shocks. The use of disaggregated data, and hence the investigation of cross-sectional differences across banks, has been simple but powerful strategy in empirical works on bank-lending channel since 1990s, aiming to disentangle loan supply from the loan demand effect. Kashyap and Stein (1995) were the first to postulate that if the bank lending channel is being identified, after monetary policy contraction, we should observe a more pronounced response of bank balance sheet variables of small banks, which face more difficulty in accessing external funds to replace reserved deposits. A number of articles followed this approach, but relying on different characteristics.[13] I develop this popular strategy here, postulating that what may matter for the heterogeneity in the risk-taking behaviour across banks is the nature of the incentives. Rajan (2005) illustrates the role of managerial compensation in creating incentives for bank managers to take excessive risk in a period of low interest rates.

In this light, I differentiate banks into two categories, **listed and unlisted**, and posit that Rajan's explanation of risk-taking incentives is more relevant to the "listed" type. Listed banks are those that are listed on the stock exchange, where stock price and dividends paid to shareholders relate to the returns that banks can generate. In order to satisfy their shareholders, bank managers thus need to ensure that bank profits reach the desired target. Investors would pull back investments in the event that banks face losses or record lower profits than others. Also, new entrants make investment decisions based on expected capital gains and dividends, which are in turn driven by bank profitability. Therefore, in an environment of low interest rates, it is likely that listed banks will take on more leverage and risk, in order to achieve targeted returns. In addition, an ability to raise funds will facilitate their risk-taking motives. Their reputation and capability in diversifying risk would give

[13]Under the bank lending channel, the degree of agency problem, and hence the ability to raise external funding to shield lending from deposit shocks, may differ across banks, generating differential lending responses to monetary shocks. The bulk of literature, such as Kashyap and Stein (2000), Kishan and Opiela (2000), Ashcraft (2006) and Cetorelli and Goldberg (2008) followed suit, arguing in favour of a more pronounced response by less-liquid banks, undercapitalised banks, stand-alone banks and local banks. The empirical strategy has also been employed to identify the balance sheet channel. They rely on the hypothesis that informational asymmetries should be more severe for small firms than large firms, and investigate whether the former's liquidity constraints become more binding after monetary tightening (see Gertler and Gilchrist, 1994; Oliner and Rudebusch, 1996).

listed banks convenient access to the debt market, apart from the rights to obtain equity financing from the stock market. Arguably, the fact that they have better skills in risk monitoring and diversification should allow them to be more aggressive in risk-taking. Under this regard, I hypothesise that "***if the risk-taking channel does exist, one should expect the risk-taking response of listed banks after monetary policy expansion to be more pronounced.***"

Investigating the differential risk-taking response across listed and unlisted banks provides an environment to uniquely identify the risk-taking over the bank lending channel. Since listed banks are likely to be larger than non-listed banks, their natural response following monetary policy shocks, if the bank lending channel is dominant, should be less pronounced than the response of the unlisted. The prediction contrasts with what might be expected from the risk-taking channel, and yields an environment to identify the two channels. Consequently, the finding of a more pronounced risk-taking response to a shift in monetary policy by listed banks should be explained through heterogeneity with respect to risk-taking incentives. The bank-lending channel cannot explain such finding.

Nevertheless, this identification strategy can still be subject to the classic counterargument based on heterogeneity in loan demand. Critics may argue that listed banks are better placed to take advantage of rising credit demand, and hence a more pronounced response by listed banks can still be explained by loan-demand interpretation. Therefore, in order to interpret the results as the bank risk-taking effect, my strategy implicitly assumes homogenous loan demand, where credit demand for both types of banks increases uniformly in response to monetary easing.

1.3.3.3 Exogenous monetary policy

Typically, a potential endogeneity problem can arise from reverse causality and the omitted variable bias. The reverse causality problem is such that banks' risk-taking behaviour enters into the central bank's reaction function and influences monetary policy decisions so that the causality runs from bank risk to monetary policy. Presumably, the central bank would raise interest rates when risk appetite is high to stabilise the economy. However, the problem can be addressed by the use of a disaggregated bank-level panel dataset, as it would be too restrictive to assume that individual bank behaviour can influence the setting of monetary policy at the aggregate level. In addition, the objective of monetary policy for most countries in the sample is directed towards achieving price stability.

The problem of omitted variable bias seems to be more relevant. As is standard in the literature, I introduce appropriate controls to deal with the problem. However, there can be undesirable effects from introducing controls, since it risks holding constant causal mechanisms through which the risk-taking channel works. Therefore, it will not be possible to estimate the true monetary policy impacts. In most of the literature outlined in section 1.2.2, there is a tendency to address the omitted-variable problem by controlling for as many variables as possible, without recognising the risk of shutting down causal mechanisms. The controls, for example, include the leverage ratio, return on assets, or the term spread, which can be relevant in the operation of risk-taking channel, according to the theories. It is thus unlikely that the true risk-taking channel is estimated. Under this regard, I shall rely on basic limited-control regression model as the baseline specification, while introducing appropriate controls in later specifications to deal with any biases.

In this study, two alternative ways are also used to deal with endogeneity problem. The first one is to use instruments. Given the difficulty in obtaining external instruments that are both valid and informative, I rely on internal instruments, that is, lagged values of the endogenous variables. The other way is to obtain exogenous monetary policy shocks directly. Taylor (1993) provides a rough guide to how the central bank makes a decision on monetary policy, making it possible to obtain an exogenous unexplained component, known as “Taylor-rule residuals”.

1.3.4 Model Specification

Following the identification strategies, a series of bank-year panel model will be estimated where the baseline specification has the following form:

$$\begin{aligned} RiskyAsset_{i,t} = \quad & \alpha + \beta_1 MonetaryPolicy_{c,t} + \beta_2 MonetaryPolicy_{c,t-1} + \pi AssetSize_{i,t} \\ & +\delta_1 GDPgrowth_{c,t} + \delta_2 GDPgrowth_{c,t-1} + \varepsilon_{i,t} \\ where \quad & \varepsilon_{i,t} = u_i + v_{i,t} \end{aligned} \tag{1.1}$$

The dependent variable is our bank risk-taking measure, the ratio of risky assets to total assets of bank i at time t. The monetary policy indicator, which varies across countries c, is included in the specification, both contemporaneously and with a one-period lag. There are reasons to suspect that monetary policy has a lagged effect on banks’ risk-taking behaviour. Bank risk-taking strategies in each year may be planned earlier, forcing them to fully respond with a certain lag to shocks. Both the risky-asset ratio and monetary policy variables enter the model in “level” form. Delis and Kouretas (2011) argue that regression in level form is more consistent with theories which usually focus on the nexus between a low level of interest rates and banks’ risk appetite. A decline in policy interest rate does not necessarily imply that its level is low.

I am inclined to introduce a limited number of controls into the baseline specification. In particular, only variables deemed necessary to control for traditional channels of monetary policy transmission mechanism are included. Firstly, to account for the interest rate channel, lagged and contemporaneous real GDP growth is included. Indeed, real GDP growth can be relevant in risk-taking equation on its own. Favourable macro-economic conditions should encourage banks to take more risks.

I additionally include a bank's asset size to uniquely identify portfolio-reallocation mechanism under the risk-taking channel. The variable enters the model as a ratio to the average assets for that bank over the periods studied ($AssetSize_{i,t} = \frac{TotalAssets_{i,t}}{\sum\limits_{s=1}^{T} TotalAssets_{i,s}}$).

Other Covariates

I introduce appropriate controls in the later specification to account for potential omitted variable bias. One set of controls involves macro-economic and institutional variables comprising inflation and the banking sector's concentration index. Jiménez et al. (2014) argue that a high inflation rate contributes to the low value of debt in real term, improving banks' risk perception. Meanwhile, Marcus (1984) posits that intense competition, by shrinking banks' franchise value, raises banks' incentives to assume more risk. I employ a three-bank concentration ratio, measuring assets of the three largest banks as a ratio to the size of the banking sector, as a proxy. Macro-level variables enter the model both contemporaneously and with a one-period lag.

The other set of controls is bank-level characteristics, consisting of bank capitalisation condition and profitability, proxied by the ratio of equity to total assets and the return on average assets (ROAA), respectively. The predicted effects for both variables in theory are inconclusive. A large holding of equity capital implies more "skin in the game" and an increased likelihood of a bank being more risk-averse. However, well-capitalised banks, by having an adequate buffer against asset losses, may afford a higher risk on their portfolio. Meanwhile, the return on assets can also have either positive or negative influences on bank risk-taking. In some cases, banks exploit accrued profits to originate more loans; in others, banks become less risk-loving once they have achieved their targeted revenue. To avoid potential endogeneity among bank-level controls, they are included in the specification only in lagged form.

Testing heterogeneity between listed and unlisted banks

This can be done so in two ways. One way is to introduce interaction terms between monetary policy indicator and a dummy variable indicating whether a bank is listed. This approach involves estimating the specification below:

$$\begin{aligned} RiskyAsset_{i,t} = \quad & \alpha + \beta_1 MonetaryPolicy_{c,t} + \beta_2 MonetaryPolicy_{c,t-1} \\ & + \beta_3 Listed_i * MonetaryPolicy_{c,t} + \beta_4 Listed_i * MonetaryPolicy_{c,t-1} \\ & + \pi AssetSize_{i,t} + \delta_1 GDPgrowth_{c,t} + \delta_2 GDPgrowth_{c,t-1} + \varepsilon_{i,t} \end{aligned} \tag{1.2}$$

where, $Listed_i$ equals one if a bank is listed and zero otherwise. The combined monetary policy effects over two-year periods on unlisted and listed banks' risky-asset ratio are $\beta_1 + \beta_2$ and $\beta_1 + \beta_2 + \beta_3 + \beta_4$, respectively. Using the Wald Test, I can test (1) whether the responses of each banking group are significant and (2) whether their responses differ from each other. The alternative way is to regress equation (1.1) separately for listed and unlisted banks. The second approach allows for heterogeneity in parameter estimates of the covariates across the two bank types.

1.3.5 Data Selection and Descriptive Statistics

The Bankscope database provides three types of banks, according to their listed nature: listed, unlisted and delisted. The latter type covers banks that used to be listed in the stock market, but are currently unlisted. I decided to exclude this type of banks from the sample since it would be difficult whether to categorise them as listed or unlisted. Moreover, the fact that delisted banks are forced off the stock market may imply that they engaged in unsuccessful activities that may be hard to be captured by existing explanatory variables.

Despite its availability since 1997, I omit the data prior to the year 2000 to account for outliers in macro-economic variables during the post-Asian crisis period.

In particular, half of the countries in the sample experienced a sharp decline in real GDP growth and an upsurge in market interest rates. In addition, the post-crisis period marks a transition towards a new monetary and financial regime in many countries. The above omission leaves 165 listed and 267 unlisted banks, with a 12-year time dimension.

Following empirical literature that employs bank balance sheet data, I further exclude bank-year observations involving the merging of two or more banks, which results in an explosion of assets. Also, an abrupt shift in business practice can occur over the merging period. Moreover, being aware of potential outliers, I also exclude bank-year observations where the ratio of risky assets to total assets is lower than three standard deviations from its sample mean.[14] In addition, when bank-level characteristics are included in the specification, I also omit observations with extreme value of those variables.

In table 1.1, I compare bank balance sheet information and financial condition between listed and unlisted banks over three time periods: 2000, 2005, 2011. Four important facts can be derived. Firstly, as expected, most of the unlisted banks have small size (almost 90 percent of the total number of unlisted banks), while listed banks have an equal portion of large and small banks.[15] This fact supports the identification strategy that the finding of more pronounced risk-taking responses by listed banks to monetary policy shocks would not be attributed to the bank lending channel.

[14] I also try using different criteria in excluding outliers, for example, by omitting observations about where the risky-asset ratio lies within 1-percent lower and upper tail of the distribution. So, this handles extreme value at both tails of the distribution. The results do not significantly change.

[15] I construct a dummy variable to indicate whether a bank is large or small. The variable equals to one if the size of bank assets (in terms of US Dollar) lies within the top 25 percent across the whole sample for most of time. As a result, the number of large banks in the sample is approximately 25 percent of the total. The threshold is based on the distribution that most banks are small, but also to allow for a sufficient number of banks in large-bank group.

Table 1.1: Descriptive Statistics: Comparison across Listed and Unlisted Banks

Bank type	Listed Banks			Unlisted Banks		
Year	2000	2005	2011	2000	2005	2011
# of Banks		165			267	
Percentage of Large Banks		50.00			11.22	
Percentage of Commercial Banks		77.71			77.89	
Risky Assets	72.56	79.46	82.95	75.71	81.55	81.71
Loans	46.84	52.13	57.14	50.43	52.04	50.17
Private Securities	8.617	9.528	11.06	9.372	9.688	11.50
Loans and Advances to Banks	13.96	9.970	9.688	15.30	15.59	15.66
Cash and Due from Banks	6.023	5.151	5.095	7.068	5.721	9.812
Government Securities	21.03	15.68	12.18	16.04	12.02	8.848
Customer Deposits	73.47	72.26	69.96	63.84	64.26	66.96
Equity	9.039	9.457	9.164	10.28	14.24	11.08
Return on Average Assets	0.340	0.875	1.179	1.968	1.790	1.019
Impaired Loans	16.78	6.226	2.308	15.02	6.430	3.152
Leverage Ratio	19.08	14.14	13.62	35.66	14.95	14.24

Most variables are expressed as a ratio of total assets, except for impaired loans, which is expressed as a ratio to total loans. Leverage ratio is defined as the ratio of assets to equity. The statistics shown are the mean of available observations. The sum over all asset categories shown above may not add up to 100 since some banks do not report complete information.

Secondly, listed banks initially hold a lower proportion of risky assets on their portfolio than unlisted banks. However, over time, it is possible to see a sharp rise in the number of risky assets for listed banks. This leads me to suspect a possible correlation with a decline in interest rates. The downward trend in global interest rates only reversed in 2008 to counter the inflationary pressure from the negative oil shock. In 2011, listed banks have a relatively higher proportion of risky assets. For both types of banks, loans to individuals and businesses constitute a large part of risky assets (around two-thirds).

Thirdly, listed banks hold a larger amount of government securities than unlisted banks. However, there is a decreasing trend for both types of banks, particularly for listed banks, consistent with an increase in risky assets in the portfolio.

Lastly, on the liabilities and equity side, listed banks always hold lower equity as a percentage of total assets than unlisted banks. There can be several explanations for this. Having a higher reputation and credibility, listed banks may face a lower cost of asymmetric information, thereby not requiring them to hold much equity capital (Dell'Ariccia et al., 2010). Also, listed banks can raise equity capital easily, and so do not need much buffer against shocks. Nonetheless, there is no evidence of a surge in leverage over time.

1.4 Main Estimation and Results

This section presents the estimation and results for the main research question: **whether monetary policy easing contributes to bank risk-taking in the case of Asian banks**. In subsection 1.4.1, I firstly show results using a within-group estimator. Then, in subsection 1.4.2, I introduce lagged dependent variables into the model, which then provides a platform to account for potential endogeneity in monetary policy, by exploiting valid internal instruments. The resulting dynamic specification is estimated using GMM. Results from both within-group and GMM panel estimations are found to be supportive of each other. The section ends with a number of robustness exercises.

1.4.1 Evidence from Within-Group Panel Estimation

Estimation

The aim is to consistently estimate equation (1.1) and (1.2). All specifications in this subsection are estimated under a fixed-effect model, or, in particular, using the within-group estimator. This is to account for unobserved heterogeneity across banks, which in turn may result from differences in individual banks' business model. Maddaloni and Peydro (2011) take a more macro perspective, arguing for the role of unobserved banking structure, regulation and supervision in shaping risk incentives of banks across countries. I ensure the existence of the correlated heterogeneity, which warrants the use of fixed-effect model, by implementing the Hausman Test. Clustered-robust standard errors, where the clustering unit is at the bank level, are reported throughout every specification to account for the correlation of the error term over time for each bank.[16]

Results

Table 1.2 shows the main estimation results. I begin with a specification without asset size. This is to illustrate how well asset size captures adjustments under the credit channel. In the second column, I find that both contemporaneous and lagged monetary policy have significant negative impacts on banks' risk-taking behaviour, consistent with the existence of the risk-taking channel. The combined magnitude over two periods is -1.01, implying that a 100-basis-point reduction in monetary policy rate results in banks holding a larger proportion of risky assets by around one percentage point. Meanwhile, real GDP growth significantly affects banks' risk profile with a one-period lag. The risk-taking channel can also be identified in the most conservative specification, where I exclude lagged monetary policy and GDP growth (column 1).

In the third column (our baseline specification), asset size is being controlled. I find asset size coefficient to be significant at 5 percent level. Unsurprisingly, monetary policy coefficients are reduced both in terms of magnitude and significance. The contemporaneous effect is weakly significant at 10 percent level. The combined effect is lowered to -0.81 (significant at 5 percent level), or a drop of around one-fifth from the initial estimate. Despite lowered effects, the finding still yields support to the

[16] Serial correlation likely happens in the case here since unobserved characteristics influencing bank risk-taking behaviour, e.g. the mean and variance of asset returns, may not vary significantly from year to year. To ensure the existence of serial correlation, I apply the test proposed by Wooldridge (2010) on equation (1.1). I find significant evidence of residual autocorrelation for the whole sample and for each banking group. The results are shown in table 1.10 in the Appendix.

notion that low interest rates contribute to higher risk-taking by banks. Note also that the Hausman Test warrants the use of fixed-effect model.[17]

Appropriate controls are included to deal with potential endogeneity. It is clear that the results with respect to monetary policy estimates are fairly robust to controls (columns 7, 9 and 11). I firstly include time effects to account for time-varying common shocks.[18] The results show that including time effects mainly affect coefficients on economic growth. Its lagged coefficient is now insignificant. This is possible since economic cycles of these countries in the sample tend to be synchronised, and can thereby being captured by the time effects. Monetary policy even has larger impacts on bank risk-taking; the combined effects over two periods improve to -1.33. An introduction of bank-level and macro-level controls, however, seems to matter for monetary policy estimates. In controlling for macro-economic variables, only lagged monetary policy significantly affects bank risk-taking, but at a 10 percent level.[19] The combined effect is reduced to -0.53, almost half the initial estimate, but the effect is significant at a 10 percent level. Another interesting result is that higher concentration within the banking sector results in subdued risk-taking. Meanwhile, coefficients on inflation are insignificant at conventional level. Also, bank-level controls tend to lower the size and significance of monetary policy coefficients. The combined monetary policy effect is at -0.57 and also significant at a 10 percent level. Both capitalisation condition and profitability are not significant.

To ensure that the risk-taking channel is actually being identified, I move towards a key part of the estimation, which is to investigate cross-sectional differences in the

[17]The Hausman Test is done for the baseline specification. The test rejects the null hypothesis of no correlated heterogeneity and random-effect model at 1 percent level. $\chi^2(5) = 38.17$. Within-group estimators are thus suitable.

[18]Introducing time effects can be beneficial in an econometric sense since it removes correlation of residuals between individuals, yielding consistent estimates of error variance. However, I refrain from including them in the first place, in order to exploit across-time information on monetary policy and bank risk-taking behaviour, which can be crucial for the identification of the risk-taking incentives.

[19]Coefficients of the macro-level and bank-level controls are not reported in the table.

Table 1.2: Main Results from Within-group Panel Model

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
		Whole Sample			Listed	Unlisted	Time Effects		Macro-level Controls		Bank-level Controls	
GDP Growth	0.074	-0.0072	0.017	0.0062	-0.012	0.015	0.070	0.063	0.088	0.077	0.031	0.026
	(0.045)	(0.054)	(0.054)	(0.055)	(0.078)	(0.077)	(0.085)	(0.085)	(0.062)	(0.062)	(0.055)	(0.056)
L.GDP Growth		0.30***	0.28***	0.25***	0.31***	0.18*	0.13	0.14	0.35***	0.31***	0.30***	0.28***
		(0.061)	(0.060)	(0.058)	(0.071)	(0.092)	(0.093)	(0.094)	(0.072)	(0.070)	(0.059)	(0.058)
Monetary Policy	-0.71***	-0.44**	-0.36*	0.30	-0.65***	0.33	-0.85***	-0.23	-0.23	0.38	-0.26	0.25
	(0.27)	(0.21)	(0.21)	(0.30)	(0.24)	(0.31)	(0.27)	(0.36)	(0.18)	(0.30)	(0.20)	(0.30)
L.Monetary Policy		-0.57***	-0.45***	-0.31	-0.44*	-0.42**	-0.48***	-0.39*	-0.30*	-0.18	-0.30*	-0.13
		(0.15)	(0.16)	(0.20)	(0.22)	(0.21)	(0.18)	(0.21)	(0.16)	(0.20)	(0.18)	(0.23)
Asset Size			0.011**	0.012**	0.019***	0.0042	0.024***	0.024***	0.0099*	0.010*	0.014***	0.014***
			(0.0048)	(0.0048)	(0.0064)	(0.0072)	(0.0084)	(0.0084)	(0.0053)	(0.0053)	(0.0049)	(0.0049)
Listed*Monetary Policy				-0.97***				-0.84**		-0.90**		-0.75**
				(0.37)				(0.37)		(0.36)		(0.37)
L.Listed*Monetary Policy				-0.22				-0.15		-0.20		-0.28
				(0.28)				(0.26)		(0.27)		(0.31)
Constant	83.1***	83.3***	81.0***	80.5***	81.4***	79.6***	83.7***	83.0***	89.7***	88.8***	78.2***	77.8***
	(1.25)	(1.55)	(1.83)	(1.72)	(2.64)	(2.18)	(2.58)	(2.57)	(3.02)	(2.75)	(1.94)	(1.92)
Wald test												
$\sum MonetaryPolicy_{t-i}$		-1.006***	-0.806**	-0.007	-1.091***	-0.088	-1.329***	-0.623	-0.531*	0.196	-0.569*	0.114
		(0.302)	(0.314)	(0.376)	(0.400)	(0.386)	(0.379)	(0.448)	(0.281)	(0.382)	(0.306)	(0.410)
$\sum MonetaryPolicy_{t-i}$				-1.200***				-1.615***		-0.900**		-0.917**
$+\sum Listed * MonetaryPolicy_{t-i}$				(0.388)				(0.424)		(0.352)		(0.385)
Test the difference between the response of listed versus unlisted banks												
F statistic				5.192				3.888		4.496		3.600
P-value				0.023				0.049		0.035		0.058
Observations	2600	2600	2600	2600	1285	1315	2600	2600	2292	2292	2317	2317
Groups	432	432	432	432	165	267	432	432	391	391	409	409
Adj R^2	0.0165	0.0531	0.0594	0.0680	0.126	0.0127	0.0872	0.0928	0.106	0.113	0.0525	0.0588

Clustered robust standard errors in parentheses

* $p<0.10$ ** $p<0.05$ *** $p<0.01$

risk-taking responses across listed and unlisted banks. In column 4, which shows results from estimating equation (1.2), the likelihood of the existence of the risk-taking channel is strengthened. The Wald Test implies that only listed banks significantly react to monetary policy at a 1 percent level. For listed banks, a 100-basis-point decrease in monetary policy rate raises the holding of risky assets on bank portfolio by 1.20 percentage points. The Wald test also suggests that the response of listed banks is significantly larger than that of unlisted banks. Estimating equation (1.1) separately for the two bank groups confirms the previous finding (columns 5 and 6). Listed banks significantly respond to both contemporaneous and lagged monetary policy. R^2 of listed-bank regression even doubles from whole-sample regression. Meanwhile, expansionary monetary policy induces unlisted banks to hold more risky assets with a one-period lag. However, the sum of the effects across two periods is close to zero and hence insignificant. These cross-sectional differences are also found to be robust to the introduction of controls (columns 8, 10 and 12). With controls, the combined effects of monetary policy over two periods range from -0.90 to -1.62 and are significant at a 5 percent level.[20]

Nevertheless, relying upon the above estimation strategy alone may not be sufficient for identification, since it is not possible to be sure that it is actually the listed nature of banks that produces the cross-sectional differences. According to descriptive statistics (section 1.3.5), the dataset shows that on average, listed and unlisted banks differ in their size and capitalisation conditions. Critics may argue that a more pronounced response towards monetary policy shocks by listed banks is due to the fact that they are large or highly-leveraged, rather than that there

[20] The results above are based upon trimmed sample where I exclude potential outliers for the dependent variable and also observations involving the merging of two or more banks. For robustness, I include those observations back and re-estimate equations (1.1) and (1.2). Monetary policy estimates change in the way that supports the existence of the risk-taking channel. For the whole sample and listed-bank sample, as monetary policy rate is lowered by 100 basis points, the ratio of risky assets to total assets rises by around 1.4 and 1.9 percentage points, respectively. Both are significant at 1 percent level.

are underlying risk-taking incentives. The fact that capitalisation conditions differ across two bank types can be problematic. According to Kishan and Opiela (2000), the highly-leveraged banks face difficulty in raising external funds to offset deposit shocks. They, consequently, react strongly to monetary policy impulses. Therefore, critics may attribute a stronger response by listed banks to bank-lending-channel interpretation.

In this regard, it is important to control for the influence of other bank-level characteristics on the cross-sectional differences between listed and unlisted banks. I use size dummy, as described in footnote 15, and the ratio of equity to total assets to reflect bank size and capitalisation condition, respectively. One way is to introduce into the specification (1.2) their interaction term with monetary policy. The other way is to partition banks into two groups according to size (large and small banks) and capitalisation condition (well-capitalised and highly-leveraged banks), and to estimate equation (1.2) separately for each bank group. If the risk-taking channel is to be identified, one should expect to observe a more aggressive risk-taking response by listed banks for both groups. It is to note that the mean of the equity ratio is used to segregate banks into two types. Table 1.3 shows the results. Firstly, controlling for bank size and equity ratio, monetary policy coefficients stay almost the same both in terms of magnitude and significance (columns 1 and 4). The exception is, when controlling for the equity ratio, unlisted banks increase risk-taking to a larger extent. But the effects remain insignificant. Partitioning banks into two groups, we observe a more aggressive response towards monetary policy shocks from listed banks for both bank groups (columns 2, 3, 5 and 6). I find in the case of well-capitalised banks that, though the combined monetary policy effects are weakly significant for listed banks, their point estimate remains much higher than that for the unlisted. In sum, the estimations above confirm the dominant role of the listed nature of banks in producing cross-sectional differences in monetary policy estimates.

Table 1.3: Main Results after Controlling for Bank-level Characteristics

	(1) Whole	(2) Large	(3) Small	(4) Whole	(5) Well-capitalised	(6) Highly-levered
Asset Size	0.012**	0.029**	0.0065	0.017***	0.0062	0.021***
	(0.0048)	(0.011)	(0.0050)	(0.0049)	(0.0084)	(0.0064)
GDP Growth	0.0020	-0.22**	0.13**	0.048	0.045	0.047
	(0.054)	(0.090)	(0.063)	(0.053)	(0.080)	(0.075)
L.GDP Growth	0.25***	0.10	0.32***	0.30***	0.32***	0.33***
	(0.058)	(0.100)	(0.070)	(0.057)	(0.10)	(0.071)
Monetary Policy	0.31	0.33	0.17	-0.32	0.70	-0.73*
	(0.30)	(0.60)	(0.31)	(0.38)	(0.50)	(0.39)
Listed*Monetary Policy	-0.98***	-0.75	-0.92**	-0.73*	-1.73***	-0.047
	(0.38)	(0.67)	(0.41)	(0.39)	(0.62)	(0.51)
L.Monetary Policy	-0.31	1.16*	-0.36*	-0.20	-0.52*	0.028
	(0.20)	(0.62)	(0.20)	(0.24)	(0.27)	(0.35)
L.Listed*Monetary Policy	-0.19	-2.10***	-0.036	-0.084	0.73*	-0.43
	(0.29)	(0.64)	(0.30)	(0.27)	(0.38)	(0.37)
Size*Monetary Policy	0.042					
	(0.40)					
L.Size*Monetary Policy	-0.16					
	(0.41)					
Equity*Monetary Policy				0.041***		
				(0.014)		
L.Equity*Monetary Policy				0.0045		
				(0.0092)		
Constant	80.5***	83.7***	79.1***	78.3***	79.4***	79.3***
	(1.72)	(2.92)	(2.04)	(1.71)	(2.55)	(2.27)
Wald Test						
$\sum MonetaryPolicy_{t-i}$	-0.001	1.491	-0.195	-0.518	0.177	-0.706
	(0.381)	(1.080)	(0.380)	(0.494)	(0.604)	(0.496)
$\sum MonetaryPolicy_{t-i}$	-1.173***	-1.357**	-1.149**	-1.331***	-0.829*	-1.181***
$+\sum Listed * MonetaryPolicy_{t-i}$	(0.435)	(0.680)	(0.456)	(0.416)	(0.452)	(0.469)
Test the difference between the response of listed versus unlisted banks						
F statistic	4.684	6.025	2.707	2.251	1.834	0.559
P-value	0.031	0.016	0.101	0.134	0.177	0.455
Observations	2600	673	1927	2346	769	1577
Groups	432	92	340	416	208	315
Adj R^2	0.0674	0.157	0.0592	0.0761	0.0414	0.0999

Clustered robust standard errors in parentheses

* $p<0.10$ ** $p<0.05$ *** $p<0.01$

The estimated monetary policy impacts on bank risk-taking can also be shown to be economically interesting. In particular, monetary policy effects are sizable if compared to effects from shocks to economic growth of the same size. Relying on the estimates of equation (1.1) for the whole-sample regression (see column 3 of table 1.2), following a one-standard-deviation negative monetary policy shock, banks raise the holdings of risky assets on their balance sheet by around 2.6 percentage points over a two-year period. Meanwhile, in response to a one-standard-deviation positive shock to real GDP growth, the risky-asset ratio is estimated to increase by approximately 1 percentage point over the same horizon. This sizable impact from monetary policy makes the risk-taking channel not what monetary authorities can simply neglect.

To conclude, our bank-panel model provides evidence for the existence of risk-taking channel. Identification is achieved by arguing that risk-taking responses are more pronounced for banks listed on the stock market, where incentives for bank managers to take on excessive risk should be more prevalent. Unlisted banks, over a two-year period, tend not to significantly respond to monetary policy. The results are fairly robust to both bank-level and macro-level controls.

1.4.2 Evidence from the GMM Panel Estimation

Endogeneity problem remains a concern for consistency of the estimates. In this subsection, I use instruments to deal with the issue for both monetary policy and other explanatory variables. In particular, I rely on lagged values of endogenous variables to be instruments. To do so, given the existence of serial correlation (see table 1.10 in the Appendix), dynamic specification which includes lagged dependent variable is necessary. The reason is that, as illustrated in Blundell and Bond (2000), in the context of static specification where disturbances ($v_{i,t}$) are serially correlated, the dynamic specification can help recover consistent parameter estimates by attempting to model the serial correlation and making it possible to exploit valid internal instruments. Static specification does not allow for any valid moment conditions, based on internal instruments.

Practically, the risk-taking measure is likely to be persistent. Bank lending is a long-term commitment and cannot be liquidated instantaneously. Thus, when risks are being taken, they cannot be easily forced-off the balance sheet. And, as banks realise that they cannot easily liquidate their position, they will become more aware when making additional loans or taking risks in general. As a result, bank risk-taking cannot be re-optimised promptly, both upward and downward, in response to shocks. Other justifications to account for dynamic risk include relationship lending, regulatory issues, etc. Importantly, this dynamic model necessarily implies that monetary policy shocks can have persistent impacts on bank risk-taking behaviour over the longer term.

Estimation

The dynamic specification is the following:

$$\begin{aligned} RiskyAsset_{i,t} = \; & \theta_0 + \theta_1 RiskyAsset_{i,t-1} + \theta_2 MonetaryPolicy_{c,t} + \theta_3 MonetaryPolicy_{c,t-1} \\ & + \theta_4 AssetSize_{i,t} + \theta_5 GDPgrowth_{c,t} + \theta_6 GDPgrowth_{c,t-1} + u_i + \xi_{i,t} \end{aligned} \tag{1.3}$$

where, $\xi_{i,t}$ must now be serially uncorrelated.

Estimating equation (1.3) above using OLS and Within-group estimators can be proven to result in bias in the AR(1) coefficient. Arellano and Bond (1991)'s Difference-GMM estimator has the benefits of eliminating fixed effects. After differencing, the differenced lagged dependent variable and error will be correlated ($E\left[RiskyAsset_{i,t-1} \triangle \xi_{i,t}\right] \neq 0$). However, given certain assumptions, the second and earlier lags of the dependent variable are available as valid instruments for the differenced equation in each period. This yields the following moment conditions $E\left[RiskyAsset_{i,s} \Delta \xi_{it}\right] = 0$ where $s < t-1$ and $t = 3, 4, ..., T$, estimated using GMM technique. Likewise, we can account for the endogeneity of explanatory variables by using their second and earlier lags as an instrument.[21] This produces additional moment conditions $E\left[X_{i,s}\Delta\xi_{it}\right]=0$ where X is a vector of endogenous explanatory variables.

Nevertheless, a finite-sample bias, caused by weak instruments, can arise when variables are highly persistent (Blundell and Bond, 1998).[22] Therefore, I instead use the System-GMM estimator, proposed by Arellano and Bover (1995) and Blundell and Bond (1998), which expands the set of instruments. Instead of relying only on instruments in "level" for the equation in "difference," the estimator also makes use of instruments in "difference" for the equation in "level".[23] We then obtain further moment conditions, $E\left[\triangle RiskyAsset_{i,t-1}\left(u_i+\xi_{it}\right)\right]=0$ and $E\left[\triangle X_{i,t-1}\left(u_i+\xi_{it}\right)\right]=0$ where $t=3,4,...,T$. The additional instruments should help correct the bias and improve the precision of the estimates.

I use a two-step GMM estimator for efficiency gain. Windmeijer (2000)'s finite-sample correction for the variance of the two-step GMM estimator is thus required.[24] A couple of specification tests are crucial for identification. Firstly, as the model is overidentified, the validity of the assumptions used to obtain moment conditions can be tested, using the Hansen J-test (Hansen, 1982), a test for overidentifying restrictions. Secondly, a test for identifying assumption of no serial correlation in

[21]The endogeneity assumption implies that the current-period explanatory variable can be influenced by past and current errors, but is uncorrelated with future errors. A more restrictive assumption is to assume variables to be predetermined so that they are also not correlated with current errors. In that case the first lag of the variables is also valid.

[22]Signs of finite-sample bias can be traced from observing autoregressive coefficients, θ_1. One should expect consistent estimators to lie between OLS and within-group estimates, given that they are biased in the opposite direction. OLS and WG estimators therefore provide a band within which one should expect consistent estimators to fall; these are another rough guide to whether the model is well-specified and not subject to any finite-sample bias. In table 1.13 in the Appendix, I report the results using OLS and within-group estimators for both type of banks.

[23]This is based on the further assumption that differences in the endogenous variables are not correlated with fixed effects, therefore suitable lags of the difference can be used as an instrument in the level equation. Blundell and Bond (1998) shows that this, in turn, depends on a mean stationarity assumption of the initial conditions.

[24]Standard errors of the two-step estimator tends to bias downward due to a reliance on the calculation of optimal weight matrix in the second step on estimated parameter from the first stage.

the disturbances is also necessary. This is equivalent to the test of no second-order serial correlation in the differenced residuals. Note that there is first-order serial correlation by construction.

Nevertheless, an important issue to note is the dangers of too many instruments, or "instrument proliferation" (Roodman, 2009b). Aside from the overfitting problem, a more threatening danger is that instrument proliferation weakens the power of the Hansen test by causing it to accept supposedly invalid moment conditions. This problem seems to be more relevant and severe in this case since the System-GMM estimator makes use of extended set of instruments. Therefore, my solution is to limit the number of instruments as much as possible, say to two to three time periods of lags, to regain the power of the test. Indeed, omitting distant lags as instruments should not entail much loss of information.

Results

Table 1.4 shows the results for both Difference-GMM and System-GMM panel estimation. I exploit "second" and "third" lags of the dependent variable as instruments. Monetary policy indicator and also the asset size are assumed to be endogenous. I also use their second and third lags of both variables as instruments. Real GDP growth is assumed to be strictly exogenous, so it instruments itself in the regression.

The first result to note is that the set of instruments is invalid for "whole-sample" GMM regression. Columns 5 and 6 show that the Hansen Test rejects the validity of moment conditions at a 1 percent level of significance. As a result, I attach importance only to estimation for separate listed- and unlisted-bank samples, where valid instruments are available. However, Difference-GMM results for both bank types lead me to suspect finite-sample bias in the AR(1) coefficient (columns 1 and 3), since the estimates are equal or even lower than the within-group estimators, which are already biased downward (see also table 1.13 in the Appendix).[25]

The System-GMM estimator is therefore preferred. The AR(1) coefficients are now more sensible, standing at around 0.8 for both bank types and are significant (columns 2 and 4). Lagged real GDP growth significantly affects the risk appetite of listed and unlisted banks at 10 and 5 percent level, respectively. However, the magnitude is lower than that of the baseline model, potentially accounted for by lagged dependent variable. So is the magnitude of monetary policy effect, where the effect over two periods is -0.34 for listed banks. Although individual effects in each period remain insignificant, the combined effect is statistically significant at 5 percent level, according to the Wald Test. However, it is necessary to be aware that such combined effect does not take into account the persistence-effect from bank risk-taking itself. In addition, the effect can also persist over the long run. The true monetary policy effects on risky-to-total asset ratio are equal to $(1+\theta_1)\theta_2+\theta_3$ over two periods and $\frac{\theta_2+\theta_3}{1-\theta_1}$ over the long term. In response to a 100-basis-point decrease in interest rate, the risky-to-total asset ratio increases by 0.46 percentage points after two years and 1.33 percentage points in the long run. Using a non-linear combination test, both reject the null hypothesis of zero effect at 5 and 1 percent level of significance [$\chi^2(1) = 4.04$ & 11.44], respectively. Despite this finding, monetary policy effects for unlisted banks remain insignificant. By comparing point estimates of monetary policy coefficients between the listed and the unlisted banks, the results remain indicative of the identification of the risk-taking channel.

[25] The within-group and OLS estimates suggest that the consistent estimates should lie within [0.56,0.82] and [0.54,0.88] for listed banks and unlisted banks, respectively. The coefficient for unlisted-bank sample should be severely biased in this case. This signals that the instruments are uninformative, which in turn results from persistence in the series. I investigate the time-series properties of each variable in the specification by estimating a simple AR(1) model using OLS, WG and Difference-GMM estimators and also testing whether the variable has a unit root. The Wald Test rejects the hypothesis that AR(1) coefficient is equal to one for all variables. But the t-test also rejects the hypothesis of no auto-correlation. Difference-GMM estimates signal a potential finite sample bias for the monetary policy indicator and risky-to-total asset ratio, since they both are severely biased in the direction of within-group estimators. Their instruments therefore are likely to be weak.

I interpret the findings as supportive of the baseline results and the existence of the risk-taking channel. Firstly, by using instrument-variable methods, it is possible to again observe that listed banks respond, in a much more active manner, to monetary policy shocks. Secondly, for the listed-bank sample, the magnitude for the long-run monetary policy effect in the dynamic model is comparable to the combined effect over two periods under baseline specification. Recall that, in the baseline specification, following a 100-basis-point reduction in interest rate, the risky-asset ratio increases by approximately 1.09 percentage points.

Table 1.4: Main Results from GMM Panel Estimation

	(1)	(2)	(3)	(4)	(5)	(6)
	Listed Banks		Unlisted Banks		Whole Sample	
GMM type	DIFF	SYS	DIFF	SYS	DIFF	SYS
L.Risky Assets	0.56***	0.75***	0.30***	0.86***	0.57***	0.76***
	(0.084)	(0.057)	(0.095)	(0.045)	(0.069)	(0.046)
Asset Size	0.0046	0.0072**	-0.0058	0.0066	-0.00029	0.0056*
	(0.0065)	(0.0030)	(0.0091)	(0.0048)	(0.0051)	(0.0032)
GDP Growth	0.13*	-0.027	-0.043	0.016	0.051	0.053
	(0.077)	(0.064)	(0.080)	(0.066)	(0.057)	(0.046)
L.GDP Growth	0.25***	0.10*	0.053	0.15**	0.16***	0.13***
	(0.091)	(0.060)	(0.087)	(0.069)	(0.059)	(0.047)
Monetary Policy	-0.37	-0.17	0.16	0.15	-0.22	-0.056
	(0.30)	(0.17)	(0.27)	(0.24)	(0.21)	(0.17)
L.Monetary Policy	0.032	-0.17	-0.27	-0.13	-0.13	-0.14
	(0.13)	(0.13)	(0.17)	(0.11)	(0.13)	(0.098)
Constant	34.0***	20.9***	58.6***	9.24**	35.5***	19.1***
	(6.82)	(5.15)	(8.06)	(3.67)	(5.68)	(3.99)
Wald Test						
$\sum MonetaryPolicy_{t-i}$	-0.340	-0.336**	-0.105	0.029	-0.348*	-0.193*
	(0.297)	(0.131)	(0.237)	(0.162)	(0.184)	(0.117)
Observations	1148	1148	1080	1080	2228	2228
Groups	163	163	239	239	402	402
Instruments	75	111	75	111	75	111
AR1	0.001	0.000	0.005	0.000	0.000	0.000
AR2	0.047	0.056	0.859	0.812	0.145	0.123
Hansen	0.071	0.107	0.112	0.282	0.001	0.001

Clustered robust standard errors in parentheses. P-value is reported for all specification tests.
* p<0.10 ** p<0.05 *** p<0.01

I conduct three robustness exercises for GMM panel estimation, with the results shown in table 1.13 in the Appendix. Firstly, I include time fixed effects.[26] With time effects, estimates of monetary policy effects even improve in the way that supports risk-taking channel (columns 5 and 6). The combined monetary policy effects over two years, for listed banks, are significant at the 1 percent level. Secondly, I exploit further moment conditions by including the fourth lag of the endogenous variables as instruments. Such inclusion does not qualitatively change the results with respect to monetary policy effects (columns 7 and 8). In the other exercise, I use a forward orthogonal transformation, proposed by Arellano and Bover (1995), instead of first-differencing, to eliminate fixed effects. The transformation involves subtracting the average of all future available observations of a variable from each-period values. The results show that the estimates of monetary policy effects for listed banks become insignificant, but remain higher than those for unlisted banks (columns 9 and 10).

1.4.3 Too Loose Monetary Policy and Bank Risk-taking

The objective of this section is twofold. Firstly, I aim to test additional hypothesis of **whether a "too low" interest rate promotes bank risk-taking and financial fragility,** as economists and commentators believe. In this regard, as is standard in the literature, I rely upon the concept of Taylor-rule residuals a la Taylor (1993), since the residuals roughly imply how expansionary or tightening monetary policy stance is relative to what is suggested by economic fundamentals. Positive (negative) Taylor-rule residuals imply too tight (too eased) a policy. In addition, given that the construction of the residuals offers way to purge monetary policy of endogenous

[26]The inclusion of time effects is recommended by Bond (2002) and Roodman (2009a) to obtain independence across banks and ensure robust estimates of coefficient standard errors. The time effects are included as strictly exogenous variables. So, they instrument themselves in this first-stage regression.

movement in response to output and inflation, it is therefore the other approach to account for endogeneity by obtaining exogenous monetary policy shocks directly.

I firstly obtain Taylor-implied interest rate from the following model:

$$MonetaryPolicy_{c,t} = \alpha * MonetaryPolicy_{c,t-1} + (1-\alpha) * [\gamma + \beta_{c,\pi} * (\pi_{c,t} - \bar{\pi}_{c,t}) + \beta_{c,y} * \hat{y}_{c,t}] \tag{1.4}$$

where, $\pi_{c,t} - \bar{\pi}_{c,t}$ and $\hat{y}_{c,t}$ represent the inflation gap and the output gap of country c at time t, respectively. The output gap is measured as a deviation of real GDP from its Hodrick-Prescott trend. α is coefficient on interest rate smoothing. γ is neutral interest rate consistent with zero inflation and output gap. $\beta_{c,\pi}$ and $\beta_{c,y}$ denote the elasticity of the policy interest rate to the inflation gap and the output gap, respectively. Using quarterly data from 1999, I regress the monetary policy indicator on its own lag, inflation, output gap and constant term, separately for each country, using OLS. I then recover the residuals and replace monetary policy indicator in equation (1.1) and (1.2) with their yearly average. Within-group estimators are used to estimate the equations. Given that monetary policy indicator is now a generated regressor, I report bootstrapped standard errors. To account for residual serial correlation, resampling is done across banks, rather than bank-year observations, so that temporally correlated rows of data are not separated in the bootstrapped dataset.

Results are shown in table 1.14 in the Appendix. For whole sample, the combined monetary policy effects over two periods have much larger magnitude of -4.4 (column 1), suggesting that whenever monetary policy rate is lower than Taylor-rule implied rate by 100-basis-point, it induces banks to increase the proportion of risky assets by 4.4 percentage points.[27] The results imply that a "too low" interest rate relative

[27] Excluding lagged monetary policy from the first-stage regression does not alter the conclusion. Also, altering the right-hand-side variables towards real GDP growth and CPI does no harm. However, the results are not robust to Taylor-rule residuals based on calibration. In Altunbas et al. (2010), Gambacorta (2009) and Michalak (2012), the computation of Taylor-implied interest rate

to what is suggested by the economic fundamentals encourages banks to take higher risk. The findings are consistent with those of Maddaloni and Peydro (2011) and Gambacorta (2009), among others. The magnitude of the effects is of large extent. I am hasten to add that the standard deviation of Taylor-rule residuals is relatively small, implying that, despite large estimated impacts, the residuals may not explain much variation of the risk-taking measure.[28] However, when the policy interest rate starts to deviate from its fundamentally justified level, banks strongly adjust their portfolio. Even unlisted banks are found to respond to Taylor-rule measures with non-negligible magnitude, but the response is insignificant (column 2). The results, therefore, raise awareness for the central bank regarding financial-stability implications of an intention to leave interest rate too low.[29]

1.4.4 Robustness Checks

Three robustness exercises are implemented for baseline specifications (1.1) and (1.2). Firstly, it is possible to suspect that the baseline results are driven by outliers. Thus, I conduct two exercises to ensure robustness through excluding potentially influential observations. The first one involves omitting bank-year observations where Cook's Distance Statistics exceed the threshold of 4/(N-k-1), where N and k are the number of observations and the estimated slope parameters respectively, as suggested

is based on calibrating parameter values, rather than estimating them. Nevertheless, I view this as too restrictive, since it implies that the same monetary policy's reaction function is imposed across countries.

[28]One-standard-deviation negative shock to Taylor-rule residuals results in a 1.35 percentage-point rise in the risky-asset ratio, much smaller than the response from actual monetary policy shock of the same size.

[29]However, the results from the above exercise should be cautiously viewed, since the first-stage regression to obtain the residuals does not take into account any structural breaks. In particular, a shift in the central bank's preference towards output stabilisation during the crisis period is evident, given the large negative shocks hitting economic growth. A change in the central bank governor can also alter the preference. Therefore, at least, parameters β should not be time-invariant. Importantly, the Taylor rule provides only a rough guide to how central bank formulates policy decisions. The whole process should involve a consideration of wider range of macro-economic and financial variables.

by Belsley et al. (2005). Using the above criteria, 235 observations are excluded. Trimmed-sample results are reported in columns 3 and 4. Unsurprisingly, monetary policy coefficients both for the whole sample and the listed banks have much lower magnitude. The estimates for the whole sample become insignificant. However, since the responses of listed banks are significantly larger than those of unlisted banks, the results remain supportive of the identification of the risk-taking channel. The other robustness exercise takes care of outliers from explanatory variables. I drop observations where either the asset size or monetary policy indicator lies within 1-percent upper or lower tail of their distribution. Monetary policy effects have barely changed from the baseline results (columns 5 and 6).

Secondly, I make use of alternative risk-taking indicators, namely the ratio of loans to households and firms to total assets and the leverage ratio. The former still focuses on asset composition. It is a subjective question which types of assets within a bank portfolio should be categorised as risky assets. For robustness, I employ a narrower set of risky assets, exclusively focusing on non-financial loans. That is to say, the risk-taking measure in equation (1.1) and (1.2) is thus replaced by the ratio of loans to households and firms to total assets. The results are shown in columns 7 and 8, where risk-taking channel is found to be more powerful. An increase in the ratio of loans to total assets by almost 1.8 percentage points follows 100-basis-point decline in monetary policy rates. Even unlisted banks significantly alter their risky-asset ratio in response to monetary policy shocks, at the 5 percent level. Nevertheless, using the leverage ratio as the bank risk-taking indicator, the evidence for the risk-taking channel is not found. The leverage ratio, indeed, does not systematically respond to any of the model's explanatory variables (columns 9 and 10). I also try to include a further lag of monetary policy, perform the estimation using a pre-crisis sample, as well as use Taylor-rule residuals as the monetary policy indicator. However, the results do not qualitatively change. I will explore the role of leverage in the risk-taking channel in detail in the next section.

Thirdly, I rerun the regression using variables in first difference. This is to account for potential non-stationarity of certain variables, particularly bank assets which tend to grow over time. Table 1.1 also shows that the median of the risky-asset ratio trends over time suggesting there may be some non-stationarity. For monetary policy, although it fluctuates over the periods considered, one may suspect that it contains unit root.[30] I take first-difference of all variables in the main specification except real GDP growth, which is already in difference form. To account for outliers, I exclude observations where the value of the dependent variable is below or above three standard deviations from its mean. The estimation is executed using Ordinary Least Squares (OLS). This is equivalent to applying first-difference estimation to the main specification (in level). The first column of table 1.15 shows the results using the whole sample. Lagged changes in policy interest rate are negative and significant at one percent level. However, the combined effects across two periods, despite being negative, are only significant at 11 percent level. The decline in significance is mainly due to a fall in the size of the monetary policy effects. The evidence that lower interest rates enhance bank risk exposure is therefore weaker when regression in difference is considered. I still find that higher real GDP growth encourages banks to take more risk. Nevertheless, changes in bank assets are insignificant. Regressing the first-difference specification separately for listed and unlisted banks, the evidence supporting the risk-taking channel can still be found. The risk-taking responses of listed banks are larger in magnitude and are significant at 10 percent level, while those of unlisted banks are not significant. It is to note that the sample size is slightly

[30] In the software STATA, most panel unit root tests are only applicable for balanced panels. The Fisher-type test, which can be applied to the unbalanced dataset, requires long time series. This is not the case for my banking sample, where each bank contains at most 11 years of data. Not only does this make reliable unit root testing infeasible, but any possible co-integration relationship would be almost impossible to test for since co-integration is all about estimating long-run relationships that take time to assert themselves in the data. With around a decade of data, the data span is not enough to know whether those relationships exist or not.

smaller for these first-difference regressions as I lose one period of data.

The fourth column show the results using Taylor-rule residuals, instead of changes in overnight intetest rates. The combined effects of monetary policy on bank risk over two periods remain large and are significant at 10 percent level (column 4). This confirms the finding that policy interest rates that are lower than the level justified by fundamentals incentivise banks to increase portfolio riskiness to a large extent. In columns 5 and 6, I explore alternative risk measures, including changes in the ratio of loans to total assets and changes in the leverage ratio. Using the former, lower interest rates now have statistically significant effects on bank risk-taking for the whole sample. However, when changes in the leverage ratio are used, I find that monetary easing even induces lower bank risk-taking. I provide potential explanation why low interest rates may coincide with low leverage in the next section.

1.5 Additional Results

Based on the main finding that expansionary monetary policy entices banks to take more risk, additional questions follow. (1) Which types of risky assets do banks select when facing with higher risk-taking incentives from low interest rates? (2) Among listed banks, where the risk-taking channel is relevant, do any other bank or market characteristics matter for the extent that banks take risks following monetary easing? Under this regard, I test whether there is a differential risk-taking response for banks across types and markets. (3) Is bank risk-taking accompanied by an increase in leverage, as predicted by the theories? The first and third questions shed light on **"how" risk-taking channel actually works**. I shall work through each of these questions in this section. All the estimations in this section are done using within-group estimators.

1.5.1 The Selection of Risky Assets

It is interesting **which types of risky assets banks invest in when their appetite for risk increases due to monetary easing**. Do they grant more loans to non-financial corporations? Are they inclined to finance consumer loans? Or do they mainly search for shorter-term and more liquid private securities within the capital market? Risky assets can be broadly grouped into five categories: mortgage, corporate loans, consumer loans, private securities, and loans and advances to banks. A major problem in this exercise is that much information is lost due to the unavailability of detailed loan data for a number of banks. To ensure accuracy of the data, I work with bank-year observations where data for all loan categories are reported. This leaves me with 109 banks. Results therefore need to be cautiously viewed since they may not be representative of the whole sample.

I estimate equation (1.1) and (1.2) above with the ratio of each type of risky assets to total assets as dependent variable. We expect to see a significant negative sign on monetary policy coefficients for asset types that banks primarily reallocate their portfolio towards. The results (in table 1.5) suggest that banks increase their risky assets following monetary easing by making **corporate loans** (column 3 and 4). Following a 1-percentage-point decline in monetary policy rate, the share of corporate lending in bank portfolio rises by around 1.5 and 1.8 percentage points for whole sample and listed banks, respectively. Potential explanation in the context of Asian banks may be that corporate loans constitute a large part of the total assets for all countries (see table 1.12 in the Appendix), making them perhaps more approachable through specialisation and relationship lending. Meanwhile, for unlisted banks, the share of all non-financial loan types does not significantly respond to monetary shocks, confirming that the inaction of unlisted banks found in previous aggregate results is not influenced by aggregation effects.

Another interesting result is how the share of private securities evolves following monetary shocks, where it behaves differently for listed and unlisted banks. Whereas unlisted banks hold a much higher proportion of private securities after monetary easing, listed banks even lower it. There is also evidence that both listed and unlisted banks significantly reduce loans to banks after expansionary monetary policy. My interpretation is that, since private securities are relatively liquid while interbank loans are short-term in nature, listed banks may also replace them, like other risk-free assets, to acquire more yield-attractive loans, in the event of low interest rates. Excess supply in the market for private securities is then met by demand from those unlisted banks. So, listed banks actually reduce their holding of private securities and loans to banks to originate additional lending to the real sector, when their appetite for risk rises. Therefore, we find no evidence of banks searching for yield from private securities and interbank loans, as part of the risk-taking channel. However, it is to note that the fact that the ratios of private securities and interbank loans to total assets fall after monetary easing does not imply that their absolute level actually declines. It may be that they do not rise enough compared with total assets, which are boosted by corporate loans origination.

Two issues mean that banks should be attentive to corporate loans. The first issue concerns concentration risk. Corporate lending is usually of large size, and therefore a large portion of loans is distributed to few counterparties or sectors. As a result, if any particular borrowers default on their obligations, banks will incur huge losses. The other issue is the fact that corporate loans are usually unsecured, leaving banks with no recourse in the case of default. However, whether unsecured loans are actually risky is an interesting question. Indeed, under the presence of asymmetric information, those who pledge collateral are likely to be risky borrowers. The question above is therefore entirely an empirical issue.

Table 1.5: The Selection of Risky Assets

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Mortgage		Corporate loans		Consumer loans		Private securities		Loans to banks	
Asset Size	-0.0015	0.000031	-0.043***	-0.038***	0.0088	0.0079	0.024**	0.016*	0.036***	0.039***
	(0.0052)	(0.0049)	(0.011)	(0.011)	(0.0071)	(0.0080)	(0.0100)	(0.0088)	(0.010)	(0.011)
GDP growth	-0.10*	-0.10	0.14	0.15*	-0.030	-0.032	0.081	0.078	-0.19**	-0.19**
	(0.062)	(0.063)	(0.091)	(0.091)	(0.070)	(0.071)	(0.093)	(0.095)	(0.092)	(0.094)
L.GDP growth	-0.090	-0.096	0.36***	0.34***	-0.020	-0.016	0.036	0.093	-0.25***	-0.26***
	(0.065)	(0.065)	(0.086)	(0.086)	(0.067)	(0.066)	(0.077)	(0.083)	(0.088)	(0.089)
Monetary Policy	0.083	0.22	-1.68***	-1.43**	-0.12	-0.21	-0.14	-1.93***	1.41***	1.74**
	(0.20)	(0.22)	(0.38)	(0.61)	(0.24)	(0.27)	(0.46)	(0.73)	(0.40)	(0.68)
L.Monetary Policy	-0.35*	-0.017	0.19	1.47**	0.059	-0.14	0.55	-0.42	-0.086	0.45
	(0.19)	(0.27)	(0.37)	(0.73)	(0.26)	(0.36)	(0.39)	(0.62)	(0.28)	(0.61)
Listed*Monetary Policy		-0.098		-0.012		0.075		2.12***		-0.31
		(0.23)		(0.63)		(0.25)		(0.70)		(0.71)
L.Listed*Monetary Policy		-0.48*		-1.85**		0.29		1.41**		-0.78
		(0.29)		(0.84)		(0.56)		(0.59)		(0.74)
Constant	10.8***	10.1***	43.1***	40.8***	6.82***	7.24***	5.66	8.76***	9.49***	8.31***
	(1.89)	(1.87)	(3.07)	(3.24)	(1.93)	(2.21)	(3.58)	(3.27)	(2.78)	(3.03)
Wald Test										
$\sum MonetaryPolicy_{t-i}$	-0.268	0.203	-1.490***	0.046	-0.058	-0.355	0.404	-2.344***	1.323***	2.192**
	(0.328)	(0.348)	(0.438)	(0.865)	(0.229)	(0.503)	(0.696)	(0.866)	(0.502)	(1.002)
$\sum MonetaryPolicy_{t-i}$		-0.377		-1.817***		0.013		1.187*		1.109**
$+\sum Listed * MonetaryPolicy_{t-i}$		(0.366)		(0.466)		(0.256)		(0.685)		(0.517)
Test the difference between the response of listed versus unlisted banks										
F statistic		2.346		4.275		0.442		17.423		1.090
P-value		0.129		0.041		0.508		0.000		0.299
Observations	340	340	340	340	340	340	340	340	340	340
Groups	109	109	109	109	109	109	109	109	109	109
Adj R^2	0.0245	0.0323	0.208	0.231	0.0203	0.0179	0.0261	0.0917	0.140	0.141

Clustered robust standard errors in parentheses

* p<0.10 ** p<0.05 *** p<0.01

1.5.2 Differential Effects across Different Types of Banks

A popular question among empirical risk-taking literature is to ask **whether there are differential responses in risk-taking behaviour across bank types and markets**. Theoretical predictions by Dell'Ariccia et al. (2010) suggest that the extent of risk-taking channel depends on a bank's capitalisation condition and market contestability. The empirical literature additionally finds a difference in risk-taking responses across bank size, liquidity condition, type of bank ownership and etc, in the non-Asian case. Therefore, in this sub-section, I take a sample of the listed banks, where the stance of monetary policy significantly matters for their risk profile, and investigate heterogeneity across five bank and market characteristics. In doing so, the following specification is estimated:[31]

$$\begin{aligned} RiskyAsset_{i,t} = \quad & \alpha + \beta_1 MonetaryPolicy_{c,t} + \beta_2 MonetaryPolicy_{c,t-1} \\ & + \beta_3 Characteristic_{i,t} * MonetaryPolicy_{c,t} \\ & + \beta_4 Characteristic_{i,t} * MonetaryPolicy_{c,t-1} \\ & + \pi AssetSize_{i,t} + \delta_1 GDPgrowth_{c,t} + \delta_2 GDPgrowth_{c,t-1} + \varepsilon_{i,t} \end{aligned} \tag{1.5}$$

I report the following findings:

Firstly, among a sample of listed banks, **large banks** are more reactive in risk-taking after a change in monetary policy stance than small banks (column 1 of table 1.6). The finding is in contrast to that of Jiménez et al. (2014). Ioannidou et al. (2015) and Boyd and Runkle (1993) argue that better portfolio diversification or "too big to fail" perceptions may entice large banks to assume greater risk. In addition, small banks, with limited access to capital market, are likely to hold liquid assets as a cushion, thereby limiting their motives to take on excessive risk.

[31] Whenever a characteristic variable is continuous, rather than a dummy, the variable itself is also included into specification without any interaction. Since a within-group estimator is used, parameters on time-invariant variables cannot be identified.

There is evidence of a more pronounced response by **highly-levered banks** than well-capitalised ones (column 2). This is inconsistent with the theoretical prediction by Dell'Ariccia et al. (2010), but in line with the empirical findings of Delis and Kouretas (2011) in the case of European banks. The former argue that banks with higher limited liability protection tend to raise risk monitoring to reap gains from lower cost of liabilities, following monetary expansion. The estimates suggest that, for listed banks that hold an average portion of equity capital, a 100-basis-point increase in the interest rate lowers the proportion of risky assets by 0.87 percentage points.[32] Nevertheless, if banks hold less equity, say by 2 standard deviations from its mean, monetary policy effects will increase to around 1.55 percentage points. The interpretation may rely on the presumption that highly-levered banks, with low own fund, are less risk-averse and hence respond more aggressively to monetary shocks.

Legal status also matters for the risk-taking channel, as only **commercial banks** raise their risk profile following monetary easing (column 3), while others even reduce their holding of risky assets (but not to a degree that is statistically significant). This finding narrows down the group of banks where incentives under the risk-taking channel are embedded. We also test differential responses with respect to other bank-level characteristics, such as bank profitability and NPL ratio, but there are no significant results.

With respect to market characteristics, **banks operating in concentrated market**, despite having a lower risk on their portfolio on average, are more aggressive towards monetary policy shocks (column 4). A standardised three-bank concentration ratio represents market contestability in this case. My result shows that banks in a highly competitive market is less reactive. The Wald Test suggests that banks operating in market with average degree of concentration do not significantly respond

[32] In this case, the ratio of equity to total assets, as a characteristic variable, is standardised to ensure that the marginal effect, $\frac{\partial RiskyAsset}{\partial MonetaryPolicy} = \beta_1 + \beta_2 + \beta_4 * L.equity = \beta_1 + \beta_2$ when the equity ratio is at its mean. I also consider the marginal effect when the equity ratio is higher and lower than its mean by two standard deviations.

to monetary policy. Only when the concentration ratio is high enough do banks react significantly. It admit the following interpretations. A "competition-stability" hypothesis by Boyd and De Nicoló (2005) predicts that banks with high market power are likely to end up having riskier portfolios as a result of their incentives to charge high premium on bank loans.[33]

Lastly, it is interesting to test the hypothesis that risk-taking is more pronounced for **banks operating in lightly-regulated environment**. It is shown that private monitoring, which reflects the extent to which regulations facilitate the private sector in monitoring banks, can help limit the extent banks take excessive risks (column 5). Time-invariant standardised private monitoring index, provided by the World Bank, is used as characteristic variable. I describe how the index is constructed in the Appendix. The finding sounds plausible since the index captures the degree to which market or private supervision exists in each country, which is in turn based on the information banks disclose to public (Barth et al., 2004). A high degree of private monitoring can help reduce asymmetric information between banks and their depositors or debtors, thereby abating bank risk-taking.[34]

1.5.3 Excessive Leverage and Bank Risk-Taking

The results from section 1.4.4 show that monetary expansion does not coincide with an increase in leverage. This is against the predominant view among economists and commentators. However, in section 1.2.1, the theoretical literature indeed yields

[33] After all, I doubt the suitability of my concentration measure. Complementary analysis using more sophisticated proxies for banking sector concentration, such as the Lerner Index or the Boone Indicator, would be welcome.

[34] I have also experimented with other regulatory and supervisory indices, for example, supervisory power index, capital stringency index or activity restriction index. Barth et al. (2004) explain how to compute these indices. However, I cannot find beneficial impacts of regulations in abating bank risk-taking during expansionary period. Evidence on the role of regulation in taming risk-taking incentives is found in Maddaloni and Peydro (2011).

Table 1.6: Differential Effects across Different Types of Banks

	(1) Bank Size	(2) Equity	(3) Commercial	(4) Concentration	(5) Monitoring
Asset Size	0.019***	0.024***	0.020***	0.018***	0.016**
	(0.0064)	(0.0058)	(0.0064)	(0.0064)	(0.0062)
GDP Growth	-0.028	0.017	0.086	0.16**	0.0027
	(0.076)	(0.068)	(0.071)	(0.074)	(0.079)
L.GDP Growth	0.30***	0.34***	0.33***	0.36***	0.26***
	(0.072)	(0.067)	(0.070)	(0.083)	(0.071)
Monetary Policy	-0.64**	-0.60**	-0.56	-0.30*	-0.62***
	(0.29)	(0.24)	(0.55)	(0.17)	(0.22)
L.Monetary Policy	-0.34	-0.27	1.68***	0.10	0.019
	(0.25)	(0.19)	(0.63)	(0.16)	(0.21)
Characteristics*Monetary Policy	0.0062		-0.12	-0.43**	0.28
	(0.46)		(0.59)	(0.17)	(0.23)
L.Characteristics*Monetary Policy	-0.44	0.34**	-2.17***	-0.033	0.69***
	(0.41)	(0.14)	(0.64)	(0.14)	(0.17)
Constant	81.6***	79.1***	79.4***	72.8***	81.1***
	(2.57)	(2.33)	(2.51)	(2.24)	(2.54)
Wald Test					
$\sum MonetaryPolicy_{t-i}$	-0.983**	-0.872**	1.119	-0.197	-0.603*
	(0.466)	(0.370)	(0.748)	(0.265)	(0.339)
$\sum MonetaryPolicy_{t-i}$	-1.418**	-0.194	-1.165***	-1.129**	1.343*
$+\sum Characteristics * MonetaryPolicy_{t-i}$	(0.669)	(0.391)	(0.409)	(0.532)	(0.720)
$\sum MonetaryPolicy_{t-i}$		-1.551***		0.735	-2.550***
$-\sum Characteristics * MonetaryPolicy_{t-i}$		(0.527)		(0.590)	(0.742)
Observations	1285	1175	1285	1062	1285
Groups	165	162	165	139	165
Adj R^2	0.128	0.175	0.145	0.242	0.147

Clustered robust standard errors in parentheses

* p<0.10 ** p<0.05 *** p<0.01

Note: for columns (2), (4) and (5), $\sum MonetaryPolicy_{t-i} + \sum Characteristics * MonetaryPolicy_{t-i}$ and $\sum MonetaryPolicy_{t-i} - \sum Characteristics * MonetaryPolicy_{t-i}$ show monetary policy effects when the standardised characteristic variables are higher and lower than their mean by two standard deviations, respectively.

contradicting predictions over how leverage evolves under the risk-taking channel. On one hand, the "leverage channel" argues in favour of the active role of leverage in shaping banks' risk-taking incentives, through moral hazard. Monetary policy expansion makes debt liabilities cheaper and hence encourages banks to take additional leverage. This in turn enhances banks' risk appetite, as they have lower skin in the game. This channel is aggravated when limited liability protection from deposit guarantees is in place. However, we hasten to add that the fact that leverage rises with bank risk-taking does not always imply causal effects of the former to the latter. Excessive leverage may be just a passive reflection (or a result) of bank risk-taking, rather than being part of the causal mechanisms. One may argue that, as banks go searching for yield, they need to leverage up to get more financing. On the other hand, another strand of literature predicts that the leverage ratio actually declines. Monetary expansion may improve "valuation, income, and cash flow", which in turn raise bank net worth and thus lowers bank leverage. As banks become more risk-tolerant by holding more capital, they can afford more risk on their portfolio. It is to note that no countries in the sample set limits on banks' leverage ratio. Therefore, variations of bank leverage are largely determined by their own incentives, though it may partially be influenced by other banking regulations. Only after the subprime crisis, regulators of China (from 2011) and Singapore (from 2013) began imposing leverage limits. In this subsection, I therefore test **whether higher risk-taking by banks following monetary easing is accompanied by excessive leverage**, as is also widely argued among economists and commentators. In other words, I test the significance of the leverage channel as an operating mechanism of the risk-taking channel.

Table 1.7: Excessive Leverage and Bank Risk-taking

	(1)	(2)	(3)	(4)	(5)	(6)
	Risky-asset Ratio			Leverage Ratio		
Asset Size	0.021***	0.019***	0.019***	-0.0054	-0.0052	-0.0049
	(0.0063)	(0.0062)	(0.0062)	(0.0048)	(0.0048)	(0.0051)
GDP Growth	0.063	0.048	0.047	-0.11**	-0.10**	-0.052
	(0.073)	(0.071)	(0.071)	(0.048)	(0.051)	(0.046)
L.GDP Growth	0.39***	0.35***	0.35***	-0.12**	-0.11*	-0.11*
	(0.070)	(0.067)	(0.067)	(0.059)	(0.065)	(0.060)
Monetary Policy	-0.79***	-0.72***	-0.72***	0.46	0.45	0.39
	(0.27)	(0.25)	(0.25)	(0.31)	(0.31)	(0.28)
L.Monetary Policy	-0.14	-0.13	-0.13	-0.028	-0.033	-0.011
	(0.21)	(0.20)	(0.21)	(0.090)	(0.087)	(0.080)
Leverage Ratio		-0.26***	-0.25***			
		(0.100)	(0.080)			
L.Leverage Ratio			-0.031			
			(0.064)			
Equity Growth					-0.010	-0.015
					(0.0092)	(0.0091)
L.Equity Growth						-0.049***
						(0.0095)
Constant	79.0***	83.1***	83.3***	14.3***	14.4***	15.2***
	(2.47)	(2.96)	(3.06)	(1.82)	(1.86)	(1.84)
Wald Test						
$\sum MonetaryPolicy_{t-i}$	-0.925**	-0.854**	-0.850**	0.428	0.421	0.375
	(0.398)	(0.382)	(0.384)	(0.299)	(0.306)	(0.302)
Observations	1172	1172	1172	1145	1145	1145
Groups	162	162	162	156	156	156
Adj R^2	0.125	0.150	0.149	0.0418	0.0459	0.119

Clustered robust standard errors in parentheses
* p<0.10 ** p<0.05 *** p<0.01

The results (in table 1.7) are found to not support the hypothesis. I include the leverage ratio, calculated as the ratio of assets to equity, into equation (1.1) for the listed-bank sample. I find that a higher leverage ratio even corresponds to lower risk-taking (columns 2 and 3), disagreeing with the idea that banks respond to moral hazard incentives. Its contemporaneous effect is significant at 1 percent level. Meanwhile, compared with the baseline results shown in the first column, monetary policy coefficients are only slightly lowered, further confirming that the leverage channel is not an important mechanism where risk-taking incentives originate. One should expect to observe a significant drop in monetary policy coefficients if the channel is a relevant causal mechanism. I go further to explore the relationship between leverage and monetary policy. The regression is similar to one in the robustness section, except that the sample includes only listed banks. Regressing the leverage ratio on the same set of explanatory variables, a positive correlation between leverage ratio and monetary policy indicator is found (column 4); that is, a decline in interest rates corresponds to lower leverage (but the estimates are insignificant). This again contradicts what would be expected under the leverage channel. Controlling for an improvement in banks' equity capital in response to monetary easing, the correlation remains positive (columns 5 and 6).

It therefore appears that there is no evidence that the leverage channel is a driving force in the risk-taking channel. I find the results to be more consistent with Adrian and Shin (2010a)'s proposition. In their model, monetary easing improves banks' net interest margin and net worth, thereby reducing leverage. This explains why a positive correlation between monetary policy and the leverage ratios is observed. And, as capital becomes more than enough to cover Value at Risk (VaR), a surplus capital then allows banks to leverage up and take on additional risk. This clarifies the finding of a negative correlation between the leverage ratios and bank risk-taking. In practice, there is also evidence that commercial banks manage their balance sheets to achieve constant leverage (see Adrian and Shin (2010b)). Therefore, whenever shocks trigger a decline in leverage, banks will demand more debt and expand their assets. Therefore, at this stage, we conclude that the findings are more in favour of the theoretical mechanism proposed by Borio and Zhu (2012), where monetary policy affects valuation, income, and cash flow, and hence bank risk-taking. However, proper empirical strategies are required to ensure this.[35]

Additionally, the results also send a message to the regulatory body. Since bank risk-taking is not always accompanied by an increase in leverage, focusing on leverage as a financial fragility indicator alone can be misleading. Risk can be accumulated on the asset side, even when there is no excessive leverage. The study thus urges regulators to focus on risk measures that evaluate riskiness from the asset side of the bank balance sheet. The risk-taking measure used in this study is in line with this.

1.6 Conclusion

The thesis provides empirical analysis of "whether" and "how" expansionary monetary policy contributes to bank risk-taking in the case of Asia. The aim is to enhance the complete understanding of monetary policy transmission mechanism, particularly its implications for financial stability. To counter misidentification, I propose two new strategies for identification. Firstly, I introduce asset size as a control variable to account for balance sheet adjustments consistent with the credit channel. Secondly, I explore the cross-sectional differences in the risk-taking responses across listed and unlisted banks, where I expect to observe more pronounced risk-taking by listed banks if the risk-taking channel is to be identified. However, the identification strategy is still based on the assumption of homogenous loan demand, so that monetary policy estimates can be interpreted as loan supply differences. I document the

[35] For robustness, I also perform regression in difference. The results are shown in table 1.16 in the Appendix. First, changes in leverage ratio are included into risky-asset ratio regression. They are insignificant and hence do not change the estimates of monetary policy effects. This once again confirms that the leverage channel is not at work as banks take more risk. Second, I focus on the effects of changes in monetary policy on changes in leverage ratio. When equity growth is not included as a control, low interest rate decreases leverage ratio, but the effects are insignificant (like in the level regression). Nevertheless, the introduction of equity growth in the specification reverses the sign of monetary policy effects on leverage, but they remain insignificant. This seems to support the notion that monetary easing lowers bank leverage through an improvement in net worth. I find that equity growth is strongly significant in the leverage ratio regression and explains substantial portion of its fluctuations as reflected by R-squared.

following results in the context of 432 banks in 9 Asian countries during the years 2000-2011.

There is evidence of a "risk-taking channel" being embedded in Asian bank behaviour. Banks are estimated to increase the ratio of risky asset on their portfolios by around 0.8 percentage points after the central bank has reduced monetary policy rate by 100 basis points. This is particularly the case for banks listed on the stock market, while unlisted banks do not significantly respond to monetary policy. The results are found to be robust to the use of instruments under dynamic specification. Additionally, in line with Maddaloni and Peydro (2011), I record a sizable impact of too low monetary policy on banks' risk-taking. For robustness, I show that the specification in first-difference form also supports the existence of the bank risk-taking channel, although the evidence is weaker.

The dataset can be exploited further for additional interesting results. Consistent with other literature, I find that, among listed banks, the extent of the risk-taking differs across banks with different characteristics or operating in different markets. Additionally, I present two new pieces of evidence on "how" the risk-taking channel works. Firstly, I show that banks take additional risk through making loans to firms, rather than purchasing private securities or financing consumer loans and mortgages. Secondly, I reject the "leverage channel" as a key mechanism through which the risk-taking channel works. The latter finding is crucial to the establishment of theories on risk-taking channel which are lack of a unified wisdom.

The thesis offers policy implications to both monetary policymakers and financial regulators. Firstly, my main finding raises awareness that monetary policymakers should be mindful when conducting expansionary monetary policy, as bank risk-taking is expected to follow. The target horizon matters in this case, as financial fragility accumulates over time and entails a negative impact on the economy in the long run, which could be beyond the horizon for which policymakers target inflation and growth. I argue that, to deal with financial stability implications of monetary policy, policymakers have to lengthen the horizon in their forecasting exercises. Macro-economic models that incorporate endogenous bank risk-taking and financial risk indicators would also be useful in policy implementation. Our results are also against political pressure or other incentives to inflate the economy by keeping interest rate lower than warranted by economic fundamentals. If interest rates are kept at too low a level, a sizable threat to bank risk-taking is predicted.

The role of financial regulators also become more important as there may exist trade-offs between inflation and financial stability objectives. Critics still argue against the effectiveness of monetary policy in dealing with financial instability. In this regard, regulatory measures might do a better job in limiting bank risk-taking, by imposing price or quantity restrictions to risky activity. My results also recommend that, in the period of monetary easing, regulatory and supervisory resources should be allocated more to banks that are (1) large, (2) highly-leveraged, (3) commercial, or (4) operating in a concentrated market. Also, strengthening the role of disclosure and private monitoring is a way to abate the agency problem and bank risk-taking.

I propose here several possible extensions of my work. To strengthen the results, it is worth repeating the whole regressions using quarterly data to trace the dynamics of bank risk-taking following monetary easing over the short to long-term. The second one is to employ alternative risk-taking measures. Wherever the data on detailed loan contract or bank lending standard is available, it is important to consider forming a smaller set of banks, but achieving better identification of the risk-taking channel. Thirdly, it may also be useful to expand the set of financial institutions to cover investment banks, finance companies and etc., where incentives to take excessive risk are likely to be more prevalent. A more critical extension is to investigate the economic importance of the risk-taking channel. Will increased risk-taking contribute to significant financial fragility? Competition and innovation have worked to strengthen the role of risk-taking channel. The last extension concerns “how” the risk-taking channel works. More empirical work is required to justify the theoretical propositions. My study has already set a stage for this extension by investigating the role of the leverage channel.

1.7 Appendix

1.7.1 Monetary Policy Regime

Table 1.8: Monetary Policy Regime of the nine Asian countries

Country	Framework	Since	Monetary Policy Indicator Chosen	Note
China	Monetary Targeting	1994	1-year household savings deposits rate	
Indonesia	Inflation Targeting	2005	Interbank overnight rate	Monetary Targeting until Jul 2005
India	Multiple Indicators Approach	1998	Repo rate	
Korea	Inflation Targeting	1998	Base rate	Overnight call rate as a target until Mar 2008
Malaysia	Interest Rate Targeting	Mid-1990s	Interbank overnight rate	A shift in exchange rate framework in 2005
Philippines	Inflation Targeting	2002	Overnight repo rate	Monetary Targeting until Jan 2002
Singapore	Exchange Rate Targeting	1981	Overnight repo rate	
Thailand	Inflation Targeting	2000	1-Day bilateral repo rate	14-day repo rate as a target until Jan 2007
Taiwan	Monetary Targeting	1992	Discount rate	

1.7.2 Data Description

Construction of "Private Monitoring Index"

The private monitoring index is computed in the same way as Barth et al. (2004), which employ it to measure the degree to which regulations facilitate the private sector in monitoring banks. The index ranges from 0 to 1, with higher values indicating more monitoring from private sector. The computation is based on survey

Table 1.9: Data Description

Variable	Description	Source	Time period	Note
Bank-level Characteristics				
Risky Assets	The ratio of risky assets to total assets	Bankscope	2000-2011	See detailed definition in section 1.3.1
Loans	The ratio of loans to total assets		2000-2011	
Private Securities	The ratio of private securities to total assets where private securities are securities other than government securities		2000-2011	
Loans and Advances to Banks	The ratio of loans and advances to banks to total assets		2000-2011	
Cash and Due from Banks	The ratio of cash and due from banks to total assets		2000-2011	
Government Securities	The ratio of government securities to total assets		2000-2011	
Customer Deposits	The ratio of customer deposits to total assets		2000-2011	
Equity	The ratio of equity to total assets, where equity is equal to assets subtracted by liabilities.		2000-2011	Measure of bank capitalisation
Return on Average Assets	The ratio of net income (profit after tax) to total assets		2000-2011	Measure of bank profitability
Impaired Loans (NPL)	The ratio of impaired loans (NPL) to total loans			
Asset Size	Total assets (in local currency and adjusted by each bank's average size over the period studied)		2000-2011	
Leverage Ratio	The ratio of total assets to equity		2000-2011	
Listed	Dummy equal to one if a bank is listed and zero otherwise		2000-2011	
Size	Dummy equal to one if a bank is large and zero otherwise		2000-2011	See footnote
Commercial	Dummy equal to one if commercial bank and zero otherwise		2000-2011	
Macroeconomic and in factors				
Monetary Policy	Average of daily policy interest rates, as specified in table 1.8	Datastream/CEIC	2000-2011	Chinese data is available in monthly frequency.
Real GDP Growth (Annual)	Annual growth of real GDP	WEO	2000-2011	
Inflation (Annual)	The growth rate of yearly-average CPI	WEO	2000-2011	
Real GDP Growth (Quarterly)	Year-on-year growth of quarterly real GDP	CEIC/IMF	2000-2011	For Taylor-rule residuals
Inflation (Quarterly)	Average of monthly inflation	CEIC/IMF	2000-2011	
Real GDP (Quarterly)	Quarterly real GDP	CEIC/OECD/ Oxford Economics	2000-2011	For VAR residuals
CPI (Quarterly)	Average of monthly CPI	CEIC/OECD/IMF	2000-2011	
3-bank Concentration Ratio	Assets of three largest banks as a share of assets of all commercial banks	Financial Structure Dataset	2000-2010	Data for Taiwan is not available.
Taylor-rule Residuals	Deviation of monetary policy rate from Taylor-implied rate	Author's Calculation	2000-2011	
Private Monitoring Index	See detailed construction of the index below	Bank Regulation and Supervision Database	2007	

questions from “Bank Regulation and Supervision Database.” The following questions are quantified according to the answers yes=1 and no=0 and then averaged up to yield the index.

(1) Is subordinated debt allowable as part of regulatory capital? (2) Is an external audit a compulsory obligation for banks? (3) Are financial institutions required to produce consolidated accounts covering all bank and any non-bank financial subsidiaries (including affiliates of common holding companies)? (4) Are off-balance sheet items disclosed to the public? (5) Must banks disclose their risk management procedures to the public? (6) Are bank directors legally liable if information disclosed is erroneous or misleading? (7) Do regulations require credit ratings for commercial banks? (8) Is there an explicit deposit insurance protection system? (9) Does accrued, though unpaid, interest/principal enter the income statement while the loan is still performing?

We use the Database, updated in 2007, where the survey is launched during 2005-2006, the mid point of our study period. The latest version is updated in 2012, but we refrain from using it since it only captures regulatory change in the post-crisis period.

1.7.3 Autocorrelation of Residuals

Table 1.10: Autocorrelation of Residuals

	Whole Sample	Listed Banks	Unlisted Banks
coefficient on lagged residuals	-0.134	-0.169	-0.102
F statistic	68.585	22.196	64.282
p-value	0.000	0.000	0.000

Note: Results show a test for serial correlation in residuals of equation (1.1) using a method proposed by Wooldridge (2010). Residuals are obtained from the first-differenced regression. Under the null of no serial correlation, the coefficient on lagged residuals should be -0.5. Wald test is performed to test the hypothesis.

1.7.4 Descriptive Statistics

Table 1.11: Descriptive Statistics

Bank Balance Sheet and Financial Condition					Macroeconomic Variables				
Variable	mean	sd	min	max	Variable	mean	sd	min	max
Risky Assets	79.2	14.7	9.14	100	Monetary Policy	4.46	3.22	0.18	14.4
Loans	52.1	17.3	0	99.6	Real GDP Growth	5.66	3.23	-2.32	14.8
Private Securities	10.2	9.86	-17.6	85.4	Inflation	3.60	2.96	-0.87	13.1
Loans and Advances to Banks	12.4	13.3	0	98.6	3-bank Concentration Ratio	54.1	19.4	30.1	96.8
Cash and Due from Banks	7.18	10.1	0	97.1	Taylor-rule Residuals	0.00012	0.30	-1.06	1.32
Government Securities	13.5	11.9	0	80.0	Private Monitoring Index	0.69	0.10	0.56	0.88
Customer Deposits	68.6	24.3	0	701.9					
Equity	10.5	18.6	-669.5	100					
Return on Average Assets	0.92	4.48	-174.3	120.0					
Impair Loans (NPL)	5.93	8.50	-0.45	92.6					
Asset Size	106.5	55.1	0.61	659.5					

Note: All bank-level variables but NPL and asset size are expressed as a ratio to total assets. NPL is expressed as a percentage to total loans, while asset size of a bank is demeaned by that bank's average size over the whole period. The maximum deposit-asset ratio of "701.9" is unusual. This happens to only a particular case when a bank records massive negative equity of "669.5" percent to total assets so that deposits are much larger than the asset size. Large negative ROAA can happen when banks record massive losses. However, this is relatively rare. As discussed, outliers in bank-level variables are always excluded.

1.7.5 Share of Each Type of Risky Assets by Country

Table 1.12: Share of Each Type of Risky Assets by Country

	Mortgage Loans	Consumer Loans	Corporate Loans	Private Securities	Loans to Banks
China	5.244	3.368	41.91	13.87	22.24
Indonesia	6.616	7.706	37.01	11.42	6.974
India	3.092	9.553	31.49	4.281	2.587
Korea	5.762	12.71	34.71	10.01	5.854
Malaysia	17.56	14.82	21.01	13.62	2.482
Philippines	5.455	5.033	33.97	7.326	14.76
Singapore	12.69	5.302	29.64	13.42	9.572
Thailand	6.479	23.63	34.10	6.774	8.593
Taiwan	17.22	10.65	30.12	7.912	14.44

Table 1.13: Supplementary Results from Dynamic Panel Model

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Listed Banks		Unlisted Banks		Time effects		More Instruments		Forward Orthogonal	
	OLS	WG	OLS	WG	Listed	Unlisted	Listed	Unlisted	Listed	Unlisted
L.Risky Assets	0.82***	0.56***	0.88***	0.54***	0.71***	0.86***	0.73***	0.85***	0.79***	0.88***
	(0.018)	(0.050)	(0.017)	(0.063)	(0.056)	(0.049)	(0.052)	(0.044)	(0.041)	(0.053)
Asset Size	0.0037	0.011***	0.0033	0.0038	0.0031	0.019**	0.0068**	0.0057	0.0067**	0.0026
	(0.0029)	(0.0037)	(0.0036)	(0.0041)	(0.0062)	(0.0077)	(0.0027)	(0.0042)	(0.0029)	(0.0036)
GDP Growth	-0.047	0.055	0.028	0.00022	-0.21**	0.082	-0.063	0.031	-0.024	-0.012
	(0.049)	(0.075)	(0.071)	(0.079)	(0.11)	(0.11)	(0.064)	(0.063)	(0.064)	(0.069)
L.GDP Growth	0.13**	0.31***	0.13**	0.19**	0.092	0.072	0.088	0.15***	0.12*	0.14*
	(0.056)	(0.061)	(0.063)	(0.086)	(0.10)	(0.10)	(0.062)	(0.057)	(0.063)	(0.075)
Monetary Policy	0.036	-0.25	-0.021	0.28	-0.14	-0.24	-0.18	0.10	0.023	0.22
	(0.22)	(0.16)	(0.22)	(0.27)	(0.26)	(0.31)	(0.16)	(0.22)	(0.23)	(0.27)
L.Monetary Policy	-0.21	-0.24	-0.070	-0.17	-0.23	0.073	-0.17	-0.12	-0.21	-0.15
	(0.22)	(0.26)	(0.21)	(0.17)	(0.20)	(0.16)	(0.14)	(0.11)	(0.23)	(0.25)
Constant	14.5***	34.0***	8.20***	34.9***	0	0	22.3***	10.5***	16.3***	8.30*
	(1.86)	(3.93)	(1.72)	(5.47)	(.)	(.)	(4.72)	(3.60)	(3.67)	(4.85)
Wald Test										
$\sum MonetaryPolicy_{t-i}$					-0.372***	-0.169	-0.352***	-0.020	-0.186	0.072
					(0.137)	(0.171)	(0.121)	(0.141)	(0.118)	(0.188)
Observations	1148	1148	1080	1080	1148	1080	1148	1080	1148	1080
Groups		163		239	163	239	163	239	163	239
Instruments					123	123	144	144	105	105
AR1					0.000	0.000	0.000	0.000	0.000	0.000
AR2					0.049	0.720	0.057	0.807	0.066	0.829
Hansen					0.031	0.265	0.372	0.445	0.038	0.209

Clustered robust standard errors in parentheses. P-value is reported for all specification tests.

* p<0.10 ** p<0.05 *** p<0.01

Table 1.14: Robustness Checks

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Taylor-rule Residuals		Cook's Statistics		1% Outliers at Tail		Loans to Assets		Leverage	
Asset Size	0.016***	0.016***	0.014***	0.014***	0.014**	0.015**	0.013**	0.013**	-0.0057	-0.0057
	(0.0055)	(0.0055)	(0.0038)	(0.0038)	(0.0059)	(0.0059)	(0.0063)	(0.0063)	(0.0035)	(0.0035)
GDP Growth	0.13***	0.12**	0.021	0.015	0.019	0.0090	0.19***	0.20***	-0.0041	-0.0030
	(0.050)	(0.051)	(0.046)	(0.047)	(0.054)	(0.055)	(0.061)	(0.062)	(0.038)	(0.038)
L.GDP Growth	0.31***	0.31***	0.25***	0.24***	0.28***	0.25***	0.44***	0.41***	-0.0075	-0.0010
	(0.054)	(0.053)	(0.051)	(0.050)	(0.060)	(0.058)	(0.072)	(0.072)	(0.036)	(0.034)
MP	-1.14	0.13	-0.15	0.19	-0.36*	0.29	-1.02***	-0.64*	0.12	0.026
	(0.94)	(1.49)	(0.14)	(0.18)	(0.21)	(0.30)	(0.17)	(0.34)	(0.12)	(0.17)
L.MP	-3.29***	-2.38**	-0.30***	-0.27*	-0.43***	-0.30	-0.74***	-0.12	0.035	-0.053
	(0.78)	(1.10)	(0.10)	(0.15)	(0.16)	(0.20)	(0.14)	(0.22)	(0.078)	(0.11)
Listed*MP		-1.80		-0.52**		-0.95**		-0.48		0.13
		(1.86)		(0.24)		(0.37)		(0.37)		(0.22)
L.Listed*MP		-1.28		-0.065		-0.22		-0.95***		0.14
		(1.43)		(0.19)		(0.28)		(0.25)		(0.12)
Crisis*MP										
L.Crisis*MP										
Constant	75.5***	75.6***	79.8***	79.7***	80.6***	80.0***	56.9***	55.9***	13.8***	13.9***
	(1.32)	(1.34)	(1.24)	(1.23)	(1.88)	(1.78)	(1.65)	(1.58)	(1.18)	(1.18)
Wald Test										
Unlisted Banks	-4.435***	-2.249	-0.444	-0.079	-0.789**	-0.008	-1.762***	-0.763**	0.157	-0.027
	(1.527)	(2.349)	(0.182)	(0.229)	(0.318)	(0.385)	(0.236)	(0.341)	(0.152)	(0.211)
Listed Banks		-5.324***		-0.666***		-1.172***		-2.193***		0.247
		(1.820)		(0.234)		(0.396)		(0.270)		(0.180)
Test the difference between the response of listed versus unlisted bank										
F statistic		-3.075		3.574		4.701		10.878		1.206
P-value		(2.935)		0.059		0.031		0.001		0.273
Observations	2600	2600	2365	2365	2565	2565	2557	2557	2554	2554
Groups	432	432	408	408	431	431	427	427	428	428
Adj R^2	-0.130	0.0582	0.0709	0.0738	0.0591	0.0669	0.144	0.159	0.00747	0.00814

Clustered robust standard errors in parentheses. The exception is columns 1 and 2, where bootstrapped standard errors are reported.
* p<0.10 ** p<0.05 *** p<0.01

Table 1.15: Robustness Checks (2)

	(1) Whole Sample	(2) Listed	(3) Unlisted	(4) Taylor Resids	(5) Loans to Assets	(6) Leverage
GDP Growth	0.021	0.086*	-0.038	0.049	0.14***	-0.089**
	(0.038)	(0.046)	(0.060)	(0.037)	(0.038)	(0.044)
L.GDP Growth	0.16***	0.22***	0.12*	0.12***	0.081**	-0.087**
	(0.042)	(0.054)	(0.065)	(0.037)	(0.038)	(0.042)
Change in Asset Size	-0.0065	-0.0029	-0.0083	-0.0088	-0.053***	0.030***
	(0.0071)	(0.0100)	(0.0096)	(0.0074)	(0.0093)	(0.0064)
Change in Monetary Policy	0.048	-0.038	0.18	0.33	-0.29***	0.30**
	(0.10)	(0.13)	(0.18)	(0.54)	(0.10)	(0.13)
L.Change in Monetary Policy	-0.31***	-0.30***	-0.32	-1.73***	-0.40***	0.19*
	(0.099)	(0.11)	(0.20)	(0.56)	(0.097)	(0.11)
Constant	-0.84***	-1.44***	-0.40	-0.68**	-0.22	0.50
	(0.33)	(0.42)	(0.49)	(0.30)	(0.32)	(0.44)
Wald Test						
$\sum MonetaryPolicy_{t-i}$	-0.258	-0.342*	-0.139	-1.399*	-0.692***	0.493**
	(0.158)	(0.195)	(0.278)	(0.775)	(0.145)	(0.222)
Observations	2054	1067	987	2054	2003	2042
Groups	390	162	228	390	383	389
Adj R^2	0.0130	0.0271	0.00441	0.0116	0.0545	0.0129

Clustered robust standard errors in parentheses.

* p<0.10 ** p<0.05 *** p<0.01

Table 1.16: Excessive Leverage and Bank Risk-taking (2)

	(1)	(2)	(3)	(4)	(5)	(6)
	Change in Risky-asset Ratio			Change in Leverage Ratio		
Change in Asset Size	-0.0049	-0.0049	-0.0039	0.028***	0.027***	0.074***
	(0.010)	(0.010)	(0.010)	(0.0086)	(0.0088)	(0.0096)
GDP Growth	0.098**	0.099**	0.095**	-0.11***	-0.12***	0.0085
	(0.047)	(0.047)	(0.048)	(0.029)	(0.030)	(0.027)
L.GDP Growth	0.22***	0.22***	0.22***	-0.0057	-0.013	0.037
	(0.056)	(0.056)	(0.056)	(0.036)	(0.037)	(0.033)
Change in Monetary Policy	-0.11	-0.11	-0.11	0.12	0.12	-0.086
	(0.13)	(0.13)	(0.13)	(0.094)	(0.094)	(0.089)
L. Change in Monetary Policy	-0.32***	-0.32***	-0.33***	-0.0083	-0.0093	-0.023
	(0.12)	(0.12)	(0.12)	(0.079)	(0.078)	(0.068)
Change in Leverage Ratio		0.00085	-0.0084			
		(0.035)	(0.041)			
L.Change in Leverage Ratio			-0.027			
			(0.028)			
Equity Growth					0.0057	-0.0014
					(0.0044)	(0.0051)
L.Equity Growth						-0.093***
						(0.015)
Constant	-1.41***	-1.41***	-1.41***	0.053	0.057	0.014
	(0.44)	(0.44)	(0.44)	(0.28)	(0.28)	(0.19)
Wald Test						
$\sum MonetaryPolicy_{t-i}$	-0.434**	-0.434**	-0.431**	0.109	0.106	-0.109
	(0.203)	(0.202)	(0.203)	(0.144)	(0.144)	(0.134)
Observations	972	972	972	971	971	971
Groups	154	154	154	154	154	154
Adj R^2	0.0282	0.0272	0.0268	0.0214	0.0224	0.413

Clustered robust standard errors in parentheses

* p<0.10 ** p<0.05 *** p<0.01

Chapter 2

Bank Risk-taking in the DSGE Model with Heterogeneous Firms, Endogenous Default and Financial Regulation

Abstract

The objective of the paper is to introduce a model that is suitable for analysing bank risk-taking. The model incorporates heterogeneity across firms, where one type of firms may default on their loan obligation. Default is modelled as a choice variable and, therefore, occurs in equilibrium endogenously. The banks also face capital requirements, which affect the size and composition of their balance sheet. We embed these features into an otherwise standard real-business-cycle model. Endogenous default and capital regulation propagate the effects of a positive productivity and bank capital shock on the real economy. The paper confirms the procyclicality effects of Basel II's capital regulation. The banks also engage in higher risk-taking, as measured by several risk-taking indicators, making their balance sheet vulnerable. The New Keynesian variant of the model supports the existence of the risk-taking channel of monetary policy transmission, i.e. expansionary monetary policy induces banks to increase the portfolio riskiness. Our results suggest the use of countercyclical capital buffers and risky to total asset ratio targeting to mitigate risk-taking. The latter is more effective and leads to lower output losses. Finally, we do not support monetary policy to preserve financial stability.

2.1 Introduction

There is a consensus that prior to the crisis, banks and shadow banks increased considerably their risk-taking. Evidence shows that they took excessive leverage to expand their balance sheet. More importantly, they tended to grant loans to riskier borrowers who were once unsuccessful in their loans application. Once the crisis occurred, the accumulated risks led to a systemic banking crisis, with the failure of many individual financial institutions. Such a phenomenon led policymakers, especially financial regulators, and economists to emphasise the effects of bank risk-taking and the design of a regulatory framework that can best curtail excessive risk-taking. Empirical literature usually relates bank risk-taking with the banks incentive structure, such as managerial compensation, board structure, ownership and etc. The Global Financial Stability Report (GFSR) of October 2014 offers an extensive review of literature. However, a handful of articles offer an insight on the role of macroeconomic factors in contributing to bank risk-taking.

Most of the recent theoretical articles have adopted a partial equilibrium model approach and linked excessive bank risk-taking to continuously loose monetary policy (Borio and Zhu, 2012). Studies within the context of a general equilibrium framework are limited, perhaps due to the emphasis on financial stability rather than business cycle fluctuations. We offer a survey of the literature that is by no means exhaustive. Gertler et al. (2012) attribute higher bank risk-taking to the improved risk perception and the moral hazard problem arising from the Central Bank's implicit role as lender of last resort.[36] The authors focus on risk exposure from increased leverage. They find that whenever banks hold less equity, which might, otherwise, absorb losses, the economy becomes more susceptible to negative shocks. In Angeloni and Faia (2013), banks invest in risky projects and are subject to the possibility of deposit

[36] As the paper introduces the concept of stochastic steady state, changes in the variance of shocks and in the policy reaction function alter risk-taking at the steady state.

runs. They show that monetary expansion and positive productivity shocks enhance bank leverage and risk-taking. The paper supports the use of countercyclical capital buffers and monetary policy that responds to financial indicators.

Our paper is more related to Bhattacharya et al. (2015) and Collard et al. (2017), which focus on bank asset composition rather than just aggregate volume. The former attributes higher bank risk-taking to increased optimism, causing banks to reallocate their portfolio towards assets with high volatility of returns.[37] This makes them vulnerable to upcoming negative shocks. However, returns on the investment alternatives are exogenously determined, which implies that pecuniary externalities on asset returns are ruled out. Meanwhile, Collard et al. (2017) allow capital producers, which are bank borrowers, to select between safe and risky production technology. It is limited liability and deposit insurance that cause excessive bank risk-taking, which can vary over the cycles due to aggregate shocks. They follow a normative approach by studying optimal interactions between monetary and prudential policies.[38] Our paper proposes new arguments for bank risk-taking. We emphasise time-varying default risk of the risky borrowers and capital adequacy ratios of the banks, which can in turn be influenced by standard macroeconomic shocks. We also follow a positive approach as we are particularly interested in how a wide range of policies influence the dynamics of the economy and risk-taking.

The objective of this paper is therefore to set out a model suitable for analysing bank risk-taking. There is no consensus on how to define and model risk-taking behavior. In this paper, we exclusively focus on allocations of bank assets, apart from considering standard risk-taking indicators such as the leverage and credit-to-GDP ratios. As a result, the model requires endogenous investment choices for banks.

[37]Increased optimism means higher probability of good state being realised. Their paper works with three-period endowment model with two possible states in the future. Probability of future good outcome is determined using Bayesian updating, where the probability increases whenever good state has realised.

[38]They propose using capital adequacy regulation to address excessive risk-taking, and consider state-contingent capital requirements to control risk-taking over the cycle.

For simplicity, we introduce limited heterogeneity where banks invest in two different types of firms. One is safe firms with full repayment of loans whereas the other is risky firms that partially default on their debt obligation. Both firms need loans to finance capital investments.[39] Default risks create a finance premium on risky loans. Banks are also subject to capital requirements, which create further cost in extending loans. We embed these features into an otherwise standard real-business-cycle (RBC) model and assess how the two financial frictions, namely endogenous default and capital regulation, affect bank risk-taking. We later extend the model to include nominal rigidities to study the monetary policy transmission and other demand impulses. Macro-prudential measures are then evaluated with respect to their effectiveness in taming bank risk-taking.

Our simulations deliver the following results. The benchmark model identifies two sources of bank risk-taking: a standard positive productivity shock and a positive bank capital shock. The existence of endogenous default, together with its interaction with capital regulation, is shown not only to generate greater procyclicality in aggregate output, but to accelerate bank risk-taking. During the boom periods, lower default risk of loans to risky firms and improvement in banks capital adequacy ratio are key factors leading banks to ease loans standards. We observe a substitution effect as banks replace safe loans with risky loans, which become less risky. The ratio of risky loans to total assets, consequently, rises. On the funding side, they take excessive leverage so as to expand their balance sheet, resulting in an increase in the credit-to-GDP ratio. Without endogenous default, the effects of such shocks on the real economy and bank risk-taking are limited. In particular, we barely observe reallocation of bank assets towards risky investment. More interestingly, the paper confirms the procyclicality effects of Basel-II-type capital regulation. We contribute

[39] The model therefore captures the real world feature that banks, in each working day, face a number of loan applicants, differing in several aspects including their degree of riskiness. Risky borrowers end up paying higher interest rate to compensate for a default risk.

by adding that such a regulation also promote risk-taking. In particular, a decline in risk weight attached to risky loans, resulted from higher expected repayment, enables banks to expand their assets and assume more risk on their portfolio. Our results are compatible with the procyclicality results of Catarineu-Rabell et al. (2005); however, they are derived within a fully fledged dynamic model.

The New Keynesian (NK) variant of the model supports the existence of the risk-taking channel of monetary policy transmission, i.e. accommodative monetary policy shock contributes to higher bank risk-taking. This result concurs with a number of articles, both theoretical and empirical, that attempt to put forward this new concept. In our paper, we do not seek to model the risk-taking channel as an independent channel. However, risk-taking is the product of the functioning of traditional transmission mechanisms. Within the NK framework, we also examine the effects of demand shocks, namely intertemporal preference and investment efficiency shocks, on banks incentive to take risk. We find both shocks produce a significant impact on bank risk-taking, with investment shocks that directly affect loans demand having larger effects.

We find a beneficial role of macroprudential measures in mitigating bank risk-taking. The results support the use of Basel III contingent capital regulation (i.e. countercyclical capital buffers) and a measure that directly targets banks asset composition (i.e. targeting the ratio of risky loans to total assets). With those policies in place, we observe a decline in risky investment and bank leverage. However, there exist adverse effects to the real economy as they constrain bank lending activities. In this regard, we find risky-to-total asset ratio targeting to be more effective, as banks make safer loans and reduce risky lending. This limits the contractionary impacts on overall credit and output. Nevertheless, those two measures are not effective in dealing with intertemporal preference shocks, where we find monetary policy tightening to be a more effective instrument. In addition, we also consider other measures of prudential regulation. Targeting the leverage ratio does not effectively reduce bank risk-taking since banks can readily adjust their capital to achieve the target. Also, it adversely affects safe investments, implying that bank portfolio still consists of a high proportion of risky loans. In addition, this measure exacerbates volatility of output and credit under bank capital shocks. In contrast, raising capital requirements makes the steady state of the economy safer, but generates even greater output procyclicality and increases bank risk-taking.

The NK variant of the model offers some recommendations on monetary policy implementation. First, having macroprudential measures in place can be useful in controlling bank risk-taking that arises from monetary expansion. Therefore, the former can help preserve financial stability whenever the latter is doing its job in securing price stability and full employment. Thus, we believe that macroprudential and monetary policies are complements rather than substitutes. When they are used prudently, they benefit the economy by taming multiple externalities. We hasten to add that we do not recommend employing monetary policy to deal with bank risk-taking problem, as it risks increasing inflation and output volatilites. This is particularly the case for productivity shocks, where prices further deviate from the target, if the policy interest rate rises beyond the level justified by inflation and output growth.

This paper follows a long tradition of modelling financial frictions in macroeconomics. In a seminal paper by Bernanke et al. (1999) (henceafter BGG), by assuming asymmetric information and costly state verification, borrowers finance premium varies with their balance sheet condition. Kiyotaki and Moore (1997), meanwhile, postulate a borrowing constraint, whereby the expected value of the collateral limits the amount of loans available. This paper proposes an alternative friction that is both simple but relevant in explaining business cycles, by directly modelling optimal default decision, which in turn affects the finance premium. Our model can be considered an extension of De Walque et al. (2010), which also feature the banking sector and endogenous default. The key difference is that our model includes firm heterogeneity and thus becomes more suitable for analysing bank risk-taking. In addition, we study macroprudential regulation, while their paper focuses on liquidity injection by the Central Bank.

In modelling default, our paper follows Goodhart et al. (2006). In particular, default arises endogenously due to moral hazard. It exists even when borrowers have sufficient income and assets for repayment, but it increases their utility. However, the presence of default penalty prevents them from defaulting excessively, thereby generating a positive repayment rate. Martinez and Tsomocos (2017) also adopt this modelling device in their DSGE model with money and cash-in-advance constraints to study the interplay between money, liquidity and default. A number of articles, including Kiyotaki and Moore (1997) and Jermann and Quadrini (2012), introduce the possibility of default as a way to motivate financial friction. However, the loans contract is written so that default does not obtain in equilibrium but it is only an out of equilibrium phenomenon. This does not coincide with the empirical evidence that a certain proportion of borrowers, ex post, renege on their loan obligation. A notable exception is BGG that allow for default in equilibrium. Nevertheless, it does not matter for lenders profitability, since the model assumes that they are able to diversify idiosyncratic risks and transfer aggregate risks to borrowers. Our paper allows default to affect banks profits and capital, which in turn matters for bank lending capacity.

In response to the recent global financial crisis, there are attempts to model banks along with some financial frictions in a DSGE framework. Gertler and Kiyotaki (2010) introduce the moral hazard incentive for banks to abscond away with part of the assets. Their net worth therefore matters for credit availability. The model of Meh and Moran (2010) also shows that the financial health of banks affects the propagation of shocks. Christiano et al. (2010) apply BGG's costly state verification argument to banks (instead of households) and further introduce a liquidity (i.e. deposits) production function to model bank funding conditions. Our model follows Gerali et al. (2010) in the way banks are modelled. In particular, they face capital requirements, implying that they are obliged to hold certain amount of capital as a proportion of their total risk-weighted assets. The presence of capital requirements immediately rejects the Modigliani-Miller theorem where capital structure is irrelevant to investment decisions. In this paper, the capital structure affects banks asset size as well as its composition. As mentioned before, capital regulation is another source of the model's propagation mechanism.

In terms of financial regulations, our model addresses the drawbacks of a group of articles that aims to measure their effectiveness. In particular, they fail to introduce endogenous default risk in their framework (see Angelini et al. (2015)). We claim that default is a necessary ingredient in any model assessing capital regulation, since its objective is to absorb losses from unexpected default. Therefore, without default, there is nothing to rationalise the existence of such regulation in the first place. More importantly, the analysis of risk-based capital regulation will be incomplete. According to the Basel II Accord, minimum required regulatory capital varies with the riskiness of assets. Therefore, without default, Basel II's risk-based capital regulation will not be different from BASEL I's standardised approach. Last, our model is enriched with banks portfolio choices, given the presence of firm heterogeneity. Risk-based capital regulation allows for the role of asset substitution as another mean to satisfy capital requirements. Banks may rebalance their portfolio towards safe assets in an attempt to boost their capital adequacy ratio, without having to reduce the size of the balance sheet. This inevitably has implications on bank risk-taking.

This paper will be organised as follow. In the next section, we offer empirical evidence in the US to establish the empirical relevance of bank risk-taking. Section 2.3 describes the benchmark model and characterises equilibrium. Simulation results are shown in Section 2.4, where we emphasise the role of endogenous default and capital regulation in business cycle fluctuations and bank risk-taking. The role of macro-prudential measures in mitigating bank risk-taking are also being assessed. In Section 2.5, we extend the model to include nominal rigidities. Section 2.6 concludes and discusses potential extensions of the model.

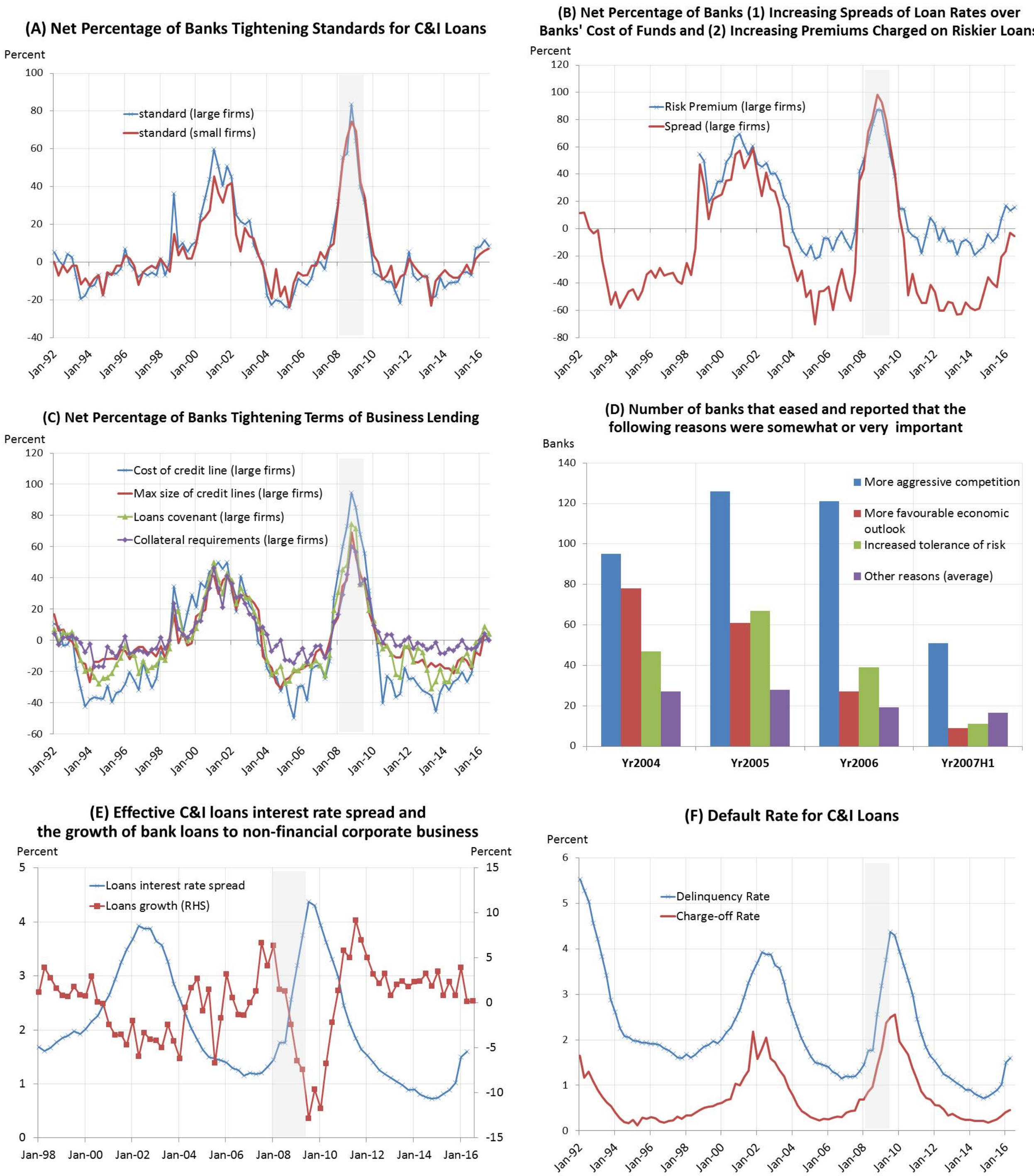
2.2 Empirical Evidence

We begin by examining empirical evidence on bank risk-taking to establish its empirical relevance. In particular, we focus on the development of US lending activity prior to the global financial crisis, when banks (and non-bank financial intermediaries) were claimed to engage in excessive risk. Such circumstance led to the eruption of the crisis, generating a reversal in the appetite for risk. We also estimate a vector autoregression (VAR) model featuring both real and financial sectors to assess how standard macroeconomic shocks affect bank risk-taking incentives. Unfortunately, there is no consensus on the proxy for bank risk-taking. We therefore use here as a proxy a measure of bank credit standards for approving applications for commercial and industrial (C&I) loans or credit lines, available from a Senior Loan Officer Opinion Survey (SLOOS) on Bank Lending Practices. Credit standards summarise both price and non-price terms of credit extension, which may in turn be influenced by banks risk-taking appetite. As argued by Lown and Morgan (2006), asymmetric information suggests the role for credit terms in reflecting risks involved. It is also straightforward to argue that loose lending standards imply higher risk exposure on banks portfolio. Fortunately, the survey has reported reasons why banks decided to ease or tighten standards, enabling us to identify whether bank risk-taking matters or not.

According to panel A of figure 2.1, from 2004 to the first half of 2007, i.e. prior to the crisis, more banks reported that they had eased credit standards for approving applications for C&I loans, signalling an incentive to acquire higher risk on their portfolio. They relaxed standards for both small and large firms. In the second half of 2007, banks began tightening loans standards again as hidden risks were unveiled. The ease of credit standards in a few years prior to crisis is consistent with information regarding credit terms. There is evidence that banks have eased both price and non-price terms for extending loans, namely by reducing the cost of credit lines, increasing the maximum maturity and size of credit lines, easing loan covenant conditions, and reducing the collateral requirement (panel C). Banks also reduced the spreads of loan rates over banks cost of funds while charging lower premium on riskier loans (panel B). Panel D suggests that easing of the credit standards can be identified with bank risk-taking incentives. Despite the fact that the key reason for credit standard easing is related to more intense competition within the financial sector, banks also reported favorable economic conditions and increased risk tolerance to be important factors as well. We see favorable economic conditions as a catalyst for improved risk perception, by affecting both mean and variance of asset returns. Therefore, we conclude that there is evidence of bank risk-taking prior to the crisis.

More quantitative indicators of lending policies, namely the price and quantity of loans, could show the consequences of bank risk-taking discussed earlier. Survey of Terms of Business Lending, in each quarter, reports effective C&I loan interest rates. In panel E, we report them as a spread over the federal funds rate. Consistent with the aforementioned panels, the spread stood below two percent from 2005 to the first half of 2008, before skyrocketing during the crisis. Loans growth from the US financial account is also supportive to increased banks risk appetite. It can be clearly

Figure 2.1: Empirical Evidence



Source: Senior Loan Officer Opinion Survey on Bank Lending Practices, Survey of Terms of Business Lending and the Board of Governors of the Federal Reserve System and author's calculations observed that loans cycle is negatively correlated with the spread, i.e. the spread shrinks during a boom period of loans growth. Real loans growth continuously rose from 2004 and peaked at 8.76 percent in the third quarter of 2007. These pieces of evidence confirm that banks have become more generous in granting loans prior to the crisis. Our theoretical model introduces endogenous default risk as a key parameter that changes incentives of the banks to change their risk appetite. We justify the previous argument by looking at how default risk, the delinquency rate of C&I loans in particular, evolved. It is clear that default is counter-cyclical – low in boom and high in bust. The delinquency rate gradually declined since the beginning of the millennium. In 2004, it stood below 3 percent and then fell below 2 percent from 2005 onwards (panel F). We see such a low default risk as a contributor to bank risk-taking, affecting both the banks risk perception and tolerance.

Figure 2.2 shows the impulse responses from a two-lag VAR with log of real Gross Domestic Product (GDP), log of implicit price deflator, effective federal funds rate, log of C&I loans and net percentage of domestic banks tightening standards for C&I loans to large and middle-market firms. All data are for the US from 1990Q2 to 2008Q2. The starting date for our VAR is dictated by data availability on loans standards. At the same time, we purposely limit our sample to 2008Q2 to exclude the period of financial turbulence. C&I loans are deflated using implicit price deflator. Relying on sign restrictions as exploited in Uhlig (2005), we identify three macroeconomic shocks, namely supply, demand and monetary policy shocks. A demand shock is defined to be a shock which jointly moves output, prices and interest rate in the same direction. A monetary policy shock moves interest rate down and output and prices up. Meanwhile a supply shock causes negative correlation between output and prices and the central bank's policy interest rate responds to stabilise prices. The restrictions are imposed on the impulse responses contemporaneously and two periods after the shock. The restrictions imposed are standard results from any textbook macro models, for instance the IS/LM, AD/AS model. We do not impose any restrictions on the responses of C&I loans and loans standards as we are agnostic about their responses following shocks. We later replace loans standards with (1) net percentage of domestic banks increasing spreads of loan rates over banks cost of funds to large and middle-market firms and (2) delinquency rate on C&I loans, one at a time.

We focus here the responses of the variables that are not sign-restricted.[40] In figure 2.2, a black line shows the median response, while blue lines represent 5th and 95th percentile response. It is to note that the band is not a standard confidence interval, but represents a mixture of sampling and model uncertainty. The results show that, whenever the shocks cause output to rise, banks tend to relax C&I loans standards. That is, of all the accepted draws, there is higher probability that standards are relaxed, rather than being tightened. The standards are persistently loosened in the case of monetary and supply shocks, while banks only ease them for a few quarters following a demand shock. It is to note that the standard variable itself reflects a change of standards from the previous quarter. Therefore a series of negative values implies that banks continuously loosen standards. Likewise, banks tend to decrease the loans spread. However, the evidence of declining loans spread is not strong. The responses of C&I loans quantity should reflect changes of standards, but can also be affected by a number of factors such as endogenous changes in loans demand. Following a demand shock, loans tend to increase and converge back to the initial level after five years. Looser standards may support an improvement in loans quantity in initial periods. However, it seems that, in the medium run, seeing that loans persistently rise, banks turn to become more stringent. This is consistent with the results found in Lown and Morgan (2006). Meanwhile, according to the median

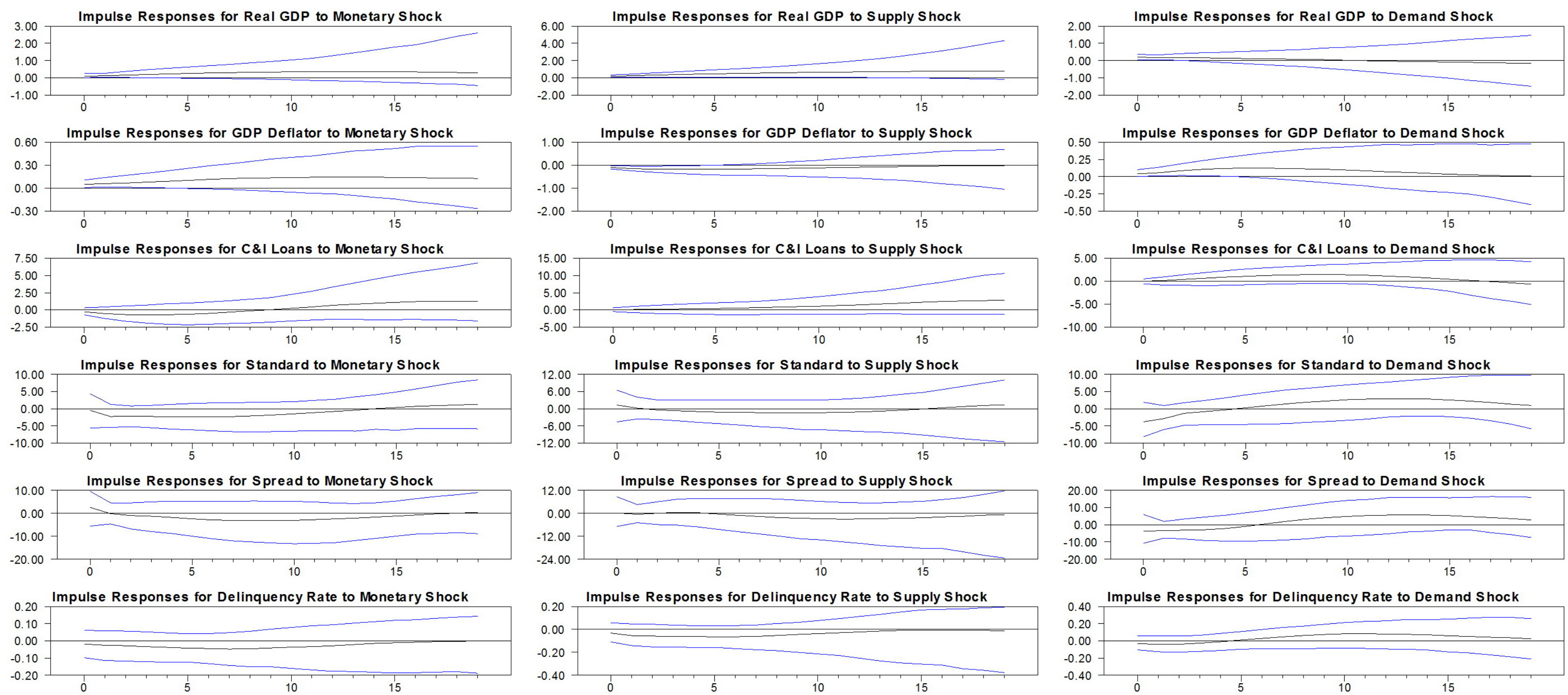
[40] All three models pass the LM autocorrelation test. Coefficients are obtained using Bayesian estimation with inverse Wishart prior. We generate impulse responses from joint draw of VAR coefficients and covariance matrix from posterior distribution and weighting matrix. We aim at 1000 accepted draws (i.e., satisfying a priori restrictions).

estimates, supply shocks lead to an increase in C&I loans after a few quarters. The loans responses tend to be more persistent than those from demand shocks. This is consistent with the fact that standards are kept relaxed for extended period of times. The VAR model, however, performs quite poorly in identifying the effects of monetary policy shocks on loans, particularly when having the responses of standards in mind. We would expect such a shock to improve loans quantity both in the short and medium run. The median results show that loans fall in the early periods, but rise after two years.[41] Finally, we look at the responses of delinquency rates for C&I loans. In response to a demand shock, the response of default closely resembles that of standards and spreads, tending to fall initially before rising. We interpret the finding as the causal reaction of standards and risk-taking to the expected default probability. We also observe that there is a significantly larger probability that default declines after a positive supply shock, which may help explain persistently eased standards and rising loans quantity. The responses of default to an expansionary monetary policy shock are mixed, but it has a slightly higher tendency to decrease.

In sum, the results point towards significant effects of standard macroeconomic shocks on loans standards, which could in turn reflect bank risk-taking and hence have consequences on financial stability. In the next section, we describe our benchmark model featuring price flexibility, where we analyse the effects of supply shocks on bank risk-taking. Our extended model incorporates price stickiness, allowing us to add demand and monetary policy shocks into the analysis.

[41] This paradoxical effect of monetary policy on C&I loans may be due to a possible identification failure. Let, for example, some IS shocks lower output in period t, but a decline in federal fund rate and loans only with lags. They could then be classified as monetary policy shocks and be the reason for the initial fall in C&I loans.

Figure 2.2: Evidence from sign-restricted VAR



Note: the black line indicates the median response, while the blue lines represent 5th and 95th response, based on 1,000 accepted draws (i.e., satisfying a priori restrictions)

2.3 The Benchmark Model

The benchmark model is a standard real-business-cycle (RBC) model with a perfectly competitive banking sector and financial frictions. The model economy is populated by households (θ), two types of firms, namely riskless firms (α) and risky firms (β), and banks (γ). Households supply labor to firms, consume and deposit the rest of their income with banks. The latter combine it with their retained earnings and lend them to firms. We assume that firms require funding to invest in physical capital. They use capital and labor to produce consumption goods. Loans are repaid next period, but are defaultable. This generates a default risk premium, which in turn constitutes firms cost of capital. Loan origination is also subject to Basel II's capital requirements, which require banks to hold certain amount of capital as a proportion of their risk-weighted assets and, consequently, influences the size and composition of their asset portfolio. The possibility of endogenous default and the presence of capital regulation are the two financial frictions of the model. The only real friction available is the presence of investment adjustment costs.

We refrain from introducing other real, as well as nominal, frictions to the benchmark model to focus on the effects of the key features, namely endogenous default, financial regulation and firm heterogeneity, in a parsimonious model with minimal complexity.

2.3.1 Firms ($F \in \{\alpha, \beta\}$)

There is a continuum of firms of measure one. Each firm is either a safe firm α (indexed by i) or a risky firm β (indexed by j). We assume that they do not switch types across periods. The proportion of safe and risky firms in the economy is equal to z and $1-z$, respectively. Firms within the same type are assumed to be identical.

All firms use a combination of physical capital (k_t^F) and household labor ($l_t^{d,F}$) to produce consumption goods (y_t^F), using similar production technology:

$$y_t^F = A_t \left(k_t^F\right)^x \left(l_t^{d,F}\right)^{1-x} \tag{2.1}$$

where, x is the capital share of income. Productivity level A_t is not firm-specific and follows an autoregressive stochastic process:

$$\ln\left(A_t\right) = \rho_A \ln\left(A_{t-1}\right) + \left(1-\rho_A\right) \ln\left(\bar{A}\right) + \varepsilon_t^A \tag{2.2}$$

where, ρ_A represents an autoregressive parameter, $\bar{A}$ is the steady-state productivity level, and $\varepsilon_t^A \sim N\left(0, \sigma_A\right)$ denotes the aggregate productivity shock.

As is standard in the literature, capital is predetermined from the previous period. In order to accumulate it, firms require loans from banks and promise to repay them in the next period. A purchase of new capital is therefore constrained by the amount of loans provided by banks:

$$p_t^k \left(k_{t+1}^F - \left(1-\tau\right) k_t^F\right) \leq \frac{\mu_t^F}{1+r_t^F} \tag{2.3}$$

where, p_t^k denotes the price of capital, and τ measures the depreciation rate of capital. In period t, they choose the amount of capital to be used for production next period, k_{t+1}^F. μ_t^F is the amount of loans promised to be repaid next period, while r_t^F is loan interest rate.

Firm profits (Π_t^F) are proceeds from selling consumption goods less wage payment and repayment of bank loans accrued from the previous period:

$$\Pi_t^F = y_t^F - w_t^F l_t^{d,F} - v_t^F \mu_{t-1}^F \tag{2.4}$$

where, w_t^F is labor wage. The defining feature of the model is the possibility of default, as each firm is allowed ex post to choose the proportion of loans to be repaid (of course, the rest is defaulted!). $v_t^F \in [0,1]$ represents the repayment rate of debt outstanding. The value of one implies full repayment, which is an implicit assumption in most of the macroeconomic models. Default exists when it chooses v_t^F to be lower than one. Such default possibility may arise from asymmetric information, where an ability to repay debt is private information to borrowers. Section 2.3.8 critically assesses this default incentive in detail. Firms do not accumulate net worth and thus rebate the entire profits to their owners.

Each firm of particular type F, therefore, chooses labor demand $l_t^{d,F}$, capital demand k_t^F, loan demand μ_t^F and the repayment rate of accrued debts v_t^F to maximise the following lifetime objective function:

$$E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^{\theta} \left[\frac{\left(\Pi_t^F\right)^{1-a_F}}{1-a_F} - max \left[o, \varphi_t^F \frac{\left(\left(1-v_t^F\right)\mu_{t-1}^F\right)^{1+\phi_F}}{1+\phi_F} \right] \right].$$

$\Lambda_{t,t+k}^{\theta}$ is the stochastic discount factor, to be defined later in the household's optimisation. The objective function comprises present discounted value of profits and default penalty. The firm is assumed to be (slightly) risk-averse to allow for loss-sharing between borrowers and lenders, when encountering unexpected shocks. Under the risk neutrality assumption, which is standard in the literature, it will absorb any unexpected gains/losses, making loan default irrelevant to lenders. a_F denotes the coefficient of relative risk aversion, which takes the same value for both firm types. The second term in the objective function measures default cost, which serves to prevent zero-repayment scenario. In such case, the market for loans would not exist in the first place and equilibrium would not obtain. The default penalty in this model is non-pecuniary, and can be regarded as reputation cost.[42] We as-

[42]The modelling of default follows Shubik and Wilson (1977). The alternative is to model pecuniary default penalty to capture for example the search cost for finding new lenders. See De Walque

sume the penalty to have a convex form, where marginal default penalty rises with defaulted amount $\left(1-v_t^F\right)\mu_{t-1}^F$. ϕ_F denotes the convexity of the default cost function. $\varphi_t^F = d_F \left(\frac{1-v^F}{1-v_t^{F,agg}}\right)^{\varrho_F}$ is the time-varying default penalty parameter. High φ_t^F discourages borrowers from defaulting. d_F, a constant term, may be determined either by financial regulators or the market to reflect the severity of the punishment, or by the firm itself to capture its "morality". Meanwhile, $\left(\frac{1-v^F}{1-v_t^{F,agg}}\right)^{\varrho_F}$ captures the influence of aggregate default conditions on the penalty, where ϱ_F measures the sensitivity. Rising equilibrium aggregate default rate $(1-v_t^{F,agg})$ relative to each firm's steady-state default rate $(1-v^F)$ implies softer punishment for an individual firm. We assume that aggregation is done across all firms of the same type. The default penalty results in a trade-off when borrowers make decision on loans repayment. By choosing higher default rate, although they receive more profits, thereby improving their utility, they face a larger disutility in terms of reputation cost.

The first-order conditions are as follow:

$$w_t^F = (1-x)\frac{y_t^F}{l_t^{d,F}} \tag{2.5}$$

$$p_t^k \lambda_t^F = E_t \Lambda_{t,t+1}^{\theta}\left[x\frac{y_{t+1}^F}{k_{t+1}^F}\left(\Pi_{t+1}^F\right)^{-a_F} + (1-\tau)\,p_{t+1}^k \lambda_{t+1}^F\right] \tag{2.6}$$

$$\lambda_t^F = E_t\left[\Lambda_{t,t+1}^{\theta}\left(1+r_t^F\right)\left(\Pi_{t+1}^F\right)^{-a_F}\right] \tag{2.7}$$

$$\left(\Pi_t^F\right)^{-a_F} = d_F\left(1-v^F\right)\left(\left(1-v_t^F\right)^{\phi_F-\varrho_F}\left(\mu_{t-1}^F\right)^{\phi_F}\right). \tag{2.8}$$

Equations (2.5)-(2.7) show optimal conditions for labor, capital and loans demand, respectively. λ_t^F is the Lagrange multiplier of the constraint (2.3). Loan interest rates have direct impacts on capital and loans demand. Given a symmetric equilibrium, equation (2.8) describes each firm's default decision. The equation equates marginal benefit and cost of default. The left hand side measures marginal benefit of default

et al. (2010).

which increases as firm profits fall. The right hand side shows marginal cost of default.

Now, we are ready to distinguish the two firm types. Heterogeneity arises from the proclivity to default on loans obligation, where one type partially repays its loans while the other does not default. The latter always chooses a repayment rate equal to one, implying that marginal disutility of default is always high enough to prevent borrowers from defaulting. We denote safe firms with α and risky firms with β. It may be that $d_\alpha \gg d_\beta$ such that firms α always conform to their loans obligation. Algebraically, $(\Pi_t^\alpha)^{-a_\alpha} \ll d_\alpha (1 - v^\alpha) \left((1 - v_t^\alpha)^{\phi_\alpha - \gamma_\alpha} \left(\mu_{t-1}^\alpha\right)^{\phi_\alpha} \right) \forall t$. Consequently, in equilibrium, $v_t^\alpha = 1$ while v_t^β evolves according to equation (2.8). In reality, safe firms can be large corporations with high profit margins or ones who are highly concerned about their own reputation.

2.3.2 Capital Producers

The existence of perfectly-competitive capital producers helps model the costs of investment adjustment. They purchase undepreciated capital $(1 - \tau) k_t = (1 - \tau) \left(\int k_t^{\alpha,i} di + \int k_t^{\beta,j} dj \right)$ at price p_t^k from both types of firms and consumption goods i_t from goods market. They combine both components into new capital $k_{t+1} = \int k_{t+1}^{\alpha,i} di + \int k_{t+1}^{\beta,j} dj$, using the following production function:

$$k_{t+1} = (1 - \tau) k_t + i_t \left(1 - \frac{k_i}{2} \left(\frac{i_t}{i_{t-1}} - 1 \right)^2 \right). \tag{2.9}$$

The production of capital goods is subject to an investment adjustment cost, where k_i represents the cost parameter. The new capital is sold back to firms at price p_t^k.

Each capital producer, therefore, maximises $E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^\theta \left[p_t^k \left(k_{t+1} - (1 - \tau) k_t \right) - i_t \right]$, subject to the aforementioned production function. This yields the following capital price equation:

$$1 = \begin{array}{c} p_t^k \left(1 - \frac{k_i}{2}\left(\frac{i_t}{i_{t-1}} - 1\right)^2 - k_i\left(\frac{i_t}{i_{t-1}} - 1\right)\frac{i_t}{i_{t-1}}\right) \\ +E_t\left[\Lambda_{t,t+1}^{\theta} p_{t+1}^k k_i \left(\frac{i_{t+1}}{i_t} - 1\right)\left(\frac{i_{t+1}}{i_t}\right)^2\right] \end{array} . \tag{2.10}$$

2.3.3 Bank (γ)

There is a continuum of banks of measure one. The role of the bank is to channel fund from households to firms. Banks, operating in a perfectly competitive environment, are assumed to be risk averse. a_γ denotes the coefficient of their relative risk aversion. They seek external sources of funds, which are households deposits, and use them together with their equity capital to finance credit extension to firms. The equity capital is essentially made up from retained earnings. They are also allowed to partially default on their deposits. However, this is again subject to a default penalty. Banks choose both the optimal size and allocation of assets, taking into account the default possibility of borrowers. In addition, the model deviates from the Modigliani-Miller theorem as there exist financial regulators who set a rule governing banks capital requirements. The representative bank chooses the amount of loans to each safe firm i ($m_t^{\alpha,i}$) and each risky firm j ($m_t^{\beta,j}$), demand for deposits (μ_t^d), the repayment rate of deposits (v_t^d), and the dividend payment rate (ψ_t^γ) to maximise the following lifetime payoff function (denoting $\Lambda_{t,t+k}^\gamma$ to be the relevant stochastic discount factor):

$$E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^{\gamma} \left[\frac{1}{1-a_\gamma}\left(\psi_t^\gamma \Pi_t^\gamma\right)^{1-a_\gamma} - max\left[o, \varphi_t^\gamma \frac{\left(\left(1-v_t^d\right)\mu_{t-1}^d\right)^{1+\phi_\gamma}}{1+\phi_\gamma}\right] + \omega \frac{\left(\frac{k_t^\gamma}{\bar{k}}\right)^{1-b} - 1}{1-b} - \frac{\mu}{2}\left(\psi_t^\gamma - \psi^\gamma\right)^2 \right]$$

where,

$$\Pi_t^\gamma = \int R_t^{\alpha,i}\left(1+r_{t-1}^\alpha\right)m_{t-1}^{\alpha,i}di + \int R_t^{\beta,j}\left(1+r_{t-1}^\beta\right)m_{t-1}^{\beta,j}dj - v_t^d\mu_{t-1}^d \tag{2.11}$$

and is subject to the following flow of fund constraint:

$$\int m_t^{\alpha,i}di + \int m_t^{\beta,j}dj \leq \frac{\mu_t^d}{1+r_t^d} + e_t^\gamma = \frac{\mu_t^d}{1+r_t^d} + (1-\psi_t^\gamma)\Pi_t^\gamma \tag{2.12}$$

Table 2.1 summarises each bank's balance sheet according to the constraint above.

Table 2.1: Balance Sheet of the Bank

Assets	Liabilities and Equity
Loans to safe firms ($\int m_t^{\alpha,i}di$)	Deposits ($\frac{\mu_t^d}{1+r_t^d}$)
Loans to risky firms ($\int m_t^{\beta,j}dj$)	Equity Capital ($(1-\psi_t^\gamma)\Pi_t^\gamma$)

The first term in the utility function represents the utility from present discounted value of dividends. Π_t^γ is banks gross profits derived from net-of-default loans repayment less net-of-default deposits repayment, where r_t^α, r_t^β and r_t^d are lending rate to safe firms i, and risky firms j, and deposit interest rate, respectively. Loans to risky firms are subject to a default risk, which is reflected in the repayment rate $R_t^{\beta,j}$. Meanwhile, safe firms always comply with their loans obligation, therefore banks anticipate $R_t^{\alpha,i} = 1$. The latter can also partially repay deposits. A decline in v_t^d raises their profits and, hence, utility. However, in the event of default, they face a non-pecuniary default penalty. The penalty is also assumed to be convex in the defaulted amount, where ϕ_γ measures the degree of convexity. $\varphi_t^\gamma = d_\gamma\left(\frac{1-v^d}{1-v_t^{d,agg}}\right)^{\varrho_\gamma}$, which is akin to the case of loans default penalty.

The third term in the utility function represents penalty (reward) when there is a shortage (an excess) of capital relative to the regulatory capital requirements. One the one hand, whenever banks fall short of capital, they have to engage in capital restructuring, which can be costly. Also, the penalty can be interpreted as reputation cost. On the other hand, they benefit from holding capital buffers, as a high amount of capital signals more skin-in-the-game and, thereby, low moral-hazard incentives. High capital also ensures sufficient loss-absorbing capacity. Therefore, whenever banks hold equity capital as a proportion of the risk-weighted assets (k_t^γ) over the requirements $\bar{k}$, they gain utility from doing so, while losing it in the case of failing to satisfy the requirements. The capital adequacy ratio can be defined as:

$$k_t^\gamma = \frac{e_t^\gamma}{rwa_t^\gamma} = \frac{(1-\psi_t^\gamma)\Pi_t^\gamma}{\int r\bar{\omega}_t^{\alpha,i} m_t^{\alpha,i} di + \int r\bar{\omega}_t^{\beta,j} m_t^{\beta,j} dj} \tag{2.13}$$

where, e_t^γ is the amount of banks equity capital, and rwa_t^γ stands for risk-weighted assets. $r\bar{\omega}_t^{\alpha,i}$ and $r\bar{\omega}_t^{\beta,j}$ are risk weight assigned to credit extension to the safe and risky firms, respectively. According to the Basel II regulation, risk weight varies mainly with expected (conditional) default probability of borrowers (PD) and loss given default (LGD). In this model, the default rate, chosen by firms, is more related to the concept of LGD, since it reflects the "amount" of outstanding debt that risky firms will default. Therefore, we assume a linear risk weight function which should closely approximate the relationship between risk weights and LGD, specified by the Basel accord:

$$r\bar{\omega}_t^{\beta,j} = r\bar{\omega}_{min} + \Omega(1 - E_t R_{t+1}^{\beta,j}) \tag{2.14}$$

where, $r\bar{\omega}_{min}$ is the lowest possible level of risk weight assigned to commercial loans, and Ω measures the sensitivity of risk weight to the expected default rate. It is to note that $r\bar{\omega}_t^{\alpha,i}$ will be constant, since safe firms always fully repay their loans in equilibrium. From the risk-weight function above, higher expected default rate implies greater risk weights, and thus more bank capital is required for loans origination. The functional form of the capital regulation penalty above makes it possible that the marginal punishment rises as the capital position deteriorates, while there is a diminishing marginal benefit of holding capital buffers. The latter property may arise from the fact that banks are reluctant to use their own funds, since they are more costly and higher capital implies more skin-in-the-game. Parameters ω and b measure the size of the utility effect from obeying/violating capital regulations.[43]

The last term in the utility function reflects dividend adjustment costs. Banks face a disutility if their dividend rate deviates from the steady state level. The introduction of dividend adjustment costs is due to technical reasons, but can also be justified from an economic standpoint.[44] Paying too high dividends may signal lack of investment opportunities, leading banks to give away more of their profits. In contrast, paying too low dividends may imply that they face losses or liquidity problems.

We thus obtain the following first order conditions. λ_t^γ is the Lagrange multiplier with respect to the constraint (2.12).

$$\lambda_t^\gamma + \omega \left(\frac{k_t^\gamma}{\bar{k}} \right)^{1-b} \frac{r\bar{w}\omega^\alpha}{rwa_t^\gamma} = E_t \left[\Lambda_{t,t+1}^\gamma \left(1 + r_t^\alpha\right) \left[\psi_{t+1}^\gamma \Pi_{t+1}^\gamma\right]^{-a_\gamma} \right] \tag{2.15}$$

$$\lambda_t^\gamma + \omega \left(\frac{k_t^\gamma}{\bar{k}} \right)^{1-b} \frac{r\bar{w}\omega^\beta}{rwa_t^\gamma} = E_t \left[\Lambda_{t,t+1}^\gamma R_{t+1}^\beta \left(1 + r_t^\beta\right) \left[\psi_{t+1}^\gamma \Pi_{t+1}^\gamma\right]^{-a_\gamma} \right] \tag{2.16}$$

$$\lambda_t^\gamma = E_t \left[\Lambda_{t,t+1}^\gamma \left(1 + r_t^d\right) \left[\psi_{t+1}^\gamma \Pi_{t+1}^\gamma\right]^{-a_\gamma} \right] \tag{2.17}$$

$$\left[\psi_t^\gamma \Pi_t^\gamma\right]^{-a_\gamma} = d_\gamma \left(1 - v^d\right)^{\varrho_\gamma} \left(1 - v_t^d\right)^{\phi_\gamma - \varrho_\gamma} \left(\mu_{t-1}^d\right)^{\phi_\gamma} \tag{2.18}$$

[43] See Catarineu-Rabell et al. (2005), Pederzoli et al. (2010) and Repullo and Suarez (2013) for alternative risk weight and penalty functions.

[44] Without dividend adjustment costs and capital requirements, we encounter determinacy problems at the "steady state". The problem arises as there are two equations determining deposit interest rate, one from the households optimisation problem, or the Euler Equation of consumption, and the other from the banks optimisation problem. Given exogenously given discount rates of the two agents, the deposit rate has to ensure constant marginal utility of consumption for both banks and households at the steady state. So, we are left with less equations than unknowns. Introducing dividend adjustment costs and/or capital requirements solves the problem. Moreover, the adjustment cost prevents banks incentive to comply with capital regulation merely through adjusting dividends.

$$[\psi_t^\gamma \Pi_t^\gamma]^{-a_\gamma} = \lambda_t^\gamma + \omega \left(\frac{k_t^\gamma}{\bar{k}} \right)^{-b} \frac{1}{\bar{k}} \frac{1}{rwa_t^\gamma} + \mu \frac{(\psi_t^\gamma - \psi^\gamma)}{\Pi_t^\gamma} . \tag{2.19}$$

Given that firms of the same type are identical, we can drop the superscripts i and j. Equations (2.15) and (2.16) are banks optimal decision to invest in loans to safe and risky firms, respectively. The left-hand side of each equation represents the marginal costs of extending additional loans. The first term captures the tightening of the flow of funds constraint. The second term is the disutility from making capital requirement constraint more binding, as an increase in loans results in a decrease in the capital adequacy ratio. The right-hand side, in turn, represents the marginal benefits of credit extension. Firms repay loans one period after, which improves banks' profits. The marginal benefit depends on "net of default" loan repayment. Equation (2.17) shows the optimal decision to obtain deposits. Assuming a symmetric equilibrium, equation (2.18) shows the deposit default decision. Banks equate the marginal benefit and cost of defaulting. Finally, equation (2.19) shows the first order condition with respect to dividends payment. Paying more dividends directly improves the banks payoff, but generates costs from reduced retained earnings and deviations from the promised dividend payment rate.

We assume that banks face equity capital shocks $\varepsilon_t^\gamma \sim N(0, \sigma_\gamma)$, which are essentially shocks on their profits. Such shocks can be interpreted as changes in banks profits unrelated to net interest income generated from loans to non-financial firms. Potential causes are profits/losses from marketable securities, off-balance-sheet entities and foreign operations. Alternatively, they capture capital injection/withdrawal by policymakers. For simplicity, we assume that the shocks enter the bank profit function (2.11) as an additive term. They are one-off, but can be later shown to have persistent effects on the real economy.

2.3.4 Household (θ)

The representative infinitely-lived household is endowed with a continuum of workers/household members of measure one to be supplied to firms. Each worker can switch firms across periods, but works for one firm at a time. The household decides how many hours each worker supplies $l_t^{s,\alpha,i}$and $l_t^{s,\beta,j}$. Given separable labor disutility, separate labor markets for each firm type are implicitly assumed and so wages can potentially differ across firm types. Using wages received in conjunction with dividends and repayment of previous-period deposits from banks, each household chooses how much to consume, c_t and to save as deposits, m_t^d. It maximises the following lifetime utility function:

$$E_0 \sum_{t=0}^{\infty} \beta_\theta^t \left[\ln c_t + \chi_n \left[\int \frac{\left(l_t^{s,\alpha,i}\right)^\eta}{\eta} di + \int \frac{\left(l_t^{s,\beta,i}\right)^\eta}{\eta} dj \right] \right]$$

where, χ_n is labor disutility parameter, giving the relative weight for utility derived from leisure, and β_θ represents the discount rate. We assume that all laborers transfer their wage income to the household, and that the head of the household decides how much each member consumes. Thus individual consumption is perfectly insured. Each household maximises its lifetime utility subject to the following flow of funds constraint:

$$m_t^d + c_t \leq \begin{array}{c} R_t^d \left(1 + r_{t-1}^d\right) m_{t-1}^d + \int w_t^\alpha l_t^{s,\alpha,i} di + \int w_t^\beta l_t^{s,\beta,j} dj \\ + \int \Pi_t^{\alpha,i} di + \int \Pi_t^{\beta,j} dj + \psi_t^\gamma \Pi_t^\gamma \end{array} \tag{2.20}$$

where, Π_t denotes dividends received from ownership of firms and banks. w_t^α and w_t^β are labor wages. Deposits are subject to default risk. In period t, banks are obliged to repay the amount of $\left(1 + r_{t-1}^d\right) m_{t-1}^d$. However, they may repay only a portion R_t^d of the total debt. Most articles assume away deposit default given the existence of a deposit insurance scheme. However, we view that deposit default captures the probability of a bank failure, which in turn generates a premium for banks financing. In addition, although depositors can reimburse the defaulted amount, the insurance scheme is eventually financed by taxpayers money, implying negative wealth effects on households. Moreover, there usually exists an upper limit on the amount of deposits that the government guarantees.

The first order conditions are shown below, where λ_t^θ is the Lagrange multiplier with respect to the budget constraint:

$$\lambda_t^\theta = \frac{1}{c_t} \tag{2.21}$$

$$\chi_n \left(l_t^{s,\alpha}\right)^{\eta-1} = \lambda_t^\theta w_t^\alpha \tag{2.22}$$

$$\chi_n \left(l_t^{s,\beta}\right)^{\eta-1} = \lambda_t^\theta w_t^\beta \tag{2.23}$$

$$\lambda_t^\theta = \beta_\theta E_t \left[R_{t+1}^d (1+r_t^d)\lambda_{t+1}^\theta\right] . \tag{2.24}$$

Equation (2.21) shows the shadow value of wealth. Equations (2.22) and (2.23) show intratemporal labor supply decision for workers of safe and risky firms, respectively. Equation (2.24) is the standard Euler equation for consumption. Now, we can define the stochastic discount factors for both firms and banks: $\Lambda_{t,t+k}^\theta = \beta_\theta^k \frac{\lambda_{t+k}^\theta}{\lambda_t^\theta}$ and $\Lambda_{t,t+k}^\gamma = \beta_\gamma^k \frac{\lambda_{t+k}^\theta}{\lambda_t^\theta}$. We assume $\beta_\gamma < \beta_\theta$ to ensure steady-state determinacy. This condition implies that banks are less patient than households.

2.3.5 Market Clearing Conditions

Six markets clear in equilibrium:

- Goods market: $\int y_t^{\alpha,i} di + \int y_t^{\beta,j} dj = c_t + p_t^k \left(k_{t+1} - (1-\tau)\, k_t\right)$.
- Two labor markets: (1) $l_t^{s,\alpha} = l_t^{d,\alpha}$ and (2) $l_t^{s,\beta} = l_t^{d,\beta}$.
- Deposits market: $m_t^d = \frac{\mu_t^d}{1+r_t^d}$.

- Two markets for loans: (1) $m_t^{\alpha} = \frac{\mu_t^{\alpha}}{1+r_t^{\alpha}}$ and (2) $m_t^{\beta} = \frac{\mu_t^{\beta}}{1+r_t^{\beta}}$.

One of the market-clearing conditions, say goods market equilibrium, is achieved by Walras' Law. We therefore set good prices as numeraire and measure other prices relative to goods prices.

2.3.6 Rational Expectations

Rational expectation conditions on loans imply that lending agents are correct in their expectations about the fraction of loans that will be repaid.

$$R_t^{\beta} = \begin{cases} v_t^{\beta}; & \mu_{t-1}^{\beta} > 0 \\ arbitrary; & \mu_{t-1}^{\beta} = 0 \end{cases} \tag{2.25}$$

$$R_t^{d} = \begin{cases} v_t^{d}; & \mu_{t-1}^{d} > 0 \\ arbitrary; & \mu_{t-1}^{d} = 0 \end{cases}. \tag{2.26}$$

R_t^{β} and R_t^{d} will be equal to the repayment rate on loans to risky firms and on deposits that will be realised in equilibrium, since agents are all rational. Deviations of actual default rate from its expected value can only result from unexpected shocks.

2.3.7 Characterisation of Equilibrium

The equilibrium is the allocations and prices satisfying equations (2.1) to (2.24), the market clearing conditions for labor, deposits and loans markets, rational expectations, and the relevant transversality conditions.

Proposition 1 (Relative Structure of the Interest Rates). *Assume that (1) the market-clearing conditions hold in deposits $m_t^d > 0$, and corporate loans markets*

$m_t^\alpha, m_t^\beta > 0$ *and (2)* $E_t R_{t+1}^\beta < 1$*. Then, in the equilibrium,* $r_t^\beta > r_t^\alpha > r_t^d$*.*

Proof. See Appendix 2.7.2.

□

In the competitive equilibrium without financial frictions, $r_t^\beta = r_t^\alpha = r_t^d$. Capital regulation and default risk create a premium on loans. Credit extension to both firm types leads to a decrease in the capital adequacy ratio from an increase in risk-weighted assets. This results in a reduction in banks payoffs. Lending rates therefore need to compensate for such disutility factor. Given higher risk weight on risky loans, lending to risky firms leads to a larger fall in the capital ratio than that to safe firms. Consequently, there is stronger compensation for risky lending. On top of this, risky loans are subject to default possibility. Since banks care about their net-of-default return, they price in expected default risk into the interest rates.

Proposition 2 (On-the-Verge Condition)**.** *Equations (2.18) and (2.8) imply that banks and risky firms repayment rate on their loans obligation depend positively on their profits and debt outstanding. That is,* $\frac{\partial v_t^d}{\partial \Pi_t^\gamma}, \frac{\partial v_t^d}{\partial \mu_{t-1}^d}, \frac{\partial v_t^\beta}{\partial \Pi_t^\beta}, \frac{\partial v_t^\beta}{\partial \mu_{t-1}^\beta} > 0$.

Borrowers weigh marginal benefit of defaulting against marginal reputational cost. The former is determined by their profits while the latter by debt outstanding. Given the assumption that borrowers are risk-averse, higher profits mean lower marginal payoff, and thereby less incentive to default. So, rising profits yield a positive effect on the repayment rates. Conversely, during recession, the default rate rises due to high marginal benefit from doing so. Risk aversion is crucial here. If borrowers were risk-neutral, marginal benefit of profits and hence default would be constant. Meanwhile, marginal cost of default rises with due amount of loans. This follows from the assumption of a convex default penalty function. Therefore, as borrowers obtain more loans, they are incentivised to raise the repayment rate. A positive relationship between loans amount and repayment is important in generating countercyclical default rate in equilibrium.

Indeed, there can be the case where borrowers engage in zero delivery since marginal gain from zero delivery is larger than marginal loss from default. However, if agents are rational, lenders will not lend money in the first place. Since firms cannot even replace depreciated capital, their capital erodes over time. Eventually, there would be no production and consumption. We rule out this case from the equilibrium and work with the case where the repayment rate is strictly positive.

2.3.8 On the Endogenous Default

Default exists in this model as a choice variable, where borrowing agents choose the optimal proportion of loans to default. So, it occurs in equilibrium and is compatible with the orderly function of the markets. As in previous articles featuring loans default, it arises from an aggregate moral hazard problem as well as uncertainty. There exists asymmetric information as borrowers ability to repay debt is private information to themselves. They can choose not to conform to loans obligation, even though they have sufficient income/assets to fully repay their loans. We compare and contrast few aspects of default in our paper and BGG, whose default probability also plays a crucial role in determining the finance premium.

First, BGG ensures incentive compatibility, by the existence of a monitoring device that forces borrowers to truthfully reveal their identity. However, this is not without cost and becomes a source of the finance premium. In our model, it is the non-pecuniary default penalty that motivates them to partially repay loans. The penalty does not give any power to lenders to observe borrowers assets, but makes the latter less prone to default. Second, since borrowers optimally choose the repayment rate ex post after realisation of shocks, default in our framework can be regarded as “strategic default”, as opposed to “ill-fortune default” seen in

BGG.[45] In the latter, borrowers choose ex ante probability of default at the time of loans origination (i.e. before realisation of the productivity level), however default is triggered ex post whenever realised productivity level turns out to be low. Default, in their paper, is therefore “semi-endogenous”, and caused by “bad luck” rather than optimising behaviour.

Third, in BGG, a large number of borrowing agents (i.e. entrepreneurs) are required to apply law of large number for lenders to perfectly diversify idiosyncratic risk, while several assumptions are needed to ensure aggregation. Except for their evolving net worth, all entrepreneurs are ex ante similar, particularly with respect to the expected default frequency. Our approach preserves minimal heterogeneity but remains useful in considering distributional, as well as aggregate, impacts. At least, our modelling device allows us to differentiate loans with respect to their riskiness. Different interest rates are established in equilibrium and loans are subject to different regulatory treatment. Finally, BGG assumes that bankrupt firms are removed from the market. We assume, instead, that they still have access to the financial market, only to be punished through a proportional reputation cost.

However, the fact that default in our paper is continuous may be subject to criticisms. One may argue that, in reality, default is discontinuous, as borrowers either repay fully or not at all. However, modelling default as a continuous variable is natural in many aspects. First, despite discontinuous individual default, our measure of default captures average default rates of the entire economy. Even with individual default, banks would anyway force their borrowers to partially repay loans. The repayment may come in the form of foreclosured assets. The latter is related to the concept of collateral default.

To our knowledge, there is another approach to model default on the debt contract as a choice variable. Jermann and Quadrini (2012) make the repayment rate on loans

[45] See Dubey et al. (2005), Goodhart et al. (2006), Shubik and Tsomocos (1990) and Tsomocos (2003) for early modelling of strategic default.

a result of Nash Bargaining. However, the paper eventually assumes non-existence of default in equilibrium. In their model, borrowers make choices between (1) default, consume absconded revenue and die, and (2) partially repay loans and continue operating their firm. The optimal repayment rate depends on various factors, ranging from the value of the firm, its liquidation cost, and relative bargaining power of the two counterparties. This modelling device is in line with the approach used in the study of default and debt reduction of sovereign debt.[46] We view this approach as a potential extension for our paper, since it makes default decision an intertemporal, rather than intratemporal, choice. The value of the firm, which is based on expected future cash flows, becomes important.

2.3.9 Bank Risk-Taking Indicators

The objective of the paper is to construct a model that is suitable for analysing bank risk-taking. In particular, our focus is on ex-ante, rather than ex-post, risk. In Goodhart et al. (2006), financial fragility is defined as increased default and decreased bank profitability. These are, nevertheless, ex-post risks, showing financial-stability implications after loans are settled. Here, we focus on ex-ante bank risk-taking, which involves risk at the point of loans origination and can be a signal for ex-post financial instability. Specifically, banks, or the banking sector in general, that engage in excessive risk ex-ante are likely to be vulnerable when adverse shocks hit ex post. Bhattacharya et al. (2015) show that, when a bad state occurs, banks that have engaged in high risk-taking by investing more in projects with large volatility of returns during good times, will face large profit losses. In Gertler et al. (2012), the economy with higher steady-state bank risk-taking, as signalled by its leverage, will experience a deeper recession. In this paper, we focus on three different risk measures that are plausible in this setup and being considered in policy and academic papers:

[46] See Yue (2010) for example.

1. The ratio of (unweighted) risky loans to total assets ($risk_t^\gamma = \frac{(1-z)m_t^\beta}{zm_t^\alpha+(1-z)m_t^\beta}$)

2. The leverage ratio ($lev_t^\gamma = \frac{zm_t^\alpha+(1-z)m_t^\beta}{e_t^\gamma}$)

3. The credit-to-GDP ratio ($\frac{credit}{GDP}_t = \frac{zm_t^\alpha+(1-z)m_t^\beta}{GDP_t}$).

Let $GDP_t = \int y_t^{\alpha,i} di + \int y_t^{\beta,j} dj$. The leverage ratio is exploited by Gertler et al. (2012) to signal bank risk-taking. Adrian and Shin (2010b) also show that financial intermediaries, particularly security broker-dealer, manage their balance sheet with respect to procyclical leverage. They find that changes in their liabilities forecast the volatility risk premium (or price of risk). Meanwhile, several empirical studies regard the credit-to-GDP ratio as a useful measure to signal financial fragility. Using historical data (1870-2008) from 14 countries, Schularick and Taylor (2012) find that a credit boom over the previous five years raises the probability of financial crisis. Drehmann (2013) also supports the use of credit-to-GDP gaps as an early warning indicator for systemic banking crises. Among these indicators, we exclusively focus on the ratio of risky loans to total assets, as it would best signal risk exposure of the bank portfolio. When the ratio increases, it implies that banks have extended a higher proportion of loans that are defaultable on their portfolio, making them fragile to negative shocks. The other two indicators provide us no information regarding asset quality and riskiness. The ratio can be conveniently computed in this model, but not from others that do not assume asset heterogeneity. In empirical studies, Delis and Kouretas (2011) exploit it as a risk measure.[47]

[47] Apart from these three indicators, Adrian and Shin (2010a) advocate that policymakers should monitor financial intermediaries' total assets, that are readily marked-to-market. They find that balance sheet quantities reflect their risk capacity and appetite.

2.4 Simulation results

This section identifies two sources of bank risk-taking. The results show that, with endogenous default and capital regulation in place, a standard positive productivity shock not only results in economic expansion, but also higher risk-taking within the commercial banking sector. In addition, a shock originating in the banking sector, namely a bank capital shock, despite being one-off, has persistent effects on both the real economy and the financial sector. Based upon these results, we study the effectiveness of financial regulations in mitigating bank risk-taking.

2.4.1 Parameterisation

We obtain most of the parameter values through calibration. We ensure that the steady-state value of certain endogenous variables is consistent with the observed US data. Based on the data from the year 1985 to 2014, the quarterly charge-off rate on C&I loans averages at 1.01 percent. We therefore target the steady-state default rate of risky loans at 1 percent. Following De Walque et al. (2010), based on the number of bank failures, the steady-state default rate of deposits is targeted at 0.5 percent. We aim the steady-state deposit interest rate at 0.7 percent (or 2.8 percent in annual term). From the Euler equation for consumption, the implied discount rate for households equals 0.998. The value is close to that estimated by Smets and Wouters (2007). We target the safe loan interest rate at 1.40 percent to match the historical value of prime rate posted by a majority of the top 25 insured commercial banks, which averages at 6.75 percent annually.

Table 2.2: Parameterisation

Description	Symbol	Value
Discount factor for household	β_θ	0.998
Discount factor for banks	β_γ	0.846
Coefficient of risk aversion for firms	a_α,a_β	0.010
Coefficient of risk aversion for banks	a_γ	0.010
Preference on leisure	χ_n	5.491
Capital intensity	x	0.360
Depreciation rate of capital	τ	0.025
Default penalty parameter on deposits	d_γ	1.125
Default penalty parameter on risky loans	d_β	3.223
Convexity parameter of banks' default penalty function	ϕ_γ	0.010
Convexity parameter of risky firms' default penalty function	ϕ_β	0.200
Default penalty parameter on deposits	ϱ_γ	0.008
Default penalty parameter on risky loans	ϱ_β	0.190
Parameter on capital violation penalty function	ω	0.003
Parameter on capital violation penalty function	b	3.000
Risk weight function parameter	Ω	30.00
Risk weight on safe loans	$r\bar{\omega}^\alpha$	0.500
Minimum risk weight	$r\bar{\omega}_{min}$	0.500
Regulatory capital requirement	k	0.080
Dividend adjustment cost parameter	μ	18.00
Target for dividend payment rate	ψ^γ	0.215
Proportion of risky firms	z	0.500
Investment adjustment cost parameter	k_i	1.00
Labor disutility parameter	η	1.250
Shock persistence	ρ_A	0.900

Based on the Basel Accord, the regulatory capital adequacy ratio is equal to 8 percent. We set the risk weight on safe loans at 50 percent. Under Basel's standardised approach for the calculation of minimum capital requirements, the figure is consistent with a risk weight for claims on A+ to A- corporates. Likewise, risk weights on risky loans are targeted at 80 percent, which is an intermediate risk weight according to such approach. The risk weight for safe loans can indeed be as low as 20 percent but that would lead to too large risky-safe loan spread at the steady state. We obtain the implied value for Ω equal to 30. Given the information above, we can calculate the steady-state interest rate on risky loans equal to 2.85 percent.

This implies a value of ω equal to 0.54. For the sake of simplicity, we assume the steady-state capital adequacy ratio at the regulatory level. To achieve this, the implied dividend payment rate has to be at 21.53 percent. The dividend adjustment cost parameter is set equal to 10. The value is high enough to ensure that banks do not rely too much on dividend payment to satisfy capital requirement. The implied discount factor for banks is 0.846. Since the steady-state capital adequacy ratio is exactly at the regulatory level, parameter b is left undetermined at the steady state. We set its value equal to 3 which ensures that the response of interest rate spreads to deviations of the capital ratio from the regulatory requirement is not too large.

We obtain a few parameters, including ϕ_β and ϱ_β, through estimation. From equation (2.8), we take logarithms and obtain $\log\left(1 - v_t^\beta\right) = \frac{-\log(d_\beta) - \varrho_\beta \log\left(1-v^\beta\right)}{\phi_\beta - \varrho_\beta} - \frac{a_\beta}{\phi_\beta - \varrho_\beta}\log\left(\Pi_t^\beta\right) - \frac{\phi_\beta}{\phi_\beta - \varrho_\beta}\log\left(\mu_{t-1}^\beta\right)$. Charge-off rates on C&I loans are used as a proxy for risky firms default rate. For profits and loans, we rely on the data from US financial accounts. For the former, we use growth of income (before taxes) of non-financial corporate business. Meanwhile, growth of depository institution loans to non-financial corporate business proxies debt outstanding. Estimating the equation above by OLS using the data from the first quarter of 1985 to the second quarter of 2016, we obtain the elasticity of firms default rate with respect to their profits and the due amount of loans. Setting risk-aversion coefficient for firms at 0.01, we can derive ϕ_β and ϱ_β equal to 0.20 and 0.19, respectively. The low value of risk-aversion coefficient preserves significant responses of the economy in the presence of shocks. We assume that banks are as risk averse as firms, so their risk-aversion coefficient is similar. We set ϕ_γ and ϱ_γ equal to 0.010 and 0.008, respectively. To target the steady-state default rates at the previously specified level, the implied default penalty parameter for deposits d_γ and loans d_β equal 1.125 and 3.223, respectively.

As is standard in the literature, we set the depreciation rate of capital and the capital share of income at 2.5 percent and 36 percent, respectively. The steady-state

Table 2.3: Endogenous Variables and Important Ratios at the Steady State

Variable	Value	Variable	Value	Variable	Value
v_t^d	0.995	y_t^α	1.067	ψ_t^γ	0.215
v_t^β	0.990	y_t^β	1.025	$r\bar{\omega}_t^\beta$	0.800
r_t^d	0.007	l_t^α	0.250	$\frac{\sum i}{GDP}$	0.328
r_t^α	0.014	l_t^β	0.242	$\frac{c}{GDP}$	0.672
r_t^β	0.0285	k_t^α	14.07	$\frac{\sum wl}{GDP}$	0.640
m_t^d	0.325	k_t^β	13.33	$\frac{\sum \Pi^F}{GDP}$	0.027
m_t^α	0.352	k_t^γ	0.800	$\frac{\psi^\gamma \Pi^\gamma}{GDP}$	0.005
m_t^β	0.333				

Table 2.4: Risk-taking Measures at the Steady State

Measure	Value
The ratio of risky loans to total assets $\frac{(1-z)m^\beta}{zm^\alpha+(1-z)m^\beta}$	0.487
Leverage ratio $\frac{zm^\alpha+(1-z)m^\beta}{e^\gamma}$	19.35
Credit-to-GDP Ratio $\frac{zm^\alpha+(1-z)m^\beta}{GDP}$	0.328

productivity level is normalised at one. We set investment adjustment cost parameter (k_i) equal to one. For households, the weight of leisure in their objective function is chosen at 5.491 to obtain the steady-state hours worked at safe firms equivalent to one-fourth. Finally, we assume equal proportion of firms from each type. Table 2.2 summarises all the parameter values, while table 2.3 shows the steady state value of some endogenous variables and important ratios. Higher cost of borrowing facing risky firms implies lower steady-state value of their labor demand, capital demand and output produced, compared with safe firms. Table 2.4 shows the value of bank risk-taking indicators at the steady state. The ratio of risky loans to total assets is equal to 48.65 percent, while the ratio of credit to GDP equals 32.75 percent. Bank assets are almost 20 times its equity capital, as suggested by the leverage ratio.

2.4.2 Shock Experiment

2.4.2.1 Productivity Shock

This first simulation shows the effects of a 1-percent increase in the aggregate productivity level on the real economy and banking sector (black solid line in figure 2.3). A positive productivity shock can represent a loans demand shock, as it improves marginal productivity of capital. We observe a significant rise in bank credit. However, the equilibrium responses of loans differ considerably across the two firm types, where only loans to risky firms rise. Their profits fluctuate over the course of a productivity boom. On impact, they increase due to higher sales. However, in subsequent periods, they fall below the steady state level due to high level of debts from capital accumulation. Only safe firms enjoy higher profits in the medium term as a shock subsides.

The repayment rate for risky loans improves. On impact, a surge in profits reduces marginal benefit of default. In subsequent periods, lower default rate is attributed to high loans demand, which raises marginal cost of default. Risk premium on risky loans consequently falls, providing a further boost to risky lending. An unexpected increase in risky firms loans repayment also, on impact, boosts up bank profits and, hence, their capital. Furthermore, improved future repayment rate implies reduced risk weights on risky loans, prompting a decline in risk-weighted assets. All these contribute to a rise in the capital adequacy ratio, which enables banks to relax their lending standards further. Loan-to-deposit interest rate spreads shrink. The low risk weight keeps the capital ratio above the steady state for extended periods despite the fact that bank capital falls considerably. At the same time, banks default less on their deposits. This lessens cost of deposits, but to a smaller extent. A positive productivity shock has positive effects on the real economy. Output, investment, labor demand and wages all respond positively. Consistent with the above, rising output is attributed primarily to risky firms.

All the indicators point towards higher bank risk-taking. There is an increase in the leverage and credit-to-GDP ratios, which peaks after a year. Given that banks have become more generous to risky firms due to the improved risk perception and tolerance, the ratio of risky loans to total assets rises, implying that an increasing proportion of loans becomes defaultable.

Default Multiplier This subsection highlights the role of endogenous default and capital regulation in generating greater output procyclicality and bank risk-taking. We intend on establishing their quantitative importance. In particular, we show that, without endogenous default, evidence of bank risk-taking is much more limited. Figure 2.3 compares the responses of three different economies, facing equivalent positive productivity shocks. The blue crossed line shows the responses of the economy assuming exogenous default, where both banks and risky firms default at exogenously-given rate every period (Exo Default); the red dashed line the responses of the economy assuming endogenous default but adopting Basel I capital regulation where risk weight is time-invariant (Basel I); the black solid line the responses of the benchmark economy (Benchmark) already discussed above.

The figure shows that the responses of GDP and bank risk-taking measures are the most pronounced in the Benchmark case, implying a large contribution from endogenous default. Without it (i.e. in Exo Default case), despite asset expansion, banks maintain almost the same proportion of risky loans on their portfolio. Safe loans increase from the steady state to the same extent as risky counterparts. Leverage rises on impact but gradually declines over time. Their capital adequacy ratio falls as they grant more loans to firms, prompting them to raise, rather than lower, spreads between loan and deposit interest rates. This slows down loans demand. In Basel I case, default adjusts over the cycle, but does not affect risk weights in the calculation of minimum capital requirements. Banks now anticipate lower default risk by risky firms. They slash the risky-safe loans spread. Lending to safe firms indeed declines from the previous case, since banks substitute towards risky projects. We can observe evident rise in risk-taking indicators, particularly the ratio of risky loans to total assets. A surge in the leverage ratio also becomes more persistent, while the balance sheet size expands further. However, the capital ratio worsens. Capital regulation in the first two cases therefore acts as economic stabiliser, as it induces higher credit spreads. Moving towards the Benchmark case, we find that the impacts on GDP and bank risk-taking from allowing risk weight to respond to improved loans repayment are non-negligible. Reduced risk weight has kept the capital ratio higher than the steady state, allowing banks to persistently originate more loans. Safe loan-deposit spread is shrinking in this case. Banks are encouraged to take excessive leverage, as the overall riskiness of their balance sheet decreases. We also observe a large increase in the proportion of risky lending, since it becomes even less costly in terms of capital regulation penalty. This is reflected in shrinking risky-safe loans spread. As stated above, such a substitution effect is so strong that safe loans even fall below the steady state, despite the initial boost from improved productivity. In sum, in the Benchmark model, the interplay of endogenous default and capital regulations enhances procyclicality.

We argue that there exists what we shall call a "default multiplier" that amplifies and propagates the effects of a positive productivity shock on the economy. The first round effect of the shock is obviously to raise risky firms repayment rate. This improves bank lending activities through the channels described earlier. Higher loans then result in larger marginal cost of default, causing risky firms to consider repaying even more. This reduces risk premia and improves banks capital ratio further. They consequently lend more to firms, which makes the latter default even less and so on. The existence of endogenous default on deposits can generate the same multiplier effect on deposits repayment, deposits demand and hence the supply of loanable funds. All these explain why we observe pronounced responses of GDP and bank risk-taking in the Benchmark economy, over the course of the productivity boom.

Endogenous default in this model therefore provides another approach in modelling the financial accelerator.[48] It captures the well-known balance sheet channel, introduced in Bernanke and Gertler (1989). As opposed to previous articles, this paper explicitly models optimal default decision, which is affected by borrowers profitability and the size of their balance sheet. The results above also support the "Procyclicality of the Basel II Capital Regulation", discussed in Catarineu-Rabell et al. (2005) and Repullo and Suarez (2013). In good times, banks capital adequacy ratio improves, which allows them to take more leverage and risk-taking. Although holding adequate capital implies better loss-absorbing capacity, this procyclicality issue has made such a regulation a propagating source of economic fluctuations. This has triggered the idea of introducing the capital requirement that can vary over the business cycles.

2.4.2.2 Bank Capital Shock

Figure 2.4 examines the effects of a one-off increase in bank profits, causing 1-percentage-point rise in the capital adequacy ratio in equilibrium. We first note that the shock is small relative to the size of the balance sheet, given that bank capital is roughly 5 percent of the total assets. However, we show that it has meaningful effects on both financial and real sectors. A positive bank capital shock, which has a first-order impact of relaxing the capital regulation constraint, can represent a loans supply shock. In particular, improving capital ratio lowers the marginal cost of granting more loans, precipitating a decline in interest rate spreads. Banks cut

[48]Early seminal contributors are BGG and Kiyotaki and Moore (1997). In the former, endogenous changes in borrowers balance sheet conditions, which influence the external finance premium, generate the accelerator effect. In the latter, endogenous variations in asset prices vary the collateral values, thereby affecting the quantity of credit available.

interest rates by more for risky loans, whose marginal disutility from capital regulation penalty is initially higher as discussed in proposition 1. This induces them to increase the risk of their loans portfolio. Reduced credit spreads imply lower net interest margin, which poses negative impacts on bank profits in the subsequent periods. However, profits and hence capital remain higher than their steady-state level for a certain number of periods since banks can still generate profits from asset expansion. This explains a persistent decline in both spreads.

We observe again that loans to safe firms fall, while those to risky firms increase. The latter benefit from improvement in their loans repayment rate. On impact, rising product sales enable them to repay more. In the subsequent periods, lower default rate is brought about by higher marginal cost of defaulting from surging loans demand. Declining default risk decreases their loans risk premium. At the same time, it lowers the risk weights imposed on risky loans, which further relaxes the capital regulation constraint. Again, the default multiplier is in action, which enhances procyclicality and bank risk-taking. More important is a fall in deposits default, which is of a large magnitude. The fact that banks earn more profits ameliorates the marginal benefit from defaulting. They then face reduced deposit interest rate and, hence, demand more loanable funds.

The real sector benefits from eased lending conditions. Firms accumulate more capital, causing an increase in GDP. A bank capital shock also has implications on financial stability. The size of the bank balance sheet and the credit-to-GDP ratio expand. Banks become more vulnerable as higher proportion of loans is granted to risky borrowers, as signaled by increasing risky to total asset ratio. However, the leverage ratio shrinks as bank assets do not rise enough to offset the improvement in capital. In sum, such a shock encourages banks to enhance their risk appetite. Figure 2.4 also shows the significance of endogenous default and the underlying default multiplier. A surge of GDP in the Benchmark case is significantly bigger than that in the Exo Default case, particularly in the short run. In the latter, we also observe a bigger decline in the leverage ratio, as banks do not lend as much. This limits the rise in the ratio of risky loans to total assets as well as the credit-to-GDP ratio.

Recent literature has emphasised the role of shocks originating in the financial sector on economic fluctuations (See, for example, Jermann and Quadrini (2012); Gerali et al. (2010)). The results here are consistent with their finding that financial shocks are crucial driving forces. However, our model also sheds light on banks risk-taking behavior, with emphasis on the endogenous default channel. In addition, if bank capital shocks are regarded as capital injection/withdrawal by the Central Bank, the results here suggest the potential real economic effects of those unconventional policies employed during the recent global financial crisis. But this may come at the expense of financial stability.

2.4.3 An Analysis of Macro-prudential Regulations

The previous section has shown that, with endogenous default, the economy falls into a worse bank risk-taking regime in response to certain types of shocks. Since the banking sector becomes vulnerable to upcoming negative shocks ex post, this section considers the impacts of macro-prudential measures in abating bank risk-taking ex ante. In particular, we examine four different measures, including (1) counter-cyclical capital buffers (2) targeting the leverage ratio (3) targeting the risky-to-total-asset ratio and (4) raising the (non-contingent) capital requirement.

2.4.3.1 Tools

(1) **counter-cyclical capital buffers** this first regulation, introduced in the Basel III regulatory framework, links minimum capital requirement to credit conditions. In particular, banks are required to hold additional capital in the event of excessive

credit-to-GDP ratio. The regulation aims to ensure that the banking sector has adequate capital to support real economic activity when it faces with negative shocks, that follow a series of positive ones, which induce higher appetite for risk. For simplicity, we refrain from modelling the discontinuity, but relate the required capital ratio linearly to deviations of the actual credit-to-GDP ratio from its steady state level:

$$\bar{k}_t = 0.08 + \Phi \left(\frac{credit}{GDP}_t - \overline{\frac{credit}{GDP}} \right) \tag{2.27}$$

where, $\overline{\frac{credit}{GDP}}$ is the steady state level of the credit-to-GDP ratio, and Φ measures the elasticity of the requirement. The regulatory capital ratio rises (declines) whenever the equilibrium credit-to-GDP ratio exceeds (falls short of) its steady state level. We note that we will set the value of the parameter Φ higher than its value in reality for the sake of an illustration.

(2) **targeting the leverage ratio** This is another measure proposed in the Basel III regulatory framework. During the global financial crisis, banks build up excessive leverage, while remain satisfying the risk-based capital requirements. When they are forced to deleverage, that leads to adverse consequences on asset prices and credit availability. Hence, this regulation is intended to complement risk-based requirements in mitigating leverage-taking. In reality, a minimum requirement of leverage, defined as the ratio of capital to total exposure, is set at 3 percent.[49] However, for simplicity, the measure is introduced into this model as a quadratic (reputation) penalty function subtracted from banks payoff function, $\frac{\Psi}{2}\left(lev_t^{\gamma} - \overline{lev^{\gamma}}\right)^2$. Banks are penalised whenever the leverage ratio deviates from the steady state level. A quadratic function that is basically mean reverting ensures that marginal cost of deviation rises as the ratio deviates further away. It is straightforward to rationalise a penalty from taking excessive leverage. However, disutility from too low leverage

[49]Note that we define leverage in this paper as the ratio of assets to capital. Also note that our parameter calibration results in an equilibrium leverage ratio that well satisfies the Basel III minimum requirement.

may result from banks' own incentive to leverage up so as to invest more. Adrian and Shin (2010b) empirically find that commercial banks appear to target constant leverage, so it is to some extent valid to assume penalty when the leverage ratio deviates from certain level. Ψ represents the disutility parameter, whose calibrated value ensures significant effects of regulation on the economy and model convergence too.

(3) **targeting the risky to total asset ratio** unlike the first two regulations, this measure exclusively focuses on allocation of bank assets. While capital and leverage regulations mainly ensure that banks have adequate capital as a cushion for future potential losses, this policy limits risk exposure on their assets in the first place. Like the leverage ratio targeting, we assume that a quadratic penalty function, $\frac{\Upsilon}{2}\left(risk_t^{\gamma} - \overline{risk^{\gamma}}\right)^2$, is imposed on bank payoffs. Again, both upside and downside deviations from the steady state level are penalised. We rationalise the penalty imposed on downside deviations by assuming that the government cares about distributional impacts from too low amount of loans to risky firms, which are usually small and medium enterprises (SMEs). Υ represents the disutility parameter.

(4) **raising the (non-contingent) capital requirement** We assume that financial regulators raise the regulatory capital ratio $\left(\bar{k}\right)$ by one-percentage-point from 8 to 9 percent. It is to note that only this measure impacts the steady state of the economy. We expect that the measure will make it more costly for banks to originate loans, especially to risky borrowers, thereby reducing their incentive to expand assets and take excessive risk.

Calibrated Policy Parameters: Φ= 1.750 Ψ= 0.000025 Υ=0.024

An introduction of the leverage ratio and risky to total asset ratio target induces changes in the banks first-order conditions (2.15), (2.16) and (2.19):

$$\begin{aligned} \lambda_t^{\gamma} + \omega \left(\frac{k_t^{\gamma}}{\bar{k}}\right)^{1-b} \frac{r\bar{\omega}^{\alpha}}{rwa_t^{\gamma}} + \Psi \frac{lev_t^{\gamma} - \overline{lev^{\gamma}}}{e_t^{\gamma}} - \Upsilon \frac{\left(risk_t^{\gamma} - \overline{risk^{\gamma}}\right) risk_t^{\gamma}}{zm_t^{\alpha} + (1-z) m_t^{\beta}} \\ = E_t \left[\Lambda_{t,t+1}^{\gamma} \frac{(1+r_t^{\alpha})}{\left[\left(1-\psi_{t+1}^{\gamma}\right)\Pi_{t+1}^{\gamma}\right]^{a_{\gamma}}}\right] \end{aligned} \tag{2.28}$$

$$\begin{aligned} \lambda_t^{\gamma} + \omega \left(\frac{k_t^{\gamma}}{\bar{k}}\right)^{1-b} \frac{r\bar{\omega}^{\beta}}{rwa_t^{\gamma}} + \Psi \frac{lev_t^{\gamma} - \overline{lev^{\gamma}}}{e_t^{\gamma}} + \Upsilon \frac{\left(risk_t^{\gamma} - \overline{risk^{\gamma}}\right)\left(1 - risk_t^{\gamma}\right)}{zm_t^{\alpha} + (1-z) m_t^{\beta}} \\ = E_t \left[\Lambda_{t,t+1}^{\gamma} \frac{R_{t+1}^{\beta}\left(1+r_t^{\beta}\right)}{\left[\left(1-\psi_{t+1}^{\gamma}\right)\Pi_{t+1}^{\gamma}\right]^{a_{\gamma}}}\right] \end{aligned} \tag{2.29}$$

$$[\psi_t^{\gamma}\Pi_t^{\gamma}]^{-a_{\gamma}} = \lambda_t^{\gamma} + \omega \left(\frac{k_t^{\gamma}}{\bar{k}}\right)^{-b} \frac{1}{\bar{k}} \frac{1}{rwa_t^{\gamma}} + \mu \frac{(\psi_t^{\gamma} - \psi^{\gamma})}{\Pi_t^{\gamma}} + \Psi \left(lev_t^{\gamma} - \overline{lev^{\gamma}}\right) \frac{lev_t^{\gamma}}{e_t^{\gamma}}. \tag{2.30}$$

Equations (2.28) and (2.29) are first-order conditions with respect to loans to safe and risky firms, respectively. Increases in bank leverage (lev_t^{γ}) raise marginal disutility from extending loans, precipitating into a rise in both interest rates. Ceteris paribus, this makes borrowing more costly. Increases in the risky to total asset ratio ($risk_t^{\gamma}$), however, have different effects on the two investment alternatives. They induce a decline in the interest rate on safe loans but tightened lending standards for risky loans. Deviations of the leverage ratio from target also have a consequence on the dividend payment decision as shown in equation (2.30). Higher leverage ratio raises the marginal cost of paying dividends since the latter makes bank capital position even worse. Therefore, banks respond by lowering dividend distribution.

2.4.3.2 Results

The focus is on how effective those measures are in controlling bank risk-taking over the boom period, as the economy encounters positive productivity and bank capital shocks. However, despite their benefits in terms of reducing financial vulnerability, the measures are not without costs. A standard result from the studies on macro-prudential regulations suggests a trade-off in terms of output loss. In this regard, we observe to what extent they limit an increase in output. Table 2.6 summarises cumulative output losses from each policy implementation, along with cumulative reduction in the ratio of risky loans to total assets and also total bank assets, over the horizon considered (i.e. 20 periods).

Productivity shock

First, the effectiveness of countercyclical capital buffers in limiting bank risk-taking is shown in figure 2.5. A positive productivity shock produces an increase in the credit-to-GDP ratio. This contingent capital regulation therefore requires banks to hold additional capital as a proportion of risk-weighted assets. This, in turn, raises their marginal cost of issuing loans. Interest rates charged on both loans rise. Since risk weight is higher for risky loans, the disutility effects from higher capital requirement is greater for them, prompting increasing risky-safe loans spread compared with the Benchmark case. Therefore, there is a switch from risky loans towards safer alternatives. Such substitution effects are intensified, as a "reverse" default multiplier resulted from declining expected repayment rates by risky firms sets in. Safe loans even improve as compared to the Benchmark case, despite the fact that they are initially constrained by a rise in capital requirements. They now rise above their steady state level. As far as the risk-taking indicators are concerned, the ratio of risky loans to total assets falls, reducing bank risk exposure. However, an increase in safe assets is not sufficient to offset a decrease in risky ones, particularly in the initial periods. Total bank assets thus decline. The credit-to-GDP ratio falls, while banks take a much lower leverage. Given calibrated parameter values, the maximum decline in the risky-to-total asset ratio is 0.36 percentage point. There is inevitably a trade-off in terms of output loss. Cumulative output losses equal 1.018 percent over 20 periods, while the ratio of risky loans to total assets declines 3.997 percentage points in total. The other advantage of this measure is that banks accumulate more capital over the boom period, which may potentially help safeguard the banking sector during adverse times.

Targeting the leverage ratio slightly curbs aggregate lending activities but does not materially affect the proportion of risky loans in the bank portfolio (see figure 2.6). Excessive leverage resulted from a positive productivity shock causes higher marginal cost of loans origination. Banks charge higher loan interest rates. This constrains demand for both loans, which in turn curtails investment. We observe a fall in both credit-to-GDP ratio and total bank assets. However, the magnitude of the impact is relatively small. As a result, GDP losses are also limited. We believe that banks rely more on improved bank capital, rather than controlling bank assets, to adjust the equilibrium leverage ratio towards its targeted level. The policy is also unsuccessful in terms of reducing the proportion of risky loans. Despite the fact that the leverage ratio has fallen by almost half, the risky-to-total asset ratio even rises cumulatively, as banks lend more to risky firms in the medium run. Since the leverage ratio attaches equal weights for all assets, it does not matter whether banks adjust by cutting risky or safe loans. This may explain why the risky-safe loans spread and the risky-to-total asset ratio barely change from the Benchmark case. The key drawback of this policy is that it adversely affects safe borrowers although they always comply with their loans obligation.

Targeting the ratio of risky loans to total assets is the most effective in terms of reducing bank risk-taking (see figure 2.7). From table 2.6, a significant reduction in the risky-to-total assets ratio is compensated by a lower contraction in GDP, as well as overall lending activities. Positive productivity shocks initially result in a rise in such ratio. With the regulation in place, this creates differential effects on lending decisions to safe and risky borrowers. In particular, marginal cost of granting loans to risky firms goes up, while banks prefer lending to safe alternatives. Interest rate spreads between risky and safe loans increases. Consequently, there exists a substitution effect. The ratio of risky loans to total assets thus declines, producing safer bank balance sheet. The credit-to-GDP and leverage ratios fall only slightly, as risky loans are replaced with safe ones. GDP and total bank assets shrink, but to a small extent. Cumulatively, they decline 0.45 and 1.69 percent, respectively, while the risky to total assets ratio falls by 4.46 percentage points (larger than when countercyclical capital buffers are employed). Unlike the results from the previous two regulations, bank capital does not significantly change.

Raising capital requirement makes the steady state of the economy safer but it becomes more procyclical in the face of shocks. Let us consider first the impact on the steady state shown in table 2.5. Higher regulatory capital ratio leads to a tightening of capital regulation constraint, creating the same effects as discussed earlier for the case of countercyclical capital buffers. There is less bank risk-taking as banks substitute away from risky borrowers. Loans to safe firms replace risky ones to some extent. In total, aggregate bank assets and the credit-to-GDP ratio decrease, while banks become less leveraged. However, there is inevitably a trade-off in terms of output loss, which is a standard result found in the literature. A one-percentage-point increase in the regulatory capital ratio results in approximately 0.32 percentage point rise in the steady-state capital adequacy ratio.

Nevertheless, in the face of productivity boom, there is greater procyclicality in output and bank risk-taking (see figure 2.8). Procyclicality can so high that the economy experiences greater bank risk-taking than the responses under Benchmark case ($\bar{k} = 0.08$), even though it starts off with lower risk-taking at the steady state. Potential reasons are that, with higher capital requirement, risky firms have become more credit-constrained. Therefore, given lower capital accumulation, their loan-demand responses to a shock are more significant. In addition, the steady-state loan interest rate spreads become larger, causing loans interest rate to be more elastic in response to shocks. In sum, the economy faces a trade-off as the banking sector is safer at the steady state, but engages in higher risk-taking over the boom period.

Table 2.5: Steady-state effects of raising capital requirement

Variable	%Change	Variable	%Change	Variable	Change
GDP	-0.101	m^{α}	+0.092	$\frac{credit}{GDP}$	-0.034
y^{α}	+0.120	m^{β}	-0.521	lev	-0.987
y^{β}	-0.332	m^{d}	-0.499	$asset$	-0.206
c	-0.050	v^{β}	-0.064	$risk$	-0.153
k^{α}	+0.092	v^{d}	+0.081	$r^{\beta} - r^{\alpha}$	+0.166
k^{β}	-0.521	k^{γ}	+0.316	$r^{\alpha} - r^{d}$	+0.111

Bank Capital Shock

We next assess the effectiveness of the four macro-prudential measures in the event of positive bank capital shocks. Three measures, including countercyclical capital buffers, risky-to-total asset ratio targeting and raising capital requirements, prima facie seem to exert the same effects on the real economy and the banking sector, as in the case of productivity shocks. Countercyclical capital buffers reduce the ratio of risky loans to total assets and total bank assets in the short run (figure 2.9). Since the credit-to-GDP ratio rises to reach its highest on impact and then declines towards the steady state, banks are required to hold additional capital only in the short term. Using risky-to-total asset ratio targeting, risky lending is directly constrained. Thus, it effectively reduces the proportion of risky loans on bank portfolio. A decline in the output level is small, as safe loans almost replace risky lending (figure 2.11). At the same time, raising capital requirements creates further procyclicality in output and bank risk-taking (figure 2.12). However, targeting the leverage ratio yields differing consequences from the case of positive productivity shocks, as it enhances output volatilites (figure 2.10). Following a positive bank capital shock, bank leverage falls. On impact, targeting leverage ratio implies that banks have to leverage up. Therefore, they lend even more to non-financial firms, charging borrowers lower interest rate. A rise in the credit-to-GDP ratio and total bank assets is exacerbated, consistent with increasing output. Nevertheless, in the subsequent periods, shrinking credit spreads adversely affect bank profits and capital. The capital adequacy ratio hence declines. Banks therefore face the need to abruptly deleverage. Lending activities and investment experience a substantial decline. Moreover, the finding may reflect strong substitution of loans demand across periods, as firms face much lower interest rates today than in the subsequent periods. As part of the deleveraging process, banks also switch from risky to safe loans, rendering a safer bank portfolio. Cumulatively, there is evidence that the measure is effective in curtailing bank risk-taking. We find that the risky-asset ratio declines considerably. However, this comes at the expense of greater output and lending volatilities.

For a bank capital shock, risky-to-total asset ratio targeting remains the most effective when comparing cumulative reduction in the ratio of risky loans to total assets against cumulative output losses. It is interesting to note that the risky-asset ratio decreases the most when the leverage ratio targeting is in place, however it depresses economic activities. Such losses can even be larger if we take into account the fact that output substantially rises in the initial period.

Summary

In summary, the results support the role of countercyclical capital buffers and targeting the ratio of risky loans to total assets, in taming bank risk-taking over the boom periods. The former mitigates procyclicality and bank risk-taking by making loans creation more costly. The model captures purported aims of such regulation emphasised in the Basel Accord, namely (1) encouraging banks to hold enough capital to become shock-resistant and (2) reducing ex-ante bank risk-taking, thereby limiting losses in the first place. Meanwhile, the latter directly affects bank asset allocation by discouraging them to take risky investment. If policymakers are concerned about contractionary impacts of macroprudential regulations, this policy yields lowest output losses. Moreover, we offer new findings that leverage ratio

Table 2.6: Cumulative impacts of each macroprudential regulation on the responses of variables of interest to each shock

	GDP	Risky to total asset ratio	Bank assets
Productivity Shocks			
Countercyclical capital buffers	-1.018	-3.997	-3.780
Leverage ratio targeting	-0.412	0.318	-1.535
Risky to total asset ratio targeting	-0.447	-4.457	-1.694
Raising capital requirements	1.062	6.035	4.075
Bank Capital Shock			
Countercyclical capital buffers	-0.021	-0.143	-0.076
Leverage ratio targeting	-0.035	-0.272	-0.099
Risky to total asset ratio targeting	-0.018	-0.231	-0.066
Raising capital requirements	0.058	0.395	0.215

Note: cumulative difference over 20 periods between the responses of the economy with macroprudential regulation and those from the benchmark model. The difference of GDP and bank assets are measured in percentages, while that of risky to total asset ratio in percentage points.

targeting is not effective in mitigating bank risk-taking and may adversely affect safe investment. Output and credit volatilites can even be exacerbated when bank capital shocks occur. At the same time, we find that raising capital requirements only make the steady state of the economy safer, but may induce even higher risk-taking over the cycles. Therefore, policymakers need to pick the right measures from macroprudential regulation toolkits to address bank risk-taking.

2.5 The New Keynesian Variant

In this section, we extend the benchmark model by incorporating New Keynesian (NK) features, namely monopolistic competition, price stickiness and monetary policy. NK DSGE model has become the workhorse model in academic and policy institutions to study monetary policy transmission mechanisms and has been used in forecasting and policy simulations. Adopting the NK tradition to this work is useful in several aspects. First, with respect to the recent global financial crisis, too accommodative monetary policy was linked with excessive bank risk taking, supporting the proposition of "the risk-taking channel of monetary policy". The NK variant of the model would allow us to understand financial-stability implications of monetary policy. Second, nominal rigidities have invigorated the role of demand impulses in business cycle fluctuations. The empirical evidence in section 2.2 suggests that demand shocks have significant effects on lending standards, particularly in the short run. We are therefore looking forward to identifying bank risk-taking consequences from demand shocks in our theoretical model. Finally, we explore policy implications in two aspects: (1) the effectiveness of monetary policy in mitigating bank risk-taking and (2) the impacts of macroprudential measures to the economy facing monetary policy shocks. The latter findings can shed light on policy interactions.

2.5.1 The Model

The key deviation of the NK variant from the benchmark RBC model is the existence of price stickiness (i.e. Calvo pricing). Thus, we introduce retailers who purchase wholesale goods from both firms and sell (final) retail goods to consumers. Retailers operate in a monopolistically competitive environment and therefore set retail goods prices. However, the opportunity to reset prices is assigned randomly through a Calvo lottery, thus yielding nominal rigidities. The optimisation problem of other agents in the economy slightly deviates from the RBC benchmark by including the role of price markup and inflation. Their first order conditions are shown in the Appendix.

Households (θ)

A representative household maximises the following lifetime utility function:

$$E_0 \sum_{t=0}^{\infty} \beta_\theta^t \varepsilon_t^\theta \left[\ln c_t + \chi_n \left[\int \frac{\left(l_t^{s,\alpha,i}\right)^\eta}{\eta} di + \int \frac{\left(l_t^{s,\beta,i}\right)^\eta}{\eta} dj \right] \right]$$

subject to

$$m_t^d + c_t \leq \begin{array}{c} R_t^d \left(1 + r_{t-1}^d\right) \frac{m_{t-1}^d}{\pi_t} + \int w_t^{\alpha,i} l_t^{s,\alpha,i} di + \int w_t^{\beta,j} l_t^{s,\beta,j} dj \\ + \int \Pi_t^{\alpha,i} di + \int \Pi_t^{\beta,j} dj + \left(1 - \psi_t^{\gamma}\right) \Pi_t^{\gamma} + F_t \end{array} .$$

All variables are expressed in real terms (i.e. measured relative to final goods price index P_t), except for interest rates which are in nominal terms. From the budget constraint, inflation ($\pi_t = \frac{P_t}{P_{t-1}}$) affects ex-post real deposit interest rate $\frac{\left(1+r_{t-1}^d\right)}{\pi_t}$ that the household receives from banks. In each period, the household therefore makes the consumption-saving decision taking into account expected inflation ($E_t \pi_{t+1}$). We assume that households are the owner of retailers, so they receive all the profits F_t the latter generate. We introduce ε_t^{θ}, an intertemporal shock to preferences, as one of the two demand shocks in this variant of the model. Such a shock has AR(1) representation with autoregressive coefficient ρ_{θ}.

Firms ($F \in \{\alpha, \beta\}$)

Firms produce homogenous wholesale goods using the same technology as in equation (2.1). They sell their products to retailers at wholesale prices P_t^W. Each firm's profits function becomes:

$$\Pi_t^F = \frac{y_t^F}{X_t} - w_t^F l_t^{d,F} - v_t^F \frac{\mu_{t-1}^F}{\pi_t} \tag{2.31}$$

where, $X_t = \frac{P_t}{P_t^W}$ is the price mark up, defined as the ratio of retail goods price index over wholesale goods price. Again, inflation affects ex-post real interest rate as firms repay bank loans. This introduces the debt-deflation channel, whereby changes in inflation rate alter the real value of debt and result in reallocation of wealth between borrowers and lenders.

Each firm maximises the following lifetime objective function:

$$E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^{\theta} \left[\frac{\left(\Pi_t^F\right)^{1-a_F}}{1-a_F} - max \left[o, \varphi_t^F \frac{\left(\left(1-v_t^F\right) \frac{\mu_{t-1}^F}{\pi_t}\right)^{1+\phi_F}}{1+\phi_F} \right] \right]$$

subject to the investment constraint:

$$p_t^k \left(k_{t+1}^F - (1-\tau) k_t^F\right) \leq \frac{\mu_t^F}{1+r_t^F} . \tag{2.32}$$

We hasten to add that the default penalty is expressed in real terms to avoid interpersonal comparison of utility. In other words, risky firms are punished on the basis of defaulted amount of loans measured in real terms.

Capital Producers

Perfectly competitive capital producers produce new capital, using the following production function:

$$k_{t+1} = (1-\tau) k_t + i_t \left(1 - \frac{k_i}{2} \left(\frac{\varepsilon_t^k i_t}{i_{t-1}} - 1\right)^2\right) . \tag{2.33}$$

We introduce shocks to marginal efficiency of investment ε_t^k as another demand shock. Such shocks have an AR(1) representation with autoregressive coefficient ρ_k. Several articles, such as Justiniano et al. (2010), find them to be important in explaining business cycle fluctuations. Each capital producer maximises $E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^{\theta} \left[p_t^k \left(k_{t+1} - (1-\tau) k_t\right) - i_t\right]$, subject to the above production function.

Banks (γ)

A representative risk-averse bank, operating in perfectly competitive environment, maximises the following lifetime objective function:

$$E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^{\gamma} \left[\tfrac{1}{1-a_\gamma} \left((1-\psi_t^\gamma)\, \Pi_t^\gamma \right)^{1-a_\gamma} - max \left[o, \varphi_t^\gamma \frac{\left(\left(1-v_t^d\right) \frac{\mu_{t-1}^d}{\pi_t} \right)^{1+\phi_\gamma}}{1+\phi_\gamma} \right] + \omega \frac{\left(\frac{k_t^\gamma}{\bar{k}} \right)^{1-b} - 1}{1-b} - \tfrac{\mu}{2} \left(\psi_t^\gamma - \psi^\gamma \right)^2 \right]$$

where,

$$\Pi_t^\gamma = \int R_t^{\alpha,i} \left(1 + r_{t-1}^{\alpha,i}\right) \frac{m_{t-1}^{\alpha,i}}{\pi_t} di + \int R_t^{\beta,j} \left(1 + r_{t-1}^{\beta,j}\right) \frac{m_{t-1}^{\beta,j}}{\pi_t} dj - v_t^d \frac{\mu_{t-1}^d}{\pi_t} \qquad (2.34)$$

subject to

$$\int m_t^{\alpha,i} di + \int m_t^{\beta,j} dj \le \frac{\mu_t^d}{1 + r_t^d} + e_t^\gamma = \frac{\mu_t^d}{1 + r_t^d} + \psi_t^\gamma \Pi_t^\gamma \,. \qquad (2.35)$$

Retailers

Retailers, operating in a monopolistically competitive environment, are the source of nominal rigidities. A continuum of retailers, indexed by n, buy homogenous wholesale goods $y_t = \int y_t^{\alpha,i} di + \int y_t^{\beta,j} dj$ from both types of firms at price P_t^W in the competitive market. They differentiate those goods at no cost into $y_t(n)$ and sell them at prices $P_t(n)$ to the retail goods market.

Consider first demand for retail goods sold by each retailer. We assume that aggregate demand for final goods is $y_t^d = \left(\int_0^1 y_t(n)^{\frac{\varepsilon}{\varepsilon-1}} dn \right)^{\frac{\varepsilon-1}{\varepsilon}}$, where ε is the elasticity of substitution. Defining price index as $P_t = \left(\int_0^1 P_t(n)^{1-\varepsilon} dn \right)^{\frac{1}{1-\varepsilon}}$, each retailer faces the demand curve:

$$y_t(n) = \left(\frac{P_t(n)}{P_t} \right)^{-\varepsilon} y_t^d \,. \qquad (2.36)$$

Price adjustment is subject to a Calvo lottery. In each period, θ proportion of retailers have their prices fixed. Those who are allowed to reoptimise the price choose a sale price $P_t(n)$, taking into account the demand and the fact that they can reset the price in the following period only with probability 1-θ. We denote with $P_t^*(n)$ the chosen price and with $y_{t+k}^*(n) = \left(\frac{P_t^*(n)}{P_{t+k}}\right)^{-\varepsilon} y_{t+k}^d$ the corresponding demand. Each retailer chooses the price $P_t^*(n)$ to maximise the following objective function

$$E_t \sum_{k=0}^{\infty} \theta^k \left[\Lambda_{t,k}^{\theta} \left(\frac{P_t^*(n)}{P_{t+k}} - mc_{t+k}\right) y_{t+k}^*(n)\right]$$

where, $mc_t = \frac{P_t^W}{P_t} = \frac{1}{X_t}$ is the real marginal cost of producing one unit of retail goods, which is essentially real price of wholesale goods. $\Lambda_{t,k}^{\theta}$ is the relevant stochastic discount factor. Since firms that are able to reset their price will eventually choose the same price, the optimal P_t^* solves:

$$E_t \sum_{k=0}^{\infty} (\beta_\theta \theta)^k \left[\lambda_{t+k}^{\theta} \left((1-\varepsilon)\left(\prod_{s=1}^{k} \frac{1}{\pi_{t+s}}\right)^{1-\varepsilon} \frac{P_t^*}{P_t} + \varepsilon \left(\prod_{s=1}^{k} \frac{1}{\pi_{t+s}}\right)^{-\varepsilon} mc_{t+k}\right) y_{t+k}^d\right] = 0 \tag{2.37}$$

This condition states that P_t^* equates expected discounted marginal revenue to the expected discounted marginal cost. Retailer profits $F_t = \left(1 - \frac{1}{X_t}\right) y_t^d$ are rebated to households. Based on the definition of price index above, as a fraction θ of prices stays unchanged, the aggregate price level evolution is

$$1 = \theta \left(\frac{1}{\pi_t}\right)^{1-\varepsilon} + (1-\theta)\left(\pi_t^*\right)^{1-\varepsilon} \tag{2.38}$$

where, $\pi_t^* = \frac{P_t^*}{P_t}$.

The Central Bank

The central bank controls deposit interest rate according to the following rule:

$$\frac{1+r_t^d}{1+r^d} = \left(\frac{1+r_{t-1}^d}{1+r^d}\right)^{r_R} \left(\left(\frac{\pi_t}{\pi}\right)^{1+r_\pi} \left(\frac{y_t^d}{y^d}\right)^{r_Y}\right)^{1-r_R} \varepsilon_t^R \tag{2.39}$$

where, r_π and r_Y measure the sensitivity of the policy interest rate to deviations of inflation and aggregate output from the steady state, respectively. r_R captures a degree of inertia of the policy interest rate. ε_t^R denotes monetary policy shocks that are assumed to be i.i.d..

Aggregate Demand

From all the budget constraints and market-clearing conditions, we obtain the following aggregate demand schedule:

$$y_t^d = c_t + p_t^k \left(k_{t+1} - (1-\tau) k_t\right) \tag{2.40}$$

2.5.2 Calibration

As is standard in literature, the elasticity of substitution (ε) is set equal to 6, which implies the steady-state price mark up of 20 percent. Probability of fixed price is equal to 0.67, which implies price duration of three quarters. Regarding the Taylor rule coefficients, we assume that the policy interest rate does not respond to output deviations. The value of r_R and r_π are in line with mainstream literature. The remaining parameters have the same value as in the benchmark model.

Table 2.7: Parameter Calibration

Description	Symbol	Value	Description	Symbol	Value
Elasticity of substitution	ε	6.00	Taylor rule coefficient	r_R	0.70
Probability of fixed price	θ	0.67	Taylor rule coefficient	r_π	0.50
Persistence parameter	ρ_θ	0.90	Taylor rule coefficient	r_Y	0.00
Persistence parameter	ρ_k	0.90			

2.5.3 Simulation Results

Monetary Policy Shocks and the Risk-taking Channel

An important question emerging from the recent global financial crisis is whether and how monetary policy affects financial stability. Borio and Zhu (2012) define the term "risk-taking channel" as the impact of changes in policy rates on either risk perceptions or risk-tolerance, and, hence, on the degree of risk in the portfolios, on the pricing of assets, and on the price and non-price terms of funding extension. A number of theoretical (mostly in a partial equilibrium framework) and empirical works have attempted to examine this issue, and tended to support that too accommodative monetary policy can result in high bank risk-taking. Our VAR results are in line with the literature, showing that expansionary monetary policy shocks induce banks to ease their loans standards. Our paper contributes further by offering a general equilibrium framework to identify bank risk-taking effects and the associated pecuniary externalities of monetary policy.

Figure 2.13 shows the effects of an accommodative monetary policy shock that results in a contemporaneous decline in the policy interest rate of 50 basis points. Consistent with literature, banks increase risk exposure after monetary expansion. A fall in loan interest rates boosts demand for loans and capital investment. Consumption and inflation also increase, as expected. As income rises, risky firms raise loans repayment rate. This in turn improves banks capital adequacy ratio. Banks attract more risky borrowers by cutting interest rate spread between risky and safe loans. They, consequently, adopt higher proportion of risky loans on their portfolio, while becoming more leveraged. Safe loans even fall below the steady state. Comparing the responses under the Benchmark model and Exo Default model, default multiplier once again plays a pivotal role in exacerbating risk-taking. Without endogenous default, an increase in risky loans is limited. The ratio of risky loans to total assets barely changes from the steady state. Bank leverage becomes smaller and less persistent. Nevertheless, the contribution of endogenous default to the responses of real GDP is small, despite the fact that investment significantly benefits from it.

This paper therefore establishes the risk-taking channel of monetary policy as one of the key model properties. However, it is noteworthy that the paper does not seek to model the risk-taking channel as an independent channel. Rather, bank risk-taking results from the workings of traditional transmission mechanisms. We argue that, considering the definition of the risk-taking channel above, it is difficult to distinguish such a channel from the traditional transmission channels. Here, we discuss balance sheet and bank capital channels.[50] The former, advocated by Bernanke and Gertler (1989), considers the effects of monetary policy on net worth of the non-financial borrowers, which in turn affects bank lending standards. Such emphasis on lenders perception towards riskiness of the borrowers is directly captured through the endogenous default probability in this model. We have shown that it is also an important catalyst for bank risk-taking. In addition, the model captures the bank capital channel introduced by Den Heuvel (2002), as monetary expansion improves bank capital and hence loans supply. We also show that, given the existence of risk-based capital regulations, changes in bank capital alter banks risk tolerance and incentives to take risk.

[50] Our model captures at least four traditional channels of monetary policy transmission, namely: cost of capital channel, balance sheet (or broad credit) channel, bank lending (or narrow credit) channel and bank capital channel. Responses under Exo Default model (red dashed line) measure monetary policy impacts through cost of capital channel.

We are next interested in whether macroprudential measures are useful in mitigating the bank risk-taking incentives resulting from monetary policy expansion. We examine two policy alternatives proven to be effective from the previous section. We confirm here in figure 2.14 and 2.15 that risky-to-total asset ratio targeting is more effective. Risky investment is replaced by safe alternative. Output, inflation, as well as bank lending conditions, only slightly change. Meanwhile, countercyclical capital buffers can limit risk exposure, but at the expense of aggregate output. The measure can induce substitution between safe and risky investment. Banks greatly deleverage, prompting the ratio of credit to GDP and total bank assets to decline. We conclude here that certain macroprudential measures, when they are in place, can be useful in controlling bank risk-taking and hence preserving financial stability, while monetary policy is doing its job in securing price stability and full employment.

Demand Shocks

The existence of nominal rigidities makes demand shocks relevant (i.e. generating significant effects) on business cycle fluctuations. Empirical evidence from sign-restricted VAR earlier show that demand shocks can promote bank risk-taking, particularly in the short run. This paper considers two demand shocks widely considered in the literature: intertemporal preference shocks and investment efficiency shocks.[51] A shock to intertemporal preferences primarily raises households demand for consumption. Investment in capital is therefore encouraged to support growing demand. Meanwhile, an investment efficiency shock raises the ability of the capital producers in transforming consumption goods into physical capital. Therefore, it influences capital prices and firms demand for investment. Consumption falls as firms demand more loans to invest in capital, implying more deposits to the banking sector. The

[51] Both are not pure demand shocks. However, they either have first-order impact on demand, i.e. consumption and investment, or have an impact effect of raising inflation. An intertemporal preference shock, for example, not only affects consumption but also causes intertemporal substitution of labor across periods.

economy, however, enjoys a boost in consumption in the medium to long term. Real GDP and inflation increase in response to both shocks.

Figures 2.16 and 2.17 suggest that both shocks can lead to financial fragility. After normalising the size of both shocks to have roughly equivalent impact on real GDP (maximum increase of 1 percent from the steady state), we can observe that a rise in bank risk-taking is bigger in the case of investment efficiency shocks, being larger in magnitude and more persistent. A deviation of the ratio of risky loans to total assets from the steady state peaks at roughly 2 percentage points after two years. Total bank assets increase by approximately 5 percent after one year. We note that the default multiplier has played an important role. In Exo Default case, banks again maintain roughly equal proportion of safe and risky loans. Also, the leverage ratio does not significantly rise. The multiplier also greatly impacts positively growth in the real sector. Investment, GDP and inflation all improve from the exogenous default case. On the other hand, facing an intertemporal preferences shock, bank risk-taking rises, but to a small extent. In particular, the ratio of credit to GDP returns to the steady state after four quarters, as investment is no longer required to support future consumption. Potential explanation of why a shock to investment efficiency has large implications on financial stability may be that it has a direct impact on the investment incentive. As investment requires financing, it matters for the banking sector.

Table 2.10 in the Appendix shows the effectiveness of the macroprudential measures in mitigating bank risk-taking. Given strong default multiplier effects in the case of investment shocks, all measures except raising capital requirement, are effective in controlling bank risk-taking. Even leverage ratio targeting successfully induces a decline in the proportion of risky loans, though not large. However, the measure constrains overall lending activities, leading to greater output losses compared with the other two alternatives. The contractionary effects on output and credit are also large when countercyclical capital buffers are in place. To avoid the trade-off, it is wise to resort to risky-to-total asset ratio targeting, given its ability to induce asset substitution. Meanwhile, the impact of macroprudential measures is more subtle in the case of intertemporal preference shocks. For countercyclical capital buffers, as the credit-to-GDP ratio falls below the steady state after one year, such measure makes loans standards even more relaxed in the medium term. We observe that, cumulatively, banks provide more funding for risky investment. Implementing risky-to-total asset ratio targeting is more useful.

Monetary Tightening to Avert Risk-taking

In this subsection, we consider how effective monetary policy tightening is in preventing higher bank risk-taking arising from demand and supply shocks. We assume that the policy interest rate not only responds to output and inflation growth, but also to certain risk-taking indicators. The latter is either credit growth or changes in risky-to-total asset ratio. For each shock, we compare the responses of the economy under two cases: (1) the central bank follows the standard Taylor rule (Benchmark case) and (2) it follows the augmented Taylor rule. In the latter case, the central bank raises the policy interest rate beyond the level justified by output and inflation growth, with the aim to preserve financial stability. We assess consequences on bank risk-taking indicators and identify the trade-off between price and financial stability.

Figure 2.18 shows that monetary policy can mitigate bank risk-taking, but the Central Bank needs to face the implications on its main objectives, inflation and output stability. This is especially true in the case of productivity shocks. An attempt to address bank risk-taking by raising the policy interest rate deflates the price level further away from the target. Hence, there is a trade-off between financial and price stability. The negative effects on output and credit are also significant. Bank risk-taking can be better mitigated through the use of macroprudential measures. This conclusion applies to investment shocks too. Bank risk-taking indicators, though responding in the right direction, do so at a negligible magnitude. We find that the augmented Taylor rule enhances inflation volatilities while generating large output losses. In contrast, monetary policy that responds to risk-taking indicator is effective in achieving both price and financial stability in the case of intertemporal preference shocks. Inflation and output, which tend on rise abruptly on impact, become more stable. At the same time, increases in bank risk-taking slow down. Nevertheless, risk-taking is less of concern for this particular shock as compared to the others. We therefore conclude, from this simple exercise, that monetary policy may be of little use in dealing with high bank risk-taking.

The Role of Inflation

Iacoviello (2005) argues that debt-deflation mechanism contributes to the financial accelerator in the event of demand shocks, but becomes a decelerator when supply shocks occur.[52] However, in this model, we argue that the role of inflation on economic decisions is more subtle. We first reconsider the propositions, outlined in section 2.3.7, and assess hence how inflation affects the dynamics of the economy. We then have the following:

$$\left(\Pi_t^{\beta}\right)^{-a_\beta} = d_\beta \left(1 - v^{\beta}\right)^{\varrho_\beta} \left(\left(1 - v_t^{\beta}\right)^{\phi_\beta - \varrho_\beta} \left(\frac{\mu_{t-1}^{\beta}}{\pi_t}\right)^{\phi_\beta}\right) \tag{2.41}$$

$$\omega \left(\frac{k_t^{\gamma}}{\bar{k}}\right)^{1-b} \frac{r\bar{\omega}_t^F}{rwa_t^{\gamma}} = E_t \left[\Lambda_{t,t+1}^{\gamma} \frac{R_{t+1}^F \left(1 + r_t^F\right) - \left(1 + r_t^d\right)}{\pi_{t+1}} \left[\left(1 - \psi_{t+1}^{\gamma}\right) \Pi_{t+1}^{\gamma}\right]^{-a_\gamma}\right]. \tag{2.42}$$

[52]Positive demand shocks raise both output and inflation. Higher inflation lowers the real value of debt, which in turn redistributes wealth from savers to borrowers. Given a higher marginal propensity to consume by the latter, this boosts aggregate demand. On the other hand, positive supply shocks decrease inflation. Rising real debt value worsens borrowers wealth, which decelerates an increase in output.

Equation (2.41) shows the revised on-the-verge condition. Inflation enters the on the verge condition through both marginal benefit and cost of default. On the marginal cost, since borrowers are penalised based on the real value of defaulted debt, inflation affects marginal cost of default. On the other hand, it affects real profits, which in turn alters marginal benefit of default. Consequently, inflation matters for the default decision. Equation (2.42) shows the revised relative structure of the interest rates. We can observe that inflation influences interest rate spreads charged on loans, as in the standard Fisher equation.

Consider first the responses of the economy to demand shocks. A rise in inflation shrinks the real value of debt and hence marginal cost of default. Meanwhile, it depresses firm profits. These, therefore, encourage risky firms to default more on their loan obligations. This adversely affects bank capital and lending, especially to risky businesses. Banks also charge larger premium on loan interest rates to compensate for higher inflation. Hence, inflation effects on default and interest rate spreads work as a financial decelerator in the event of demand shocks. Conversely, those channels generate a financial accelerator when the economy faces supply shocks. Figure 2.19 considers quantitative importance of the channels described above. In the figure, we compare the impulse responses of the benchmark economy against those from the economy assuming away inflation effects on default and spread. We show that the role of inflation is evident in the case of demand shocks. However, the effect is less significant on GDP, but more on risk-taking indicators. By excluding those channels, a surge in the proportion of risky investment and leverage becomes more pronounced.

Empirical Evaluation

With a complete set of frictions and shocks, this subsection shows how successful the model is in terms of matching empirical moments. In this regard, we focus on (1) the correlation between certain variables and the output gap, (2) their volatilites and (3) autocorrelation. The variables include real GDP, consumption, investment, risky firms default rate, bank loans, and effective interest rate spread. For an interest rate spread, we use as a proxy the spread between effective loans interest rate and the federal funds rate, as described in section 2.2. We compare it with the spread between weighted average of risky and safe loans interest rate and deposits interest rate. All the real variables and real C&I loans are detrended via HP filter. The charge-off rate is used as a proxy for risky firms default rate. We assume a standard deviation of the economy's structural shocks, namely productivity shock, bank capital shock, monetary policy shock, preference shock and investment shock to be equal to 1.00, 0.345, 0.95, 3.25 and 10.8, respectively.

Table 2.8 shows that the model performs relatively well in matching empirical moments. The rank of volatilities of all variables is almost correct, except that the volatility of investment from the model should be lower than that of bank loans. The model simulations show high volatilites for both variables, consistent with empirical properties. In addition, interest rate spread should not have the least volatility. The model is also correct in terms of the correlation of those variables with output. Consumption, investment and loans are procyclical, while the rest are countercyclical. Nonetheless, the model tends to overstate the correlation of default rate, interest rate spread and loans, all of which are the model's key financial variables, while understating the correlation with consumption. Real frictions may be required to match better these cyclical properties. The autocorrelation is extremely high from the model simulations, but remains in line with empirical facts. One important failure of the model (not shown in the table) is to match correlation of firm and bank profits with output. Profits tend to be procyclical in the data. But, theoretical simulations arrive at negative correlation. For firm profits, this may result from the fact that debt is largely procyclical, and therefore profits decline as debt is repaid. For

Table 2.8: Moments

Variable	Empirical Moments			Theoretical Moments		
	Vol	Cor	Per	Vol	Cor	Per
Output (GDP_t)	0.011	1	0.884	0.065	1	0.906
Consumption (c_t)	0.009	0.891	0.888	0.045	0.611	0.885
Investment (i_t)	0.056	0.906	0.872	0.211	0.807	0.982
Interest rate spread (z*r_t^α+(1-z)*r_t^β-r_t^d)	0.006	-0.476	0.765	0.027	-0.950	0.909
Bank loans (z*m_t^α+(1-z)*m_t^β)	0.085	0.307	0.938	0.190	0.864	0.958
Firm's default rate $(1 - v_t^\beta)$	0.003	-0.481	0.940	0.036	-0.933	0.964

Note: Vol for volatility; Cor for correlation coefficient with output; Per for first-order autocorrelation coefficient

banks, in the boom periods, they are willing to accept lower profits as their capital adequacy ratio improves. We leave this an open question for future work.

2.6 Conclusion and Potential Extensions

The model incorporates firm heterogeneity to make it suitable for analysing bank risk-taking. A certain proportion of firms is assumed to be risky, where they have an incentive to renege on their loan obligation and partially repay their debt outstanding. In equilibrium, the default rate is endogenously determined by borrowers profitability and loans quantity. In this paper, banks also face Basel II's capital requirements, which link the size and composition of their assets to the net worth. The simulation results show that endogenous default and capital regulation help generate greater procyclicality in output and bank risk-taking in the face of supply, demand, monetary as well as bank capital shocks. In this regard, the paper confirms the procyclicality effect of Basel II's capital regulation. Over the boom periods, banks leverage up while granting more loans to risky borrowers. The ratio of credit to GDP significantly increases as a result. This makes the banking sector vulnerable to future negative shocks. With regard to monetary policy shocks, the paper, therefore, supports the existence of the risk-taking channel of monetary policy transmission.

An analysis of macroprudential measures shows that countercyclical capital buffers and risky-asset ratio targeting can be useful in mitigating bank risk-taking. Countercyclical capital buffers serve their purported aim outlined by the Basel committee and counter the procyclicality of non-contingent capital regulation. However, financial regulators must be aware of a trade-off in terms of output losses. The measure can also negatively affect safe borrowers, as banks raise credit spreads for all loans. The risky to total asset ratio targeting, on the other hand, is more effective as it induces a substitution between risky and safe investment. We thereby observe low output losses, while total flow of bank credit remains intact. The paper does not recommend employing monetary policy actively to prevent bank risk-taking, since it has broader externalities on the real economy and inflation. In particular, to preserve financial stability in the face of productivity shocks, price stability may be at risk.

We next discuss potential extensions of the model. There are three main issues. First, rational expectation is assumed such that lenders correctly predict the portion of loans borrowers will repay in the future period. In reality, when lenders form expectation with respect to the expected default rate for each loan application, they take into account also past default history, for example by viewing borrowers information at the Credit Bureau. Past credit history is therefore crucial to credit rationing and pricing. As a result, it may be more realistic to have adaptive, rather than rational, expectations. Modeling lenders expectation in this way would allow for the concept of "learning", where agents update their belief overtime when they receive new information. It is also likely to add more persistence to the effects of shocks. Second, proper welfare analysis should be conducted to see how the economy's aggregate welfare changes as a result of policy implementation. It is interesting to assess both welfare changes as policymakers attempt to mitigate risk-taking during the upturn and overall welfare changes taking into account also how well the economy is being cushioned during the downturn. Last, modelling default as an intertemporal, rather than intratemporal, choice should be more realistic and materially affect the way the model behaves. In the current model, the marginal cost of default occurs in terms of reputation loss within the same period default takes place. The punishment can be made more powerful by modelling it to affect firms production or ability to access the capital markets, which happen in periods after default occurs.

2.7 Appendix

2.7.1 Data Description

Based on the definition provided in the Federal Reserve website, charge-offs are the value of loans and leases removed from the books and charged against loss reserves. Charge-off rates are annualised, net of recoveries and measured as a percentage of average loans. Delinquency loans and leases are those past due thirty days or more and still accruing interest as well as those in nonaccrual status. They are measured as a percentage of end-of-period loans. Effective (compounded) annual interest rates are calculated from the stated rate and other terms of the loans and weighted by loan amount.

2.7.2 Proof of Proposition 1

From equations (2.15) and (2.17),

$$\omega \left(\frac{k_t^{\gamma}}{\bar{k}}\right)^{1-b} \frac{r\bar{\omega}^{\alpha}}{rwa_t^{\gamma}} = E_t \left[\Lambda_{t,t+1}^{\gamma} \left(r_t^{\alpha} - r_t^{d}\right) \left[\left(1 - \psi_{t+1}^{\gamma}\right) \Pi_{t+1}^{\gamma}\right]^{-a_{\gamma}}\right]$$

Therefore, given $0 \leq \psi_t^{\gamma} < 1$, $r_t^d < r_t^{\alpha}$.

Table 2.9: Data Description

Data	Unit	Source
Real GDP	Billions of chained 2009 dollars, SAAR	US. Bureau of Economic Analysis
Implicit price deflator	Index 2009=100, SA	US. Bureau of Economic Analysis
Effective federal funds rate	Percent, NSA, quarterly average	Board of Governors of the Federal Reserve System (US)
C&I loans	Billions of dollars, SA	Board of Governors of the Federal Reserve System (US)
Net percentage of domestic banks tightening standards for C&I loans to large and middle-market firms	Percent, NSA, end of period	Senior loans officer opinion survey on bank lending practices
Net percentage of domestic banks increasing spreads of loan rates over banks' cost of funds to large and middle-market firms	Percent, NSA, end of period	Senior loans officer opinion survey on bank lending practices
Delinquency rate on C&I loans	Percent, SA, end of period	Board of Governors of the Federal Reserve System (US)
Charge-off rate on C&I loans	Percent, SA	Board of Governors of the Federal Reserve System (US)
Weighted-average effective loan rate	Percent	Survey of Terms of Business Lending

From equations (2.16) and (2.17),

$$\omega\left(\frac{k_t^{\gamma}}{\bar{k}}\right)^{1-b}\frac{r\bar{\omega}_t^{\beta}}{rwa_t^{\gamma}}=E_t\left[\Lambda_{t,t+1}^{\gamma}\left(R_{t+1}^{\beta}\left(1+r_t^{\beta}\right)-\left(1+r_t^{d}\right)\right)\left[\left(1-\psi_{t+1}^{\gamma}\right)\Pi_{t+1}^{\gamma}\right]^{-a_{\gamma}}\right]$$

Therefore, given $0\leq\psi_t^{\gamma}<1$, $r_t^d<r_t^{\beta}$.

Combining equations (2.15) and (2.16) yields:

$$\frac{R_{t+1}^{\beta}\left(1+r_t^{\beta}\right)-\left(1+r_t^{d}\right)}{\left(1+r_t^{\alpha}\right)-\left(1+r_t^{d}\right)}=\frac{r\bar{\omega}_t^{\beta}}{r\bar{\omega}^{\alpha}}$$

Given $E_tR_{t+1}^{\beta}<1$ and the consequence that $r\bar{\omega}_t^{\beta}>r\bar{\omega}^{\alpha}$ (based on equation (2.14)), we conclude that $r_t^{\alpha}<r_t^{\beta}$.

2.7.3 First Order Conditions (the New Keynesian Variant of the Benchmark Model)

Households

$$\chi_n\left(l_t^{s,\alpha}\right)^{\eta-1}=w_t^{\alpha}\frac{\chi_c}{c_t} \tag{2.43}$$

$$\chi_n\left(l_t^{s,\beta}\right)^{\eta-1}=w_t^{\beta}\frac{\chi_c}{c_t} \tag{2.44}$$

$$\frac{\varepsilon_t^{\theta}}{c_t}=\beta_{\theta}E_t\left[R_{t+1}^{d}\frac{\left(1+r_t^{d}\right)}{\pi_{t+1}}\frac{\varepsilon_{t+1}^{\theta}}{c_{t+1}}\right] \tag{2.45}$$

Firms

$$v_t^{\alpha}=1\;\forall t \tag{2.46}$$

$$\left(\Pi_t^{\beta}\right)^{-a_{\beta}}=d_{\beta}\left(1-v^{\beta}\right)^{\varrho_{\beta}}\left(\left(1-v_t^{\beta}\right)^{\phi_{\beta}-\varrho_{\beta}}\left(\frac{\mu_{t-1}^{\beta}}{\pi_t}\right)^{\phi_{\beta}}\right) \tag{2.47}$$

$$\lambda_t^{F}=E_t\left[\Lambda_{t,t+1}^{\theta}\frac{\left(1+r_t^{F}\right)}{\pi_{t+1}}\left(\Pi_{t+1}^{F}\right)^{-a_F}\right],\quad F\in\{\alpha,\beta\} \tag{2.48}$$

$$w_t^F = \frac{(1-x)}{X_t}\frac{y_t^F}{l_t^{d,F}}, \quad F \in \{\alpha, \beta\} \tag{2.49}$$

$$p_t^k \lambda_t^F \quad = E_t \Lambda_{t,t+1}^{\theta} \left[\frac{x}{X_{t+1}} \frac{y_{t+1}^{\alpha}}{K_{t+1}^{\alpha}} \left(\Pi_{t+1}^F\right)^{-a_F} + (1-\tau)\, p_{t+1}^k \lambda_{t+1}^F \right], \quad F \in \{\alpha, \beta\} \tag{2.50}$$

$$p_t^k \left(k_{t+1}^F - (1-\tau)\, k_t^F\right) = \frac{\mu_t^F}{1+r_t^F}, \quad F \in \{\alpha, \beta\} \tag{2.51}$$

Capital Producers

$$1 = \begin{array}{l} p_t^k \left(1 - \frac{k_i}{2}\left(\frac{\varepsilon_t^k i_t}{i_{t-1}} - 1\right)^2 - k_i \left(\frac{\varepsilon_t^k i_t}{i_{t-1}} - 1\right) \frac{\varepsilon_t^k i_t}{i_{t-1}}\right) \\ + E_t \left[\Lambda_{t,t+1}^{\theta} p_{t+1}^k k_i \left(\frac{\varepsilon_{t+1}^k i_{t+1}}{i_t} - 1\right) \left(\frac{\varepsilon_{t+1}^k i_{t+1}}{i_t}\right)^2\right] \end{array} \tag{2.52}$$

$$k_{t+1} = (1-\tau)\, k_t + i_t \left(1 - \frac{k_i}{2}\left(\frac{\varepsilon_t^k i_t}{i_{t-1}} - 1\right)^2\right) \tag{2.53}$$

Banks

$$\omega \left(\frac{k_t^{\gamma}}{\bar{k}}\right)^{1-b} \frac{r\bar{\omega}^{\alpha}}{rwa_t^{\gamma}} = E_t \left[\Lambda_{t,t+1}^{\gamma} \frac{\left(r_t^{\alpha} - r_t^d\right)}{\pi_{t+1}} \left[\left(1-\psi_{t+1}^{\gamma}\right) \Pi_{t+1}^{\gamma}\right]^{-a_{\gamma}}\right] \tag{2.54}$$

$$\omega \left(\frac{k_t^{\gamma}}{\bar{k}}\right)^{1-b} \frac{r\bar{\omega}^{\beta}}{rwa_t^{\gamma}} = E_t \left[\Lambda_{t,t+1}^{\gamma} \frac{R_{t+1}^{\beta}\left(1+r_t^{\beta}\right) - \left(1+r_t^d\right)}{\pi_{t+1}} \left[\left(1-\psi_{t+1}^{\gamma}\right) \Pi_{t+1}^{\gamma}\right]^{-a_{\gamma}}\right] \tag{2.55}$$

$$\left[(1-\psi_t^{\gamma})\, \Pi_t^{\gamma}\right]^{-a_{\gamma}} = d_{\gamma} \left(1-v^d\right)^{\varrho_{\gamma}} \left(1-v_t^d\right)^{\phi_{\gamma}-\varrho_{\gamma}} \left(\frac{\mu_{t-1}^d}{\pi_t}\right)^{\phi_{\gamma}} \tag{2.56}$$

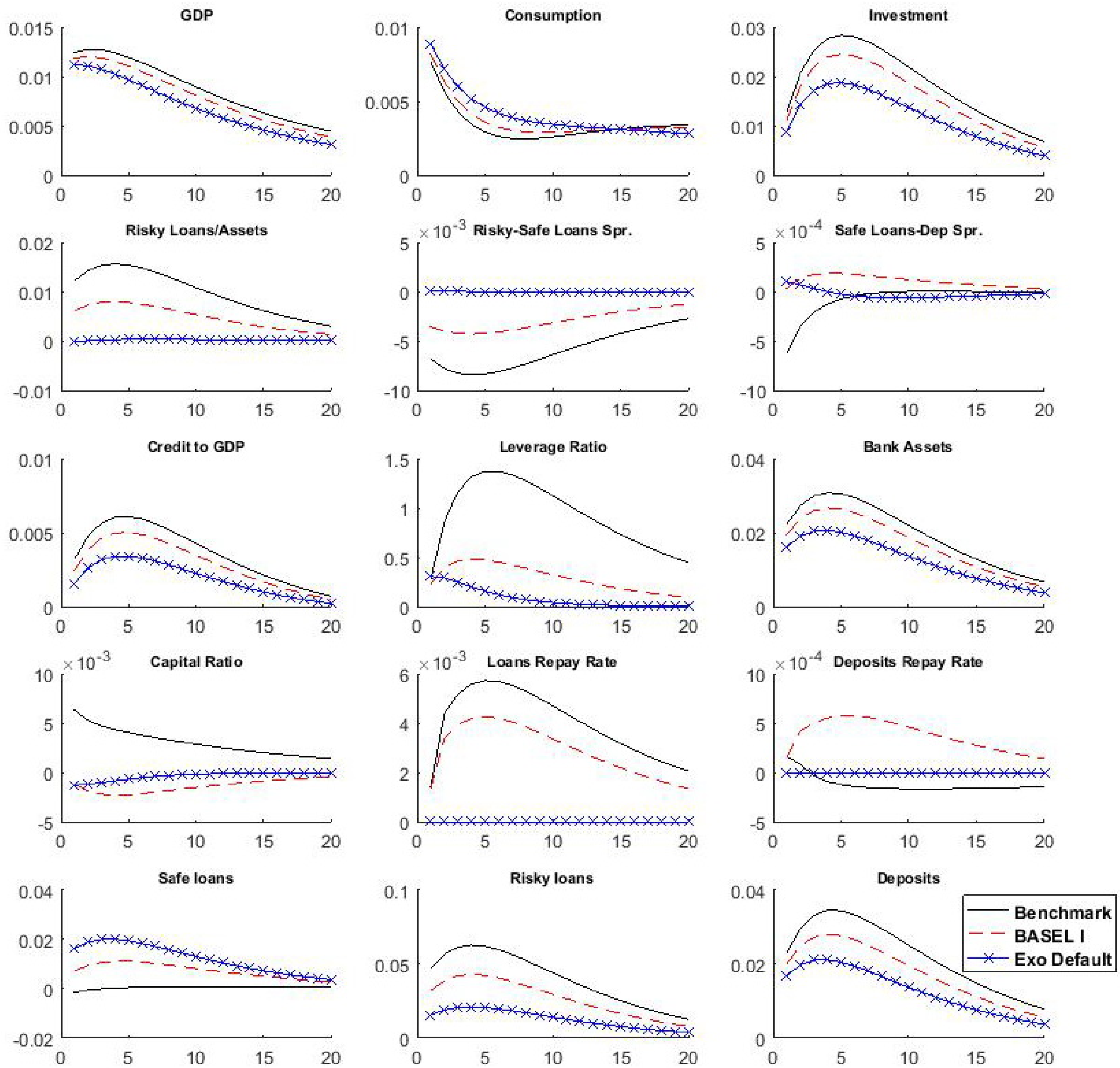
$$\begin{array}{c} \left[(1-\psi_t^{\gamma})\, \Pi_t^{\gamma}\right]^{-a_{\gamma}} - \omega \left(\frac{k_t^{\gamma}}{\bar{k}}\right)^{-b} \frac{1}{\bar{k}} \frac{1}{rwa_t^{\gamma}} + \mu \frac{\left(\psi_t^{\gamma} - \psi^{\gamma}\right)}{\Pi_t^{\gamma}} \\ = E_t \left[\Lambda_{t,t+1}^{\gamma} \frac{\left(1+r_t^d\right)}{\pi_{t+1}} \left[\left(1-\psi_{t+1}^{\gamma}\right) \Pi_{t+1}^{\gamma}\right]^{-a_{\gamma}}\right] \end{array} \tag{2.57}$$

$$\int m_t^{\alpha,i} di + \int m_t^{\beta,j} dj = \frac{\mu_t^d}{1+r_t^d} + e_t^{\gamma} = \frac{\mu_t^d}{1+r_t^d} + \psi_t^{\gamma} \Pi_t^{\gamma} \tag{2.58}$$

2.7.4 Simulations Figures and Table

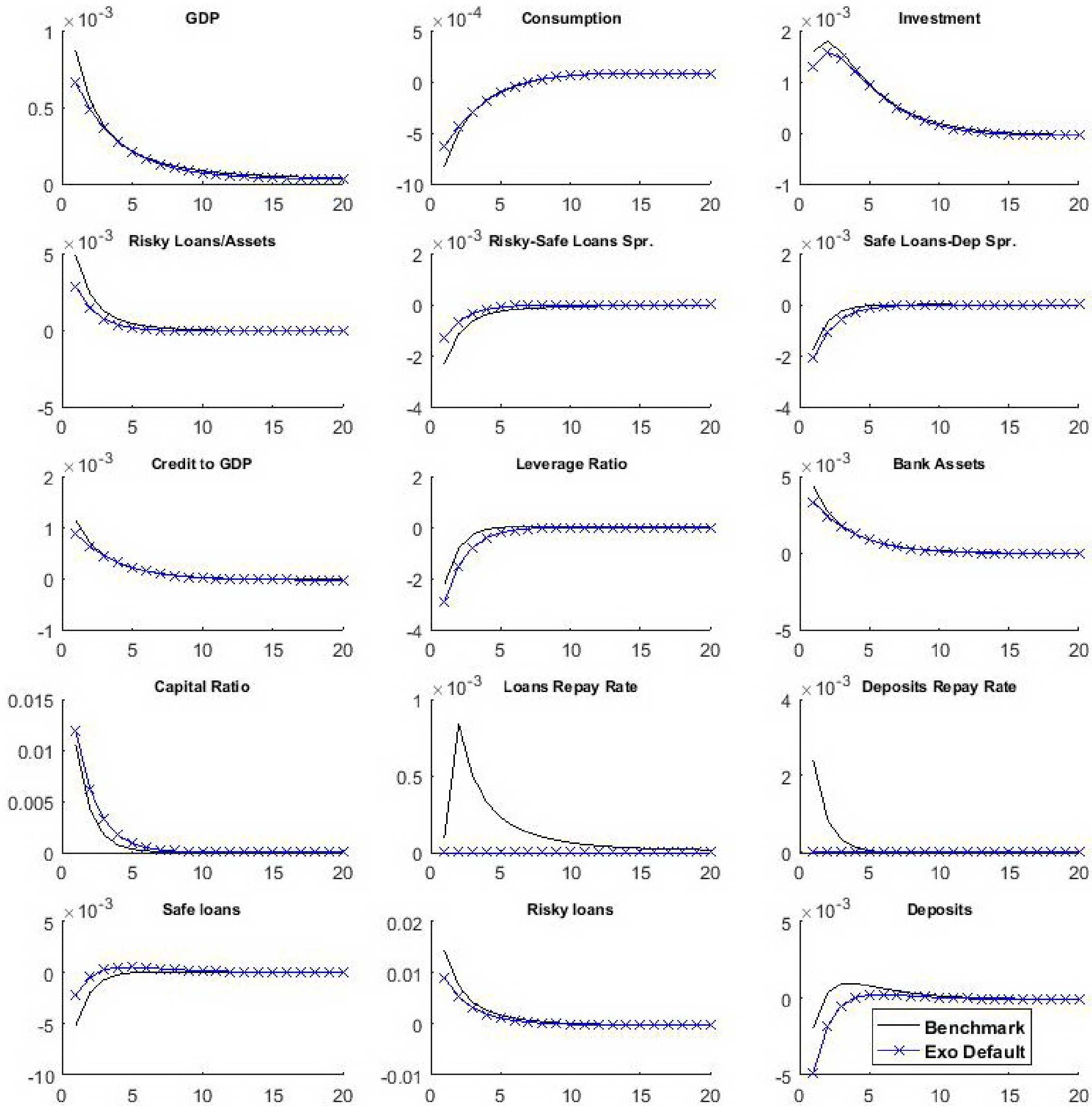
The responses of inflation, the ratio of risky loans to total assets, interest rates, interest rate spreads, the credit-to-GDP ratio, the leverage ratio, the capital adequacy ratio and the repayment rates are expressed in terms of percentage-point deviation from the steady state. The rest is expressed in terms of percentage deviation.

Figure 2.3: The response of the economy to a positive productivity shock



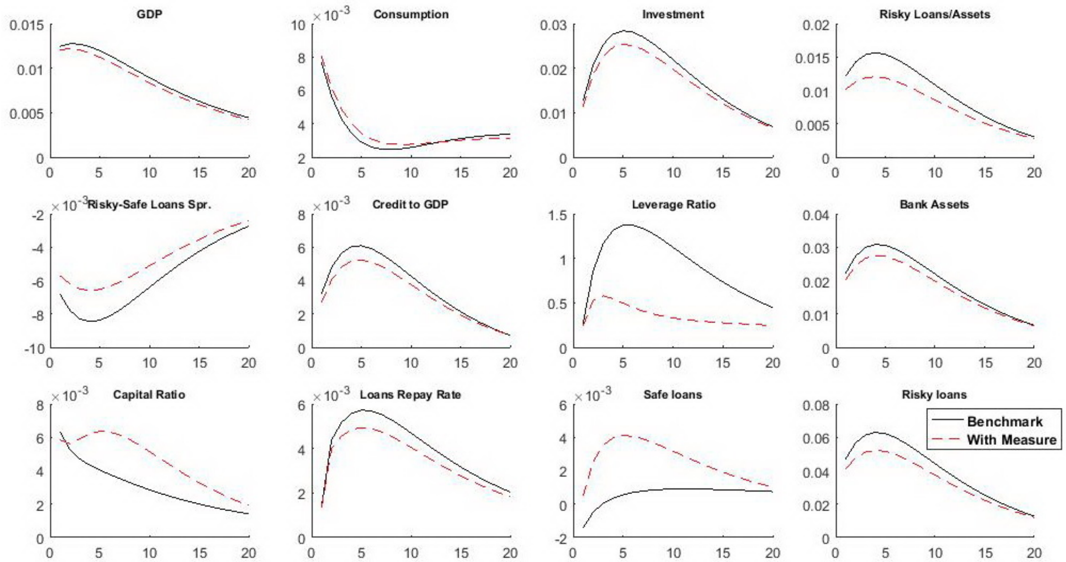
Note: black solid line shows the responses under benchmark model, red dashed line from the model assuming Basel I capital regulation and blue crossed line from the model assuming exogenous default

Figure 2.4: The response of the economy to a positive bank capital shock



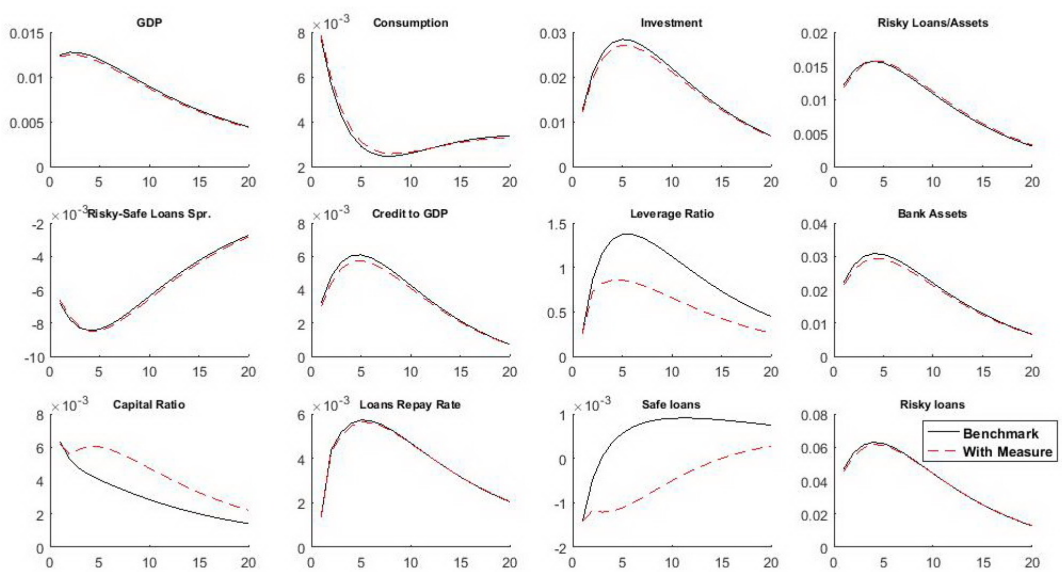
Note: black solid line shows the responses under benchmark model, and blue crossed line from the model assuming exogenous default

Figure 2.5: The response of the economy with countercyclical capital buffers to a positive productivity shock



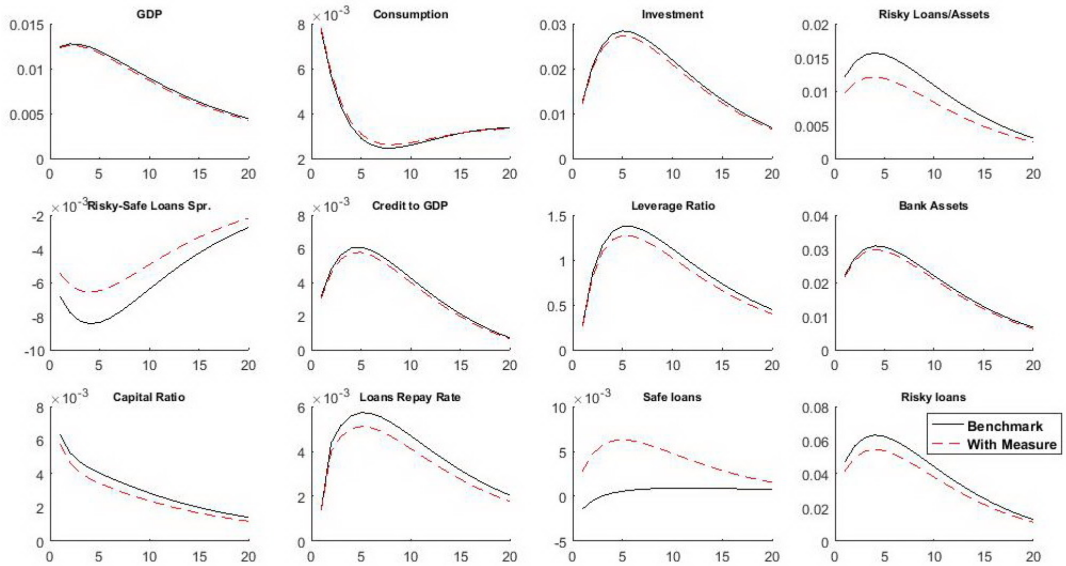
Note: black solid line shows the responses under benchmark model, and red dashed line from the model with macroprudential regulation

Figure 2.6: The response of the economy with leverage ratio targeting to a positive productivity shock



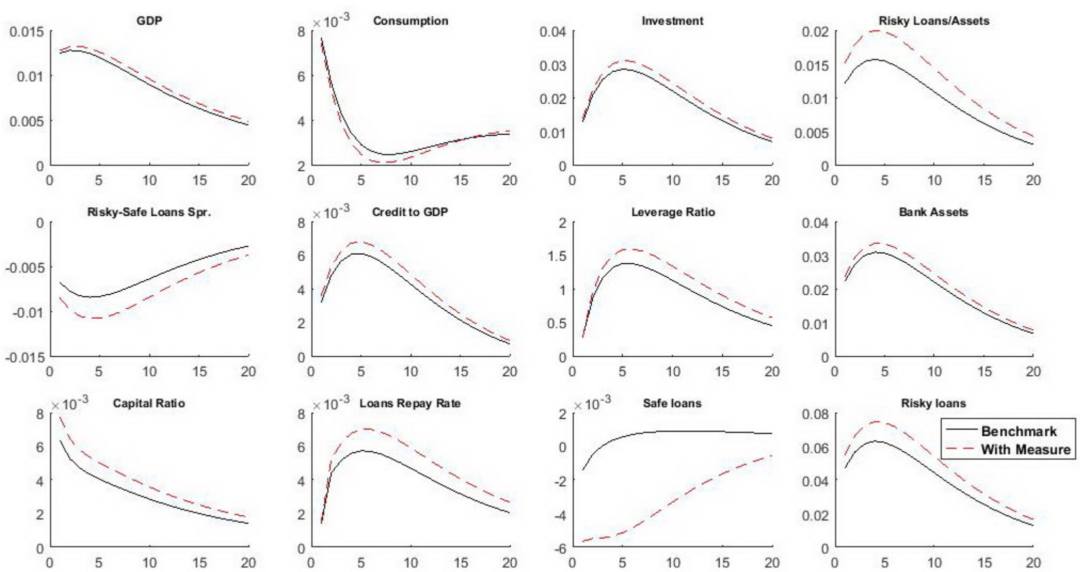
Note: black solid line shows the responses under benchmark model, and red dashed line from the model with macroprudential regulation

Figure 2.7: The response of the economy with risky to total asset ratio targeting to a positive productivity shock



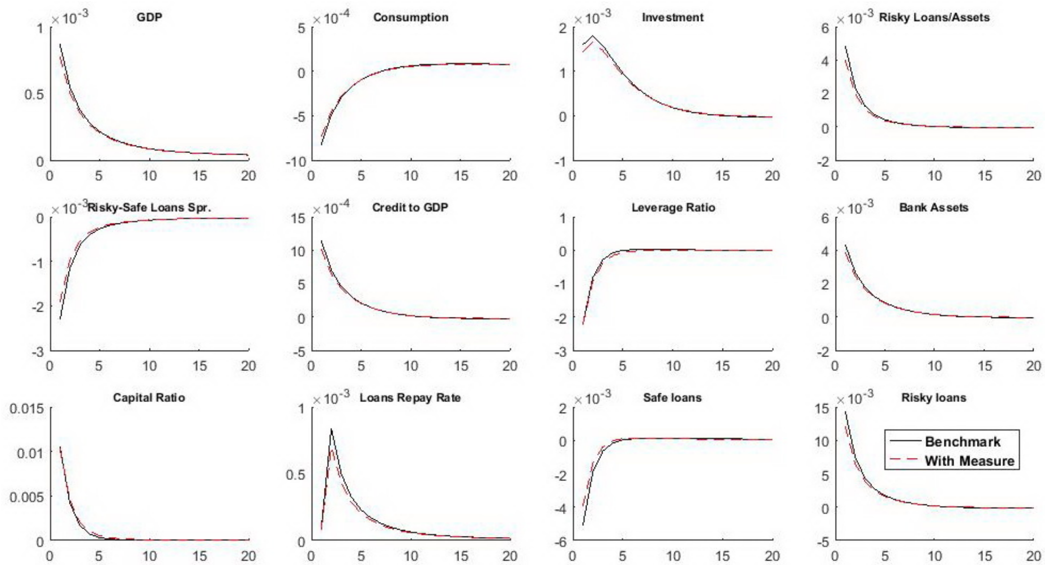
Note: black solid line shows the responses under benchmark model, and red dashed line from the model with macroprudential regulation

Figure 2.8: The response of the economy with high capital requirement to a positive productivity shock



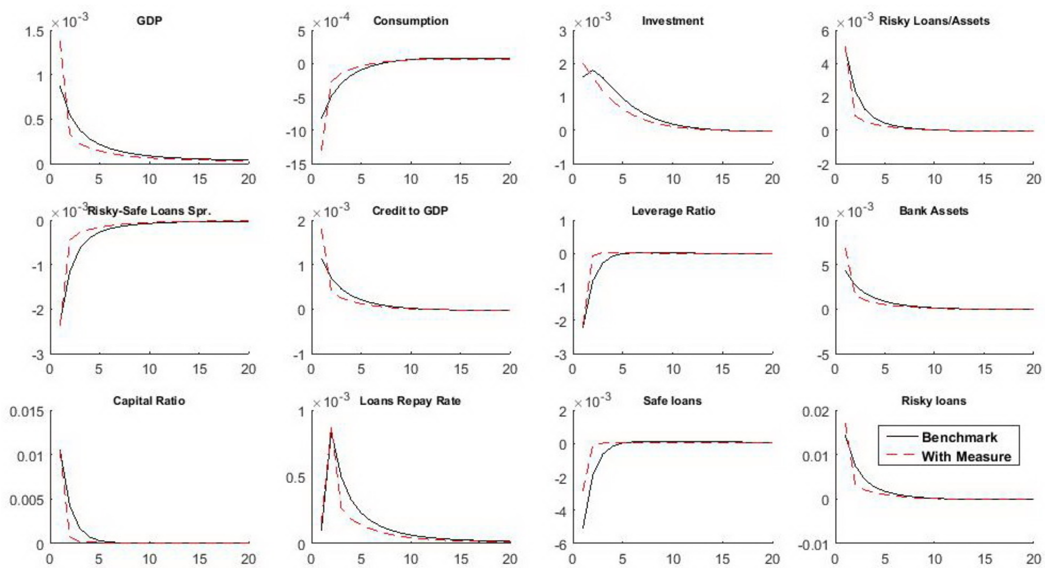
Note: black solid line shows the responses under benchmark model, and red dashed line from the model with macroprudential regulation

Figure 2.9: The response of the economy with countercyclical capital buffers to a positive bank capital shock



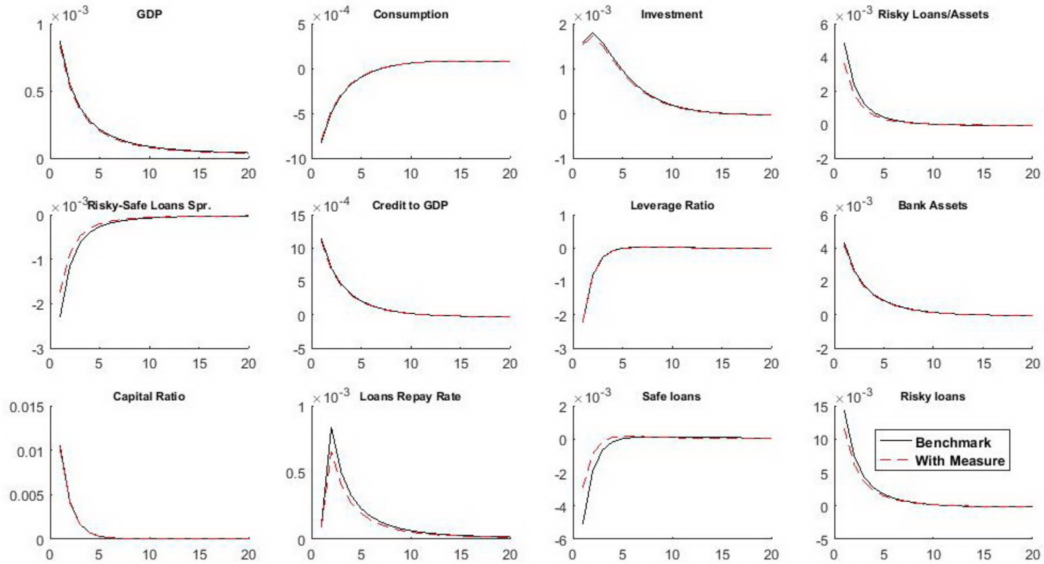
Note: black solid line shows the responses under benchmark model, and red dashed line from the model with macroprudential regulation

Figure 2.10: The response of the economy with leverage ratio targeting to a positive bank capital shock



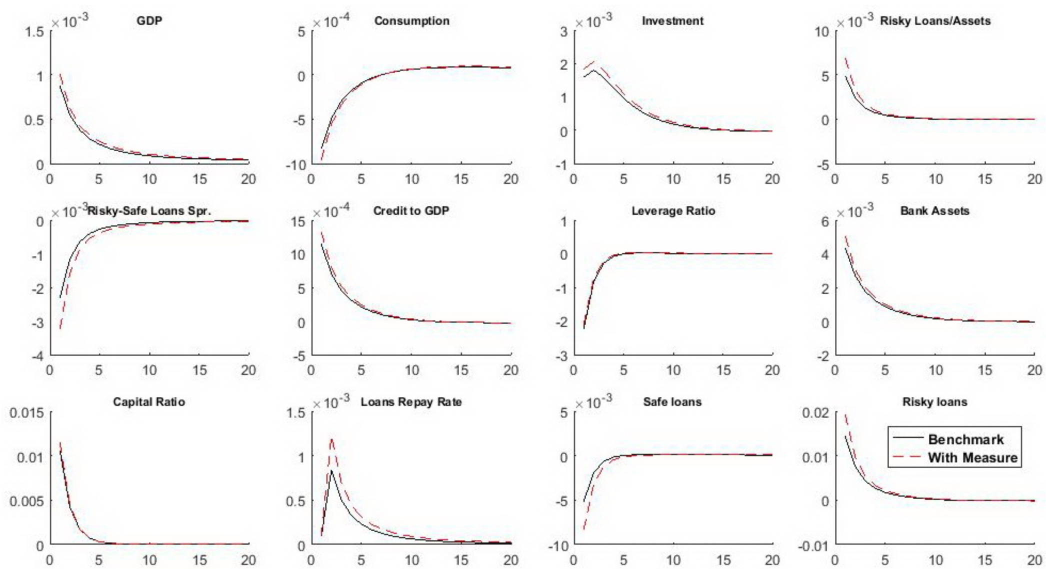
Note: black solid line shows the responses under benchmark model, and red dashed line from the model with macroprudential regulation

Figure 2.11: The response of the economy with risky to total asset ratio targeting to a positive bank capital shock



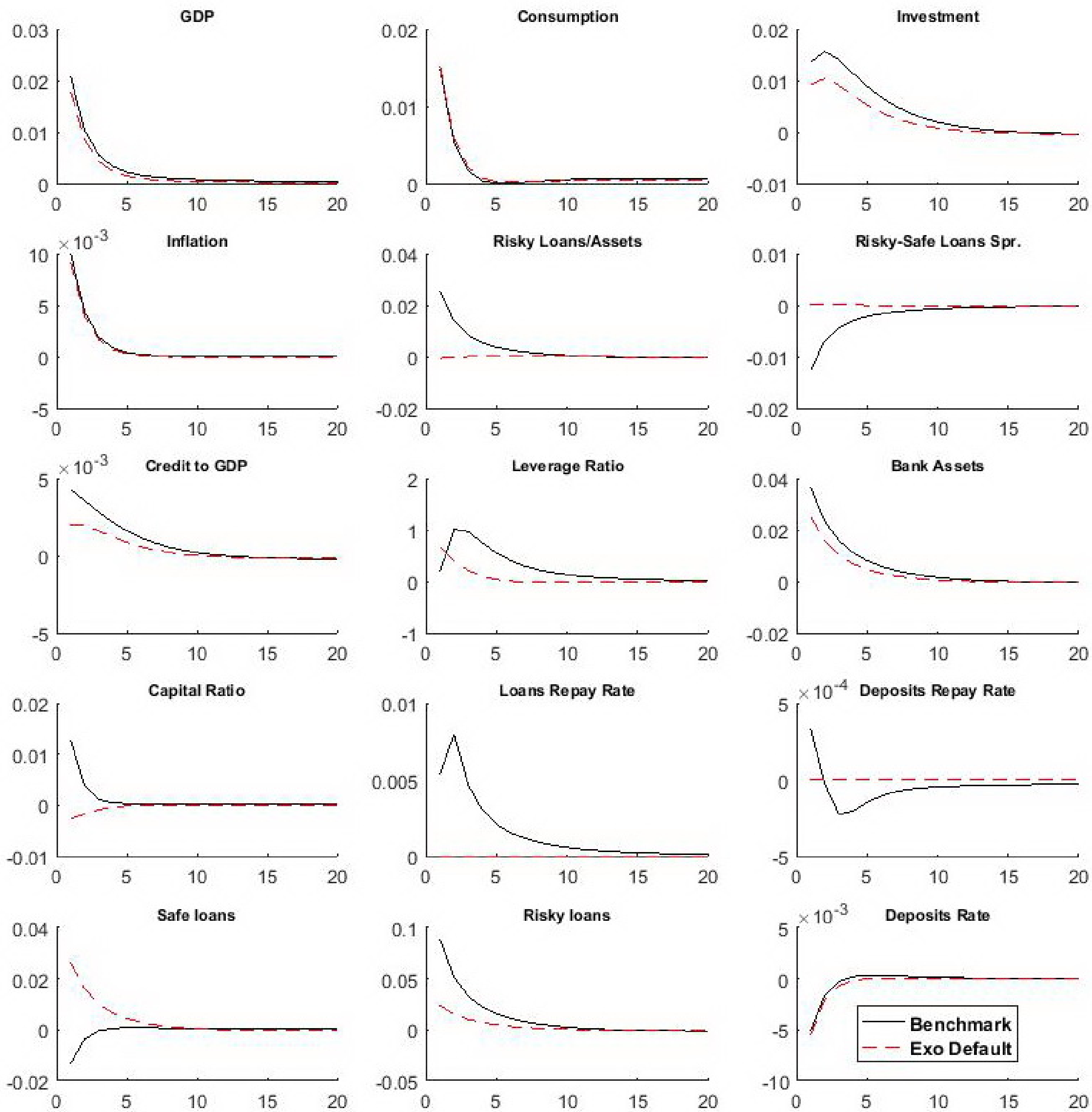
Note: black solid line shows the responses under benchmark model, and red dashed line from the model with macroprudential regulation

Figure 2.12: The response of the economy with high capital requirement to a positive bank capital shock



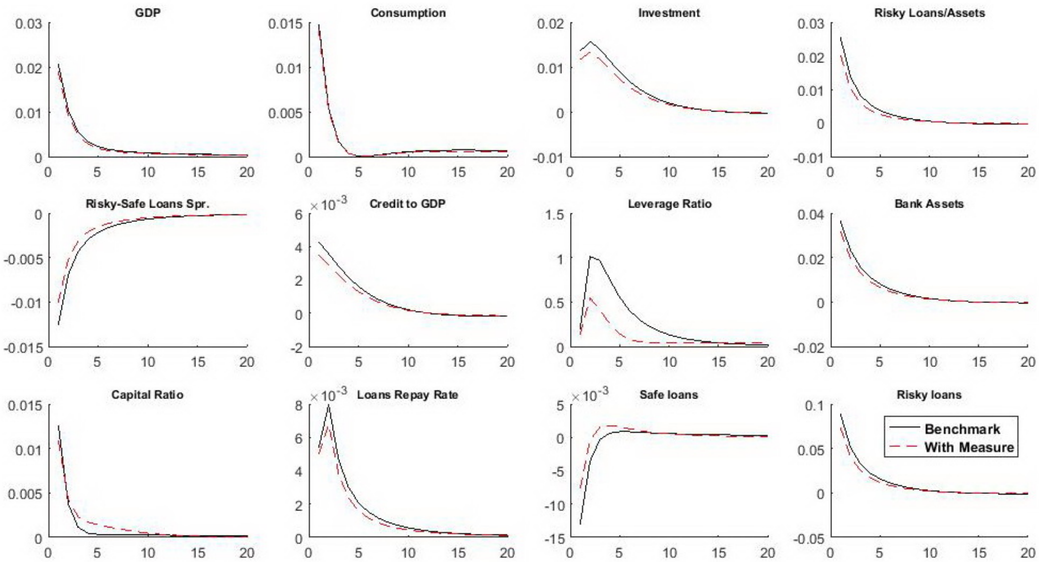
Note: black solid line shows the responses under benchmark model, and red dashed line from the model with macroprudential regulation

Figure 2.13: The response of the economy to an expansionary monetary policy shock



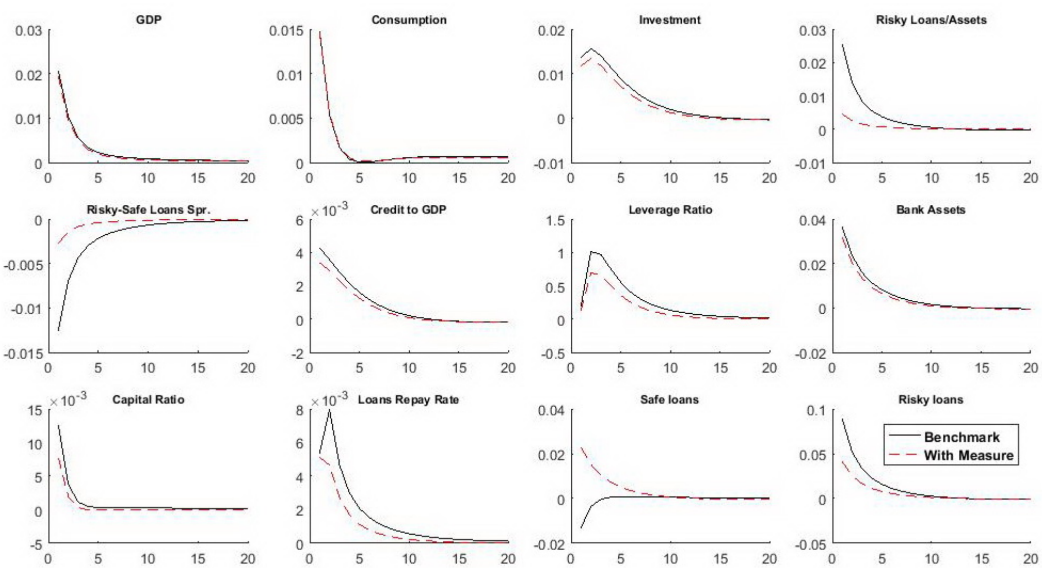
Note: black solid line shows the responses under benchmark model, red dashed line from the model assuming exogenous default

Figure 2.14: The response of the economy with countercyclical capital buffers to an expansionary monetary policy shock



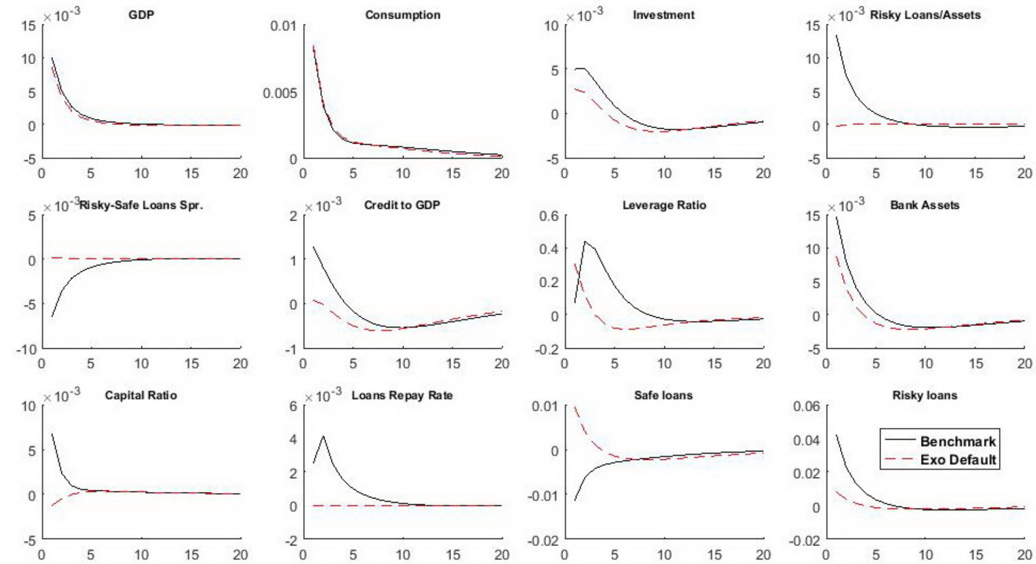
Note: black solid line shows the responses under benchmark model, and red dashed line from the model with macroprudential regulation

Figure 2.15: The response of the economy with risky to total asset ratio targeting to an expansionary monetary policy shock



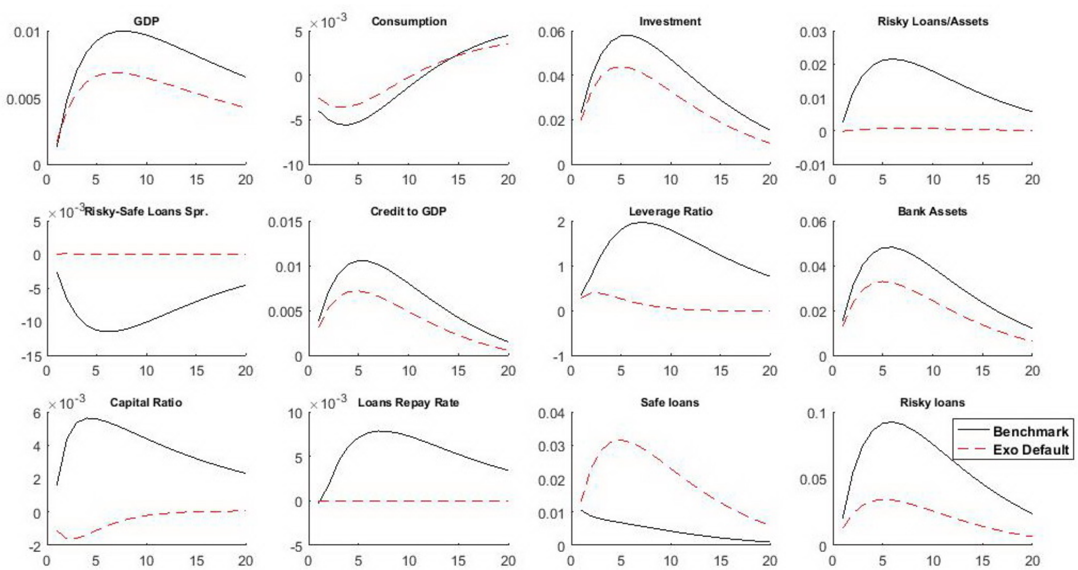
Note: black solid line shows the responses under benchmark model, and red dashed line from the model with macroprudential regulation

Figure 2.16: The response of the economy to an intertemporal preference shock



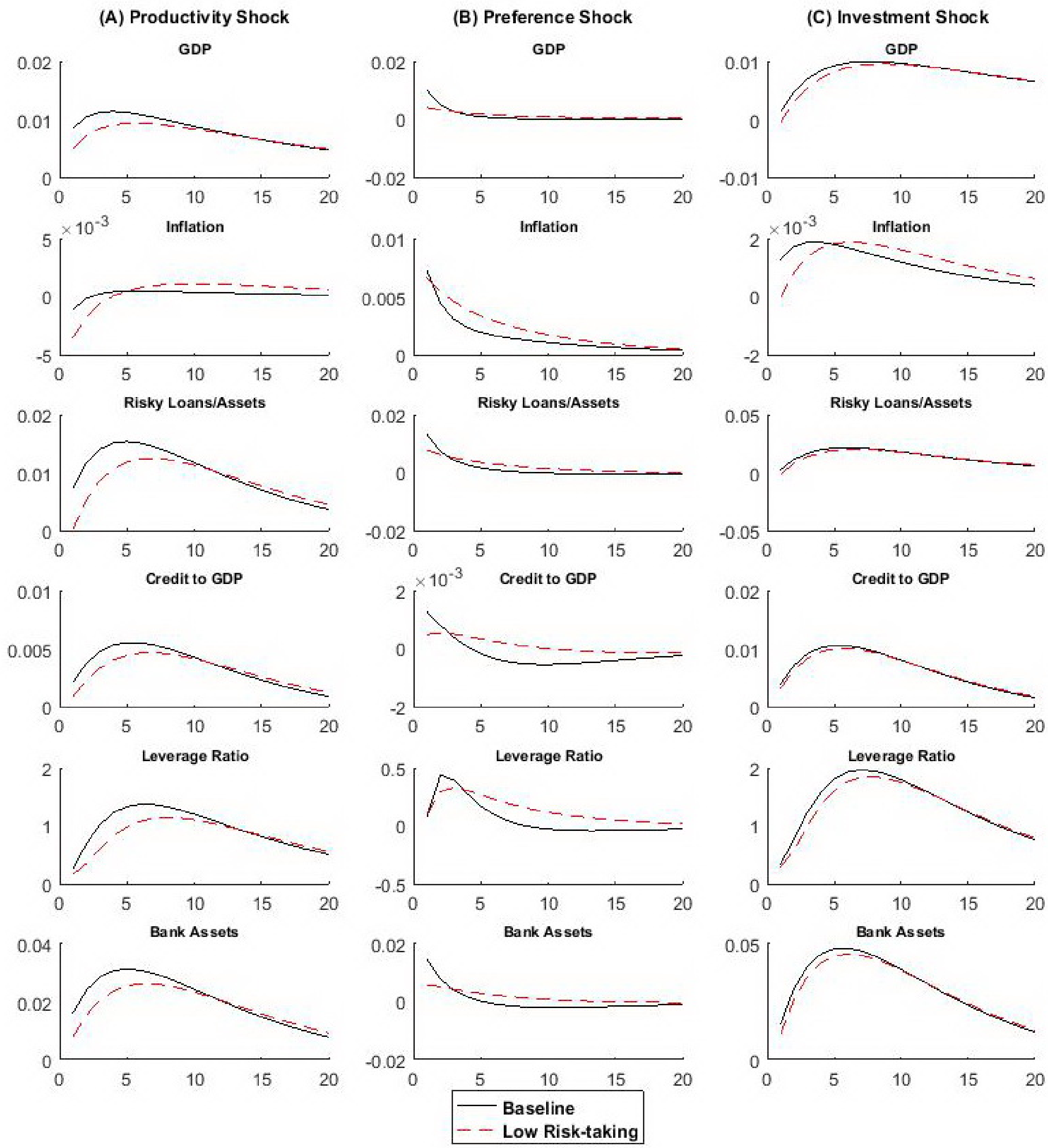
Note: black solid line shows the responses under benchmark model, and red dashed line from the model assuming exogenous default

Figure 2.17: The response of the economy to an investment efficiency shock



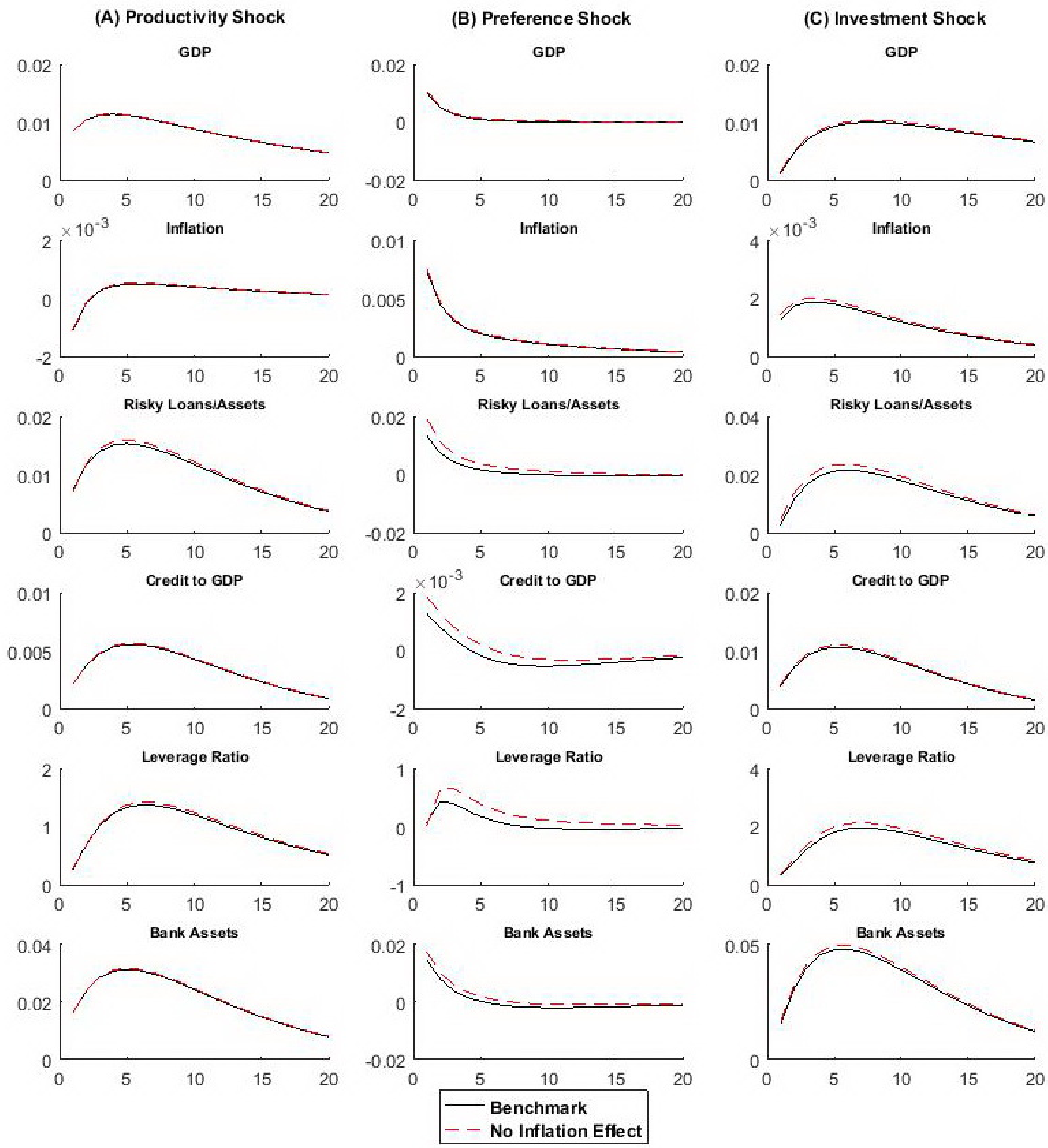
Note: black solid line shows the responses under benchmark model, and red dashed line from the model assuming exogenous default

Figure 2.18: The response of the economy under different bank risk-taking aversion



Note: black solid line shows the responses under benchmark model, red dashed line from the model assuming the augmented Taylor rule to reflect bank risk-taking aversion

Figure 2.19: The response of the economy assuming no inflation effect on default decision



Note: black solid line shows the responses under benchmark model, red dashed line from the model assuming no inflation effect on default decision and interest rate spreads

Table 2.10: Cumulative impacts of each macroprudential regulation on the responses of variables of interest to each shock

	GDP	Risky to total asset ratio	Bank assets
Productivity Shocks			
Countercyclical capital buffers	-2.382	-5.900	-8.039
Leverage ratio targeting	-1.581	-1.463	-5.115
Risky to total asset ratio targeting	-1.805	-15.900	-7.384
Raising capital requirements	1.368	6.904	5.667
Bank Capital Shocks			
Countercyclical capital buffers	-0.146	-0.331	-0.378
Leverage ratio targeting	0.102	-0.496	-0.038
Risky to total asset ratio targeting	-0.144	-1.158	-0.483
Raising capital requirements	0.174	0.694	0.540
Monetary Policy Shocks			
Countercyclical capital buffers	-0.657	-1.480	-1.730
Leverage ratio targeting	-0.483	-0.368	-1.220
Risky to total asset ratio targeting	-0.638	-5.066	-2.156
Raising capital requirements	0.192	1.914	1.123
Preference Shocks			
Countercyclical capital buffers	0.080	0.258	0.464
Leverage ratio targeting	-0.115	-0.066	-0.210
Risky to total asset ratio targeting	-0.283	-2.225	-0.919
Raising capital requirements	0.085	0.971	0.742
Investment Shocks			
Countercyclical capital buffers	-4.419	-11.117	-15.110
Leverage ratio targeting	-2.189	-2.109	-7.307
Risky to total asset ratio targeting	-2.357	-21.667	-10.029
Raising capital requirements	1.806	9.449	7.967

Note: the numbers measure cumulative difference over 20 periods between the responses of the economy with macroprudential regulation in place and those from the benchmark model. The difference of GDP and bank assets are measured in percentage, while that of risky to total asset ratio in percentage points.

Chapter 3

Mortgage Default, Financial Disintermediation and Macroprudential Policies

Abstract

The recent global financial crisis has highlighted the spillover effects of shocks originating in the housing and financial markets on the real economy. This paper embeds endogenous mortgage default into a New Keynesian model that features housing and non-trivial banking sectors. In particular, loan origination is subject to capital requirements. We study shocks to the variance of an idiosyncratic housing shock (housing risk shocks) and to the penalty on capital regulation (risk premium shocks). A large adverse housing risk shock results in higher mortgage default, which in turn raises the mortgage spreads. It also generates losses to banks, which subsequently constrains their lending activity. Capital regulation and housing adjustment costs are shown to be important for propagating the effects of a shock and explaining the substantial decline in GDP. A risk premium shock, meanwhile, raises mortgage and business loan interest rates. This has negative effects on aggregate demand. We later introduce three macroprudential measures to explore whether they improve economic stability and welfare. These include caps on loan-to-value (LTV) ratio, countercyclical capital buffers and a state-contingent LTV ratio. The results support the use of the first two measures, while the latter may exacerbate a decline in the welfare of mortgage borrowers.

3.1 Introduction

The recent global financial crisis has highlighted the spillover effects of shocks originating in the housing and financial markets on the real economy. Prior to the crisis, banks granted easier access to funds for subprime mortgage borrowers, supported by a number of factors including continuously-rising house prices, excess liquidity, securitisation activity, and so on. Households enjoyed increased possession of houses, while ultimate investors/lenders received high returns with a low perceived risk from mortgage-backed securities (MBS). However, the situation reversed. The housing bubble collapsed, triggering a widespread default on mortgages. Financial intermediaries inevitably faced immense losses, which were further exacerbated by a decline in the market value of those MBS. As bank capital eroded, they encountered the need to deleverage to satisfy the capital adequacy regulation. Being aware of counterparty risks, they were also reluctant to lend to one another, giving rise to liquidity problems. A credit crunch occurred and put pressures on both domestic and global economy.

Policymakers around the world have then provided unprecedented amounts of economic stimuli. At the same time, macroprudential regulation measures were introduced to prevent systemic risks and improve the resilience of the overall financial system. Drawing on the precedent crisis, the paper therefore aims to embed mortgage default into a New Keynesian (NK) model that features housing and non-trivial banking sectors. To replicate the crisis event, we see mortgage default as a necessary ingredient in generating shocks and the presence of the banking sector as a sufficient ingredient to bring about a meaningful financial accelerator. We are then interested in whether macroprudential regulation can help promote economic stability and welfare.[53]

[53] See Brunnermeier (2008) for a brief description of the causes and consequences of the global financial crisis.

Examining the composition of household debt and bank assets may offer an idea of why problems in the mortgage market can precipitate into financial and economic crises. It also underscores the necessity to introduce the housing sector and mortgages into the model, if one seeks to understand macroeconomic fluctuations. The data from the US flow of funds accounts (Table 3.7 in the Appendix) have shown that mortgages constitute a large part of the balance sheet for both households and commercial banks. On household liabilities, home mortgages constitute 65.38 percent of total liabilities at the end of 2015. This figure is far greater than consumer credits which is the second biggest component. Mortgages also form 16 percent of total liabilities of non-financial businesses.[54]

At the same time, on the asset side of bank balance sheet, 39.74 percent of total financial assets are mortgage related. They can be in the form of either individual mortgage loans or MBS. In terms of the latter, even though they are backed by an agency and government-sponsored enterprises, banks may still suffer from the deterioration of their value, particularly when asset fire-sales occur. Banks, as well as non-bank financial institutions, recorded considerable losses from investment in both mortgages and MBS during the past crisis. Therefore, studying behaviors of households and banks without taking mortgage origination into consideration would lead to an incomplete picture of the modern financial economy. In addition, without the mortgage market the recent crisis cannot be assessed properly.

Our benchmark model builds on Gerali et al. (2010), who embed the housing and banking sectors in the NK framework. Two households differing in their discount rates derive utility from both consumption goods and housing services. Patient households save in equilibrium while impatient households acquire mortgages from

[54] We do not focus on commercial mortgages in this paper. See Iacoviello (2005) for the model including both residential and commercial mortgages. The data from the Federal Reserve Board suggests that the majority of the real estate loans (53.48 percent) is of residential type (excluding multifamily property, but including both revolving home equity loans and closed end residential loans). In addition, MBS backed by the government are mostly those collateralised by a pool of residential mortgages. These justify the importance of studying residential mortgages.

banks using the houses as collateral. Their model is suitable for an analysis of mortgage default and macroprudential regulation. The existence of housing and mortgages makes it straightforward to extend and include the possibility of default. We follow the approach by Bernanke et al. (1999) (hereinafter called BGG) and Forlati and Lambertini (2011) in modeling it. In particular, mortgage borrowers can choose to default on loan obligation and have their collateral seized by banks, whenever the ex-post value of the collateral falls below debt outstanding. Their model also includes banks that face capital requirements. This feature generates interactions between the real and financial sectors, as an erosion in bank net worth can trigger a credit crunch. The model with such Basel-II-type capital regulation will serve as our benchmark economy where only microprudential regulation is in place. We then extend this model to incorporate several macroprudential tools. Moreover, to allow for the role of investment in macroeconomic fluctuations, the model includes another agent, the entrepreneur who owns the economy's capital. We will show both with empirical evidence as well as model simulations that a slump in investment is the key factor that decreased Gross Domestic Product (GDP) during the recent crisis.

Empirical evidence in section 3.3 shows an acceleration of mortgage default and increased credit spreads during the crisis, which coincide with a deep and persistent economic recession. We study two main shocks to explain what have happened. First, a shock to the variance of idiosyncratic housing shocks is introduced to capture a trigger that generates a rise in mortgage default. We model this similarly to that introduced in Christiano et al. (2014) in the case of entrepreneurial loans. We show that adverse housing risk shocks depress economic activities. An unanticipated rise in default generates losses to banks and lowers their capital ratios. The latter leads banks to reduce new loans, particularly mortgages which become riskier. Entrepreneurs also receive less funding, which negatively affects their investment.

Banks also anticipate a persistent rise in mortgage default and thus charge higher mortgage spreads. Given fewer mortgages, impatient households cut both durable and non-durable consumption. We show that capital regulation and housing adjustment costs are crucial in propagating the effects of a shock and explaining the substantial decline in GDP. Second, a capital regulation penalty shock aims to capture rising credit spreads. As in Gilchrist and Zakrajšek (2012), we consider that the evolution of credit spreads partly reflects changes in bank risk-bearing capacity, which deteriorated immensely during the recent crisis. We show that this shock can also contribute to significant economic downturns. Banks raise the premia on both mortgages and business loans, prompting impatient households and entrepreneurs to reduce consumption and investment.

We then assess three macroprudential regulations to analyse their effectiveness in stabilising the effects of these two shocks. These include caps on the loan-to-value (LTV) ratio, countercyclical capital buffers and a state-contingent LTV ratio, which responds to the ratio of mortgages to GDP. We report four key results. First, imposing LTV caps benefits mortgage borrowers in the steady state. This may sound counterintuitive as the policy should constrain mortgage lending in the first place. However, it also brings down the steady-state probability of default. Due to a lower default risk, impatient households face a lower mortgage spread and are able to obtain more mortgages for consumption and housing accumulation. Therefore, their welfare improves, while the banking system becomes safer. Second, LTV caps are effective in limiting a surge in mortgage default in the face of housing risk shocks. The decline in mortgages and aggregate demand becomes much more muted. However, the level of the caps needs to be sufficiently stringent for impatient households to reap the welfare benefits. When risk premium shocks occur, the measure again limits a fall in mortgages, which in turn improves the welfare of impatient households.

Third, countercyclical capital buffers that react to the credit-to-GDP ratio may improve allocations and the welfare of both impatient households and entrepreneurs. As the effects of both shocks are transmitted through the banking sector, policies that ease the constraint faced by banks are effective in resolving the problems. In the face of housing risk shocks, the buffers also yield large macroeconomic stabilisation benefits when LTV caps are not available. However, financial regulators have to be aware that the credit-to-GDP ratio may send a false signal in certain circumstances which can destabilise the economy. This happens when the economy faces risk premium shocks and already has a LTV constraint in place. Last, our results do not support the use of state-contingent LTV caps when the economy faces housing risk shocks. The measure helps relax impatient households borrowing constraint during the crisis period. However, it exacerbates default and eventually reduces their welfare. This last result disagrees with the literature most of which supports state-contingent LTV ratios. For example, see Lambertini et al. (2013) and Rubio and Carrasco-Gallego (2014).

The rest of the paper is organised as follows. Section 3.2 reviews the existing literature in the area. Section 3.3 offers empirical evidence for the US during the crisis. We also offer a vector autoregression (VAR) analysis to motivate empirical relevance of the two shocks. Sections 3.4 and 3.5 describe the benchmark model and macroprudential regulation, respectively. Calibration of the model parameters is discussed in Section 3.6. Section 3.7 provides the simulation results, showing the responses of the economy with respect to the proposed shocks. In Section 3.8, we analyse the effectiveness of macroprudential measures in improving economic stability and welfare. The thesis ends with concluding remarks and potential extensions of future work.

3.2 Literature Review

This paper relates to literature that incorporates financial friction a la Kiyotaki and Moore (1997) in the dynamic stochastic general equilibrium (DSGE) model with housing. Iacoviello (2005) assumes that impatient households face borrowing constraints linked to the expected value of houses. Such constraints produce a financial accelerator in the face of demand shocks. Furthermore, Iacoviello and Neri (2010) further model the supply side of the housing market. Changes in house prices in their model impact both the collateral constraint of households and the profitability of the housing production sector. They show that shocks originating from the housing market, namely housing demand and housing technology shocks, have a significant contribution on economic fluctuations. In this respect, our paper follows Iacoviello (2005) in assuming fixed supply of houses, in order to exclusively focus on shock amplification through the demand side. Meanwhile, Monacelli (2009) exploits such borrowing constraints to capture the comovement of the durable and non-durable sectors in response to monetary policy shocks–an empirical finding established in Erceg and Levin (2006). In response to the Great Recession, Gerali et al. (2010) further imposed monopolistically competitive banks and capital regulation into the DSGE model with housing. They study the feedback loop between the real and financial sectors that magnifies the effects of productivity and monetary policy shocks. Moreover, they find considerable effects of a negative shock to bank capital on the real economy. Our model relies on the framework of the latter, however we introduce the possibility of mortgage default and utilise such framework to study the effectiveness of macroprudential tools.

Since the recent crisis, economists have become interested in embedding mortgage default into the DSGE framework. The literature relies on the modelling device introduced in BGG by introducing idiosyncratic shocks to the housing value. Mortgage borrowers default whenever the realised value of the collateral turns out to be lower than their debt. Forlati and Lambertini (2011) were the first to do so. They find that the real effects of mortgage default are amplified in highly-leveraged economy, while sluggish response of monetary policy can result in deeper recession. Similarly to BGG, they assume adjustable mortgage interest rates to satisfy the ex-post participation constraint of lenders, implying that borrowers absorb all the losses from aggregate risk. This seems an unrealistic assumption since during the crisis lenders suffered from extensive mortgage default. More importantly, their model does not include financial intermediaries. Hence, it is not possible to study the interactions between the banking and real sectors, which were instrumental during the Great Recession.

Quint and Rabanal (2014) instead assume a predetermined mortgage interest rate so as to permit loss-sharing between lenders and borrowers. Working with a two-economy model with financial intermediaries, they study the effectiveness of macroprudential regulation in improving economic stability and welfare within the context of the Euro Area. They find the measures to be useful when the economy faces housing market, rather than productivity, shocks. However, the key drawback of the paper is that the introduction of macroprudential regulation is fundamentally ad hoc. They assume that only a certain proportion of deposits is available as loanable funds, and that financial regulators adjust this proportion to implement macroprudential policies. Moreover, domestic financial intermediaries, being risk-neutral, have a naive and rather mechanical role in the economy. In our paper, the non-trivial role arises from the existence of capital requirements that link the size and composition of the banks balance sheet to their capital. Clerc et al. (2015) introduce three layers of default (deposits, mortgages and entrepreneurial loans) to study the interplay between the net worth of the borrowing agents and examine the effectiveness of the countercyclical capital buffers. Deposits default gives a special role to the net worth of financial intermediaries in determining loans supply conditions. However, the paper does not put any particular emphasis on mortgage default.[55]

Ferrante (2015) is the closest precursor to our paper, as the paper seeks to explain a slump in investment and output during the crisis through financial disintermediation. Housing risk and MBS collateral shocks affect banks' net worth, which subsequently widens an interest rate spread required on both mortgages and business loans. However, the key difference is that the banking friction in our model arises from the capital regulation as in Gerali et al. (2010), while that in Ferrante (2015) is generated by the moral hazard incentive as banks can divert away assets from depositors, an idea originated in Gertler and Karadi (2011). The framework of the latter is suitable for studying unconventional measures. In terms of policy implications, his focus is therefore not on macroprudential regulation but on credit policies that were recently employed during the crisis.

A handful of papers attempt to model mortgage default in dynamic general equilibrium model with finite periods, finite states and incomplete market. Campbell and Cocco (2015) model mortgage default that is driven not only by home equity consideration but the tightness of the borrowing constraint. They also emphasise mechanisms how increases in the LTV ratio and loan-to-income (LTI) ratio raise default probability. Goodhart et al. (2011) and Goodhart et al. (2013) have an endowment-economy model with heterogeneous households and banks, cash-in-advance constraint, housing and mortgage default. The latter further introduces shadow banks and securitisation to emphasise risks and consequences of asset fire sales. They study multiple financial regulations and show that the economy can benefit from their right combination (for example, using countercyclical capital buffers in conjunction with margin

[55]Capital regulations are imposed strictly in their model, while in ours banks optimally weigh benefits and costs of complying with the regulations. The capital adequacy ratio can then be time-varying. In addition, borrowers again have to satisfy lenders participation constraint ex-ante. We instead opt for Quint and Rabanal (2014)'s approach where loans pricing is done through the market.

requirements).

This paper is also related to literature exploring the effectiveness of macroprudential regulation. This strand of the literature can be split into two groups. The first group conducts a normative analysis seeking to identify distortions that result in inefficient allocation and examines how regulation improves the outcomes. Bianchi (2011), for example, constructs an international model featuring an occasionally binding borrowing constraint. During normal time, the failure of the agents to internalise the effects of their borrowing decisions on collateral prices gives rise to the so-called "pecuniary" externalities and hence the problem of "overborrowing". This raises the probability and severity of the crisis, driven by the Fisherian debt-deflation dynamics. He concludes that taxes on debt can yield welfare improvements. In a related framework, two-period setting, Jeanne and Korinek (2010) argue that imposing Pigouvian taxes on capital inflows during the boom periods can reduce the probability of sudden stops. Bianchi and Mendoza (2010), on the other hand, consider a closed economy where the borrowing constraint is tied with the price of assets (i.e. land) rather than goods. They show that taxes on debt and dividends can help a decentralised economy obtain constrained Pareto allocations.

Our work belongs to the second group, which features a positive approach. In particular, we take the existence of macro-prudential measures for granted and examine whether regulation reduces macroeconomic fluctuations and improves welfare. Angelini et al. (2014), using the model of Gerali et al. (2010), examine the effectiveness of countercyclical capital buffers and find that the measure helps promote economic stability when it is used to counterweigh financial shocks, namely shocks to bank capital. They also stress the importance of the cooperation between monetary and macroprudential authorities. Angelini et al. (2015) use wide ranges of DSGE models and tend to support countercyclical capital buffers as tools to dampen output volatility. Bean et al. (2010) modify the framework of Gertler and Karadi (2011) to study the effects of lump-sum levy or subsidy on the banking sector. They also support the use of macroprudential regulation and suggest that policymakers coordinate to avoid "push-me, pull-you" outcome, particularly when facing inflation shocks. Like Angelini et al. (2014), Kannan et al. (2012) suggest that using a macroprudential tool that responds to credit growth can improve welfare in the face of credit spread and housing demand shocks, as opposed to productivity shocks. However, their model lacks microfoundation on the determination of credit spreads, which are ad-hocly assumed to depend on the LTV ratio, macroprudential regulation and exogenous shocks.

One of the key contributions of our paper is with respect to the effects of the LTV regulation on mortgage default. A handful of articles have assessed the effectiveness of state and non-state contingent LTV caps in the model with housing. However, none of them includes mortgage default, which is the key aspect of the global financial crisis and the, subsequent, Great Recession. DSGE papers with mortgage default above are yet to consider LTV regulations which should be the most relevant to housing market fluctuations. Lambertini et al. (2013) model mortgage boom-bust cycles driven by news shocks. They find that countercyclical LTV and interest rates that respond to credit growth are socially optimal. They also stress the impact of heterogeneity on welfare across borrowers and savers. Gelain et al. (2013) deviate from rational expectations and assume that a subset of agents instead adopt a simple moving average forecast rule. This helps explain excessive volatility in debt and house prices. They find that a debt-to-income type constraint is more effective than LTV caps in terms of dampening excess volatility, while interest rates that respond to financial indicators can result in higher inflation volatility.[56] In addition, more restrictive LTVs makes impatient households worse off at the steady state. This result differs from ours. Finally, Rubio and Carrasco-Gallego (2014) suggest that the

[56]However, the paper considers only standard macroeconomic shocks as a source of disturbances.

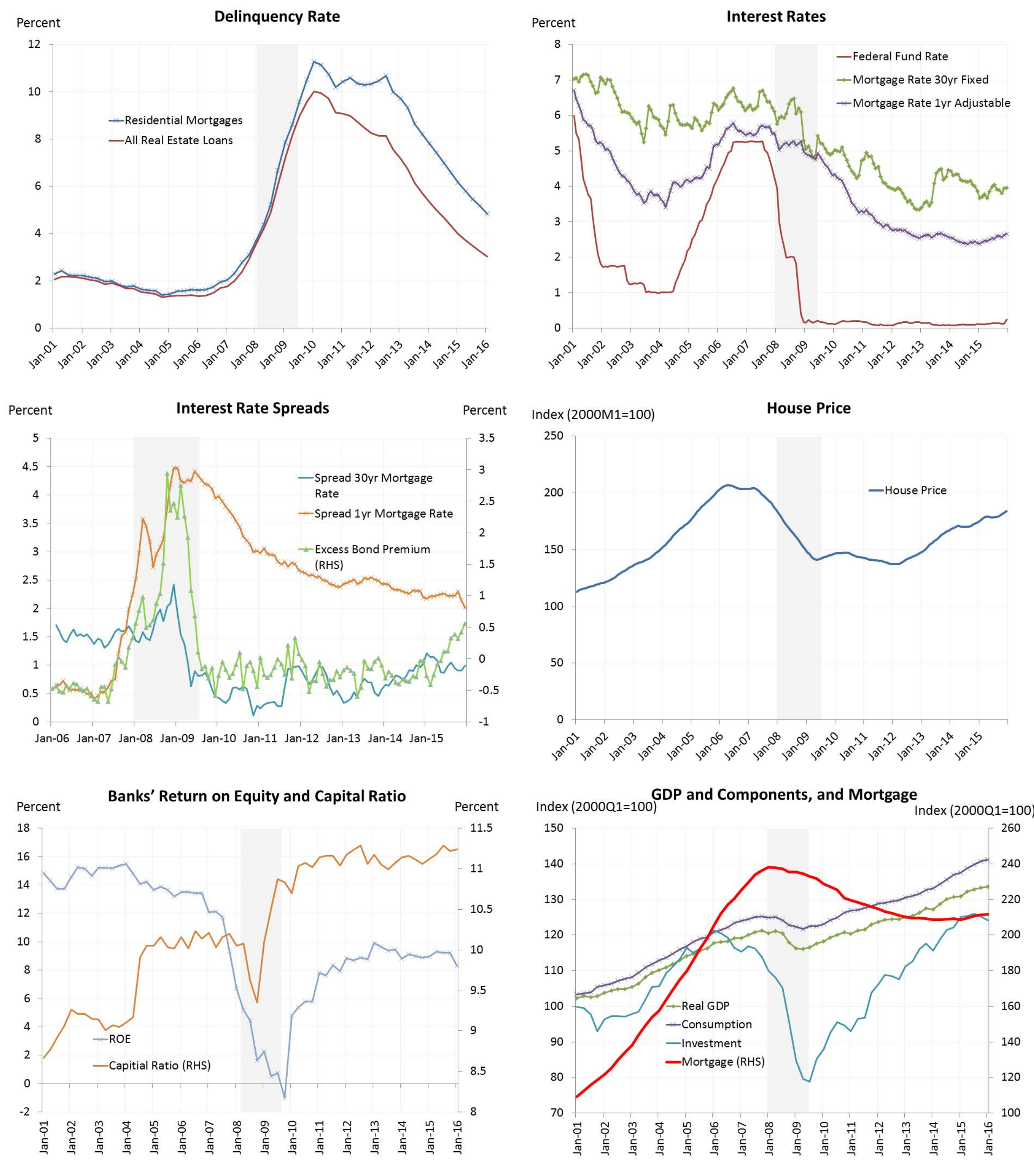
optimal LTV rule which responds to credit growth improves both macroeconomic stability and welfare. However, they support non-cooperation between the central bank and financial regulators. Our paper will show that state-contingent LTV caps may potentially be undesirable in the face of housing risk shocks. Meanwhile, countercyclical capital buffers, in certain circumstances, may destabilise the economy when encountering risk premium shocks.

3.3 Empirical Evidence

This section briefly examines empirical evidence on how the housing, banking and real sectors interacted during the Great Recession. We offer a VAR analysis, where the model's two key shocks, namely housing risk shocks and risk premium shocks, are identified using standard Cholesky decomposition, to explore whether they are empirically relevant in explaining the housing and financial crises.

We consider that the trigger to such a deep and prolonged recession was the rise in mortgage default and a reduction in bank risk-bearing capacity, the latter reflected in increasing credit spreads. In figure 3.1, we present evidence from the US and highlight the data during the economic recession period in grey. The delinquency rate on real-estate loans rose from below 2 percent before 2007 to its peak at 10 percent in the first quarter of 2010, and then gradually declined. Far worse was the delinquency rate on residential mortgages, the only type of mortgages considered in this model, which climbed above 11 percent and stood higher than 10 percent for almost three years. The trend of mortgage interest rates closely follows that of the federal funds rate. We can observe that from 2007 interest rates are declining to ward off recession. Nevertheless, mortgage spreads seem to reflect heightened default risk and tight credit supply conditions. The spread between 30-year mortgages and government bonds of the same maturity stood at around 1.5 percent pre-crisis. The

Figure 3.1: Empirical Evidence



Note: see data description in the Appendix.

spread is even lower for 1-year mortgages. However, both began rising in 2007 to reach the maximum at the end of 2008 at 2.42 and 4.13 percent, respectively.[57] Gilchrist and Zakrajšek (2012) construct a credit spread index from the corporate bond market, namely the excess bond premium (EBP), to reflect banks risk-bearing capacity and hence credit supply conditions. They show that EBP is a powerful predictor for future economic activity. From the figure, we see EBP skyrocketing during the crisis.

S&P/Case-Shiller house price index began falling from the second quarter of 2007. The index only stabilised in 2009 and started to increase again in 2012. Return on average equity, a measure of bank profitability, for all US banks fell sharply in 2007-2008 from above 13 percent, and reached its bottom at -1.03 percent during the last quarter of 2009. A period of decline in house prices and bank profits is consistent with the timing of a surge in mortgage default. Bank capital-to-asset ratios exhibited an upward trend for decades. The crisis interrupted this trend during the second half of 2008. Data on bank profitability and capitalisation all signal financial fragility. Based on the data from the US flow of funds accounts, the stock of household mortgages delivered a consistent picture, despite the decline that took place later in 2008. This may be due to the fact that borrowers can still exercise credit lines (in particular from home-equity borrowing), although new loans can already become constrained. However, the decline is persistent and reached its trough in 2014.

As far as real economic variables are concerned, we can observe a fall in real GDP from the third quarter of 2008 until the second quarter of 2009. Subsequently, the figure rebounded and has already surpassed its pre-crisis level in 2011. Real consumption and non-residential investment exhibited the same pattern, but the decline in investment is much deeper and more persistent, highlighting the need to

[57] It can be observed from 1987 that there are three episodes where mortgage default soared, and they all coincide with widening mortgage spreads.

consider and model the slump in capital investment.[58]

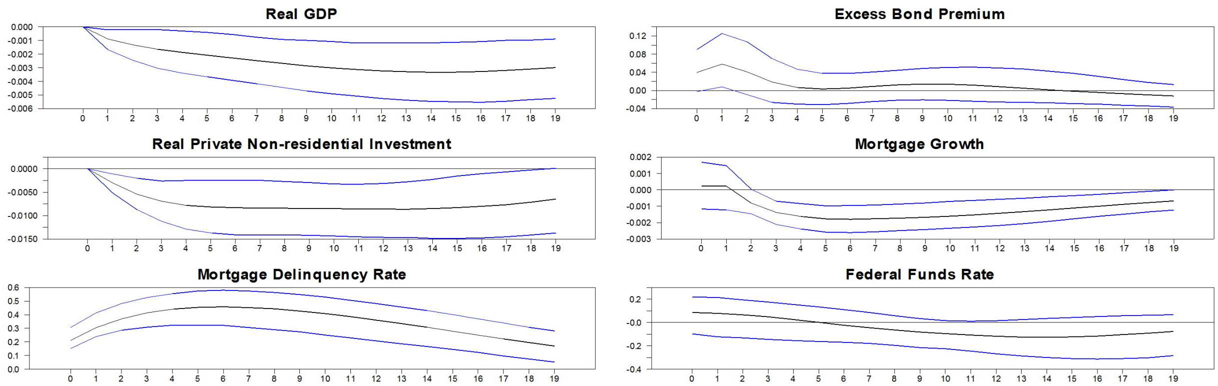
Next we examine VAR evidence to observe macroeconomic effects of the two shocks of interest in the theoretical model. Our 2-lag quarterly US VAR model consists of seven variables, namely log of real GDP, log of real private non-residential investment, log of GDP deflator, the delinquency rate of loans secured by real estate (also known as mortgage default), EBP, growth of mortgages and the federal funds rate. We use an orthogonalised shock to mortgage default and EBP, identified with Cholesky decomposition, to trace the effects of theoretical housing risk and risk premium shocks, respectively. Mortgage growth is ordered below mortgage default and EBP, because we consider that a shock to the latter variables may exert immediate pressure on lending activity but not vice versa. Altering the order of the three variables does not qualitatively change the results. The estimation period covers the first quarter of 1987 to the second quarter of 2008, based on the availability of delinquency data. The confidence interval is based on 90-percent bootstrapped band.[59]

Figure 3.2 shows that a positive shock to mortgage default and EBP causes adverse effects on real GDP, investment and lending activity. In the upper panel, a positive impulse to mortgage default leads to a fall in bank risk-bearing capacity, as implied by a rise in EBP. Banks tighten their loans supply and hence extend fewer mortgages. We hasten to add that mortgage growth declines significantly three quarters after the shock. The results show no significant responses during the initial periods. This is consistent with the stylized fact described above that mortgages began declining in 2008 (or one year after default rose). The responses of EBP to

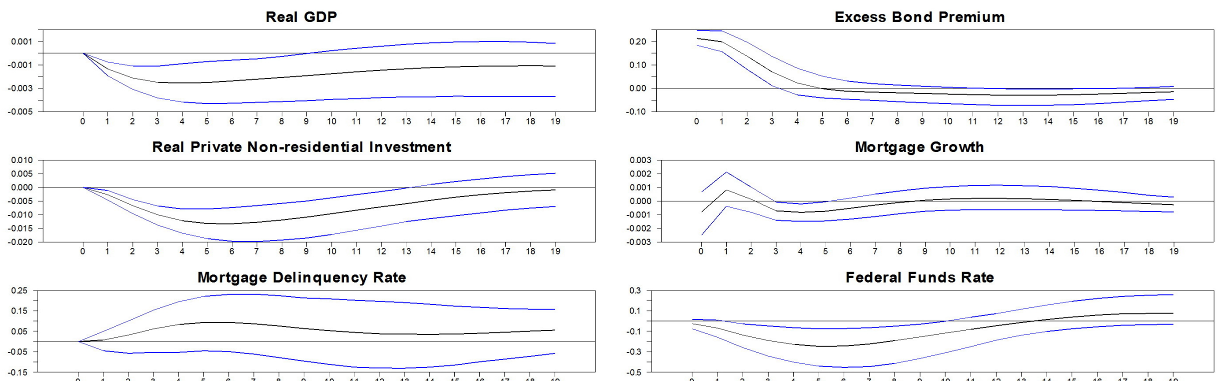
[58]Not being described in the figure, the residential fixed investment manifests an even sharper decline and has not yet returned to the pre-crisis level. However, we did not model such a type of investment in this paper. This may be an interesting extension, but for now, given that housing investment is a small portion of the overall investment and GDP, the theoretical results should not change significantly without it.

[59]Serial correlation LM test shows that the model does not reject the null hypothesis of no serial correlation among VAR residuals at 10 percent significant level.

Figure 3.2: VAR Evidence



(a) Mortgage Default Shock



(b) EBP Shock

Note: the blue lines show 5- and 95-percentile responses from bootstrapping. The black line shows median responses.

mortgage default shock is crucial as we view bank financial condition as an important amplifier and propagator of shocks. Consistent with credit contraction, real economic activities experience a downturn. Real GDP, real private non-residential investment and prices fall, taking certain amount of time to reach their trough. The Federal Reserve responds by lowering its policy interest rate. However, the responses only become significant after two years. This may signal that, before the Great Recession, the Central Bank did not react promptly to shocks that originated in the housing markets, and tended to wait and see until they had materially large impacts on the real economy. In sum, the responses to mortgage default shocks can explain very well the economic variables during the Great Recession.

The lower panel of figure 3.2 shows the economy's responses to a positive EBP shock, which signals a tightening of credit supply conditions. Such a shock causes a decline in mortgages, which again takes effect after three quarters, but the decline is not as persistent as the responses under a default shock.[60] Mortgage delinquency rate rises, but is not significant. We suspect that a decline in mortgage extension as well as economic activity puts downward pressure on house prices and leads to higher default. A rise in default can in turn cause banks to be more vigilant in lending, resulting in an adverse feedback loop. Real GDP and investment falls, while the Federal Reserve promptly reacts to a shock. An EBP shock is, therefore, another potential candidate to explain the crisis event. Overall, the VAR evidence shows that shocks that we are interested in identifying in our model in the next section, despite originating in financial sector, have significant effects on real economic activities. Importantly, their identified responses do match the behavior of both real and financial data during 2008-2009 global financial crisis.

3.4 The Benchmark Model

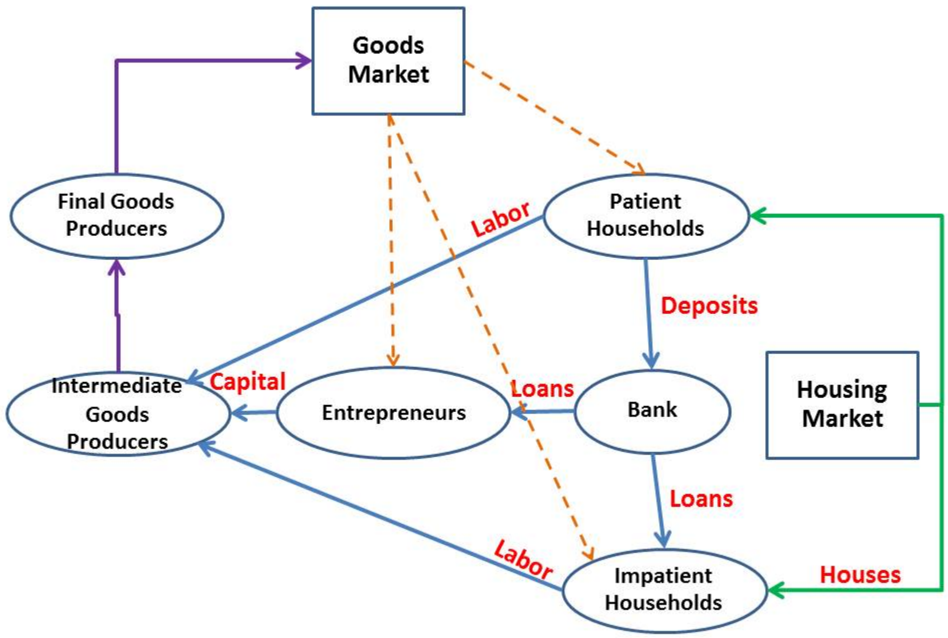
The benchmark model follows Gerali et al. (2010), who embed housing and the banking sector in the NK framework. The economy consists of two types of households, patient and impatient households, which fundamentally differ in their discount rate and flow of income. Heterogeneity of the discount rates generates positive flows of borrowing and lending in equilibrium. The two agents derive utility from consuming both non-durable and durable goods. The former are standard consumption goods whereas the latter are houses, which can also be used as collateral in acquir-

[60] One may suspect that the model is subject to an identification problem, as higher growth of mortgages may result in contemporaneous rise in EBP. This creates an attenuation bias such that we do not observe a significant decline in mortgages immediately after the shock. However, as stated above, changing the order of these variables does not alter the results.

ing mortgages. Having lower discount rate, patient households become lenders in equilibrium and, hence, deposit their savings with banks. The latter, taking into account capital adequacy regulation, make loans to impatient households and entrepreneurs in terms of mortgages and business loans, respectively. Entrepreneurs invest in the economy's physical capital and rent it to firms for the production of consumption goods. The existence of capital allows us to model non-residential investment, whose fluctuations have a large contribution to the slowdown in the US economy during the Great Recession. Two agents are involved in producing consumption goods: monopolistically-competitive intermediate goods producers and perfectly-competitive final goods producers. As is standard in the literature, the existence of the former is to model price stickiness that gives rise to demand-driven macroeconomic fluctuations. They hire households labor and rent entrepreneurial capital to produce heterogeneous intermediate goods and set their prices subject to Calvo (1983) lottery. Final goods producers, on the other hand, combine intermediate goods into homogenous consumption goods. As in Christiano et al. (2005) and Smets and Wouters (2007), the economy features several real frictions, which are crucial in generating persistent responses of the economy in the face of shocks. Figure 3.3 summarises the structure of the economy.

The crucial new feature of the model is the possibility of endogenous default on mortgages. In particular, impatient households can choose to default on their loan obligation and have their collateral foreclosed by banks. In Gerali et al. (2010) and Iacoviello (2005), a pledge of collateral rules out any default possibility. In particular, the exogenously-assumed loan-to-value (LTV) constraint ensures that the value of the houses, which can be affected by economy-wide shocks, is always larger than outstanding debt. Lenders therefore anticipate full repayment at all circumstances. This is, however, inconsistent with evidence during the Great Recession where problems in the mortgage market, particularly the increase in default, are claimed to be

Figure 3.3: The Structure of the Economy



a major source of shocks. In this model, triggered by idiosyncratic shocks to the value of the houses owned by individual household members, mortgage default occurs and generates losses to the banking sector. Unlike the two articles cited above, the LTV ratio results from the optimisation problems of borrowers and lenders and will matter for future mortgage default probability. Banks charge premium on mortgage interest rates to compensate for any anticipated net-of-collateral losses. In the extended model introduced in section 3.5, we impose an exogenous LTV constraint on mortgage borrowing in order to study the effects of macroprudential regulation. Business loans, on the other hand, are always subject to an exogenous borrowing constraint such that their default possibility is zero.[61]

[61] In this paper, banks are assumed to be perfectly competitive. In Gerali et al. (2010), they are monopolistically competitive and subject to interest rate adjustment costs. These assumptions allow the authors to assess differential responses of various interest rates to monetary policy shocks, which is not the focus of this paper.

3.4.1 Patient Households

There is a continuum of patient households of measure one. They supply labor, consume, accumulate housing, while saving the rest of their income with banks in order to smooth consumption. They also own banks and intermediate goods firms which return them dividends and profits, respectively. A lifetime utility function of the representative patient household i is given by:

$$E_0 \sum_{t=0}^{\infty} \beta_P^t \left[(1 - a_P) \ln \left(c_t^P (i) - a_P c_{t-1}^P \right) + j \ln h_t^P (i) - \frac{\left(l_t^{P,s} (i) \right)^\eta}{\eta} \right]$$

where, β_P denotes the discount rate, c_t^P is non-durable goods consumption, h_t^P is housing accumulated, j measures the housing weight in the utility function, $l_t^{P,s}$ is the amount of labor supplied, and η represents a labor disutility parameter. We assume that both types of households face an external and group-specific habit formation in consumption, where $a_H : H \in \{P, I\}$ measures the degree of habit formation. The representative patient household maximises its objective function above given the budget constraint:

$$\begin{array}{c} c_t^P (i) + q_t^h \triangle h_t^P (i) + d_t^P (i) + \phi_h \left(\frac{h_t^P (i) - h_{t-1}^P (i)}{h_{t-1}^P (i)} \right)^2 \frac{q_t^h h_{t-1}^P (i)}{2} \\ = \frac{r_{t-1} d_{t-1}^P (i)}{\pi_t} + w_t^P l_t^{P,s} (i) + div_t (i) + F_t (i) + t_t^P (i) \end{array} . \tag{3.1}$$

The household deposits its savings d_t^P with banks, who promise to pay interests at the nominal interest rate r_t. It therefore receives deposits repayment in real term equivalent to $\frac{r_t d_t^P}{\pi_{t+1}}$. $\pi_t = \frac{P_t}{P_{t-1}}$ is the gross inflation rate, where P_t is the price of consumption goods. q_t^h and w_t^P denote real house price and real labor wage, respectively. div_t are dividends from banks, while F_t are profits from intermediate goods producers. As in Iacoviello (2005), both types of households face a pecuniary cost whenever they adjust their housing demand. ϕ_h represents a housing adjustment cost parameter. Since we do not model the house production sector or introduce other frictions associated with housing, we will show that this friction is sufficient in generating significant real economic impacts from shocks originating within the housing market. t_t^P is the income from monitoring activities that shall be explained later.

Each patient household optimally chooses c_t^P, h_t^P, d_t^P and $l_t^{P,s}$. Assuming a symmetric equilibrium, we obtain the following first order conditions (λ_t^P is the Lagrange multiplier with respect to the budget constraint):

$$\lambda_t^P = \frac{1 - a_P}{c_t^P - a_P c_{t-1}^P} \tag{3.2}$$

$$\lambda_t^P = \beta_P E_t \left[\frac{r_t}{\pi_{t+1}} \lambda_{t+1}^P \right] \tag{3.3}$$

$$\begin{aligned} & q_t^h \lambda_t^P \left(1 + \phi_h \left(\tfrac{h_t^P - h_{t-1}^P}{h_{t-1}^P} \right) \right) \\ = \tfrac{j}{h_t^P} + \beta_P E_t & \left[q_{t+1}^h \lambda_{t+1}^P \left(1 + \tfrac{\phi_h}{2} \left(\tfrac{h_{t+1}^P - h_t^P}{h_t^P} \right) \left(\tfrac{h_{t+1}^P + h_t^P}{h_t^P} \right) \right) \right] \end{aligned} \tag{3.4}$$

$$w_t^P \lambda_t^P = \left(l_t^{P,s} \right)^{\eta - 1} . \tag{3.5}$$

Equation (3.2)-(3.5) are the shadow price of wealth, the Euler equation for consumption, housing demand equation and labor supply equation, respectively. From equation (3.4), neglecting the adjustment costs, housing accumulation yields two distinct benefits to the households: utility from housing services in period t and additional wealth from reselling it in period $t + 1$.

3.4.2 Impatient Households

There is a continuum of impatient households of measure one. Like their patient counterparts, they supply labor, consume and accumulate housing. However, having higher discount rate, i.e. $\beta_I < \beta_P$, they have incentive to borrow to spend.

Houses serve as collateral in acquiring loans from banks. The representative impatient household i maximises a lifetime utility function given by:

$$E_0 \sum_{t=0}^{\infty} \beta_I^t \left[(1-a_I) \ln \left(c_t^I(i) - a_I c_{t-1}^I \right) + j \ln h_t^I(i) - \frac{\left(l_t^{I,s}(i) \right)^{\eta}}{\eta} \right]$$

subject to the following budget constraint:

$$\begin{aligned} c_t^I(i) + q_t^h h_t^I(i) + (1 - F_t(\bar{\omega}_t(i))) \frac{r_{t-1}^I b_{t-1}^I(i)}{\pi_t} + \phi_h \left(\frac{h_t^I(i) - h_{t-1}^I(i)}{h_{t-1}^I(i)} \right)^2 \frac{q_t^h h_{t-1}^I(i)}{2} \\ = b_t^I(i) + w_t^I l_t^{I,s}(i) + (1 - G_t(\bar{\omega}_t(i))) q_t^h h_{t-1}^I(i) \end{aligned} . \quad (3.6)$$

The definition of each variable parallels with the case of patient households. $F_t(\bar{\omega}_t)$ denotes the probability of mortgage default, while $G_t(\bar{\omega}_t)$ measures the proportion of houses seized by banks in case of mortgage default. To model mortgage default, we follow the approach of Forlati and Lambertini (2011). Each impatient household consists of a continuum of members j. Of the total housing demand $h_t^I(i)$, it allocates houses equally to each member $h_t^I(i,j)$, where $\int h_t^I(i,j)\,dj = h_t^I(i)$. It also orders each member to be liable for repaying equal amount of loans $b_t^I(i,j)$, where $\int b_t^I(i,j)\,dj = b_t^I(i)$. $b_t^I(i)$ hence denotes total mortgages obtained from banks. Each mortgage contract faces the same mortgage interest rate r_t^I, and so the amount of $r_t^I b_t^I(i,j)$ has to be repaid next period by each member. The total amount of debts owed to the banks (in nominal term) is therefore $r_t^I b_t^I(i)$. We can compute the LTV ratio at the household level as follows,

$$m_t^I(i) = E_t \left[\frac{r_t^I b_t^I(i)}{q_{t+1}^h h_t^I(i) \pi_{t+1}} \right] . \quad (3.7)$$

Ex post (i.e. in the following period), we assume that there is an idiosyncratic housing risk such that the housing value for each household member becomes $\omega_{t+1}(i,j)\, q_{t+1}^h h_t^I(i,j)$. $\omega_{t+1}(i,j)$ represents an idiosyncratic shock, which is independently and identically distributed across members, justifying a homogenous mortgage interest rate. We also assume that $E_t\left(\omega_{t+1}\left(i,j\right)\right)=1$ so that $E_t\left(\omega_{t+1}\left(i,j\right)q_{t+1}^{h}h_t^{I}\left(i,j\right)\right)=q_{t+1}^{h}h_t^{I}\left(i\right)$. This assumption implies that such idiosyncratic risk does not have consequences on the aggregate housing value and keeps the model tractable. In practice, the shock may capture the risk associated with housing investment. Alternatively, Quint and Rabanal (2014) view ω as housing quality shock.

Given the realised value of $\omega_{t+1}\left(i,j\right)$, for each mortgage contract, the household member has choices of whether (1) to conform to loan obligation by fully repaying debts or (2) to default and face seizure of the houses. Rational household members will tend to default on mortgages with low realisation of $\omega_{t+1}\left(i,j\right)$ since the houses yield low resale value, making paying back debt a more expensive option. Therefore, at the household level, mortgage default decision amounts to choosing the cut-off point $\bar{\omega}_{t+1}\left(i\right)$, such that its members default on the contracts with $\omega_{t+1}\left(i,j\right)$ lower than $\bar{\omega}_{t+1}\left(i\right)$. Denoted with $f\left(\omega\right)$ the density function of ω. We can compute the cumulative distribution function of $\bar{\omega}$, $F\left(\bar{\omega}\right)$, and the expected value of ω conditional on $\omega<\bar{\omega}$, $G\left(\bar{\omega}\right)$, as follow:

$$F\left(\bar{\omega}\right)=\int_0^{\bar{\omega}}f\left(\omega\right)d\omega \tag{3.8}$$

$$G\left(\bar{\omega}\right)=\int_0^{\bar{\omega}}\omega f\left(\omega\right)d\omega\,. \tag{3.9}$$

Given the formulae above, each impatient household defaults by the total amount of $\int_0^{\bar{\omega}_t(i)}\frac{r_{t-1}^{I}b_{t-1}^{I}(i,j)}{\pi_t}f_t\left(\omega_t(i,j)\right)d\omega=F_t\left(\bar{\omega}_t\left(i\right)\right)\frac{r_{t-1}^{I}b_{t-1}^{I}(i)}{\pi_t}$ in real term. The total value of the houses seized by banks is equal to $\int_0^{\bar{\omega}_t(i)}\omega_t\left(i,j\right)q_t^{h}h_{t-1}^{I}\left(i,j\right)f_t\left(\omega_t(i,j)\right)d\omega=G_t\left(\bar{\omega}_t\left(i\right)\right)q_t^{h}h_{t-1}^{I}\left(i\right)$. These two terms appear in the above budget constraint.

Denote with λ_t^{I} the Lagrange multiplier of the budget constraint. Each impatient household chooses c_t^{I}, h_t^{I}, b_t^{I}, $l_t^{I,s}$ and $\bar{\omega}_t$, which yields the following first order conditions, given a symmetric equilibrium:

$$\lambda_t^I = \frac{1 - a_I}{c_t^I - a_I c_{t-1}^I} \tag{3.10}$$

$$\lambda_t^I = \beta_I E_t \left[\left(1 - F_{t+1}(\bar{\omega}_{t+1}) + \frac{G_{t+1}(\bar{\omega}_{t+1})}{m_t^I} \right) \frac{r_t^I}{\pi_{t+1}} \lambda_{t+1}^I \right] \tag{3.11}$$

$$\begin{aligned} & q_t^h \lambda_t^I \left(1 + \phi_h \left(\tfrac{h_t^I - h_{t-1}^I}{h_{t-1}^I} \right) \right) \\ = & \tfrac{j}{h_t^I} + \beta_I E_t \left[q_{t+1}^h \lambda_{t+1}^I \left(1 + \tfrac{\phi_h}{2} \left(\tfrac{h_{t+1}^I - h_t^I}{h_t^I} \right) \left(\tfrac{h_{t+1}^I + h_t^I}{h_t^I} \right) \right) \right] \end{aligned} \tag{3.12}$$

$$w_t^I \lambda_t^I = \left(l_t^{I,s} \right)^{\eta - 1} \tag{3.13}$$

$$\frac{b_{t-1}^I r_{t-1}^I}{\pi_t} = \bar{\omega}_t q_t^h h_{t-1}^I \,. \tag{3.14}$$

Equations (3.10)-(3.13) are the shadow value of wealth, the Euler equation for consumption, housing demand equation and labor supply equation, respectively. With mortgage default, the Euler equation becomes nonstandard. The effective repayment rate takes into account the possibility that the households decide not to fully repay their debts and face asset foreclosure. Equation (3.14), namely the on-the-verge condition, shows the first order condition with respect to the mortgage default decision. It suggests that the household defaults on the mortgage contracts where the ex-post housing value falls below real debt outstanding. This condition is exogenously imposed in most articles featuring mortgage default, whereas our paper derives it endogenously from the households optimisation problem. As mentioned in section 3.2, Campbell and Cocco (2015) find that mortgage borrowers do not default immediately as the house value plunges below debts, but their default decision also depends on the tightness of the borrowing constraint. Therefore, we believe it is theoretically consistent to derive such a condition from agent optimisation, rather than assuming it in an ad hoc manner.

Mortgage Default Probability

As in BGG and Forlati and Lambertini (2011), we assume the distribution of an idiosyncratic housing shock to be log-normal: $\log(\omega_t) \sim N(\mu_{\omega,t}, \sigma^2_{\omega,t})$. In addition, $E_t[\omega_{t+1}(i)] = 1$ requires that $\mu_{\omega,t} = -\frac{\sigma^2_{\omega,t}}{2}$. To model a trigger for an increase in mortgage default, we assume that the variance of an idiosyncratic housing shock is time-varying and follows an autoregressive process subject to random shocks:

$$ln(\sigma_{\omega,t}) = \rho_\omega ln(\sigma_{\omega,t-1}) + (1-\rho_\omega) ln(\sigma_\omega) + \varepsilon_{\omega,t} \tag{3.15}$$

where $\varepsilon_\omega \sim N(0, \vartheta_\omega)$.

We can then deduce factors determining the "default probability" of mortgages from the cumulative distribution function $F_t(\bar{\omega}_t)$ and the "on-the-verge" condition:

$$\bar{\omega}_t = \frac{b^I_{t-1} r^I_{t-1}}{q^h_t h^I_{t-1} \pi_t} \frac{E_{t-1}\left[q^h_t \pi_t\right]}{E_{t-1}\left[q^h_t \pi_t\right]} = m^I_{t-1} \frac{E_{t-1}\left[q^h_t \pi_t\right]}{q^h_t \pi_t}.$$

In the benchmark model, the probability of default is driven by three factors, the variance of an idiosyncratic housing shock, the LTV ratio and a deviation of nominal house price from expectation. From equation (3.8), and assuming $\mu_{\omega,t} = -\frac{\sigma^2_{\omega,t}}{2}$, we can show that the default probability increases with the housing shock variance ($\sigma^2_{\omega,t}$) and the cut-off level ($\bar{\omega}_t$).[62] The on-the-verge condition (3.14) suggests that the cut-off level rises with the LTV ratio, but declines whenever nominal house prices unexpectedly rise. Consequently, the default probability increases when the LTV ratio is higher or when unexpected shocks drive nominal house prices down. It is to note that default in this paper arises from strategic considerations as well as from that due to "ill-fortune". It is caused by ill fortune in the sense that adverse shocks cause a deterioration in the house value, thus increasing the incentive to default. It

[62] $F(\bar{\omega}_t) = \int_0^{\bar{\omega}_t} f_t(\omega_t)\, d\omega = \frac{1}{2} + \frac{1}{2} erf\left[\frac{\ln(\bar{\omega}_t) - \mu_{\omega,t}}{\sqrt{2}\sigma_{\omega,t}}\right] = \Phi\left(\frac{\ln(\bar{\omega}_t) - \mu_{\omega,t}}{\sigma_{\omega,t}}\right)$, where Φ represents cumulative distribution function of the standard normal distribution.

also arises strategically due to an implicit assumption that the mortgage contract is non-recourse. Certainly, impatient household members could rely on other sources of income to repay debts, but this possibility is ruled out in this framework, without loss of generality.

3.4.3 Entrepreneurs

Similarly, there is a continuum of entrepreneurs of measure one. They possess the economy's physical capital and rent it to intermediate goods producers. Given that $\beta_E < \beta_P$, they also have an incentive to borrow from banks. Using loans and rental income, they make consumption-investment decisions. Collateral is required to acquire business loans (b_t^E), such that there exists a borrowing limit based upon the expected undepreciated capital value:

$$r_t^E b_t^E \leq m^E E_t \left[(1-\delta) q_{t+1}^k k_t \pi_{t+1} \right] \tag{3.16}$$

where, r_t^E is business loan interest rate, m^E is an exogenous cap on the LTV ratio set by financial regulators, and k_t is capital demanded which will be available for rent next period. δ measures the depreciation rate of capital, while q_t^k denotes real capital price. The representative entrepreneur maximises a lifetime utility function given by:

$$E_0 \sum_{t=0}^{\infty} \beta_E^t \left[(1-a_E)\, ln \left(c_t^E (i) - a_E c_{t-1}^E \right) \right]$$

subject to the above borrowing constraint and the following flow of fund constraint:

$$\begin{aligned} c_t^E (i) + \tfrac{r_{t-1}^E b_{t-1}^E (i)}{\pi_t} + q_t^k \left(k_t (i) - (1-\delta) k_{t-1} (i) \right) + \Psi (u_t) k_{t-1} (i) \\ = r_t^k u_t (i) k_{t-1} (i) + b_t^E (i) \end{aligned} \quad . \tag{3.17}$$

In each period, each entrepreneur chooses the utilisation rate of capital (u_t), i.e. the proportion of owned capital to be rented to production firms. There exists a cost of capital utilisation $\Psi(u_t) = \varepsilon_{k,1}(u_t - 1) + \frac{\varepsilon_{k,2}}{2}(u_t - 1)^2$.

The entrepreneur chooses c_t^E, b_t^E, k_t and u_t to maximise its objective function. Assuming a symmetric equilibrium, we obtain the following first order conditions (λ_t^E and ξ_t^E are the Lagrange multiplier with respect to the budget constraint and the tightness of the borrowing constraint, respectively):

$$\lambda_t^E = \frac{1 - a_E}{c_t^E - a_E c_{t-1}^E} \tag{3.18}$$

$$\lambda_t^E = \beta_E E_t \left[\frac{r_t^E}{\pi_{t+1}} \lambda_{t+1}^E \right] + \xi_t^E r_t^E \tag{3.19}$$

$$\lambda_t^E q_t^k = \begin{array}{c} \beta_E E_t \left[\lambda_{t+1}^E \left(r_{t+1}^k u_{t+1} + (1-\delta) q_{t+1}^k - \Psi(u_{t+1}) \right) \right] \\ + \xi_t^E m^E E_t \left[(1-\delta) q_{t+1}^k \pi_{t+1} \right] \end{array} \tag{3.20}$$

$$r_t^k = \Psi'(u_t) = \varepsilon_{k,1} + \varepsilon_{k,2}(u_t - 1)\ . \tag{3.21}$$

Equations (3.18)-(3.21) are the shadow value of wealth, the Euler equation for consumption, capital demand equation and capital utilisation equation, respectively.

3.4.4 Capital Producers

The existence of capital producers is to model asset prices that matter for the tightness of the entrepreneurs borrowing constraint as well as the cost of capital investment. Perfectly-competitive capital producers purchase undepreciated capital $(1-\delta) k_{t-1}$ at the price q_t^k from entrepreneurs and consumption goods i_t from final goods producers. They combine both components into new capital k_t, using the production function:

$$k_t = (1-\delta)\, k_{t-1} + i_t \left(1 - \frac{k_i}{2}\left(\frac{i_t}{i_{t-1}} - 1\right)^2\right). \tag{3.22}$$

The production of capital goods is subject to investment adjustment costs, where k_i represents a cost parameter. They sell new capital back to entrepreneurs at the price q_t^k.

Capital producers maximise their lifetime utility function $E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^E \left[q_t^k \left(k_t - (1-\delta)\, k_{t-1}\right) - i_t\right]$ with the stochastic discount factor $\Lambda_{t,k}^E = \beta_E^k \left(\frac{\lambda_{t+k}^E}{\lambda_t^E}\right)$, subject to the above production function. This yields the following capital price equation:

$$1 = \begin{array}{c} q_t^k \left(1 - \frac{k_i}{2}\left(\frac{i_t}{i_{t-1}} - 1\right)^2 - k_i \left(\frac{i_t}{i_{t-1}} - 1\right)\frac{i_t}{i_{t-1}}\right) \\ +\beta_E E_t \left[\frac{\lambda_{t+1}^E}{\lambda_t^E} q_{t+1}^k k_i \left(\frac{i_{t+1}}{i_t} - 1\right)\left(\frac{i_{t+1}}{i_t}\right)^2\right] \end{array}. \tag{3.23}$$

3.4.5 Commercial Banks

Perfectly-competitive risk-neutral commercial banks channel funds from savers to two borrowers: impatient households and entrepreneurs. They use deposits obtained from patient households in conjunction with retained earnings (e_t^B) to fund lending activities. Loan origination is subject to capital adequacy regulations, as financial regulators specify capital adequacy ratio ($\bar{k}$) to which banks have to conform. Bank capital adequacy ratio (k_t^B) is measured as the ratio of the bank equity capital to risk-weighted assets (rwa_t):

$$k_t^B = \frac{e_t^B}{rwa_t} \tag{3.24}$$

where,

$$rwa_t = rw_t^I b_t^I + rw^E b_t^E \,. \tag{3.25}$$

rw_t^I and rw^E are the risk weight on mortgages and business loans, respectively. We assume the latter to be time-invariant given that the borrowing constraint has already ruled out default possibility for business loans. Meanwhile, consistent with the Basel Accord, risk weights on mortgages are an increasing function of the default probability:

$$rw_t^I = rw^I + \Upsilon E_t \left[F_{t+1} \left(\bar{\omega}_{t+1} \right) - F \left(\bar{\omega} \right) \right] \tag{3.26}$$

where, Υ measures the sensitivity of risk weights to the expected probability of mortgage default, rw^I denotes the steady-state risk weight on mortgages, and $F(\bar{\omega})$ is the steady-state mortgage default frequency. In each period, banks receive net-of-default gross profits:

$$\Pi_t^B = \left(1 - F_t \left(\bar{\omega}_t\right)\right) \frac{r_{t-1}^I b_{t-1}^I}{\pi_t} + (1 - \Theta) \, G_t \left(\bar{\omega}_t\right) q_t^h h_{t-1}^I + \frac{r_{t-1}^E b_{t-1}^E}{\pi_t} - \frac{r_{t-1} d_{t-1}^P}{\pi_t} \,. \tag{3.27}$$

For those mortgage contracts that impatient household members decide to default, we assume that banks have to bear an additional cost proportional to the value of the houses seized from impatient households, $\Theta G_t \left(\bar{\omega}_t\right) q_t^h h_{t-1}^I$. Such a cost may represent cost of state verification, asset liquidation (or fire-sale) cost, or even legal and accounting costs. In this paper, we follow BGG and assume that asymmetric information requires banks to pay monitoring (or state-verification) costs to observe the true value of the houses.[63] Banks allocate part of their profits as dividends (div_t) to their shareholders, the patient households, and retain the rest as retained

[63] This mechanism also obliges impatient household members to truthfully reveal their identity.

earnings. After dividend payments, their equity capital is given by:

$$e_t^B = (1-\delta_B)\frac{e_{t-1}^B}{\pi_t} + (1-\gamma_B)\left(\Pi_t^B - \frac{e_{t-1}^B}{\pi_t}\right) \tag{3.28}$$

where, δ_B and γ_B are dividend payout parameters. Bank dividends thus equal $\delta_B \frac{e_{t-1}^B}{\pi_t} + \gamma_B\left(\Pi_t^B - \frac{e_{t-1}^B}{\pi_t}\right)$.

Each bank maximises its objective function:

$$E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^P \left[\Pi_t^B + \phi_t^k \left(\frac{\left(\frac{k_t^B}{k}\right)^{1-\sigma_B} - 1}{1-\sigma_B}\right)\right]$$

subject to the balance sheet constraint:

$$b_t^I + b_t^E \;\; = d_t^P + e_t^B \tag{3.29}$$

where, $\Lambda_{t,k}^P = \beta_P^k\left(\frac{\lambda_{t+k}^P}{\lambda_t^P}\right)$ is the relevant stochastic discount factor. Capital adequacy regulations are modelled as non-pecuniary cost (gain) in terms of utility, whenever the capital adequacy ratio is lower (higher) than capital requirements.[64] It is important to note that the functional form of the penalty above implies increasing marginal cost of failure to comply with the regulations and diminishing marginal benefits from satisfying the regulatory requirements. This non-linearity is crucial to why downside deviations from the requirements can create a significant credit supply contraction. $\sigma_B > 1$ and ϕ_t^k denote capital regulation penalty parameters. The former captures this non-linearity feature, while the latter measures the weight of such penalty in the utility function, which is assumed to be time-varying. We obtain the following first order conditions (λ_t^B represents the Lagrange multiplier with respect to the balance

[64] Gerali et al. (2010) model capital regulations as pecuniary costs to deviations of the capital ratio from the regulatory required level. So, banks are penalised whenever their capital ratio deviates from the target. With such a functional form, there is possibility that loan interest rates fall below the deposit interest rate when the capital ratio is sufficiently high. Such possibility is even more likely in the perfectly-competitive banking sector.

sheet constraint):

$$\lambda_t^B = \beta_P E_t \left[\frac{\lambda_{t+1}^P}{\lambda_t^P} \frac{r_t}{\pi_{t+1}} \right] \tag{3.30}$$

$$\begin{aligned} &\lambda_t^B + \phi_t^k \left(\frac{k_t^B}{\bar{k}} \right)^{1-\sigma_B} \left(\frac{rw_t^I}{rwa_t} \right) \\ &= \beta_P E_t \left[\frac{\lambda_{t+1}^P}{\lambda_t^P} \left(1 - F_{t+1} \left(\bar{\omega}_{t+1} \right) + (1 - \Theta) \frac{G_{t+1}(\bar{\omega}_{t+1})}{m_t^I} \right) \frac{r_t^I}{\pi_{t+1}} \right] \end{aligned} \tag{3.31}$$

$$\lambda_t^B + \phi_t^k \left(\frac{k_t^B}{\bar{k}} \right)^{1-\sigma_B} \left(\frac{rw^E}{rwa_t} \right) = \beta_P E_t \left[\frac{\lambda_{t+1}^P}{\lambda_t^P} \frac{r_t^E}{\pi_{t+1}} \right] . \tag{3.32}$$

Equations (3.30) to (3.32) describe the first order conditions with respect to deposits, mortgages and business loans, respectively.

Interest Rate Spreads

Interest rate spreads are an important indicator of the loans supply conditions as they directly affect borrowers cost of consumption and investment. We can combine the first order conditions (3.30)-(3.32) above to study factors affecting spreads between loan and deposit interest rate:

$$\phi_t^k \left(\frac{k_t^B}{\bar{k}} \right)^{1-\sigma_B} \frac{rw_t^I}{rwa_t} = \beta_P E_t \left[\frac{\lambda_{t+1}^P}{\lambda_t^P} \frac{\left(1 - F_{t+1} \left(\bar{\omega}_{t+1} \right) + (1 - \Theta) \frac{G_{t+1}(\bar{\omega}_{t+1})}{m_t^I} \right) r_t^I - r_t}{\pi_{t+1}} \right]$$

$$\phi_t^k \left(\frac{k_t^B}{\bar{k}} \right)^{1-\sigma_B} \frac{rw^E}{rwa_t} = \beta_P E_t \left[\frac{\lambda_{t+1}^P}{\lambda_t^P} \frac{r_t^E - r_t}{\pi_{t+1}} \right] .$$

The first equation show, on the one hand, how banks price into the mortgage interest rate any anticipated losses from mortgage default, which include (1) the amount of unrepaid loans less the value of the seized collateral and (2) the additional default cost from state verification. Capital adequacy regulation, on the other hand, affects both credit spreads, as it makes loan origination costly. When banks extend additional loans, their capital ratio declines. Consequently, this depresses their utility and induces them to raise spreads to reap more profits in return. The size of spreads depends critically on: first, the size of a deviation of the capital adequacy ratio from the regulatory required level, second, the risk weight on loans, and third, the weight of capital regulation penalty in the utility function. First, given non-linear penalties, banks are penalised more from loan origination whenever the capital ratio is low. Banks thus demand a higher compensation. The sensitivity of the spreads to the capital ratio depends on the size of σ_B. Second, a higher risk weight leads to a larger increase in the risk-weighted assets and a greater decrease in bank capital ratio from making loans. Banks therefore widen interest rate spreads to a larger extent to compensate for the resulting utility loss. In this paper, we put emphasis on the last factor, namely stochastic variations of the parameter ϕ_t^k, as another source of shocks that explain widening credit spreads during the Great Recession. We assume it to follow an autoregressive process:

$$\ln(\phi_t^k) = \rho_k \ln(\phi_{t-1}^k) + (1-\rho_k)\ln(\phi^k) + \varepsilon_{k,t} \tag{3.33}$$

where, $\varepsilon_k \sim N(0, \sigma_k^2)$. A rise in ϕ_t^k implies greater importance of capital regulation penalty in the bank utility function, making loan origination more costly, thus resulting in a surge in interest rate spreads. The time-varying property of such parameter could reflect changes in the strictness of financial regulators in enforcing the regulation or changes in the market perception towards it. Alternatively, we exploit this parameter to reflect exogenous variations in lenders risk-bearing capacity, which matters for credit supply conditions. Gilchrist and Zakrajšek (2012) show that excess bond premium, a component of corporate bond spreads unexplained by default risk, rose considerably during the crisis. The authors attribute such a rise to a reduction in financial intermediaries risk-bearing capacity. We also believe that the crisis greatly impaired individual banks balance sheet and reduced their risk tolerance.

This led them to tighten their lending standards to an extent that is difficult to be explained with increased default risk and their capitalisation condition only.

3.4.6 Final Good Producers

Perfectly-competitive final goods producers combine intermediate goods into homogenous final consumption goods using the production function:

$$Y_t = \left(\int_0^1 Y_t^{\frac{\varepsilon-1}{\varepsilon}} (j) \, dj \right)^{\frac{\varepsilon}{\varepsilon-1}}$$

where, ε measures the elasticity of substitution. They purchase intermediate goods $Y_t(j)$ from intermediate goods firm j at price $P_t(j)$ and sell final products at price P_t. They maximise profits $P_t Y_t - \int_0^1 Y_t(j) P_t(j) \, dj$ subject to the production function above, taking both prices as given. The input demand function derived from this optimisation problem is:

$$Y_t(j) = \left(\frac{P_t(j)}{P_t} \right)^{-\varepsilon} Y_t \; \forall j$$

where, the price index $P_t = \left(\int_0^1 P_t^{1-\varepsilon}(j) \, dj \right)^{\frac{1}{1-\varepsilon}}$.

3.4.7 Intermediate Good Producers

There is a continuum of monopolistically-competitive intermediate goods producers. Each producer j possesses the following technology

$Y_t(j) = A_t (k_{t-1}(j))^{\mu} \left(l_t^{P,d}(j) \right)^{\alpha(1-\mu)} \left(l_t^{I,d}(j) \right)^{(1-\alpha)(1-\mu)}$ where, A_t is the productivity level and is assumed to follow an autoregressive process: $\ln A_t = \rho_A \ln A_{t-1} + (1-\rho_A) \ln A + \varepsilon_A$, μ denotes the share of capital income, and α denotes the share of labor income paid to patient households. The producers rent physical capital $k_{t-1}(j)$ from entrepreneurs, while hiring labor $l_t^{P,d}(j)$ and $l_t^{I,d}(j)$, to produce intermediate goods $Y_t(j)$. They then sell those intermediate goods to final goods firms.

Given their monopolistic power, intermediate goods producers set the product price $P_t(j)$ with markup over nominal marginal cost $MC_t(j)$ of producing one unit of goods. To obtain an expression for the marginal cost, each firm rents $l_t^{P,d}(j)$, $l_t^{I,d}(j)$ and $k_{t-1}(j)$ in the perfectly-competitive factor markets in order to minimise real marginal cost $mc_t(j) = \frac{MC_t(j)}{P_t}$:

$$r_t^k k_{t-1}(j) + w_t^P l_t^{P,d}(j) + w_t^I l_t^{I,d}(j)$$

subject to the production function above. Therefore, we obtain the following first order conditions:

$$w_t^P = \frac{(1-\mu)\,\alpha}{\mu} \frac{r_t^k k_{t-1}(j)}{l_t^{P,d}(j)} \tag{3.34}$$

$$w_t^I = \frac{(1-\mu)(1-\alpha)}{\mu} \frac{r_t^k k_{t-1}(j)}{l_t^{I,d}(j)}. \tag{3.35}$$

We can then compute real marginal cost as follow:

$$mc_t(j) = mc_t = \frac{\left(r_t^k\right)^{\mu} \left(w_t^P\right)^{(1-\mu)\alpha} \left(w_t^I\right)^{(1-\mu)(1-\alpha)}}{(\mu)^{\mu} \left((1-\mu)\,\alpha\right)^{(1-\mu)\alpha} \left((1-\mu)(1-\alpha)\right)^{(1-\mu)(1-\alpha)}} \frac{1}{A_t}. \tag{3.36}$$

Given an expression for real marginal cost, each producer then chooses intermediate goods price that maximises discounted real lifetime profits. However, in each period, due to Calvo (1983) lottery, only a fraction θ of firms are allowed to reoptimise their prices. Those who have chances to reoptimise will therefore choose the price $P_t^*(j)$, considering the possibility that this price will remain effective in later periods. All other firms keep their price the same as in the previous period. Subject to the demand from final goods producers, the problem of each intermediate goods firm is then to maximise the following objective function:

$$E_t \sum_{k=0}^{\infty} \theta^k \left[\Lambda_{t,k}^P \left(\frac{P_t^* (j)}{P_{t+k}} Y_{t+k}^* (j) - mc_{t+k} Y_{t+k}^* (j) \right) \right]$$

where, $\Lambda_{t,k}^P$ is the relevant stochastic discount factor and $Y_{t+k}^* (j) = \left(\frac{P_t^*(j)}{P_{t+k}} \right) Y_{t+k}$. Assuming a symmetric equilibrium, we obtain the following first order condition:

$$E_t \sum_{k=0}^{\infty} (\beta_P \theta)^k \left[\lambda_{t+k}^P \left((1-\varepsilon) \left(\prod_{s=1}^{k} \frac{1}{\pi_{t+s}} \right)^{1-\varepsilon} \frac{P_t^*}{P_t} + \varepsilon \left(\prod_{s=1}^{k} \frac{1}{\pi_{t+s}} \right)^{-\varepsilon} mc_{t+k} \right) Y_{t+k} \right] = 0\,. \tag{3.37}$$

The condition suggests that intermediate goods producers set their product price by considering both present and expected future nominal marginal cost. The producers rebate their profits, $F_t = (1 - mc_t)\, Y_t$, back to patient households.

We can now express the aggregate price index (P_t) above in terms of optimal prices (P_t^*):

$$1 = \theta \left(\frac{1}{\pi_t} \right)^{1-\varepsilon} + (1-\theta) \left(\pi_t^* \right)^{1-\varepsilon} \tag{3.38}$$

where, $\pi_t^* = \frac{P_t^*}{P_t}$. Log-linearising and combining equations (3.37) and (3.38) yield standard New Keynesian Phillips Curve (NKPC).

3.4.8 Aggregation and Market Clearing Conditions

Aggregate demand is made up from agents consumption, investment, capital utilisation cost, housing adjustment cost and state-verification cost following mortgage default:

$$Y_t = c_t^P + c_t^I + c_t^E + i_t + \Psi(u_t) + \phi_h(.) + (1 - rec)\Theta G_t(\bar{\omega}_t)\, q_t^h h_{t-1}^I \tag{3.39}$$

In this paper, we introduce the recovery rate, rec, being the proportion of monitoring cost that is returned as profits to patient households. This may result from the fact that they own companies specialising in monitoring activities. Consequently, we can define $t_t^P = rec\Theta G_t(\bar{\omega}_t)\, q_t^h h_{t-1}^I$. The treatment of default cost differs among articles featuring mortgage default. Quint and Rabanal (2014) assume that such cost is paid back to patient households as profits from debt-collection agency (rec=1). On the other hand, following BGG, Clerc et al. (2015) assume that the monitoring cost causes deadweight losses to the economy (rec=0).[65] Ferrante (2015) examines both cases. Our paper adopts an intermediate approach by setting $0 < rec < 1$.

Based upon market clearing conditions of the labor and capital markets, (1) $\int_0^1 l_t^{P,d}(j)\,dj = l_t^{P,s} = l_t^P$ (2) $\int_0^1 l_t^{I,d}(j)\,dj = l_t^{I,s} = l_t^I$ and (3) $\int_0^1 k_{t-1}(j)\,dj = u_t k_{t-1}$, and intermediate goods demand function, we can aggregate up the production function of intermediate good firms, which yields the following expression:

$$A_t \left(u_t k_{t-1}\right)^{\mu} \left(l_t^P\right)^{\alpha(1-\mu)} \left(l_t^I\right)^{(1-\alpha)(1-\mu)} = Y_t \int_0^1 \left(\frac{P_t(j)}{P_t}\right)^{-\varepsilon} dj\,. \tag{3.40}$$

The supply of houses is assumed to be fixed:

$$h_t^P + h_t^I = H\,. \tag{3.41}$$

3.4.9 The Central Bank

The central bank controls the deposit interest rate based on a simple rule, which links the interest rate to deviations of current inflation from the steady state and GDP growth:

$$\frac{r_t}{r} = \left(\frac{r_{t-1}}{r}\right)^{r_R} \left(\left(\frac{\pi_t}{\pi}\right)^{1+r_\pi} \left(\frac{GDP_t}{GDP_{t-1}}\right)^{r_Y}\right)^{1-r_R} \tag{3.42}$$

[65] Forlati and Lambertini (2011) adopt a different approach by assuming that this monitoring cost results in the destruction of the housing stock. However, this results in a rise in housing construction immediately after adverse housing risk shocks that is counterfactual.

where, r is the steady-state deposit interest rate. r_π and r_Y measure the sensitivity of the policy interest rate to inflation deviations and GDP growth, respectively. Meanwhile, r_R denotes the degree of interest rate stickiness. GDP, or Gross Domestic Product, is defined as the sum of consumption and investment:

$$GDP_t = c_t^P + c_t^I + c_t^E + k_t - (1-\delta)\, k_{t-1}\,. \tag{3.43}$$

Recall that $k_t - (1-\delta)\, k_{t-1} \neq i_t$ due to the existence of investment adjustment costs. It properly measures effective investment that can be used for production next period.

3.5 Macroprudential Regulations

The benchmark model includes only one banking regulation, namely capital adequacy regulation. The regulation ensures that individual banks accumulate sufficiently large buffers to face unexpected losses. It also has side benefits of putting more skin-in-the-game to prevent excessive risk-taking and over-leveraging. Nevertheless, the Great Recession has proven that microprudential regulation alone, which promotes the soundness of individual financial institutions, is not adequate to cope with systemic risks. Policymakers and academics therefore have greatly supported the use of macroprudential tools to address such risks and to reduce the probability and severity of the financial crisis. In this paper, we focus on three different macroprudential regulations and assess whether they help promote economic stability and welfare in the face of large adverse shocks.

Caps on Loan to Value Ratio

Caps on LTV ratio have been popular in such Asian countries as Singapore, Hong Kong and Korea to prevent house price bubbles and mortgage booms. According to the IMF's Global Macroprudential Policy Instruments (GMPI) database, Jacome and Mitra (2015) suggest that 47 countries imposed limits on LTVs during the year 2000-2013. Cerutti et al. (2015); Claessens et al. (2013); Crowe et al. (2013); Kuttner and Shim (2016) have provided empirical cross-country evidence to support that caps on LTV ratio are effective in mitigating boom in the real estate market and stabilising growth in bank assets and leverage. In this model, we introduce such regulations as a constraint on mortgages demand, as in Iacoviello (2005). In particular, mortgage borrowing cannot exceed the maximum LTV ratio times the value of the collateral provided,

$$r_t^I b_t^I \leq \widetilde{m}^I q_t^h h_t^I \,. \tag{3.44}$$

We assume that the collateral is valued at current real house prices in contrast with previous articles that often assume valuation at expected future prices. We will show that this assumption allows changes in asset prices to influence the default probability. In addition, our approach is consistent with actual practices. Impatient households now maximise their objective function taking into account both the budget constraint (3.6) and the borrowing constraint (3.44). The first order conditions with respect to loans and housing demand become (ξ_t^I is the Lagrange multiplier with respect to the borrowing constraint):

$$\lambda_t^I = \beta_I E_t \left[\left(1 - F_{t+1}\left(\bar{\omega}_{t+1}\right) + \frac{G_{t+1}\left(\bar{\omega}_{t+1}\right) q_{t+1}^h \pi_{t+1}}{\widetilde{m}^I q_t^h} \right) \frac{r_t^I}{\pi_{t+1}} \lambda_{t+1}^I \right] + \xi_t^I r_t^I \tag{3.45}$$

$$\begin{aligned} & q_t^h \lambda_t^I \left(1 + \phi_h \left(\tfrac{h_t^I - h_{t-1}^I}{h_{t-1}^I}\right)\right) \\ = & \tfrac{j}{h_t^I} + \beta_I E_t \left[q_{t+1}^h \lambda_{t+1}^I \left(1 + \tfrac{\phi_h}{2} \left(\tfrac{h_{t+1}^I - h_t^I}{h_t^I}\right) \left(\tfrac{h_{t+1}^I + h_t^I}{h_t^I}\right)\right)\right] + \xi_t^I \widetilde{m}^I q_t^h \end{aligned} \,. \tag{3.46}$$

As is standard in the literature, the LTV constraint disturbs consumption smoothing incentive of the agent, as shown in equation (3.45). Moreover, from equation (3.46), the shadow value of housing includes not only utility derived from housing services and gains from reselling houses in the following period but also the benefits from relaxing the borrowing constraint. Introducing LTV regulations has important impacts on mortgage default, since we earlier show that default probability depends on the LTV ratio. From the "on-the-verge" condition, it follows that

$$\bar{\omega}_t = \frac{b^I_{t-1} r^I_{t-1}}{q^h_t h^I_{t-1} \pi_t} \frac{q^h_{t-1}}{q^h_{t-1}} = \widetilde{m}^I \frac{q^h_{t-1}}{q^h_t \pi_t} \, .$$

Caps on LTV ratio fix the equilibrium LTV ratio as well as the steady-state mortgage default probability. In equilibrium, the probability of default is determined by the variance of an idiosyncratic housing shock and the quarterly growth rate of nominal house prices. Rising nominal house prices from the previous quarter contribute to a lower default frequency. The assumption that assets are evaluated at the current price also affects how banks determine the interest rate spread between mortgages and deposits; i.e.,

$$\phi^k_t \left(\frac{k^B_t}{\bar{k}} \right)^{1-\sigma_B} \left(\frac{rw^I_t}{rwa_t} \right) = \beta_P E_t \left[\frac{\lambda^P_{t+1}}{\lambda^P_t} \frac{\left(1 - F_{t+1} \left(\bar{\omega}_{t+1} \right) + (1-\Theta) \frac{G_{t+1}(\bar{\omega}_{t+1}) q^h_{t+1} \pi_{t+1}}{\widetilde{m}^I q^h_t} \right) r^I_t - r_t}{\pi_{t+1}} \right] .$$

Expected changes in asset prices now matter for mortgage loan pricing. If the value of the houses is anticipated to rise, banks will charge a lower mortgage spread, as they can resale foreclosed assets at higher prices.

It is straightforward to prove that the borrowing constraint binds at the steady state. To ensure that the constraint always binds in equilibrium, Iacoviello (2005) assumes that the size of shocks is sufficiently small. However, in this paper, we are interested in large shocks that trigger a significant rise in mortgage default. Therefore, it is possible that, in response to shocks, impatient households demand fewer mortgages than the restricted amount and, therefore, the constraint does not bind. One alternative is to solve the model with occasionally binding constraints. Otherwise, one may introduce LTV caps as an equality constraint. We, nevertheless, proceed by ensuring that the constraint is initially binding with a sufficiently high shadow value of borrowing (ξ^I). Specifically, in the model with LTV caps, we purposely decrease impatient households discount factor (β_I) so that they have greater incentive to borrow. This will result in tighter borrowing constraints at the steady state (higher ξ^I) and they will keep binding in equilibrium despite the economy facing large shocks. Nonetheless, this comes with a drawback. We need to be cautious that the impulse responses from the benchmark model and the model with LTV caps cannot be legitimately compared as β_I differs across these two models. Therefore, for the sake of consistency, when we analyse the effectiveness of this regulation, we rely on the framework with caps on LTV ratio and focus on the effects from imposing more stringent LTV caps (by varying $\widetilde{m}^I$).

Countercyclical Capital Buffers

The Basel III regulatory framework proposes countercyclical capital buffers with the aim to prevent excessive credit growth and risk accumulation during the boom periods. This reduces the probability of crisis in the first place. The buffers also ensure that the banking sector has sufficient capital whenever the crisis occurs. In particular, whenever the ratio of credit to GDP has risen above its trend beyond certain threshold, banks are required to hold additional capital. The opposite does not hold over the period of credit crunch as the credit-to-GDP ratio moves below its trend. However, we take a different approach here by allowing minimum capital adequacy ratio to adjust over the boom-bust cycles. Therefore, we allow this macroprudential regulation to actively serve as a crisis-resolution tool. This ensures that capital regulation, while incentivising banks to hold enough buffers in normal times, does not constrain their lending activity in adverse times, especially when they are in need to deplete such buffers. We assume that the minimum capital adequacy ratio adjusts according to the following formula:

$$\bar{k}_t = \rho_{\bar{k}}\bar{k}_{t-1} + (1-\rho_{\bar{k}})\left[\bar{k} + \Phi_k\left(\frac{b_t^I + b_t^E}{GDP_t} - \frac{b^I + b^E}{GDP}\right)\right]. \tag{3.47}$$

Capital requirements are adjusted upward (downward) whenever the ratio of credit to GDP is higher (lower) than the steady state value. Φ_k measures the sensitivity of the capital ratio to deviations of the credit-to-GDP ratio from the steady state.

Indeed, from 2016, several countries have already made this regulation operational. More precisely, Hong Kong, Sweden and Norway authorities already require banks to hold additional capital. However, the implementation does not rely on an analytical framework that evaluates its effectiveness. Empirical researchers, meanwhile, have relied on counterfactual analysis and yield inconsistent results. Repullo and Saurina (2011) find that the buffers can even exacerbate procyclicality because the credit-to-GDP ratio tends to be negatively correlated with GDP growth, causing capital requirements to decline in the boom period. On the other hand, Drehmann et al. (2011) and Drehmann and Gambacorta (2012) show that the measure helps dampen credit cycles and support the use of the ratio of credit to GDP as a signaling indicator due to its ability to predict recession.

State-contingent Caps on Loan to Value Ratio

State-contingent LTV caps, though not formally proposed by regulatory institutions, have been introduced in a number of theoretical articles to improve cyclical properties of the economy. Indeed, Jacome and Mitra (2015) point out that around 27 countries have adjusted LTV caps over time to reduce systemic risks and promote the resilience of the financial sector. In this paper, we assume that they vary systematically over the cycle in response to mortgages supply condition, according to the following formula:

$$\hat{m}_t^I = \rho_m \hat{m}_{t-1}^I + (1-\rho_m)\left[\hat{m}^I - \Phi_m\left(\frac{b_t^I}{GDP_t} - \frac{b^I}{GDP}\right)\right]. \tag{3.48}$$

LTV caps are adjusted upward (downward) whenever the mortgage-to-GDP ratio is lower (higher) than the steady state value. In the bust period where mortgage extension is constrained, higher LTV limits enable borrowers to obtain more loans given the same collateral value. Consequently, this should allow them to boost consumption and housing accumulation. Φ_m measures the sensitivity of LTV caps to deviations of the mortgage-to-GDP ratio from its steady state.

3.6 Parameter Calibration

The calibration aims to target the steady state value of some of the model's endogenous variables at certain level consistent with historical US data. We set patient households discount factor at 0.991 to target the steady-state deposit rate at 3.67 percent annually. Following Monacelli (2009), the steady-state LTV ratio is targeted at 70 percent, which in turn determines the steady-state cut-off level of idiosyncratic housing shocks ($\bar{\omega}$). Forlati and Lambertini (2011) suggest that the average US LTV ratio between 1973 and 2008 is 75.7 percentage points. The delinquency rate on single-family residential mortgages during pre-crisis averaged at 2 percent. Therefore, we set the steady-state variance of idiosyncratic housing shocks at 0.167 to ensure the steady-state value of mortgage default probability close to such figure. Monitoring cost (Θ) is set at 16 percent, the intermediate value of the range of 12 and 20 percent calibrated by other articles.[66] We work with a relatively high steady-state annualised mortgage interest rate of 6.80 percent, implying a spread with deposit rate of 3.13 percent. In the data, the spread between 30-year con-

[66] Forlati and Lambertini (2011) suggest that the median foreclosure price in California in 2006 was 12 percent lower than the median market price of home sold without having previously been foreclosed. Meanwhile, Ferrante (2015) picks 20 percent in line with the average foreclosure losses.

ventional mortgage rate and the Treasury constant maturity rate averaged at 1.59 percent during ten years run up to the crisis. However, we note that the average value of the 30-year conventional mortgage rate itself is almost 8.00 percent during 1990s, while it is close to 6.80 percent in a few years prior to the crisis. The discount rate of impatient households can be implied by equation (3.11).

Table 3.1: Parameters

	Description	Value		Description	Value
β_P	Patient household's discount rate	0.991	σ^2_ω	Variance of idiosyncratic housing shocks	0.167
β_I	Impatient household's discount rate	0.984	Θ	Cost of state verification	0.160
β_E	Entrepreneur's discount rate	0.980	rec	Recovery rate	0.500
j	Housing weight	0.200	m^E	Business loans LTV caps	0.200
η	Labor supply aversion	2.000	$\bar{k}$	Minimum capital adequacy ratio	0.080
δ	Depreciation rate of capital	0.025	rw^E	Risk weight on business loans	1.000
μ	Share of capital income	0.330	rw^I	Risk weight on mortgages	0.350
α	Patient household's wage share	0.640	Υ	Sensitivity of risk weight	7.473
A	Steady-state productivity level	1.000	ϕ^k	Capital regulation penalty	0.044
$\frac{\varepsilon}{(\varepsilon-1)}$	Mark up in the goods market	1.100	σ_B		6.000
θ	Probability of fixed price	0.750	δ_B	Dividend payout rate	0.135
H	Fixed supply of houses	33.27	γ_B		0.010
ϕ_h	Housing adjustment cost	0.330	a_P	Habit coefficient	0.500
r_R	Taylor-rule coefficient on r_{t-1}	0.800	a_I		
r_Y	Taylor-rule coefficient on GDP_t	0.50/4	a_E		
r_π	Taylor-rule coefficient on π_t	0.500	k_i	Investment adjustment cost	0.200
ρ	persistence of shocks	0.900	$\varepsilon_{k,1}$	Capital utilisation cost	0.0452
			$\varepsilon_{k,2}$		0.0452

We turn to banking parameters. Before the crisis, qualified residential real estate exposures receive a flat risk weight of 35 percent. Under the December-2015 proposed revision by the Basel Committee, risk weight will be determined based upon the exposure's LTV ratio. If the LTV ratio falls within the range of 60-80 percent, risk weight of 35 percent is applied. However, the proposed revision also considers the scenario of non-recourse debt where mortgage repayment is only dependent on cash flows generated by property. Such exposure, which is more relevant in the context of subprime crisis, faces 90-percent risk weight. Despite the non-recourse nature of debt, we however apply a steady-state risk weight of 35 percent with moderate sensitivity to the expected default risk, so as to be consistent with the pre-crisis context. Risk weights for corporate exposure vary with external credit ratings of the counterparty. The values range between 20 and 150 percent. Despite the fact that default on business loans is ruled out in equilibrium, we choose intermediate risk weights of 100 percent, the figure applied to BB+ to BB- companies. Given risk weights, we can compute the steady-state business loan spread equivalent to 4.06 percent. The spread between bank prime loan rate and 1-year Treasury constant maturity rate (or effective federal funds rate) in the data is roughly 3 percent annually. For the initial conditions to be characterised as financial stability, we assume the bank capital ratio to be at the regulatory level at 8 percent. The dividend payment rates (δ_B and γ_B) are calibrated to ensure this. We can now obtain implied steady-state capital regulation penalty weight ϕ^k.

As is standard in the literature, the depreciation rate of capital equals 2.50 percent quarterly. The capital share of income is at 33 percent. The rest of the income is split among the two households; we set α at 0.64, as estimated in Iacoviello (2005). The discount rate of entrepreneurs is set at 0.98. Entrepreneurs face the borrowing constraint, with caps on LTV ratio set at 20 percent. The value is much lower than that calibrated in Gerali et al. (2010) in the case of Euro Area (35 percent). However, it matters for the steady-state proportion of business loans on banks portfolio. As discussed in the introduction, it is crucial to ensure that mortgages constitute the largest proportion of bank assets. Frisch elasticity of labor supply is assumed at 1. Housing weight equals 0.20, implying the steady-state ratio of mortgages to quarterly output at 170 percent. We assume the steady-state markup in the goods market to be 10 percent. Probability of fixed price equals 0.75. The steady-state productivity level is normalised at 1. Fixing real house price at 1, we can obtain the implied (fixed) supply of houses. Real frictions, including habit formation, capital utilisation costs

Table 3.2: Important Rates and Ratios at the Steady State

	Description	Value
$F(\omega)$	Mortgage default probability	2.007 %
m^I	Loan-to-value ratio	70.00 %
r	Deposit interest rate (p.a.)	3.673 %
r^I	Mortgage interest rate (p.a.)	6.800 %
r^E	Business loan interest rate (p.a.)	7.736 %
$\frac{b^I}{b^I+b^E}$	Proportion of mortgages	57.26 %
$\frac{b^I}{Y}$	Mortgages to output	170.1 %
$\frac{b^E}{Y}$	Business loans to output	127.0 %
$\frac{c^P}{Y}$	Patient household consumption to output	52.96 %
$\frac{c^I}{Y}$	Impatient household consumption to output	19.24 %
$\frac{c^E}{Y}$	Entrepreneur consumption to output	10.95 %
$\frac{i}{Y}$	Investment to output	16.59 %
$\frac{\Theta G(\omega) q^h h^I}{Y}$	Monitoring cost to output	0.523 %
$\frac{q^h h^P}{Y}$	Patient household's housing demand to output	1164 %
$\frac{q^h h^I}{Y}$	Impatient household's housing demand to output	247.1%
k^B	Bank capital ratio	8.000 %

and investment adjustment costs, are necessary to generate persistent responses of the economy to shocks. Rigidities are kept as low as possible to generate persistence. We use a conventional value for the Taylor rule coefficients, with r_R, r_Y and r_π equal 0.80, 0.13 and 0.50, correspondingly. The important rates and ratios at the steady state are summarised in table 3.2.

We are left with a few more parameters. As σ_B affects the sensitivity of interest rate spreads to the capital adequacy ratio, it will be calibrated to match cyclical property of the data. In particular, in the data, 1-year mortgage spread rose by approximately 4 percentage points annually during the crisis. We set the housing adjustment cost parameter (ϕ_h) at 0.33. Both parameters will be shown to have important impacts on the dynamics of the economy with respect to adverse housing risk shocks.

3.7 Model Properties

This section presents simulation results from the benchmark model. The model is log-linearised around the steady state. We firstly examine responses with respect to standard macroeconomic shocks to see whether the model, after including endogenous mortgage default, still produces reasonable results. To capture key aspects of the Great Recession, we then introduce two shocks originating from the financial market, namely shocks to the variance of an idiosyncratic housing shock (in short, housing risk shock) and shocks to the capital regulation penalty (in short, risk premium shock). These shocks explain the unusual surge in mortgage default and credit spreads that is observed in the US data. We explore the responses of the economy to large adverse shocks, emphasising the role of the banking sector friction in the shock propagation. In the next section, we examine whether the implementation of the three macroprudential tools improves economic stability and welfare of the agents.

3.7.1 Responses to Standard Macroeconomic Shocks

We begin by exploring whether the benchmark model possesses good properties in terms of identifying the effects of standard macroeconomic shocks. In particular, we focus on three shocks, explored in Gerali et al. (2010), namely monetary policy, productivity and bank capital shocks. The latter is introduced as one-off losses to bank profits. We also assess how mortgage default and bank capitalisation evolve in response to these shocks. The impulse responses are shown in figure 3.4.

With nominal rigidities, a contractionary monetary policy shock exerts a negative effect on real economic activities and prices. An increase in borrowing costs causes all components of GDP to suffer a persistent drop. Both mortgages and business loans fall. The dynamics of mortgage default can be important to the economy's dynamics. Contemporaneously, a fall in both house prices and consumption good prices triggers more mortgage defaults. Default remains persistently higher than the steady state over the horizon considered as the LTV ratio has increased. Despite less mortgage origination, an increase in the LTV ratio can be explained by the fact that nominal house prices plunge while mortgage interest rates pick up. Anticipated increases in default widen mortgage spread, which in turn adversely affects demand from impatient households, thereby generating a financial accelerator. Meanwhile, the banking sector's capital deteriorates, prompting banks to raise both loan spreads. As in the literature, real house prices fall and gradually return to the steady state. The calibrated size of the policy tightening results in an increase in annualised deposit interest rate of 50 basis points, precipitating 0.81-percent contemporaneous decline in GDP.

A one-percent positive productivity shock generates hump-shaped responses of GDP and household consumption. Inflation falls as marginal cost of producing goods is reduced, prompting the central bank to lower its policy interest rate. However, the model fails to predict immediate increases in investment and GDP. This may result from the fact that higher consumption discourages households incentive to supply labor due to the labor-leisure trade-off. In the financial sector, banks grant more mortgages and business loans to support higher demand for consumption. Mortgage default declines due to an unexpected surge in house prices, but soars up above the steady state in the subsequent periods as the equilibrium LTV ratio rises. However, the magnitude of the changes is relatively small and therefore should not significantly affect the economy's dynamics. In the short run, lower mortgage default improves banks' capital adequacy ratio, allowing them to ease lending standards.

Last, we show that one-off negative bank capital shock may have long-lasting impacts on the economy.[67] The size of the shock is calibrated to generate 5-percent drop in bank profits. Banks' capital ratio therefore diminishes, causing them to raise

[67] We assume that bank capital losses are transferred to patient households. The shock, in this case, is more or less a "dividend-like" transfer from banks to patient households.

credit spreads. This has adverse consequences on lending activities and aggregate demand. Total bank assets shrink. The capital ratio remains below the steady state for certain periods since spreads do not sufficiently rise to boost profits to counter the contraction of the banks balance sheet. This results in a persistent rise in the spreads, which continues to drag the economy down for certain periods. These results are important to understanding why unanticipated increase in mortgage default, which depresses bank capital, can generate significant effects on the real economy.

3.7.2 Responses to Shocks to the Variance of an Idiosyncratic Housing Shock

A housing risk shock is the main focus in this paper as it was arguably the main reason of the Great Recession. We precisely analyse the transmission mechanisms of a large adverse housing risk shock to the banking sector and the real economy. The black solid lines in figures 3.5 and 3.6 show the responses of the benchmark model.

The first-order impact of an adverse housing risk shock (or an unexpected increase in the variance of an idiosyncratic housing shock) is to raise the mortgage default probability. That is, an increasing number of impatient household members decide to default on their loan obligations. Banks face losses from reduced mortgage repayment and an additional cost of state verification. Consequently, their profits and hence equity capital deteriorate. This in turn prompts them to begin tightening credit extension. The size of shocks is calibrated to trigger a 2.5-percentage-point surge in the probability of mortgage default on impact. We note that the default probability rises by more than 8 percentage points during the crisis. Gross bank profits consequently decline by 5.54 percent.

Given the persistence of a housing risk shock, the default probability stays above the steady state for certain periods, despite the fact that the equilibrium LTV ratio is below the steady state by more than 1 percentage point for 3 years following the shock. Banks anticipate a higher future default risk and, therefore, charge a default premium on mortgage interest rates. Increased default risk also makes the overall bank portfolio riskier, as reflected by larger risk-weighted assets. This becomes another factor that worsens their capital adequacy ratio, causing a persistent rise in credit spreads. In the figures, the capital ratio declines by 1.45 percentage point. At the outset, annualised mortgages and business loans spread increase by 3.56 and 3.20 percentage points, respectively. The mortgage spread remains above the steady state during the horizons considered, while that of business loans recovers within a year. Mortgages exhibit a hump-shaped decline, with a maximum reduction of 8.06 percent one year after shocks. Business loans drop 0.57 percent at most on impact, but rebound immediately afterwards.

Facing rising mortgage interest rate, impatient households demand fewer consumption goods and houses. Lower demand from households, along with tighter credit conditions, discourages investment in capital. Meanwhile, entrepreneurs consumption is also adversely affected by reduced rental income. The model correctly predicts a substantial decline in investment, which accounts for large portion of the GDP downfall. However, it fails to match its persistence, as investment picks up within a year. When the shock occurs, impatient households consumption, entrepreneurial investment and GDP fall by 1.10, 4.77 and 1.03 percent, respectively. Inflation decreases below the steady state, but to a small extent. The central bank reacts by slashing its policy interest rate.[68] In sum, our results suggest that negative shocks originating in the housing market contribute towards a significant output contraction, led by a slump in investment.[69]

[68]Declining deposit interest rate induces patient households to increase their expenditure. Deposits fall is compatible with banks need to deleverage. The adverse housing risk shock reallocates welfare from those who demand funding to savers. The latter also benefit from revenue from the monitoring activity.

[69]To illustrate the sensitivity of the results with respect to the assumption on the recovery of the monitoring costs, Figure 3.7 shows impulse responses under two extreme cases: (1) $rec = 1$ and

The Role of Asset Prices

The interactions between mortgage default, house prices and credit supply conditions could be a potential financial accelerator that lies behind a significant economic downturn. The decline in impatient households demand for housing depresses house prices, which according to the on-the-verge condition, raises default probabilities further. The latter worsens banks' capitalisation, thus forcing them to reduce mortgages even more. Their capital is also affected by losses from a deterioration of the value of the seized collateral. With fewer mortgages, demand for housing is further eroded with knock-on effects on asset prices and so on and so forth. Moreover, on the loans demand side, since housing is utilised as collateral in acquiring mortgages, lower housing accumulation by impatient households directly implies that they can obtain less funding. This is exacerbated by falling future nominal house prices. However, like Forlati and Lambertini (2011), we find that real house prices quickly rebound, which is counterfactual. Also, the magnitude of their decline in the impact period is small. These findings weaken the role of asset prices in explaining the downturn.[70]

Capital Regulation and Housing Adjustment Costs

The model simulations instead identify two frictions that are crucial in contributing to deep and persistent recessions, namely capital regulation and housing adjustment costs. The red dashed line in figure 3.5 shows the impulse responses of the economy without bank capital frictions. In particular, we assume the component of both

(2) $rec = 0$. We observe that varying the recovery rate does not affect much the dynamics of real GDP. However, there are certain allocative differences. When the monitoring costs are paid back to patient households, their consumption unsurprisingly does not decline as much as in the case where such costs become deadweight losses. Nevertheless, inflation falls by less in the latter case. Since monitoring costs form part of aggregate demand, they exert upward pressure on inflation. Deposit interest rate, therefore, does not decline as much. In addition, investment is raised to support aggregate demand, making up for the greater decline in household consumption.

[70] In Ferrante (2015), he simulates housing market shocks to replicate a persistent house prices fall. His model assumes that only the impatient households consume housing services. Consequently, there is no demand from patient households to pick up the slack.

credit spreads driven by capital regulation to be time-invariant. The effects of an adverse housing risk shock on GDP and inflation are considerably smaller, with GDP falling by merely 0.23 percent on impact. The direct effect of an increase of the expected default probability on mortgage interest rate remains. However, by assumption, banks do not tighten credit standards in response to lower capital adequacy ratio. Business loan spread and hence investment barely change from their steady state as compared with the benchmark case. The responses of consumption and housing demand by both households are less pronounced but remain significant. In particular, impatient households consumption shrinks by 0.76 percent on impact. The bank capital ratio gradually recovers towards the steady-state level. Their assets fall by a lesser extent, as they do not face a constraint to deleverage from capital regulation.

The interplay between housing adjustment costs and capital regulation is another factor that leads to pronounced responses of the economy. Figure 3.6 compares the responses of the benchmark economy against (1) the economy without the adjustment costs and (2) the economy with even higher costs. The key differences, when the housing adjustment cost disappears, are that mortgages plunge considerably more, by around 18.3 percent on impact. The LTV ratio declines by almost 4 percentage points. Impatient households housing demand tumbles to a much larger extent. However, this allows them to afford higher level of consumption. Their non-durable consumption falls by 0.54 percent at most. Furthermore, declining LTV ratio implies a decrease in the future mortgage default probability. Banks thus charge lower mortgage spreads. Moreover, an abrupt fall in mortgages during the times that their risk weight is high mitigates a decrease in their capital ratio. They, therefore, face less pressure to deleverage. Investment and GDP, on impact, fall by merely 1.98 and 0.42 percent, respectively. On the other hand, in the case of high adjustment cost, the slump in GDP and inflation is even more pronounced. In reality, households may not be able to adjust housing demand abruptly due to several reasons ranging from habit formation to difficulty in reselling houses (and searching for new residence). Such inflexibility could explain why the recent crisis has been so severe.

3.7.3 Responses to Capital Regulation Penalty Shocks

As explained earlier, risk premium shocks aim at capturing exogenous changes in bank risk-bearing capacity, which in turn influences loan pricing. This section focuses on the effects of a large adverse shock to capital regulation penalty (higher ϕ_t^k), providing us another potential source of widening interest rate spreads during the crisis.

The first-order impacts of such a shock, shown in figure 3.8, are to increase marginal cost of loan origination. Banks therefore raise premium on both loan interest rates. This results in negative consequences on borrowers. Widening mortgage spreads discourage demand for consumption and housing from impatient households. At the same time, entrepreneurs suffer from a rise in business loan spreads, whereas entrepreneurial consumption and investment both are declining. Investment is also adversely affected by weak aggregate demand. Both GDP and inflation consequently adjust downwards, leading the central bank to cut its policy interest rate. Declining deposit rates induce patient households to raise consumption while reducing deposits to banks, which is consistent with the latter's incentive to deleverage.

We calibrate the size of the shock to generate a surge in annualised business loan spread by 2 percentage points. Since mortgages face lower risk weight, the shock raises their spread to a smaller extent at 0.68 percentage point. Bank assets plunge 0.49 percent on impact. The consequences on the real economy are non-trivial. On impact, impatient households consumption, entrepreneurial consumption, investment and GDP decline by 0.08, 0.54, 3.01 and 0.52 percent, respectively. The effects on both consumption components are highly persistent, thus depressing the welfare of both agents. Due to fewer mortgages, impatient households housing demand also drops, which potentially enhances procyclicality through limited collateral. As anticipated, bank capital ratio improves, achieved by deleveraging and an increase in intermediation margins. The ratio rises by 0.59 percentage point after two quarters. This is one factor that mitigates widening spreads.

Given persistence of a risk premium shock, spreads remain above the steady state level for certain periods. However, mortgage spread can be reduced by lower default probability. Banks restrictive lending practice implies falling LTV ratio, which brings default down. In the first period, impatient households also default less on their mortgage obligations as real house prices rise. Improving mortgage repayment should help ease impaired lending conditions. Nevertheless, its impact may be modest as the default probability only declines by 0.03 percentage point on impact.[71]

3.8 Analysis of Macroprudential Regulations

Having discussed adverse consequences of housing risk shocks and risk premium shocks, we now explore in this section how the three macroprudential regulations influence the dynamics of the economy. We summarise their effects on macroeconomic stability and agents welfare in subsection 3.8.4.

3.8.1 Steady State Effects of LTV Caps

The LTV regulation not only influences cyclical properties of the economy but also affects its non-stochastic steady state.[72] In this exercise, we assume all parameter

[71] In figures 3.9 and 3.10 in the Appendix, I present the responses of the economy to both shocks using second-order approximation. The results explained earlier do not qualitatively alter.

[72] Indeed, all the three measures should affect the steady state if the stochastic version is considered. This is because they all affect the dynamics of the economy and hence its future uncertainty. The latter in turn influences agents decision, given risk-averse preferences.

values, including impatient households discount factor to be the same as in the benchmark model. Caps on LTV ratio impose a limit on the amount of mortgages impatient households can borrow for any given housing value. This may sound unsatisfactory for them. However, in this model which incorporates a time-varying mortgage default probability, this policy tool favours them. The last four columns of table 3.3 show the steady state of the economy with different levels of regulatory LTV ratio (from 67 percent to 55 percent). The last column reflects the most constrained scenario. Recall that the steady-state LTV ratio for the benchmark economy is 70 percent. So, any LTV limits that are lower than such a level will make the borrowing constraint binding. Positive steady-state value of the tightness of the constraint (ξ^I) confirms this.

As the policy becomes more stringent, we surprisingly observe a rise in impatient households demand for both consumption goods and housing. They also enjoy more leisure. All of these arguments benefit their welfare. Mortgage default plays a pivotal role here. At the steady state, $\bar{\omega} = m^I$. Therefore, the LTV ratio is the only determinant of the steady-state probability of default. Decreasing LTV ratio limits chances that idiosyncratic housing shocks will force the collateral value to be lower than the debt outstanding. The default probability consequently declines. In particular, imposing LTV limit at 55 percent almost prevents mortgage default from occurring. This curtails the risk premium charged on mortgage lending and eases impatient household's borrowing costs.

However, the effects on mortgages are non-linear. Due to the reduced default risk, the amount of mortgages rises when LTV caps are initially imposed. Nevertheless, as the caps are reduced to a certain level, mortgages begin to fall as the beneficial effects on default are outweighed by their direct negative ones in constraining borrowing. The steady-state capital adequacy ratio improves slightly since the bank portfolio becomes less risky. Nonetheless, the business loan interest rate rises since

Table 3.3: Steady State Effects of the Introduction of LTV Caps

Variable	Benchmark	Case 1	Case 2	Case 3	Case 4
Steady State					
LTV ratio	70.00%	67.00%	65.00%	60.00%	55.00%
Default Probability	2.007%	1.032%	0.628%	0.146%	0.024%
Mortgage Interest Rate	1.700%	1.417%	1.302%	1.167%	1.133%
Business Loan Interest Rate	1.934%	1.943%	1.948%	1.956%	1.961%
Capital Adequacy Ratio	8.000%	8.070%	8.108%	8.173%	8.212%
Percentage Change from the Benchmark Case					
Mortgages		6.523%	8.055%	5.031%	-3.121%
Business Loans		-0.212%	-0.325%	-0.513%	-0.624%
GDP		-0.048%	-0.081%	-0.157%	-0.224%
Patient HH Labor Supply		0.083%	0.148%	0.323%	0.498%
Impatient HH Labor Supply		-0.557%	-0.887%	-1.554%	-2.072%
Capital		-0.204%	-0.311%	-0.491%	-0.597%
Patient HH Consumption		-0.332%	-0.549%	-1.044%	-1.479%
Impatient HH Consumption		0.948%	1.521%	2.709%	3.661%
Entrepreneur Consumption		-0.201%	-0.308%	-0.486%	-0.591%
Investment		-0.204%	-0.311%	-0.491%	-0.597%
Patient HH House Demand		-2.008%	-2.918%	-4.004%	-4.202%
Impatient HH House Demand		8.949%	12.70%	16.96%	17.71%
Change from the Benchmark Case					
Patient HH Welfare		-0.6907	-1.0627	-1.7155	-2.1412
Impatient HH Welfare		1.8595	2.7642	4.1688	4.9377
Entrepreneur Welfare		-0.0504	-0.0771	-0.1216	-0.1477

banks supply fewer business loans so as to increase mortgage lending. GDP and investment fall, though not to a large extent. This is mainly due to a decline in the consumption of patient households, who lend more to the banking sector. Therefore, there exists trade-off in terms of permanent GDP loss when financial regulators attempt to impose tighter LTV caps. The policy helps reallocate welfare towards impatient households, which prima facie seems counterintuitive.

3.8.2 The Effects of Shocks to Capital Adequacy Ratio and LTV caps

Before exploring the impacts of countercyclical capital buffers and state-contingent LTV caps, we examine how the economy benefits from relaxation of these two policy tools. We assume that $\Phi_m = \Phi_k = 0.9$. Figure 3.11 shows the effects of a negative shock to the capital adequacy ratio in both the benchmark model and the extended model with caps on LTV ratio.[73] In the benchmark case, its effects are unsurprisingly close to those resulted from risk premium shocks. A decrease in the regulatory capital ratio exerts expansionary consequences on the economy. Banks charge smaller spreads on both mortgages and business loans. A temporary fall in credit spreads encourages consumption and investment by borrowers. Patient households switch from consumption to deposits. Welfare is reallocated from them to borrowers who benefit from bank balance sheet expansion. The mortgage default probability rises but not significantly.

The measure has different allocative effects when caps on LTV ratio are in place.[74] Given the same size of shocks as in the benchmark case, their effects on mortgages and hence total bank assets are smaller. As a result, a rise in impatient households consumption, particularly on housing, is less pronounced. LTV regulations also have important implications on the behavior of mortgage default. The caps help anchor the probability of default after the shock. An increase in mortgage default may weaken expansionary effects of lower regulatory capital ratio in the benchmark case, however this is not the case in the model with LTV caps. Consumption decision

[73] In the latter model, we now adjust impatient households discount factor to 0.975 to ensure that the borrowing constraint always binds given the size of shocks assumed in the previous section. However, as explained before, given different discount factors, the simulation results for these two models are not suitable for comparison. We show the steady state value of the model with LTV caps in table 3.8 in the Appendix. We still find that more stringent LTV caps (moving from 67.5 percent to 65 percent) benefit impatient households as default declines.

[74] Under the model with LTV caps, we henceforth assume that financial regulators set the caps equal to 67.5 percent.

made by impatient households is another interesting aspect. Despite having more mortgages, their non-durable goods consumption does not immediately rise. They instead spend on housing which yields an extra return since it can also serve as collateral. Overall, the effect on GDP and investment is similar to the benchmark case.

A positive shock to the LTV caps also entails expansionary effects on the economy, as shown in figure 3.12. The shock relaxes impatient households borrowing constraint. Their consumption and housing demand rise as a result. GDP improves, while investment rises in the medium run. However, there exist trade-offs from elevated mortgage default risk and weakened banks financial condition. Increasing equilibrium LTV ratio leads impatient households to default more on their mortgages. This raises mortgage spread, which in turn partially crowds out the initial positive impact to the economy. In addition, more mortgage origination and higher default risk lessen bank capital ratio. Banks hence need to tighten their lending standards. This has negative short-run consequences on business loans and investment. Surprisingly, impatient households welfare worsens as they end up having to repay higher outstanding debt in the medium run. Therefore, even though the policy improves their short run utility, it is detrimental to their lifetime utility. However, the welfare of both patient households and entrepreneurs increases because they reap the gains from the economic expansion.

3.8.3 Can Macroprudential Regulations Stabilise Crisis Shocks?

More Stringent LTV Caps

We now consider how imposing more stringent LTV caps influences the path of the economy with respect to the shocks of interest. Figure 3.13 compares the responses of the economy facing a large adverse housing risk shock in the model with different levels of LTV caps (67.5 percent versus 65.0 percent).[75] The size of the shock is assumed to be the same as in the previous section. More stringent LTV caps manage to contain an increase in mortgage default probabilities. Mortgage spreads behave accordingly. A fall in mortgages and hence demand from impatient households is more limited. Non-durable consumption even picks up in the short run. Given lower default, banks' capital position improves. This reduces their need to tighten loan standards, benefiting both investment and GDP. Therefore, as financial regulators reduce limits on the LTV ratio, the adverse impacts of a housing risk shock on lending activities and GDP become more limited. According to table 3.4, both impatient households and entrepreneurs achieve an improvement in their welfare. We also note that the extended model with LTV caps predicts a persistent decline in house prices, which lasts for two years.

We underscore certain qualitative changes in the model dynamics from the benchmark case. The decline in mortgages is substantially lower in the model with LTV caps, partly because bank capitalisation conditions improve. The latter also boosts investment. However, when LTV caps are at 67.5 percent, an increase in mortgage default probabilities and spreads is lower than the benchmark responses only in the short run. In the medium run, the fact that equilibrium LTV ratio significantly falls in the benchmark case helps curb a rise in default. A trade-off then exists in terms of worsening future impatient households consumption, which precipitates into a further decline of their welfare from the benchmark case. A potential solution is that financial regulators tighten LTV caps further. Default and hence mortgage spreads will be more controlled in the medium run. Impatient households can thus be better off from this policy.

Facing a risk premium shock, more stringent LTV caps can help limit a decline in mortgages (see figure 3.14). Improvement in mortgages is partly attributed by

[75] The graph is juxtaposed with the responses under the benchmark case. However, comparison across the two models should be made with caution as we have already explained.

a decline in mortgage spread. Since the steady-state mortgage spread is smaller at lower caps on LTV, the first-order effects of a shock on mortgage spreads become less pronounced. Impatient households can afford higher consumption on both non-durable and durable goods. In the model with LTV limits, demand for consumption goods is even positive in the short run. Meanwhile, mortgage default negligibly deviates from the steady state (except in the first period). The welfare of impatient households hence improves (see table 3.5). Nonetheless, the measure only benefits mortgage borrowers, without significant spillover effects to other parts of the economy. Investment and GDP fall to the same extent. Entrepreneurs welfare marginally declines because banks substitute away from corporate lending.

Countercyclical Capital Buffers

We next explore whether countercyclical capital buffers can mitigate the adverse impacts of housing risk and risk premium shocks. Hereafter, we set $\Phi_m = \Phi_k = 0$, i.e. allowing the policy tools to only vary with specified financial indicators. In the face of a housing risk shock, declining credit-to-GDP ratio after the shock triggers a decrease in the regulatory capital ratio. This relaxes banks need to deleverage and rebuild capital. From figure 3.15, which assumes away LTV regulations, their capital ratio falls more, contemporaneously, and only gradually returns to the steady state. Both interest rate spreads increase to a lesser extent, which helps boost lending activities. Impatient households can afford to purchase more consumption goods and housing. Investment also picks up significantly. GDP and inflation therefore are more stabilised. This macroprudential measure significantly improves the welfare of impatient households and entrepreneurs at the expense of patient households.

Figure 3.17 shows that, when LTV caps are already in place, countercyclical buffers can benefit the economy further. However, such benefits are limited, partly because the existence of LTV regulations has already mitigated a decline in the credit-to-GDP ratio in the first place. We can observe that credit spreads are mildly reduced. The previous subsection also shows that adjusting capital requirements has limited impacts on mortgages in the model with LTV caps. However, borrowers can still reap some benefits from more relaxed lending standards. Impatient households housing demand and entrepreneurial investment significantly improve, resulting in a rise of both agents welfare. Consistent with the results found in the previous subsection, there is evidence that impatient households postpone non-durable goods consumption.

In the face of risk premium shocks, as shown in figure 3.16, the measure has insignificant effects on GDP, but significant redistributive effects. However, the measure may have destabilising effects on the economy in the short run, as the ratio of credit to GDP does not fall immediately after the shocks. A rise in such ratio results from the fact that investment immensely declines, making the denominator more elastic than the numerator. Banks are thus required to hold even more capital, exacerbating their already-constrained capacity to supply loans. This results in a further decline in GDP, though to a negligible extent. This finding is consistent with that of Repullo and Saurina (2011) who suggest that using the credit-to-GDP ratio as a systemic-risk indicator can destabilise the economy. Nevertheless, both borrowers benefit from more relaxed loans supply conditions in periods after, as banks face less pressure to rebuild capital. They raise goods demand, allowing them to achieve higher welfare. The fact the GDP does not change implies that the measure mainly redistributes resources away from patient households who consume less.

Figure 3.18 shows the results when caps on LTV ratio are in place. In this case, LTV caps help limit the decline in mortgages. Given less pronounced responses of mortgages, the credit-to-GDP ratio rises more significantly in the short term. The indicator therefore sends a wrong signal to financial regulators. Such ratio, which is expected to decline in the bust periods, thereby suggesting to the regulators to implement more relaxed regulation, does the opposite. Again, capital requirement is raised at the times bank credit is already constrained. Credit spreads expand in the initial periods, prompting borrowers to reduce borrowing. This has destabilising effects on the economy. We can observe a considerable decline in impatient households consumption and housing accumulation. However, the welfare of both impatient households and entrepreneurs still improves since the measure helps ease lending standards in the medium term. This is at the expense of their short-term utilities.

State-contingent LTV caps

We consider implementing state-contingent LTV caps only in the case of housing risk shock, as the measure is sector-specific and so financial regulators may not exploit it to deal with shocks that affect lending across all sectors. The measure, though raising impatient households consumption in the initial periods, tends to lower their welfare as consumption declines in later periods. This is reminiscent of the results obtained when examining shocks to LTV caps themselves. As shown in figure 3.19, in response to a large adverse housing risk shock, the ratio of mortgages to GDP decreases. Financial regulators respond by raising the LTV caps in order to relax a borrowing constraint for mortgage borrowers. Mortgages massively improve from the responses under time-invariant LTV caps. This allows impatient households to demand more consumption goods and housing. We also observe improvement in both investment and GDP, though only in the short run. The medium- to long-run consequences are complicated due to the increased default and debt. With higher LTV ratio, the mortgage default probability and interest rate spreads constantly accelerate. This means higher debt outstanding that impatient households are obliged to repay in later periods. They therefore reduce consumption in the medium run, which ultimately hurts their welfare. Finally, entrepreneurs benefit from such a policy, given a rise in investment and overall economic activity.

3.8.4 Implications on Welfare and Volatility

The section summarises welfare and volatility implications from implementing macroprudential regulations. The welfare analysis follows from the previous section by considering welfare changes when the economy faces large adverse impulses. In particular, we consider deviations of each agent's welfare from the steady state at period 0 (i.e. when the shock hits) for each particular set of policies. Such a welfare measure can be referred to as a "conditional" welfare measure, since it is conditional on the same initial non-stochastic steady state of the economy, as well as on the shock being large and one-off. We find that no policies considered Pareto improve the welfare. So, we focus on a set of policies that can improve the welfare of those agents adversely affected by the shocks. In terms of volatility implications, we compute, for each particular set of policies, the volatility of key economic variables given the existence of shocks with variance specified in the table below.[76] The variables include GDP, inflation, investment, and total bank credit.

Tables 3.4 and 3.5 show the results for housing risk and risk premium shocks, respectively. In the tables, 'Mon Pol Only' row in the benchmark case assumes away all macroprudential measures. Both shocks cause welfare reallocation to patient households from impatient households and entrepreneurs. For the housing risk shock, the adverse effects on impatient households welfare are much stronger. By imposing LTV caps, the volatilities of both real and financial variables are substantially reduced. However, impatient households welfare worsens, if caps on the LTV ratio are not stringent enough. As shown in the previous section, a properly calibrated

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	Standard Deviations		Standard Deviations
Housing risk shock	0.226	Monetary policy shock	0.002
Risk premium shock	0.520	Bank capital shock	0.020
Productivity shock	0.010		

Table 3.4: Welfare and Volatility Analysis: Housing Risk Shocks

	Welfare change from the steady state			Volatility as a ratio to the benchmark case			
	Patient h.	Impatient h.	Entrepreneur	GDP	Inflation	Investment	Credit
Benchmark Model							
Mon Pol Only	0.0397	-0.2001	-0.0129	-	-	-	-
with countercyclical capital buffers							
Φ_k=0.375	0.0218	-0.1860	0.0023	0.72	0.84	0.82	0.90
Φ_k=0.75	0.0065	-0.1734	0.0155	0.54	0.71	0.00	0.81
LTV Model							
$\widetilde{m}^I$=0.675	0.0588	-0.2127	-0.0037	0.19	0.51	0.32	0.32
$\widetilde{m}^I$=0.65	0.0391	-0.1352	-0.0022	0.08	0.22	0.14	0.12
with countercyclical capital buffers							
Φ_k=0.375	0.0440	-0.2036	0.0068	0.17	0.52	0.29	0.29
Φ_k=0.75	0.0313	-0.1955	0.0161	0.17	0.53	0.29	0.27
with state-contingent caps on LTV ratio							
Φ_m=0.25	0.0877	-0.2665	-0.0013	0.10	1.49	0.26	0.24
Φ_m=0.5	0.1176	-0.3157	-0.0001	0.09	2.42	0.24	0.21

Note: Welfare is expressed as an absolute deviation from the steady state of each model. Volatility is expressed as a ratio to the benchmark case (i.e., without macro-prudential regulation). We assume $\widetilde{m}^I$=0.675 for the last four rows.

Table 3.5: Welfare and Volatility Analysis: Risk Premium Shocks

	Welfare change from the steady state			Volatility as a ratio to the benchmark case			
	Patient h.	Impatient h.	Entrepreneur	GDP	Inflation	Investment	Credit
Benchmark Model							
Mon Pol Only	0.0293	-0.0308	-0.0237	-	-	-	-
with countercyclical capital buffers							
Φ_k=1.5	0.0223	-0.0275	-0.0187	0.97	0.98	0.96	0.89
Φ_k=3.0	0.0180	-0.0256	-0.0155	0.96	0.96	0.93	0.79
LTV Model							
$\widetilde{m}^I$=0.675	0.0280	-0.0203	-0.0240	0.96	0.80	1.05	0.61
$\widetilde{m}^I$=0.65	0.0276	-0.0174	-0.0242	0.96	0.77	1.06	0.54
with countercyclical capital buffers							
Φ_k=1.5	0.0223	-0.0172	-0.0205	1.03	0.96	1.04	0.43
Φ_k=3.0	0.0188	-0.0153	-0.0182	1.09	1.10	1.04	0.32

Note: Welfare is expressed as an absolute deviation from the steady state of each model. Volatility is expressed as a ratio to the benchmark case (i.e., without macro-prudential regulations). We assume $\widetilde{m}^I$=0.675 for the last two rows.

value of the caps is required to reduce the mortgage default risk in the medium term. Nevertheless, we must not forget that their steady-state welfare has permanently improved from the benchmark case due to lower default risk. This steady-state effect has turned out to be quite large. Next, countercyclical capital buffers improve the welfare of both impatient households and entrepreneurs. However, they are more effective in terms of stabilisation when financial regulators do not simultaneously impose LTV caps. As opposed to the first two measures, state-contingent LTV caps are undesirable as they exacerbate impatient households welfare. The policy is found to escalate the extent of mortgage default. Thus, new loans are issued with even higher mortgage spread. Impatient households then have larger contractual obligations to fulfill in the future. This property is in stark contrast with countercyclical capital buffers that entail more, but "cheaper", credit. The simulations also identify another adverse consequences as inflation volatility picks up.

In the face of risk premium shocks, none of the policies are successful in taming GDP volatility, since a rise in demand from one agent is offseted by a fall in demand from others. More stringent LTV caps again are effective in reducing volatilities in credit (as well as inflation), while improving impatient households welfare. However, this comes at the expense of entrepreneurial welfare, though to a small extent. Countercyclical capital buffers also curtail fluctuations within the banking sector. The measure is effective in raising the welfare of both agents. But, when LTV caps are in place, the credit-to-GDP ratio may send a wrong signal, which results in higher output and inflation volatilities.

3.9 Concluding Remarks and Extensions

The paper embeds mortgage default into a New Keynesian model that incorporates housing and the non-trivial banking sector. Banks are subject to capital adequacy regulation, which makes their loan origination tied to the availability of bank capital. We study the spillover effects of shocks originating in the mortgage and financial markets on the real sector. Moreover, we explore whether the use of macroprudential regulation can mitigate the adverse effects of shocks on allocations and welfare.

We establish that adverse housing risk shocks depress lending activities and economic outcomes. Such shocks lead to a rise in mortgage default, which in turn weakens bank balance sheet. The banks charge higher interest rate spreads on both mortgages and business loans. Borrowers therefore lower their consumption and investment. Banking sector friction, namely capital regulation and housing adjustment costs, are found to propagate the effects of shocks. Risk premium shocks, meanwhile, cause tougher lending standards and generate an economic downturn. Banks raise both credit spreads, prompting impatient households and entrepreneurs to reduce their corresponding demand. These two candidate shocks capture, at least qualitatively, the behaviour of real and financial variables during the recent global financial crisis.

Three macroprudential regulations are examined with respect to their effectiveness in stabilising the proposed shocks impact. We provide several new results to the literature on macroprudential regulation. First, imposing LTV caps lowers the steady-state probability of default. This results in reduced mortgage spreads that improve impatient households consumption and welfare. Second, LTV caps helps limit a plunge in mortgages when facing both shocks. This measure also has substantial macroeconomic stabilisation benefits when the economy is facing housing risk shocks. Third, countercyclical capital buffers can improve allocations and welfare further for borrowers. But financial regulators need to be aware of receiving a wrong signal from the credit-to-GDP ratio, which might occur in the case of risk premium shocks. Last, as opposed to the literature, our results do not support state-contingent LTV ratios. In the event of adverse housing risk shocks, the policy exacerbates impatient households welfare.

For future work, the mortgage market and contracts can be extended in a number of ways to be more realistic. First, it is assumed that mortgage debt is non-recourse. In reality, even though mortgages become “underwater”, borrowers can rely on other sources of income to repay debt. Campbell and Cocco (2015) have a model where borrowers do not default immediately after the market value of the houses is lower than debt outstanding. Second, it is important to differentiate between the case of fixed-rate and adjustable-rate mortgages since it can influence default decision and the transmission of shocks. Despite the fact that majority of mortgages in the US is fixed-rate mortgages, this is not true in several countries. Calza et al. (2013) explore how features of mortgage contract affect transmission of monetary policy. Moreover, mortgages are usually long-term, as opposed to a one-period contract assumed in this paper. Assuming mortgages to be long-term would allow us to differentiate between the stock and flow of mortgages. Excessive accumulation of mortgages prior to the crisis makes the balance sheet weaker and susceptible to shocks. Other potential extensions to the model include modelling the production of houses and debt securitisation, as in Goodhart et al. (2012). The latter is crucial to understanding why credit risk is underestimated and, yet, there is abundant liquidity in the mortgage market.

In addition, the paper mainly focuses on policies to mitigate the effects after adverse shocks have occurred (i.e. crisis management). It would be interesting to explore what could have been done prior to the crisis (i.e. crisis prevention) to reduce the probability and magnitude of a potential crisis. That is, if policymakers decided to “lean-against-the-wind” or impose tougher regulatory requirements in the mortgage market, how would the crisis be transmitted to the real economy?

3.10 Appendix

3.10.1 Data Description

Based on the definition provided in the Federal Reserve website, delinquency loans and leases are those past due thirty days or more and still accruing interest as well as those in nonaccrual status. They are measured as a percentage of end-of-period loans. The excess bond premium is a component of corporate bond credit spreads (accounted for duration bias) that is not directly attributable to expected default risk (see Gilchrist and Zakrajšek (2012)).

3.10.2 Log-linearised Version of the Benchmark Economy

Let hatted values denote percentage changes from the steady state, and those without subscript denote steady-state values. Assume $\gamma_E = \beta_E \left[(1-\delta) + \frac{\mu Y}{Xk} - m^E (1-\delta)\right] = 1 - \frac{m^E(1-\delta)}{r^E}$ and $\omega = \beta_E \frac{\mu Y}{Xk} = 1 - \frac{m^E(1-\delta)}{r^E} + \beta_E m^E (1-\delta) - \beta_E (1-\delta)$, the model can be reduced to the following linearised system:

Patient Households

$$\hat{\lambda}_t^P = -\frac{1}{1-a_P}\hat{c}_t^P + \frac{a_P}{1-a_P}\hat{c}_{t-1}^P \tag{3.49}$$

$$\hat{\lambda}_t^P = \hat{\lambda}_{t+1}^P + \hat{r}_t - \hat{\pi}_{t+1} \tag{3.50}$$

$$\hat{q}_t^h + \hat{\lambda}_t^P = (1-\beta_P)\left(-\hat{h}_t^P\right) + \beta_P\left(\hat{q}_{t+1}^h + \hat{\lambda}_{t+1}^P\right) - \phi_h\left(\Delta\hat{h}_t^P - \beta_P\Delta\hat{h}_{t+1}^P\right) \tag{3.51}$$

$$\hat{w}_t^P + \hat{\lambda}_t^P = (\eta - 1)\,\hat{l}_t^P \tag{3.52}$$

Table 3.6: Data Source

Data (US)	Unit	Source
Delinquency Rate on Loans Secured by Real Estate	Percent, SA, end of period	Board of Governors
Delinquency Rate on Single-Family Residential Mortgages		
30-Year Fixed Rate Mortgages	Percent, NSA, monthly average	Freddie Mac
1-Year Adjustable Rate Mortgages		
Effective Federal Funds Rate	Percent, NSA, monthly average	Board of Governors
30-Year Treasury Constant Maturity Rate		
1-Year Treasury Constant Maturity Rate		
Excess Bond Premium	Percent, monthly	Board of Governors
S&P/Case-Shiller 20-City Composite Home Price Index	Index Jan 2000=100, SA, monthly	S&P Dow Jones Indices LLC
Return on Average Equity for all U.S. Banks	Percent, SA, quarterly, end of period	Federal Financial Institutions Examination Council
Total Equity to Total Assets for Banks		
Real Gross Domestic Product	Billions of Chained 2009 Dollars, SAAR, quarterly	US. Bureau of Economic Analysis
Real Personal Consumption Expenditures		
Real Gross Private Domestic Investment: Nonresidential		
Households and Nonprofit Organisations: Home Mortgages	Billions of Dollars, SA, quarterly, end of period	Board of Governors
Implicit Price deflator	Index 2009=100, SA, quarterly average	US. Bureau of Economic Analysis

Impatient Households

$$\frac{b^I}{Y}\hat{b}_t^I = \frac{c^I}{Y}\hat{c}_t^I + \frac{q^h h^I}{Y}\left[\hat{q}_t^h + \hat{h}_t^I\right] + (1 - F(\bar{\omega}))\frac{r^I b^I}{Y}\left[\hat{r}_{t-1}^I + \hat{b}_{t-1}^I - \hat{\pi}_t\right] - F(\bar{\omega})\frac{r^I b^I}{Y}\hat{F}_t(\bar{\omega}_t)$$
$$-\frac{(1-\mu)(1-\alpha)}{X}\left[\hat{Y}_t - \hat{X}_t\right] - (1 - G(\bar{\omega}))\frac{q^h h^I}{Y}\left[\hat{q}_t^h + \hat{h}_{t-1}^I\right] + G(\bar{\omega})\frac{q^h h^I}{Y}\hat{G}_t(\bar{\omega}_t) \tag{3.53}$$

$$\hat{b}_{t-1}^I + \hat{r}_{t-1}^I - \hat{\pi}_t = \hat{\bar{\omega}}_t + \hat{q}_t^h + \hat{h}_{t-1}^I \tag{3.54}$$

$$\hat{m}_t^I = \hat{r}_t^I + \hat{b}_t^I - \hat{q}_{t+1}^h - \hat{h}_t^I - \hat{\pi}_{t+1} \tag{3.55}$$

$$\hat{\lambda}_t^I = -\frac{1}{1-a_I}\hat{c}_t^I + \frac{a_I}{1-a_I}\hat{c}_{t-1}^I \tag{3.56}$$

$$\hat{\lambda}_t^I = \hat{\lambda}_{t+1}^I - \frac{F(\bar{\omega})}{\beta_I r^I}\hat{F}_{t+1}(\bar{\omega}_{t+1}) + \frac{G(\bar{\omega})}{\beta_I r^I m^I}\left(\hat{G}_{t+1}(\bar{\omega}_{t+1}) - \hat{m}_t^I\right) + \hat{r}_t^I - \hat{\pi}_{t+1} \tag{3.57}$$

$$\hat{q}_t^h + \hat{\lambda}_t^I = (1-\beta_I)\left(-\hat{h}_t^I\right) + \beta_I\left(\hat{q}_{t+1}^h + \hat{\lambda}_{t+1}^I\right) - \phi_h\left(\Delta\hat{h}_t^I - \beta_I\Delta\hat{h}_{t+1}^I\right) \tag{3.58}$$

$$\hat{w}_t^I + \hat{\lambda}_t^I = (\eta - 1)\,\hat{l}_t^I \tag{3.59}$$

$$\hat{F}_t(\bar{\omega}_t) = \frac{1}{F(\bar{\omega})\,\sigma_\omega\sqrt{2\pi}}\exp\left[-\left(\frac{ln(\bar{\omega}) + \frac{\sigma_\omega^2}{2}}{\sqrt{2}\sigma_\omega}\right)^2\right]\left[\hat{\bar{\omega}}_t - \left(ln(\bar{\omega}) - \frac{\sigma_\omega^2}{2}\right)\hat{\sigma}_{\omega,t}\right] \tag{3.60}$$

$$\hat{G}_t(\bar{\omega}_t) = \frac{1}{G(\bar{\omega})\sigma_\omega\sqrt{2\pi}}\exp\left[-\left(\frac{ln(\bar{\omega}) - \frac{\sigma_\omega^2}{2}}{\sqrt{2}\sigma_\omega}\right)^2\right]\left[\hat{\bar{\omega}}_t - \left(ln(\bar{\omega}) + \frac{\sigma_\omega^2}{2}\right)\hat{\sigma}_{\omega,t}\right] \tag{3.61}$$

Entrepreneurs

$$\frac{b^E}{Y}\hat{b}_t^E = \frac{c^E}{Y}\hat{c}_t^E + \frac{r^E b^E}{Y}\left[\hat{r}_{t-1}^E + \hat{b}_{t-1}^E - \hat{\pi}_t\right] + \frac{i}{Y}\hat{i}_t + \varepsilon_{k,1}\frac{k}{Y}\hat{u}_t - \frac{\mu}{X}\left[\hat{Y}_t - \hat{X}_t\right] \tag{3.62}$$

$$\hat{r}_t^E + \hat{b}_t^E = \hat{q}_{t+1}^k + \hat{k}_t + \hat{\pi}_{t+1} \tag{3.63}$$

$$\hat{\lambda}_t^E = -\frac{1}{1-a_E}\hat{c}_t^E + \frac{a_E}{1-a_E}\hat{c}_{t-1}^E \tag{3.64}$$

$$\gamma_E\hat{\lambda}_t^E + \hat{q}_t^k = \gamma_E\hat{\lambda}_{t+1}^E + (1-\omega)\,\hat{q}_{t+1}^k + \omega\left(\hat{Y}_{t+1} - \hat{X}_{t+1} - \hat{k}_t\right) - (1-\gamma_E)\left(\hat{r}_t^E - \hat{\pi}_{t+1}\right) \tag{3.65}$$

$$\hat{r}_t^k = \frac{\varepsilon_{k,2}}{\varepsilon_{k,1}} \hat{u}_t \tag{3.66}$$

$$\hat{k}_t = (1-\delta)\hat{k}_{t-1} + \delta \hat{i}_t \tag{3.67}$$

$$\hat{q}_t^k = k_i \left(\Delta \hat{i}_t - \beta_E \Delta \hat{i}_{t+1} \right) \tag{3.68}$$

Commercial Banks

$$\frac{b^I}{Y}\hat{b}_t^I + \frac{b^E}{Y}\hat{b}_t^E = \frac{d^P}{Y}\hat{d}_t^P + \frac{e^B}{Y}\hat{e}_t^B \tag{3.69}$$

$$\frac{e^B}{Y}\hat{e}_t^B = \left(\gamma_B - \delta_B\right)\frac{e^B}{Y}\left(\hat{e}_{t-1}^B - \hat{\pi}_t\right) + \left(1-\gamma_B\right)\frac{\Pi^B}{Y}\hat{\Pi}_t^B \tag{3.70}$$

$$\begin{aligned} \frac{\Pi^B}{Y}\hat{\Pi}_t^B = \quad & \left(1 - F\left(\bar{\omega}\right)\right)\tfrac{r^I b^I}{Y}\left[\hat{r}_{t-1}^I + \hat{b}_{t-1}^I - \hat{\pi}_t\right] - F\left(\bar{\omega}\right)\tfrac{r^I b^I}{Y}\hat{F}_t\left(\bar{\omega}_t\right) + \tfrac{r^E b^E}{Y}\left[\hat{r}_{t-1}^E + \hat{b}_{t-1}^E - \hat{\pi}_t\right] \\ & + \left(1-\Theta\right)G\left(\bar{\omega}\right)\tfrac{q^h h^I}{Y}\left[\hat{G}_t\left(\bar{\omega}_t\right) + \hat{q}_t^h + \hat{h}_{t-1}^I\right] - r\tfrac{d^P}{Y}\left[\hat{r}_{t-1} + \hat{d}_{t-1}^P - \hat{\pi}_t\right] \end{aligned} \tag{3.71}$$

$$\hat{k}_t^B = \hat{e}_t^B - r\hat{w}a_t \tag{3.72}$$

$$\frac{rwa}{Y} r\hat{w}a_t = rw^I \frac{b^I}{Y}\left(r\hat{w}_t^I + \hat{b}_t^I\right) + rw^E \frac{b^E}{Y}\hat{b}_t^E \tag{3.73}$$

$$r\hat{w}_t^I = \frac{\Upsilon F\left(\bar{w}\right)}{rw^I}\hat{F}_{t+1}\left(\bar{\omega}_{t+1}\right) \tag{3.74}$$

$$\begin{aligned} \hat{\phi}_t^k + \left(1-\sigma_B\right)\left(\hat{k}_t^B\right) + r\hat{w}_t^I - r\hat{w}a_t = \hat{\lambda}_{t+1}^P - \hat{\lambda}_t^P - r\left[\left(1 - F\left(\bar{\omega}\right) + \left(1-\Theta\right)\tfrac{G(\bar{\omega})}{m^I}\right)r^I - r\right]^{-1}\hat{r}_t \\ + \frac{\left[-F(\bar{\omega})r^I\hat{F}_{t+1}(\bar{\omega}_{t+1}) + (1-\Theta)\frac{G(\bar{\omega})}{m^I}r^I\left(\hat{G}_{t+1}(\bar{\omega}_{t+1}) - \hat{m}_t^I\right) + \left(1-F(\bar{\omega}) + (1-\Theta)\frac{G(\bar{\omega})}{m^I}\right)r^I\hat{r}_t^I\right]}{\left(1-F(\bar{\omega}) + (1-\Theta)\frac{G(\bar{\omega})}{m^I}\right)r^I - r} - \hat{\pi}_{t+1} \end{aligned} \tag{3.75}$$

$$\hat{\phi}_t^k + \left(1-\sigma_B\right)\left(\hat{k}_t^B\right) - r\hat{w}a_t = \hat{\lambda}_{t+1}^P - \hat{\lambda}_t^P + \left[\frac{r^E}{r^E - r}\right]\hat{r}_t^E - \left[\frac{r}{r^E - r}\right]\hat{r}_t - \hat{\pi}_{t+1} \tag{3.76}$$

Production Sector

$$\hat{Y}_t = \hat{A}_t + \mu\left(\hat{u}_t + \hat{k}_{t-1}\right) + \alpha\left(1-\mu\right)\hat{l}_t^P + \left(1-\alpha\right)\left(1-\mu\right)\hat{l}_t^I \tag{3.77}$$

$$\hat{w}_t^P = \hat{Y}_t - \hat{X}_t - \hat{l}_t^P \tag{3.78}$$

$$\hat{w}_t^I = \hat{Y}_t - \hat{X}_t - \hat{l}_t^I \tag{3.79}$$

$$\hat{r}_t^k = \hat{Y}_t - \hat{X}_t - \hat{u}_t - \hat{k}_{t-1} \tag{3.80}$$

$$\hat{mc}_t = \mu \hat{r}_t^k + \alpha (1-\mu) \hat{w}_t^P + (1-\alpha)(1-\mu) \hat{w}_t^I - \hat{A}_t \tag{3.81}$$

$$\hat{\pi}_t = \beta_P \hat{\pi}_{t+1} + \frac{(1-\theta)(1-\beta_P \theta)}{\theta} \hat{mc}_t \tag{3.82}$$

The Central Bank

$$\hat{r}_t = r_R \hat{r}_{t-1} + (1-r_R)\left((1+r_\pi)\hat{\pi}_t + r_Y\left(G\hat{D}P_t - G\hat{D}P_{t-1}\right)\right) \tag{3.83}$$

$$\frac{GDP}{Y} G\hat{D}P_t = \frac{c^P}{Y}\hat{c}_t^P + \frac{c^I}{Y}\hat{c}_t^I + \frac{c^E}{Y}\hat{c}_t^E + \frac{i}{Y}\hat{i}_t \tag{3.84}$$

Market-Clearing Conditions

$$\hat{Y}_t = \frac{c^P}{Y}\hat{c}_t^P + \frac{c^I}{Y}\hat{c}_t^I + \frac{c^E}{Y}\hat{c}_t^E + \frac{i}{Y}\hat{i}_t + \varepsilon_{k,1}\frac{k}{Y}\hat{u}_t + (1-rec)\Theta G(\bar{\omega})\frac{q^h h^I}{Y}\left(\hat{G}_t(\bar{\omega}_t) + \hat{q}_t^h + \hat{h}_{t-1}^I\right) \tag{3.85}$$

$$\hat{h}_t^P = -\frac{h^I}{h^P}\hat{h}_t^I \tag{3.86}$$

Shocks

$$\hat{\sigma}_{\omega,t} = \rho_\omega \hat{\sigma}_{\omega,t-1} + \hat{\varepsilon}_t^\omega \tag{3.87}$$

$$\hat{\phi}_t^k = \rho_A \hat{\phi}_{t-1}^k + \hat{\varepsilon}_t^k \tag{3.88}$$

$$\hat{A}_t = \rho_A \hat{A}_{t-1} + \hat{\varepsilon}_t^A \tag{3.89}$$

Steady State

This subsection shows how the steady-state rates and ratios that show up in the log-linearised model above are computed. By targeting the steady-state LTV ratio, we can conveniently compute the steady state of this economy as follow:

$\bar{\omega} = m^I$

$$r = \frac{1}{\beta_P}$$

$$r^I = \frac{1}{\beta_I\left(1-F(\bar{\omega})+\frac{G(\bar{\omega})}{m^I}\right)}$$

$$r^E = \left[\left(1 - F\left(\bar{\omega}\right) + \left(1 - \Theta\right)\frac{G(\bar{\omega})}{m^I}\right)r^I - r\right]\frac{rw^E}{rw^I} + r$$

$$X = \frac{\varepsilon}{\varepsilon-1}$$

$$\frac{k}{Y} = \frac{\beta_E}{\omega}\frac{\mu}{X}$$

$$\frac{i}{Y} = \delta\frac{k}{Y}$$

$$\frac{b^E}{Y} = \frac{m^E(1-\delta)}{r^E}\frac{k}{Y}$$

$$\frac{c^E}{Y} = \frac{\mu}{X} + \left(1 - r^E\right)\frac{b^E}{Y} - \frac{i}{Y}$$

$$\frac{c^I}{Y} = \frac{\beta_I r^I}{\beta_I r^I + m^I j}\frac{(1-\alpha)(1-\mu)}{X}$$

$$\frac{q^h h^I}{Y} = \frac{j}{1-\beta_I}\frac{c^I}{Y}$$

$$\frac{b^I}{Y} = \frac{m^I}{r^I}\frac{q^h h^I}{Y}$$

$$\frac{c^P}{Y} = 1 - \frac{c^I}{Y} - \frac{c^E}{Y} - \frac{i}{Y} - \left(1 - rec\right)\Theta G\left(\bar{\omega}\right)\frac{q^h h^I}{Y}$$

$$\frac{q^h h^P}{Y} = \frac{j}{1-\beta_P}\frac{c^P}{Y}$$

$$\frac{rwa}{Y} = rw^I\frac{b^I}{Y} + rw^E\frac{b^E}{Y}$$

$$\frac{d^P}{Y} = \frac{\left[(1+\delta_B-\gamma_B)\left(\frac{b^I}{Y}+\frac{b^E}{Y}\right)-(1-\gamma_B)((1-F(\bar{\omega}))\frac{r^I b^I}{Y}+(1-\Theta)G(\bar{\omega})\frac{q^h h^I}{Y}+\frac{r^E b^E}{Y})\right]}{[1+\delta_B-\gamma_B-(1-\gamma_B)r]}$$

$$\frac{\Pi^B}{Y} = \left(1 - F\left(\bar{\omega}\right)\right)\frac{r^I b^I}{Y} + \left(1 - \Theta\right)G\left(\bar{\omega}\right)\frac{q^h h^I}{Y} + \frac{r^E b^E}{Y} - r\frac{d^P}{Y}$$

$$\frac{e^B}{Y} = \frac{b^I}{Y} + \frac{b^E}{Y} - \frac{d^P}{Y}$$

$$k^B = \frac{e^B}{Y}/\frac{rwa}{Y}$$

3.10.3 Tables

Table 3.7: Household and Bank Balance Sheet (end of 2015)

Household liabilities			Private Depository Institutions Assets		
	Amount	Percent		Amount	Percent
Total	14,520		Total	17,372.7	
Debt Securities	218	1.50%	Vault Cash	74.2	0.43%
Loans	14,012.1	96.50%	Reserves at Federal Reserve	1,977.2	11.38%
- Home Mortgages	9,493.8	65.38%	Federal Funds and Repo	428.4	2.47%
- Consumer Credit	3,534.6	24.34%	Debt Securities	3,865.4	22.25%
- Depository Institution Loans	325.8	2.24%	- GSE- Backed Securities	2,125.2	12.23%
- Other Loans and Advances	437.4	3.01%	Loans	9,755.5	56.15%
- Commercial Mortgages	220.5	1.52%	- Depository Institution Loans	3,206.4	18.46%
Trade Payables	259.4	1.79%	- Mortgages	4,779.1	27.51%
Deferred and Unpaid Life Insurance Premiums	30.6	0.21%	- Consumer Credit	1,770.1	10.19%
			Corporate Equities	100	0.58%
			Mutual Fund Shares	56.8	0.33%
			Life Insurance Reserves	156.2	0.90%
			Direct Investment Abroad	241.8	1.39%
			Miscellaneous Assets	717.3	4.13%

Unit: billion USD
Source: US Flow of Funds Accounts

Table 3.8: Important Rates and Ratios at the Steady State

Variable	Description	Benchmark Model	LTV Model	
			$\widetilde{m}^I$=0.675	$\widetilde{m}^I$=0.65
GDP	Gross Domestic Product	2.349	2.347	2.346
$F(\omega)$	Mortgage default probability	2.007 %	1.160 %	0.628 %
m^I	Loan-to-value ratio	70.00 %	67.50 %	65.00 %
r	Deposit interest rate	3.673 %	3.673 %	3.673 %
r^I	Mortgage interest rate	6.800 %	5.826 %	5.216 %
r^E	Business loan interest rate	7.736 %	7.800 %	7.825 %
$\frac{b^I}{b^I+b^E}$	Proportion of mortgages	57.26 %	54.44 %	54.48 %
$\frac{b^I}{Y}$	Mortgages to output	170.1 %	151.6 %	151.7 %
$\frac{b^E}{Y}$	Business loans to output	127.0 %	126.9 %	126.8 %
$\frac{c^P}{Y}$	PH's consumption to output	52.96 %	52.52 %	52.41 %
$\frac{c^I}{Y}$	IH's consumption to output	19.24 %	19.82 %	20.00 %
$\frac{c^E}{Y}$	Entrepreneur's consumption to output	10.95 %	10.95 %	10.94 %
$\frac{i}{Y}$	Investment to output	16.59 %	16.58 %	16.58 %
$\frac{\Theta G(\omega) q^h h^I}{Y}$	Monitoring cost to output	0.523 %	0.270 %	0.147 %
$\frac{q^h h^P}{Y}$	PH's housing demand to output	1164 %	1154 %	1152 %
$\frac{q^h h^I}{Y}$	IH's housing demand to output	247.1%	227.8 %	236.5 %
k^B	Bank capital ratio	8.000 %	8.126 %	8.177 %

Note: $\beta_I = 0.984$ in the benchmark model while $\beta_I = 0.975$ in all models with LTV caps

3.10.4 Figures

The impulse responses of inflation, mortgage default probability, deposit interest rate, mortgage spread, business loan spread, capital adequacy ratio, credit to GDP ratio and mortgages to GDP ratio are expressed in terms of absolute deviations from the steady state. The rest is expressed in terms of percentage deviations.

Figure 3.4: Response of the Benchmark Economy to Standard Macroeconomic Shocks

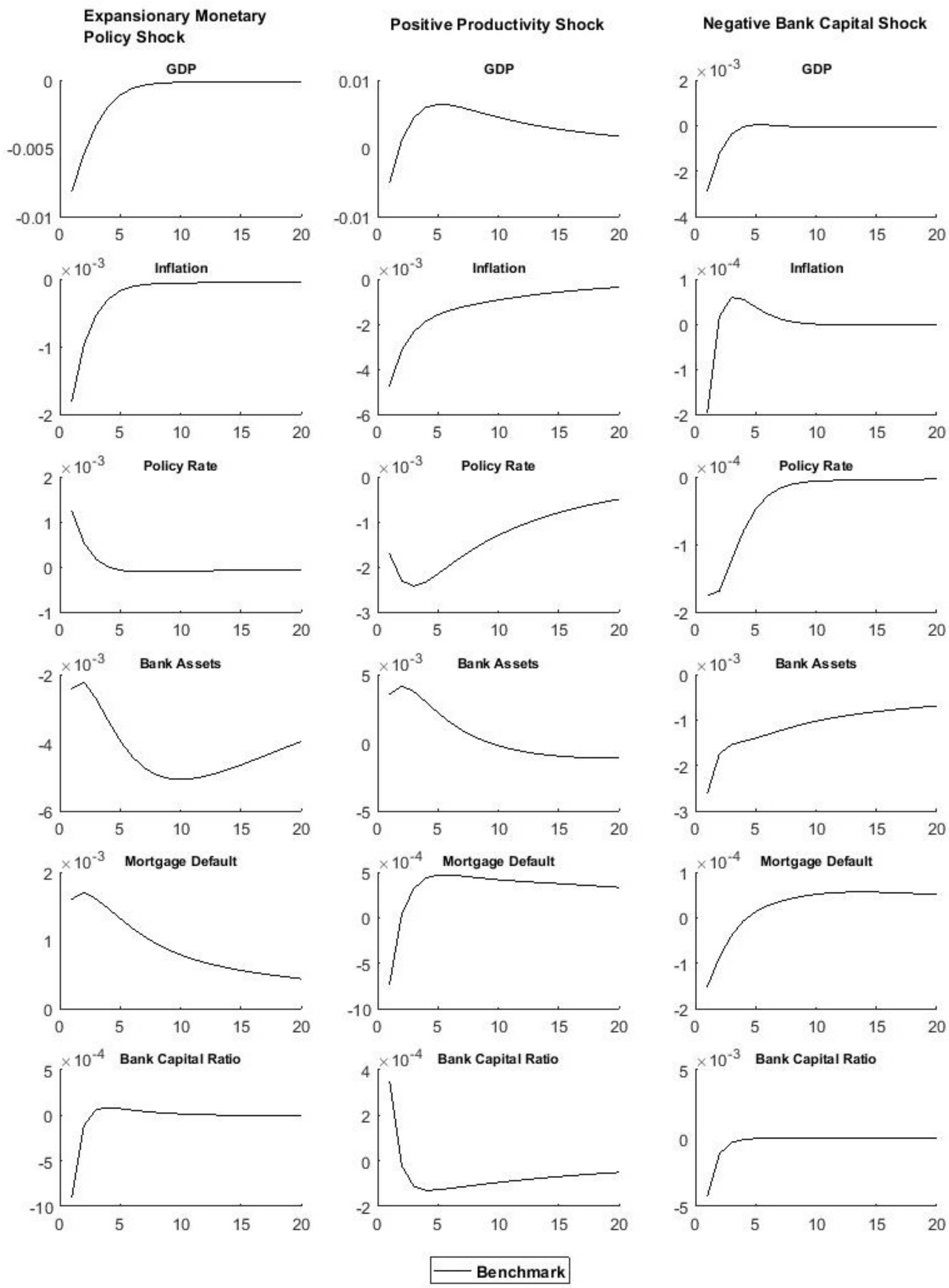
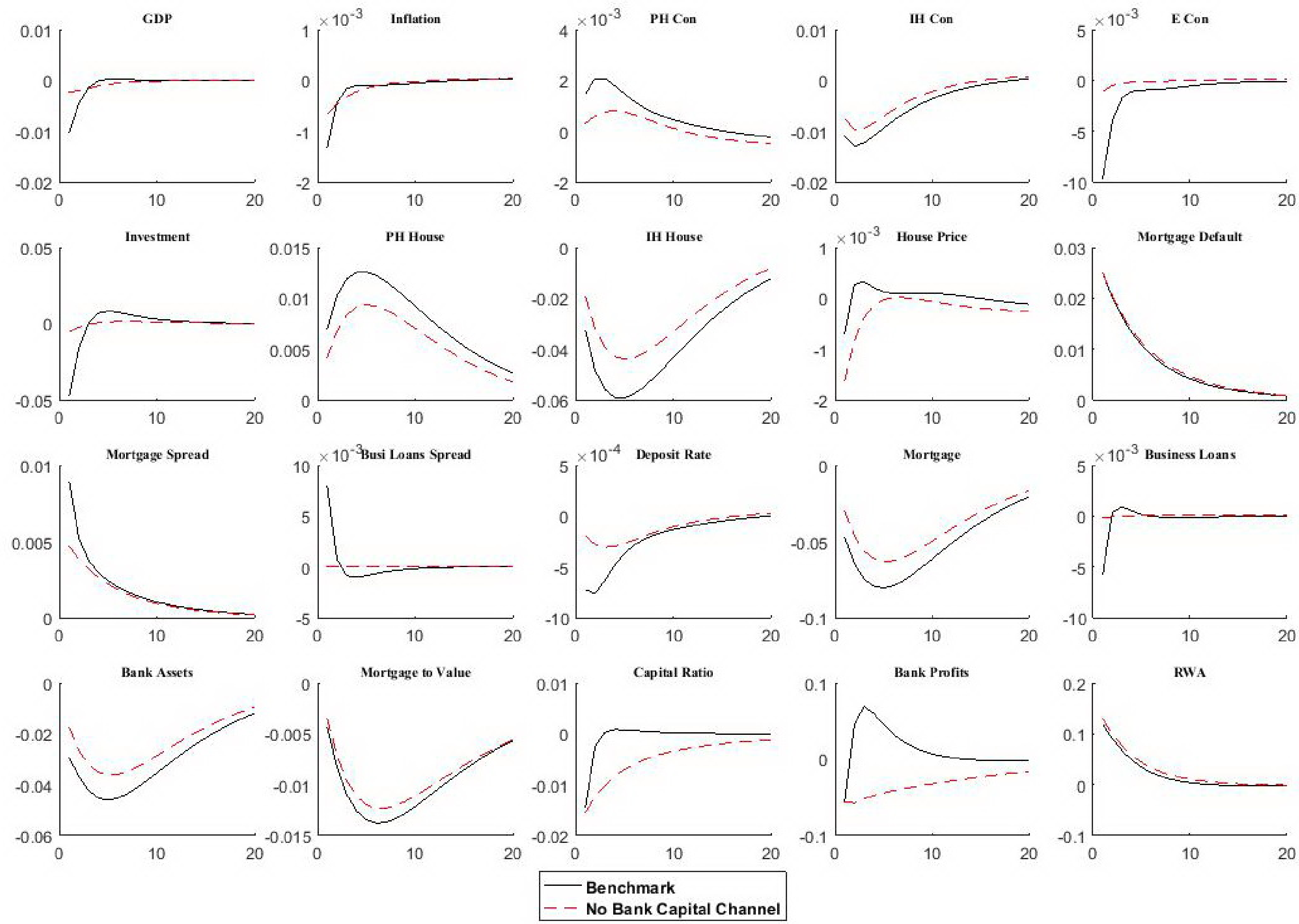
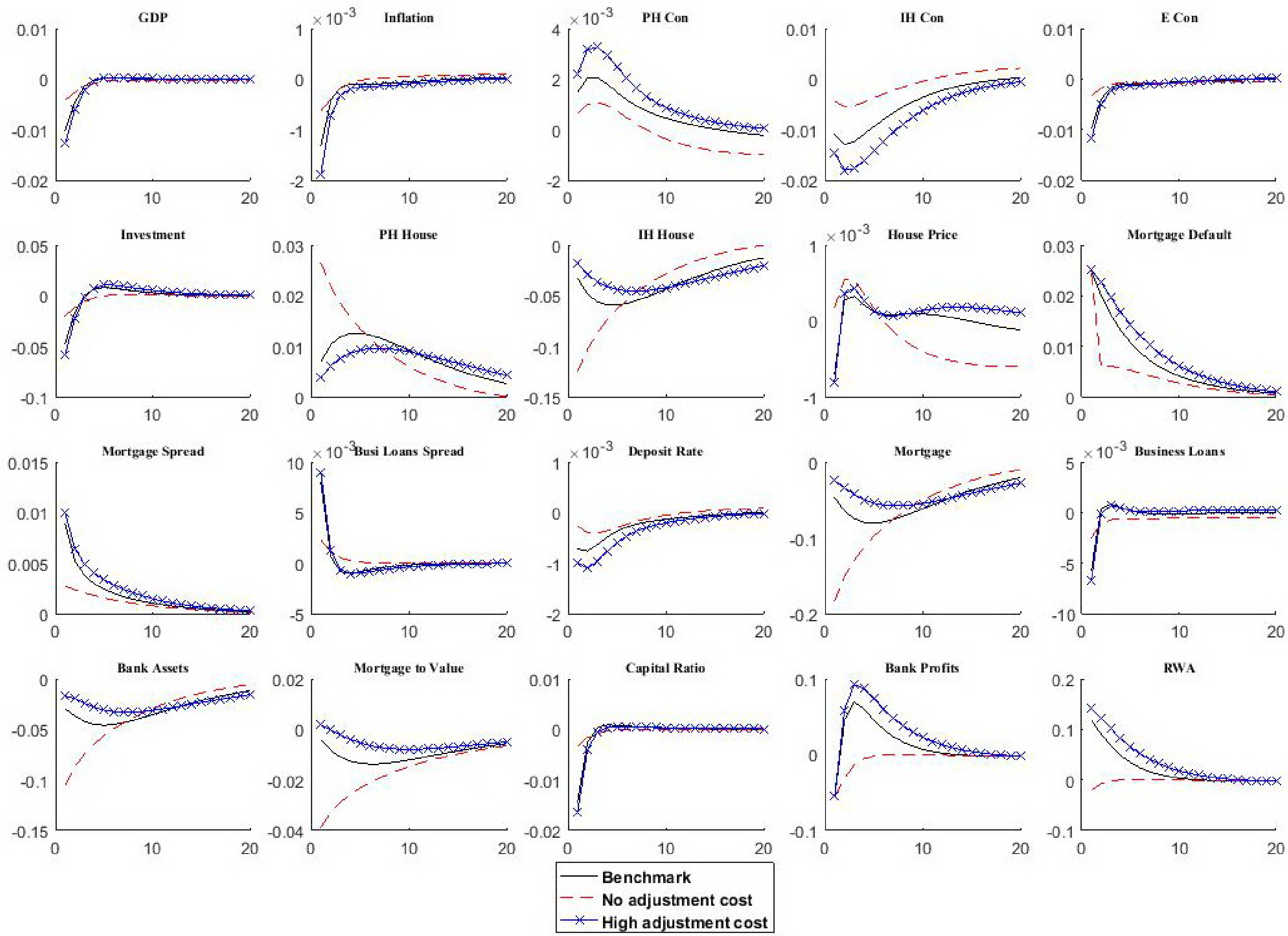


Figure 3.5: Response of the Economy to Housing Risk Shocks (1)



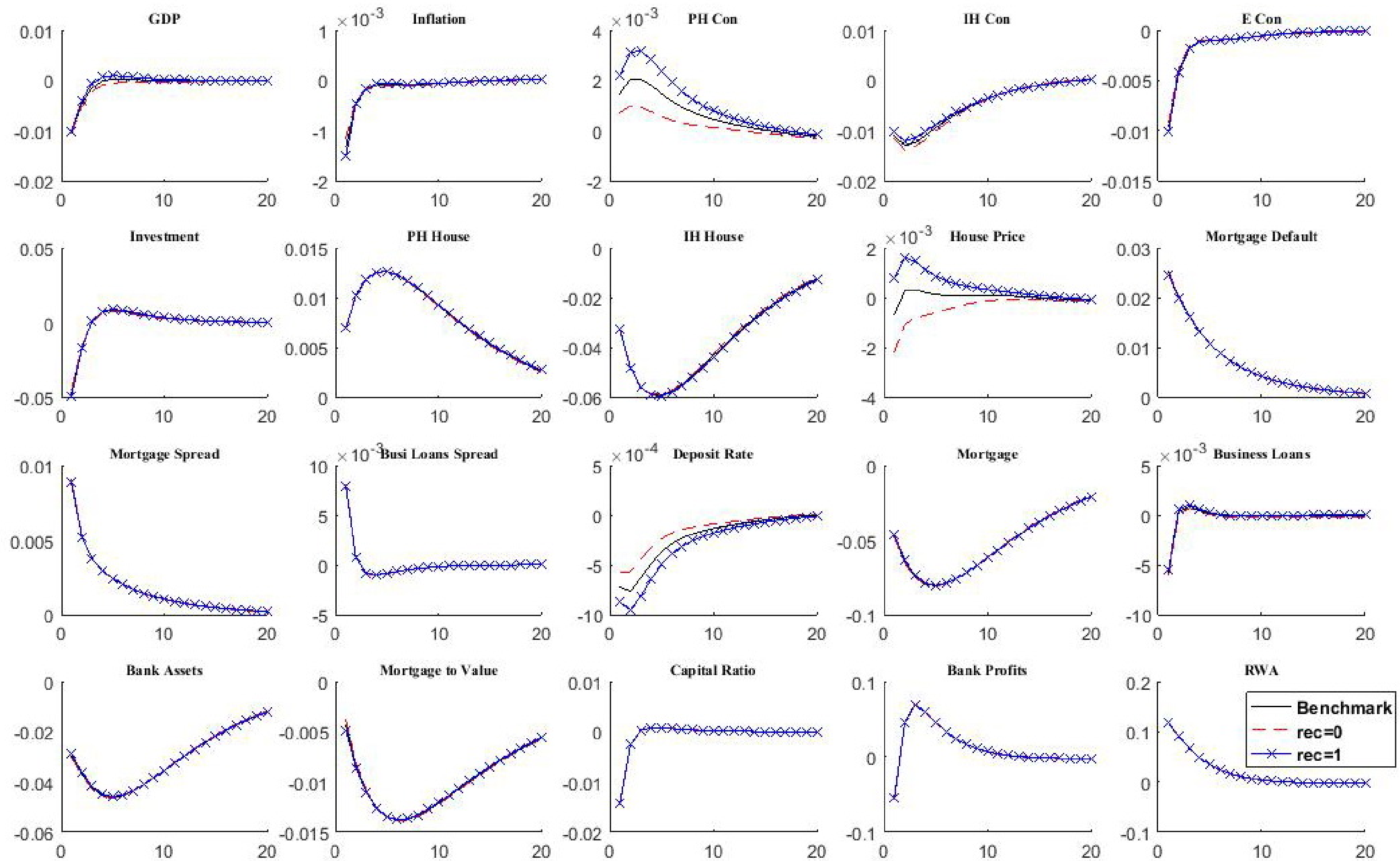
Note: the black solid line shows the response of the benchmark economy. The red dashed line shows the response of the economy assuming no impact of capital regulations on interest rate spreads.

Figure 3.6: Response of the Economy to Housing Risk Shocks (2)



Note: the black solid line shows the response of the benchmark economy ($\phi_h = 0.5$). The red dashed line shows the response of the economy assuming no housing adjustment cost ($\phi_h = 0$). The crossed blue line shows the response of the economy assuming high adjustment cost ($\phi_h = 1$).

Figure 3.7: Response of the Economy to Housing Risk Shocks (3)



Note: the black solid line shows the response of the benchmark economy ($rec = 0.5$). The red dashed line shows the response of the economy assuming zero recovery of the monitoring cost ($rec = 0$). The crossed blue line shows the response of the economy assuming full recovery ($rec = 1$).

Figure 3.8: Response of the Benchmark Economy to Risk Premium Shocks

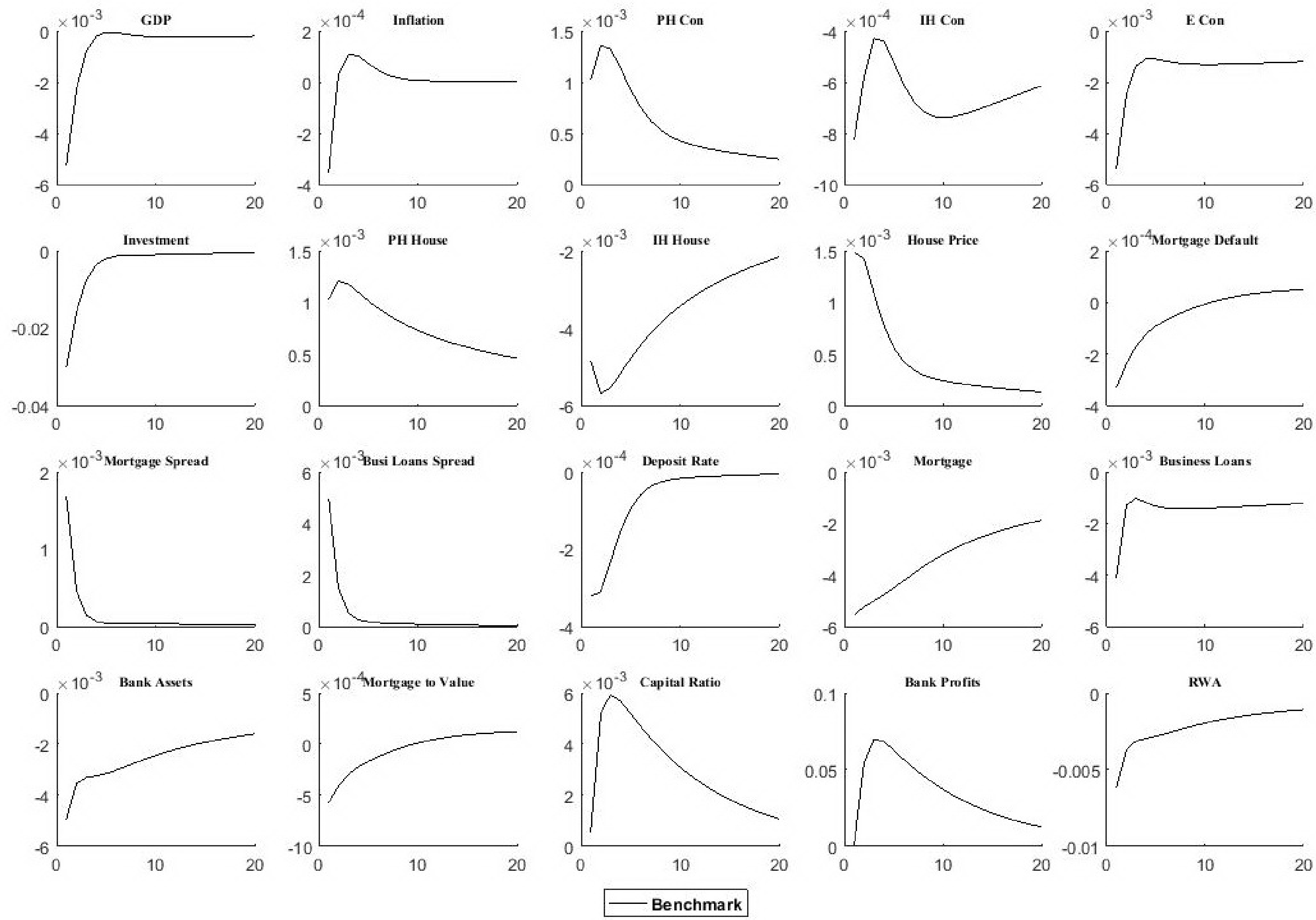
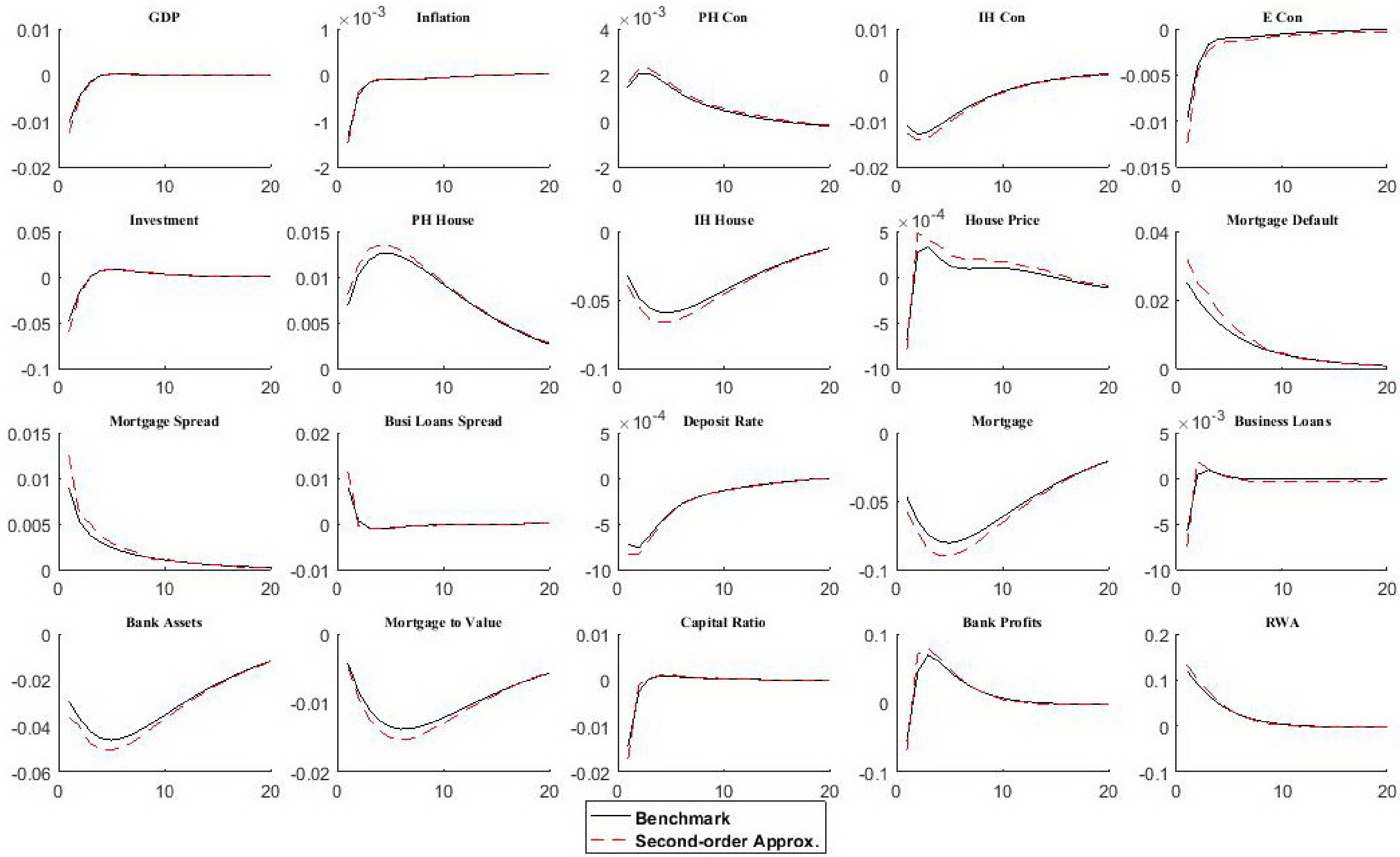
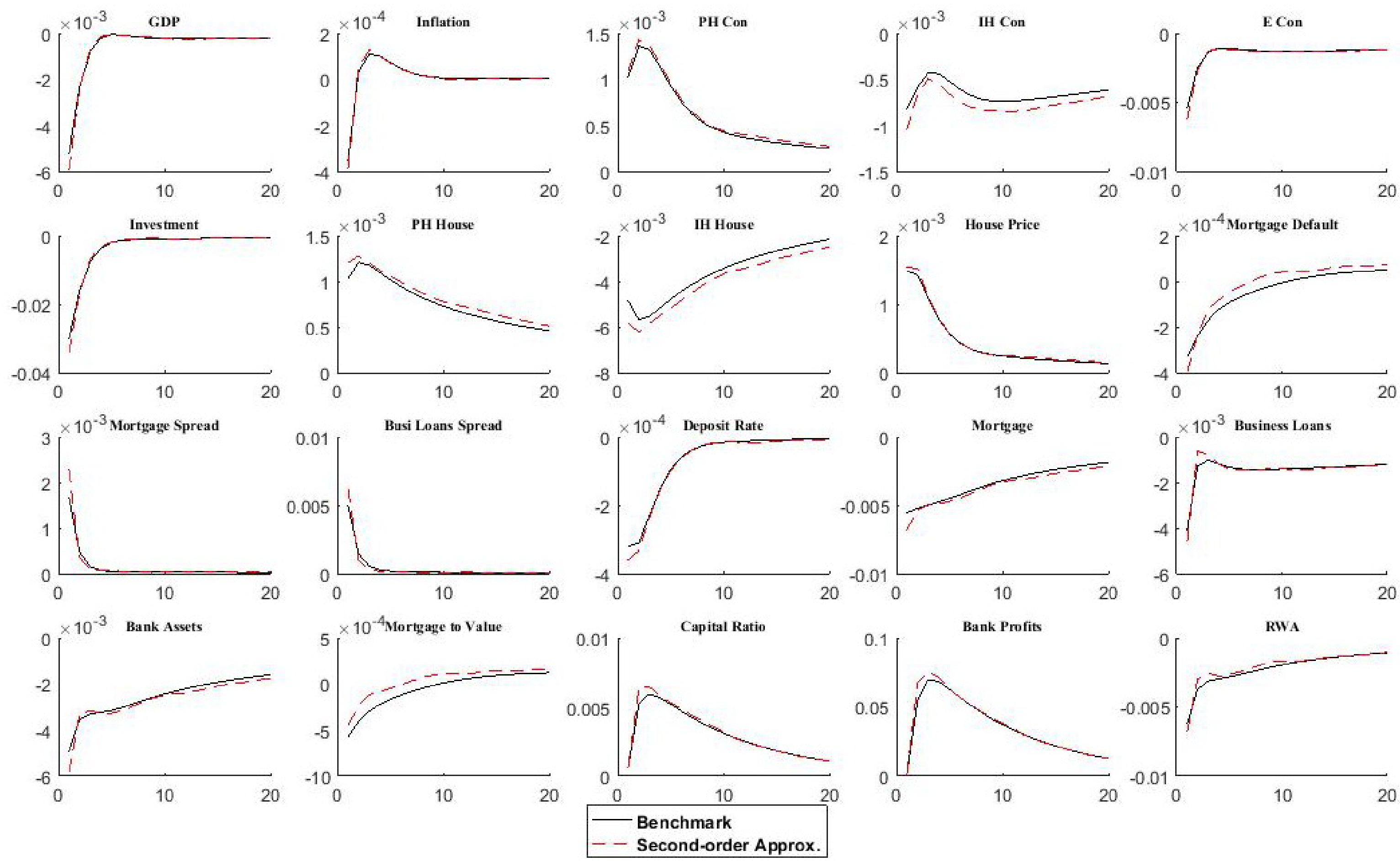


Figure 3.9: Response of the Economy to Housing Risk Shocks (4)



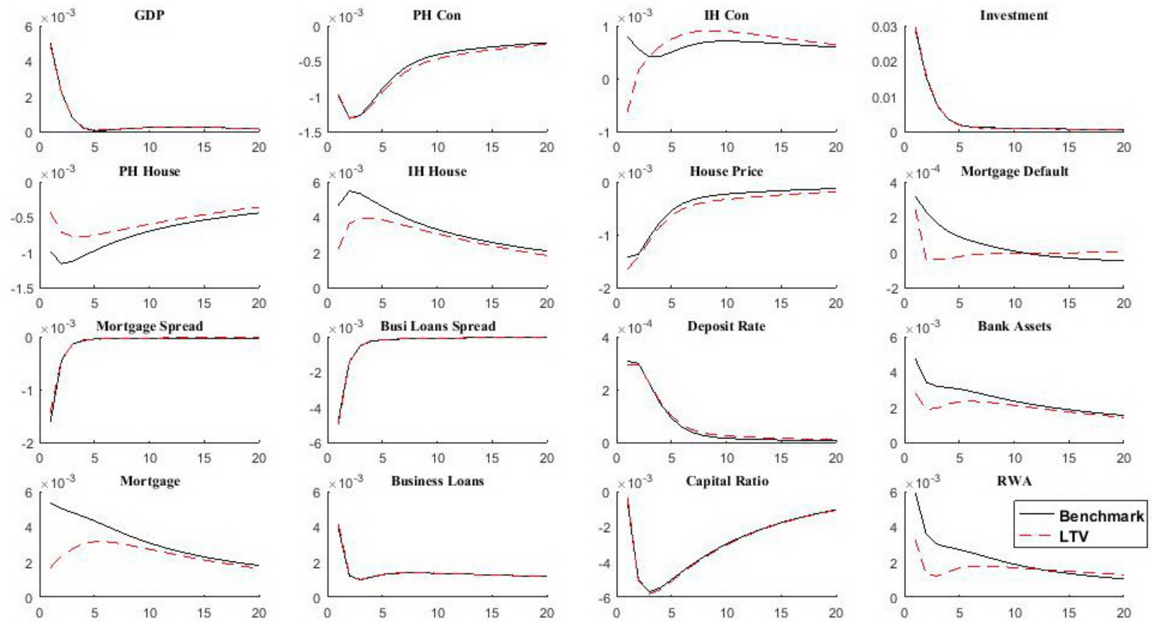
Note: the black solid line shows the response of the benchmark economy. The red dashed line shows the response of the economy using second-order approximation.

Figure 3.10: Response of the Benchmark Economy to Risk Premium Shocks



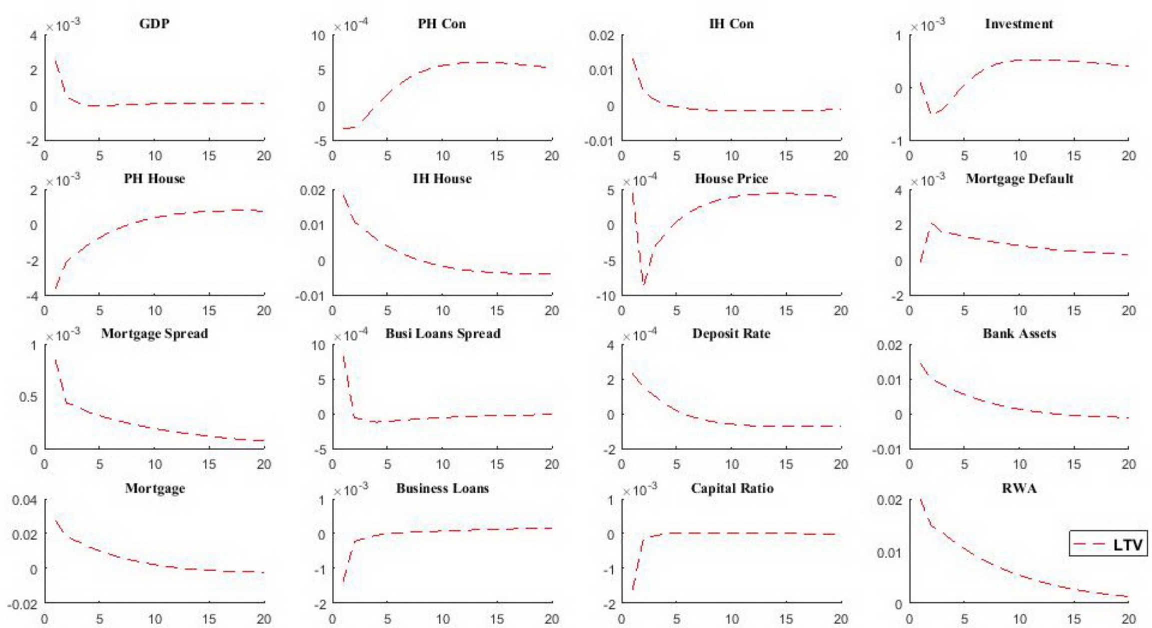
Note: the black solid line shows the response of the benchmark economy. The red dashed line shows the response of the economy using second-order approximation.

Figure 3.11: Response of the Economy to Capital Adequacy Ratio Shocks (Benchmark VS LTV)



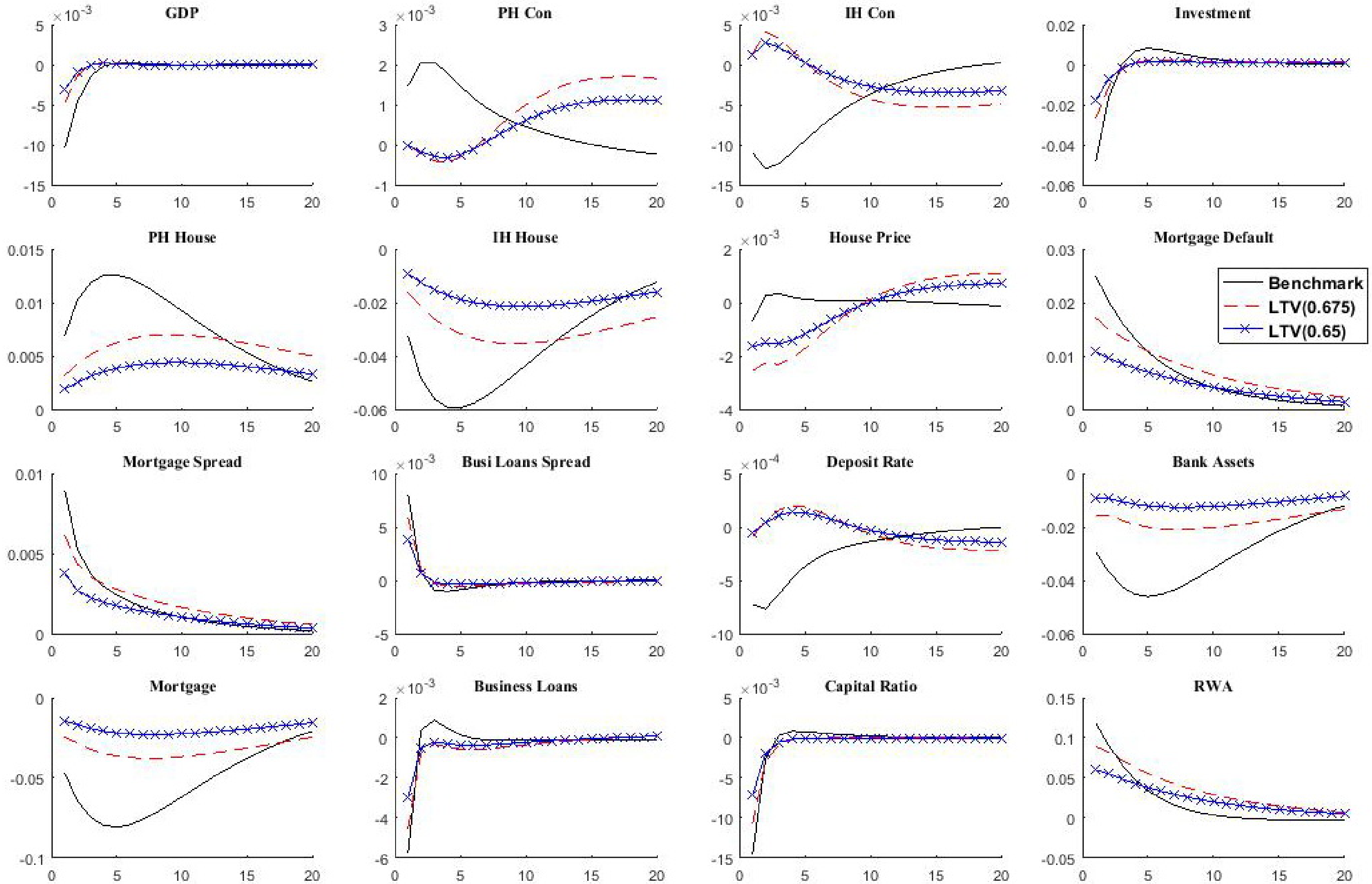
Note: the black solid line shows the response of the benchmark economy. The red dashed line shows the response of the economy with LTV caps.

Figure 3.12: Response of the Economy to LTV Caps Shocks



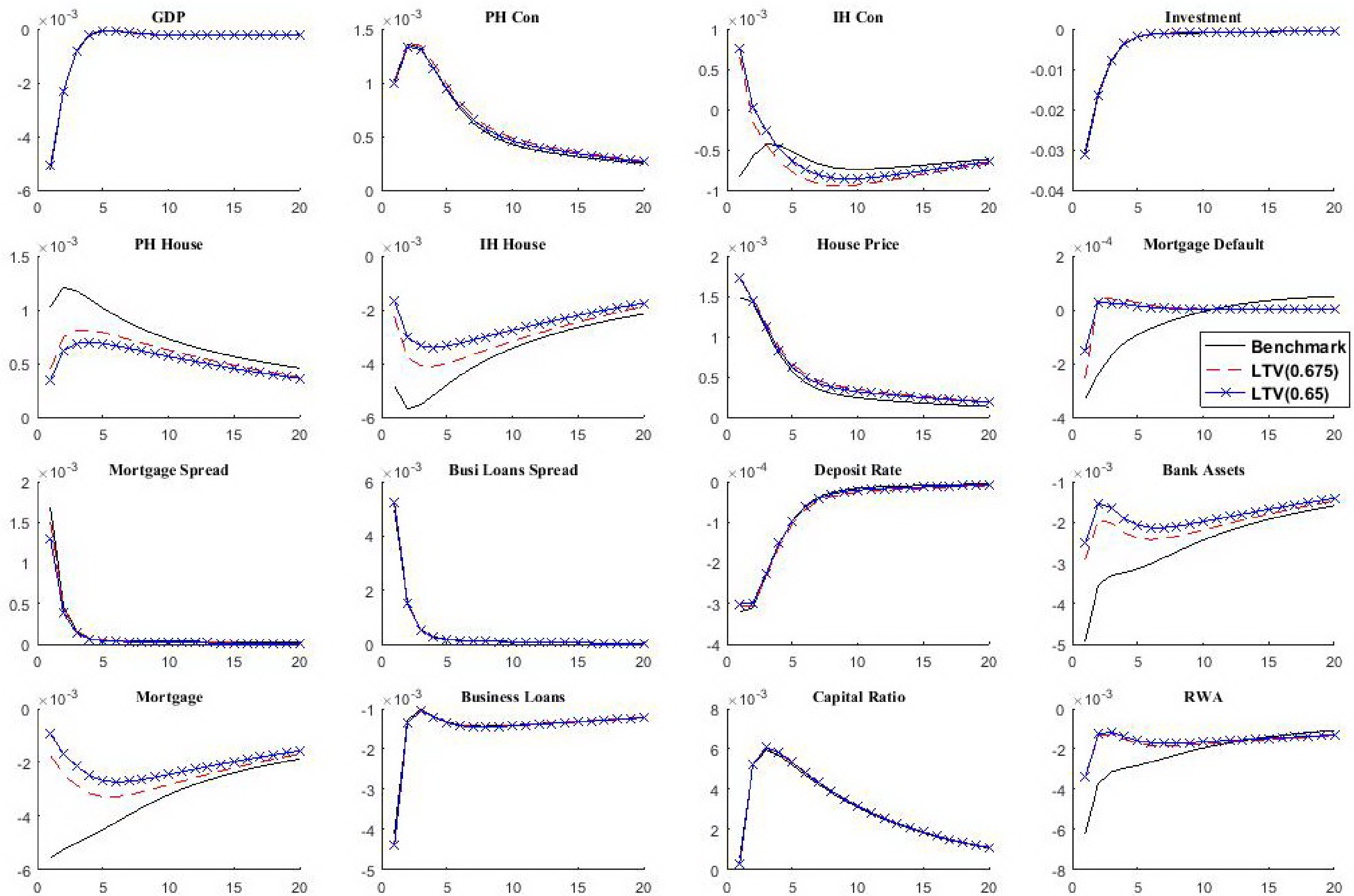
Note: the red dashed line shows the response of the economy with LTV caps.

Figure 3.13: Response of the Economy to Housing Risk Shocks (Benchmark VS LTV)



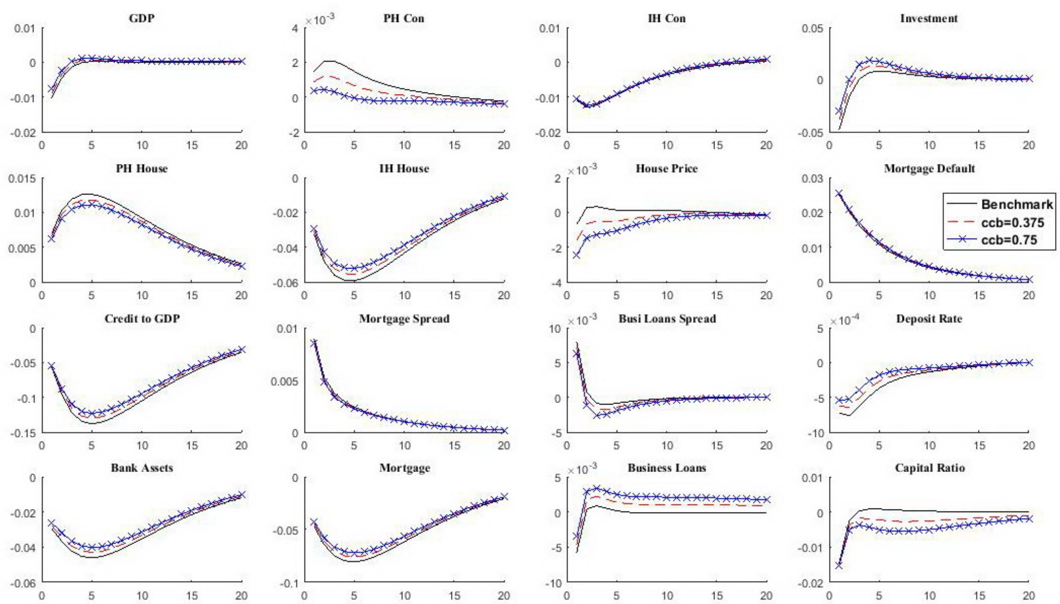
Note: the black solid line shows the response of the benchmark economy. The red dashed line and blue crossed line show the response of the economy with LTV caps $\widetilde{m}^I = 0.675$ and $\widetilde{m}^I = 0.65$, respectively.

Figure 3.14: Response of the Economy to Risk Premium Shocks (Benchmark VS LTV)



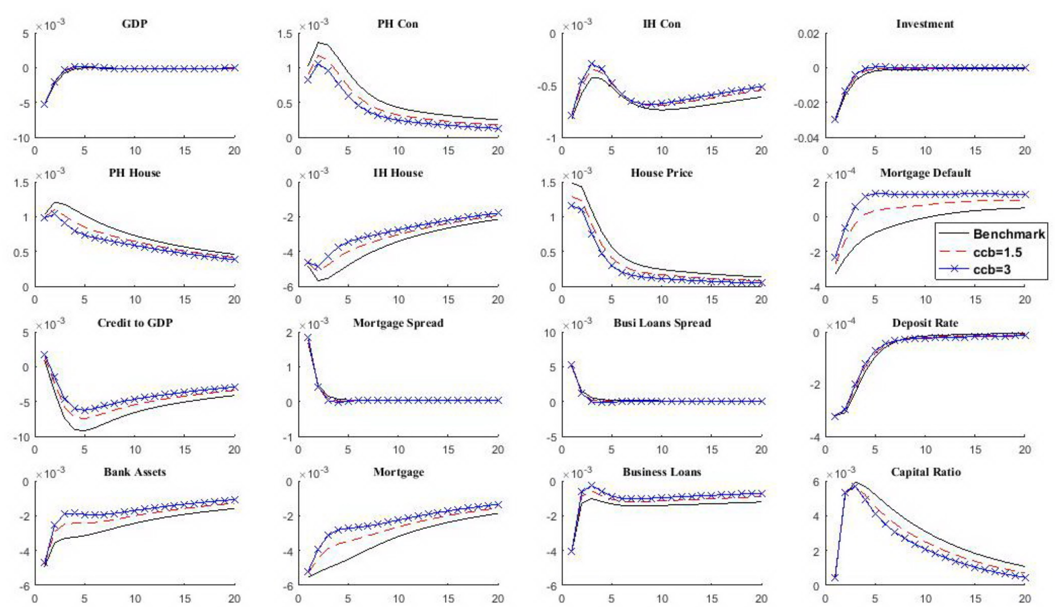
Note: the black solid line shows the response of the benchmark economy. The red dashed line and blue crossed line show the response of the economy with LTV caps $\widetilde{m}^I = 0.675$ and $\widetilde{m}^I = 0.65$, respectively.

Figure 3.15: Assessing the Effectiveness of Countercyclical Capital Buffers in the Event of Housing Risk Shocks (Benchmark Model)



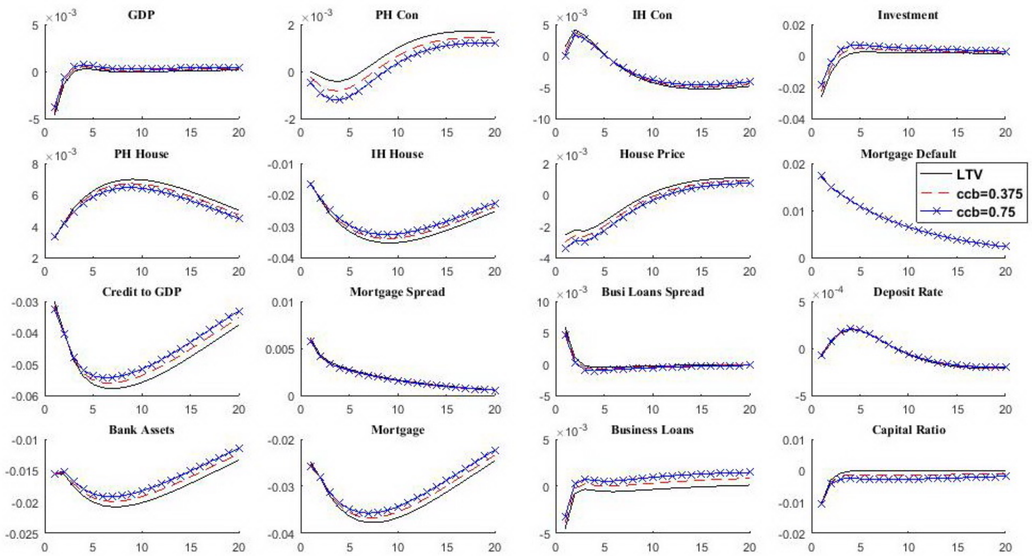
Note: The red dashed and the crossed blue lines show the response of the economy with countercyclical capital buffers with $\Phi_k = 0.375$ and $\Phi_k = 0.75$, respectively.

Figure 3.16: Assessing the Effectiveness of Countercyclical Capital Buffers in the Event of Risk Premium Shocks (Benchmark Model)



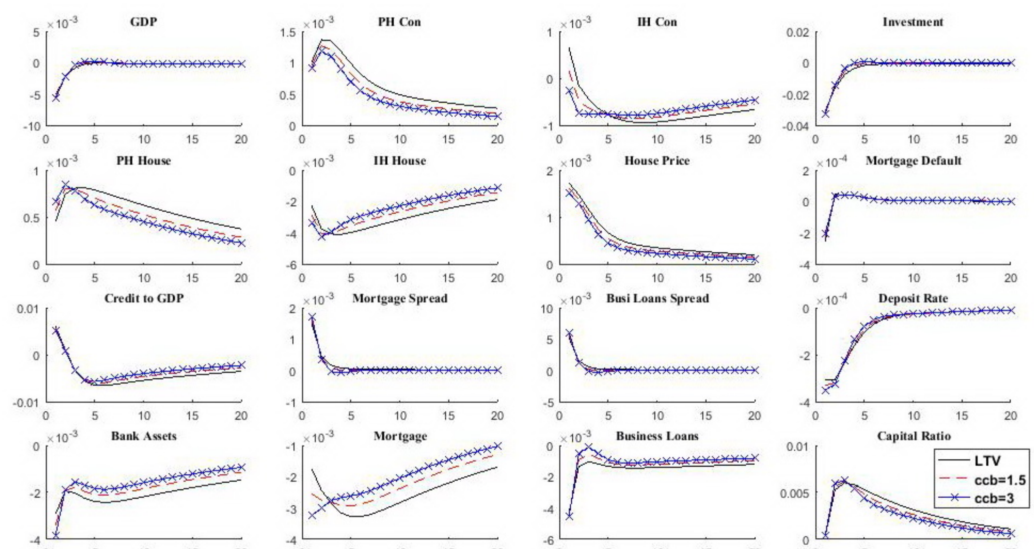
Note: The red dashed and the crossed blue lines show the response of the economy with countercyclical capital buffers with $\Phi_k = 1.5$ and $\Phi_k = 3.0$, respectively.

Figure 3.17: Assessing the Effectiveness of Countercyclical Capital Buffers in the Event of Housing Risk Shocks (LTV Model)



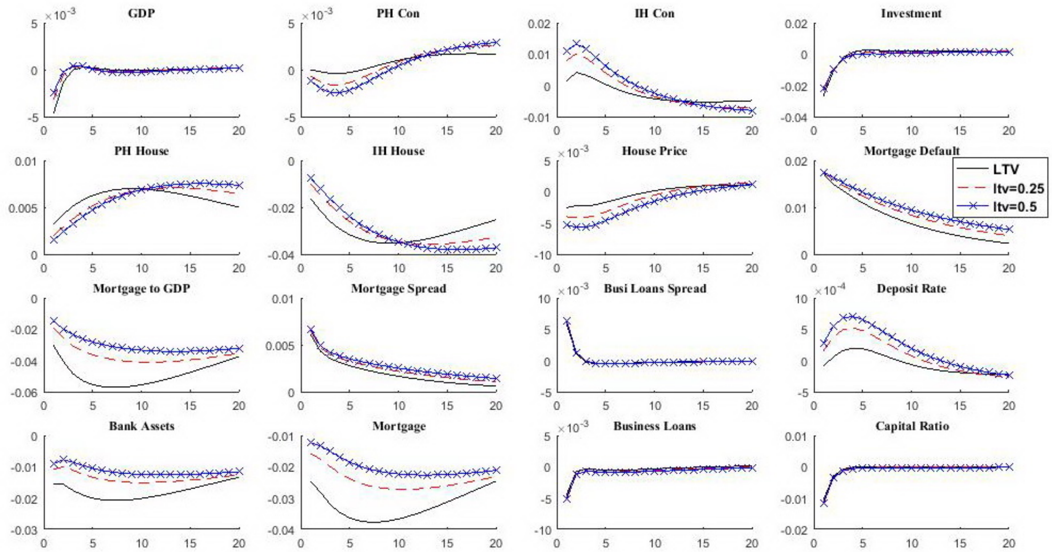
Note: The red dashed and the crossed blue lines show the response of the economy with countercyclical capital buffers with $\Phi_k = 0.375$ and $\Phi_k = 0.75$, respectively.

Figure 3.18: Assessing the Effectiveness of Countercyclical Capital Buffers in the Event of Risk Premium Shocks (LTV Model)



Note: The red dashed and the crossed blue lines show the response of the economy with countercyclical capital buffers with $\Phi_k = 1.5$ and $\Phi_k = 3.0$, respectively.

Figure 3.19: Assessing the Effectiveness of State-contingent LTV Ratio in the Event of Housing Risk Shocks (LTV Model)



Note: The red dashed and the crossed blue lines show the response of the economy with state-contingent LTV ratio with $\Phi_m = 0.25$ and $\Phi_m = 0.5$, respectively.

Concluding Remarks

The recent global financial crisis has once again urged policymakers to rethink macroeconomic policies. The key lesson learnt is that price stability alone is not sufficient to achieve macroeconomic stability and sustainable growth. Policymakers are advocated to be vigilant on financial stability risks since they, if excessive, can precipitate into financial and economic crises. In this regard, two important policy questions need to be addressed. First, what policy instruments should policymakers employ to handle risks towards financial stability? Second, how can macroeconomic models be developed to address financial-stability issues?

I end the thesis by summarising its key contributions to the literature, which shed light on both issues outlined earlier. The first chapter studies whether expansionary monetary policy contributes to bank risk-taking, in the case of Asia. Relying on panel data analysis, the results support the existence of the bank risk-taking channel, which is more pronounced for banks listed on the stock market. I make contributions with respect to both identification strategies and the findings. First, I propose two new strategies to counter the misidentification problem. In particular, the finding that bank risk rises after monetary expansion may be interpreted as the working of traditional monetary policy transmission mechanisms. Therefore, bank asset size is included in the regression as the main explanatory variable to account for bank balance sheet adjustments consistent with the credit channel. In addition, I develop the technique widely used in the bank-lending literature by investigating cross-sectional differences in the risk-taking responses to monetary policy shocks across banks. To identify the risk-taking channel, I hypothesise that listed banks, whose bank managers have more incentives for risk-taking, should be more responsive.

Second, I report new findings on how banks take more risk following monetary easing. Banks are found to increase risk on their portfolios mainly through origination of corporate loans. In addition, I test the hypothesis of whether bank risk-taking is accompanied by an increase in leverage, as predicted by the theory. The results show no such evidence but even suggest that decreased leverage induces higher bank risk-taking incentives. The latter finding is possible, since improved bank net worth following expansionary monetary policy may improve bank risk-bearing capacity.

The results of this chapter, therefore, support the belief that continuously loose monetary policy incentivised banks to search for yield. These raise awareness that the Central Bank should be mindful when implementing expansionary monetary policy, as bank risk-taking is expected to follow. In particular, if the policy interest rate is lower than the level justified by economic fundamentals, the impact on bank risk-taking can be sizeable.

The second chapter constructs a model for analysing bank risk-taking. I embed firm heterogeneity, endogenous default risk and capital requirements into an otherwise standard DSGE model. A subset of the firms can partially default on their loan obligation but are subject to non-pecuniary default penalty. My focus is on how banks reallocate their assets across safe and risky investment. The macroeconomic literature usually attributes bank risk-taking to limited liability, moral hazard problems (e.g., those arising from either explicit or implicit intervention by the Central Bank) and increased optimism. I abstain from introducing those features and propose new arguments. In my model, bank risk-taking is induced by lowered default risk of the risky borrowers and improved bank capital ratio that respond to standard macroeconomic shocks. The result, therefore, confirms the procyclicality effects of Basel II's capital regulation. I contribute further by adding that such a regulation also promotes risk-taking.

Another main contribution of the chapter is on the evaluation of macroeconomic policies. In response to the question of whether monetary policy should lean against risks towards financial stability, this chapter does not support such a role. Monetary policy is found to be ineffective in curtailing bank risk-taking, while causing significant output losses and, in certain cases, higher inflation volatilities. This result supports the notion that monetary policy is a blunt instrument. Having said that, evidence for the bank risk-taking channel is also found in my theoretical model.[77] Therefore, even though the Central Bank may not adjust monetary policy to mitigate financial stability risk, it should be aware that the policy is not too expansionary, hence becoming a source of fragility by itself. However, the results also shed light on monetary and macroprudential policies interaction. When the right macroprudential measures are in place, risk-taking that is induced by monetary easing becomes limited. This should allow monetary policy to pursue its own objectives of securing price stability and full employment, without having to worry about financial-stability consequences.

Certain macroprudential regulation measures are proven to be effective in mitigating bank risk-taking. The results support the use of Basel III's contingent capital regulation (i.e. countercyclical capital buffers) and the measure that directly targets bank asset composition (i.e. targeting the ratio of risky loans to total assets). Comparing their short-term negative impacts on output and inflation, I find risky-to-total asset ratio targeting to be less costly. This measure induces banks to extend more safe loans to replace risky ones, hence limiting the aggregate impact on credit conditions. Nevertheless, not all macroprudential measures are useful. The results show that leverage ratio targeting does not have significant effect on bank risk, while raising capital requirements may even exacerbate risk-taking. In sum, this chapter lends support to the use of macroprudential regulation in leaning against risks towards financial stability, particularly during the run-up to the financial crisis when banks tend to engage in excessive risk-taking.

[77] In this regard, my model is among the very first general equilibrium models to emphasise the bank risk-taking channel of monetary policy transmission.

The last chapter emphasises the spillover effects of large adverse shocks originating in the housing and financial market on the real economy. I embed endogenous mortgage default into a New Keynesian model that features housing and the banking sector. The latter faces capital requirements. My model is the first to combine together three ingredients: mortgage default as a source of shocks, the banking sector as a shock propagator, and macroprudential regulation as a policy to alleviate the crisis. I study two main shocks to explain an acceleration of mortgage default and increased credit spreads during the crisis. To complement housing risk shocks which are already studied in the literature, I introduce shocks to the penalty on capital regulation. Such shocks may reflect changes in banks risk-bearing capacity and directly affect credit spreads. This is one major contribution to the literature. I find that both shocks constrain bank lending and real economic activities, potentially explaining what have happened in the recent crisis.

As in the previous chapter, I offer policy recommendations regarding the effectiveness of macroprudential regulation. I deliver several new findings. First, imposing caps on loan-to-value (LTV) ratio yields permanent benefits to mortgage borrowers, while the banking system becomes safer. I claim that this result only obtains in the model that incorporates endogenous mortgage default. I find LTV caps are effective in limiting a decline in mortgages when the economy encounters both shocks. Second, I do not support the use of state-contingent LTV caps when the economy faces housing risk shocks. This measure exacerbates default and eventually the welfare of mortgage borrowers. This result disagrees with the literature most of which supports this policy tool. Third, countercyclical capital buffers that react to the credit-to-GDP ratio may improve allocations and the welfare of those adversely affected by shocks. However, financial regulators have to be aware that the credit-to-GDP ratio may send a false signal in certain circumstances which can destabilise the economy. In light of this last result, financial regulators have to select carefully financial indicators to serve as a target, which may differ across sectors and economies. A failure to do so would derail the benefits of the regulation.

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