Financial Frictions and the Business Cycle

by

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Abstract

This dissertation emphasizes the financial instability inherent in modern financial markets and the real economy and introduces a different aspect to dynamic stochastic general equilibrium (DSGE) models with financial frictions. Specifically, I introduce a role for the equity market in financial intermediation, firm production and household consumption—termed the equity price channel. This innovative model forms the foundation of three research papers which successively studies: the systemic and pro-cyclical effect of equity, the sources of credit spread variability, and the role of contingent convertible capital (CoCos) in Basel III macroprudential regulation.

In chapter two, I show that the equity price channel significantly exacerbates business cycle fluctuations through both financial accelerator and bank capital channels. I find that a New-Keynesian DSGE model with an equity price channel well mimics the U.S. business cycle and reproduces the strong procyclicality of equity. The results also reflect the increasing emphasis on common equity capital in Basel regulations. This is beneficial in terms of financial stability, but amplifies and propagates shocks to the real economy.

In chapter three, I establish the prevailing financial factors that influence credit spread variability, and its impact on the U.S. business cycle over the Great Moderation and Great Recession periods. Over both periods, I find an important role for bank market power (sticky rate adjustments and loan rate markups) on credit spread variability in the U.S. business cycle. Equity prices exacerbate movements in credit spreads through the financial accelerator channel, but cannot be regarded as a main driving force of credit spread variability. Both the financial accelerator and bank capital channels play a significant role in propagating the movements of credit spreads. Across the last three U.S. recession periods (1990−91, 2001, and 2007−09) I observe a remarkable decline in the influence of technology and monetary policy shocks. Whereas, there is an increasing trend in the contribution of loan rate markup shocks to the variability of retail credit spreads. The influence of loan-to-value shocks has declined since the 1990−91 recession, while the bank capital requirement shock exacerbates and prolongs credit spread variability over the 2007−09 recession period.

In chapter four, I show that countercyclical capital requirements (as in Basel III) and contingent convertible capital provide an effective dual approach to macroprudential policy. On the one hand, a countercyclical capital adequacy rule dominates CoCos in the stabilization of real shocks. That

is, by raising a capital buffer the Basel III regime mitigates the build-up of excess credit supply and, as a result, constrains the expansion of overleveraged banks. On the other hand, CoCos have a strong advantage over the Basel III regime against negative financial shocks. Here, CoCos effectively re-capitalize banks, reduce financial distress in a timely manner, and mitigate knock-on effects to the real economy. Countercyclical capital requirements and contingent convertible capital instruments therefore limit financial instability, and its influence on the real economy.

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Dedications

To my wife and best friend, Gwen.

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Chapter 1

Introduction

The global financial crisis and recession that began in 2007 continues to shape macroeconomic research and, more importantly, it has revitalized the role of financial frictions in shaping business cycle fluctuations. In this respect, modern business cycle theory provides a coherent framework for research on the dynamic interactions between financial markets and the real economy. Until recently, however, the core general equilibrium framework used in policy analysis excluded any formal specification of financial markets.[1]

This dissertation emphasizes the financial instability inherent in modern financial markets and the real economy, and provides a framework to study the financial factors that give rise to financial instability. More specifically, it provides a deeper understanding of how financial intermediation modifies the transmission mechanism of monetary policy and other macroeconomic shocks; and includes new insights on limiting financial instability, and its associated influence on the real economy.

To do this, I introduce a different aspect to dynamic stochastic general equilibrium (DSGE) models with financial frictions. Namely, I develop a role for the equity market in financial intermediation, firm production and household consumption—termed the equity price channel. The idea here is to capture the systemic interconnection between the financial system and the real economy. This innovative model forms the foundation of three research papers which successively incorporates: the systemic and pro-cyclical effect of equity, the sources of credit spread variability over the Great Moderation and Great Recession periods, and the role of contingent convertible capital in Basel III macroprudential regulation.

Since the onset of the crisis, a number of challenges have come to face modern business cycle theory. That is to say, without a formal specification for financial intermediation, general equilibrium models fail to explain important regularities in the business cycle. Firstly, asset prices have prevalent consequences for real economic activity. On the one hand, asset price fluctuations affect the real economy through, for example, households' financial wealth and the market value of

[1] See Appendix A for a description of the core DSGE framework, which summarizes the benchmark model used in policy analysis from the late 1980s up to the financial crisis (see also, Tovar, 2009).

collateral. On the other hand, asset prices absorb and react to market expectations and macroeconomic conditions which, in turn, reflect information about the expected path of the business cycle. This interconnection between financial markets and the real economy, however, has received much less attention in general equilibrium models.

Secondly, one notable recurring characteristic of financial stress in recessions is that of widening credit spreads. As a result, systemic disruptions to financial intermediation have shown how large variations in credit spreads dislocate the interaction between short-term interest rates and real economic activity. The recent crisis has therefore also called into question the lack of a prominent role for bank market power and multiple interest rate setting in dynamic macroeconomic models, and subsequently, the effectiveness of the interest-rate policy of central banks (Woodford, 2010; Gertler and Kiyotaki, 2011).[2] At the same time, the synonymous role of the equity market cannot be ignored. As pointed out by Brunnermeier (2009) and Adrian and Shin (2011), both credit spreads and equity markets in the U.S. exhibited significant financial stress during the Great Recession of 2007−09, and both significantly affected real economic activity and the business cycle (see also, Castelnuovo and Nisticò, 2010; Gilchrist and Zakrajšek, 2012). In fact, the 1990−91 and 2001 U.S. recessions during the Great Moderation exhibited similar financial stress through widening credit spreads and collapsing equity prices. Farmer (2012b) goes further and argues that it is the stock market crash of 2008, triggered by a collapse in house prices, that caused the Great Recession.

Thirdly, it has become far more urgent to provide research on the dynamic interactions between macroprudential policies and the real economy (Galati and Moessner, 2013). Especially since macroprudential guidelines stipulated in the Basel Accord failed to mitigate recent global episodes of financial distress. In doing so, policy analysis and macroeconomic prediction can be better organised and efficiently executed to avoid the build-up of financial imbalances.

Indeed, from the late 1980s up to the financial crisis, most quantitative macroeconomic models assumed a rather primitive treatment of the interaction between financial markets and the real economy. The most prominent work to introduce a role for credit market frictions in business cycle fluctuations is that of Bernanke and Gertler (1989). Thereafter, seminal works by Kiyotaki and Moore (1997) and Bernanke et al. (1999) showed how credit market frictions amplified and propagated business cycle fluctuations.[3] However, these frictions arise solely from the creditworthiness of borrowers—the so-called 'financial accelerator' channel. In fact, the benchmark model lacked any significant role for monetary aggregates, financial intermediation, or multiple interest rates. That said, Goodfriend and McCallum (2007) was an early and much needed contribution on the role of banking in monetary policy.

Lacking an equity market and a detailed banking sector underestimates the explanatory power

[2]Bank market power, here, specifically refers to sticky interest rate adjustment and interest rate markups.

[3]A number of notable contributions in the literature include, amongst others: Carlstrom and Fuerst (1997), Kocherlakota (2000) and Cooley et al. (2004).

of financial frictions, and inhibits financial stability research and policy analysis for central banks and government. To be sure, the benchmark framework is fast adapting to incorporate these features (e.g., Castelnuovo and Nisticò, 2010; Christiano et al., 2010; Cúrdia and Woodford, 2010; Gerali et al., 2010; de Walque et al., 2010). Yet, continued work is required in modeling financial markets that better capture the macroeconomic consequences of: the heterogeneous banking sector; the equity market in an interconnected financial system; Basel bank regulation; and financial frictions associated with collateralized debt, heterogeneous rate stickiness, and bank leverage.[4] These are the critical features identified in this dissertation that will be incorporated within the current benchmark framework.

Following Smets and Wouters (2003), Christiano et al. (2005) and Gerali et al. (2010), this dissertation adopts the mainstream methodology for model calibration, estimation and robustness analysis. The models are estimated with Bayesian technique using macroeconomic time-series data of the U.S. economy. Similarly, the calibration of the model matches key steady-state features of the U.S. economy. Four methods are used to validate the model results. The first compares the closeness of well-established estimated parameters in the literature. The second shows how well the cyclical properties of the model (i.e., the second moments) compare with that of the data and the literature evidence. The third determines whether the model results—for impulse response functions, forecast error variance decompositions, and historical variance decompositions—conform to business cycle theory and evidence. The fourth compares the predictive power and robustness of the DSGE model to changes in its assumptions, and to the vector auto-regression approach.

The layout and main findings of the dissertation are as follows. In chapter two, I show that the equity price channel significantly exacerbates business cycle fluctuations through both the financial accelerator channel and the bank capital channel. I find that a New-Keynesian DSGE model with an equity price channel well mimics the U.S. business cycle and reproduces the strong procyclicality of equity. The results also reflect the increasing emphasis on common equity capital in Basel regulations. This is beneficial in terms of financial stability, but amplifies and propagates shocks to the real economy.

In chapter three, I establish the prevailing financial factors that influence credit spread variability, and the mechanisms through which shocks impact credit spread variability over the Great Moderation and Great Recession periods. Over both periods, I find an important role for bank market power (sticky rate adjustments and loan rate markups) on credit spread variability in the U.S. business cycle. Equity prices exacerbate movements in credit spreads through the financial accelerator channel, but cannot be regarded as a main driving force of credit spread variability. Both the financial accelerator and bank capital channels play a significant role in propagating the movements of credit spreads. Across the last three U.S. recession periods (1990−91, 2001, and

[4]Other important shortcomings include, for example, financial frictions associated with imperfect information (i.e., moral hazard, monitoring costs, and adverse selection) and risk premiums.

2007−09) I observe a remarkable decline in the influence of technology and monetary policy shocks. Whereas, there is an increasing trend in the contribution of loan rate markup shocks to the variability of retail credit spreads. The influence of loan-to-value shocks has declined since the 1990−91 recession, while the bank capital requirement shock exacerbates and prolongs credit spread variability over the 2007−09 recession period.

In chapter four, I introduce a role for contingent convertible capital (CoCos) in countercyclical macroprudential policy, and study the effectiveness of bank capital requirements and CoCos in limiting financial instability. I find that countercyclical capital requirements (as in Basel III) and contingent convertible capital provide an effective dual approach to macroprudential policy. On the one hand, a countercyclical capital adequacy rule dominates CoCos in the stabilization of real shocks. That is, by raising a capital buffer the Basel III regime mitigates the build-up of excess credit supply and, as a result, constrains the expansion of overleveraged banks. On the other hand, CoCos have a strong advantage over the Basel III regime against negative financial shocks. Here, CoCos effectively re-capitalize banks, reduce financial distress in a timely manner, and mitigate knock-on effects to the real economy. Countercyclical capital requirements and contingent convertible capital instruments therefore limit financial instability and its associated influence on the real economy.

Chapter 2

The equity price channel in a New-Keynesian DSGE model with financial frictions and banking

2.1 Introduction

This paper studies the role of the equity price channel in business cycle fluctuations, and highlights the equity price channel as a different aspect to general equilibrium models with financial frictions and, as a result, emphasizes the systemic influence of financial markets on the real economy. To do so, I develop a canonical New-Keynesian dynamic stochastic general equilibrium (DSGE) model incorporating the financial accelerator channel (see, Bernanke and Gertler, 1989; Bernanke et al., 1999) and the bank capital channel (see, Markovic, 2006; Meh and Moran, 2010).[1] Moreover, I introduce a tractable role for the equity market in banking, entrepreneur and household economic activities. By synthesizing the roles of the bank's capital structure, the entrepreneur's net worth and the demand side of the equity market, this paper highlights the systemic influence of the equity price channel on business cycle fluctuations through consumption, production and banking activities.

Asset prices have prevalent consequences for real economic activity.[2] On the one hand, asset price fluctuations affect the real economy through, for example, households' financial wealth and the market value of collateral (e.g., Iacoviello, 2005). On the other hand, asset prices absorb and react to market expectations and macroeconomic conditions which, in turn, reflect information about the expected path of the business cycle (e.g., Castelnuovo and Nisticò, 2010). This interconnection between financial markets and the real economy, however, has received much less attention in general equilibrium models (BCBS, 2011).

[1]The financial accelerator captures the "endogenous developments in credit markets [that] work to propagate and amplify shocks to the macroeconomy" (Bernanke et al., 1999, p.1345). Whereas, the bank capital channel "encompasses shocks to the cost or the value of bank capital that can affect bank lending" (Markovic, 2006, p.9).

[2]Cochrane (2008) provides an extensive overview of asset prices in financial markets and the real economy.

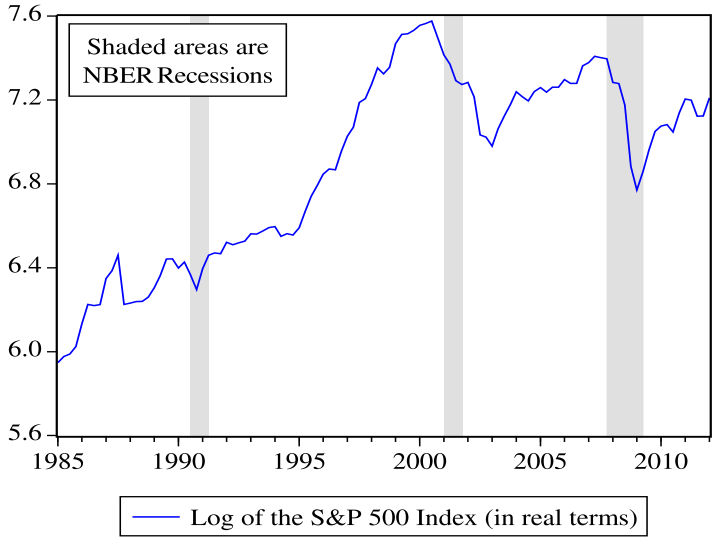

Figure 2.1: Equity market collapses and U.S. recessions

There are at least three reasons for including a direct role for equity in consumption, production and banking activities. Firstly, the strong correlation between financial markets and the U.S. business cycle is well established (e.g., Bernanke and Lown, 1992; Brunnermeier, 2009; Adrian and Shin, 2011; Gilchrist and Zakrajšek, 2012; Jermann and Quadrini, 2012). Figure 2.1 highlights the common occurrence of equity price collapses and U.S. recessions. Moreover, Christiano et al. (2008) and Farmer (2012a) show how self-fulfilling asset price expectations can induce equity market collapses and macroeconomic instability. Secondly, banking sector data supports the inclusion of the equity price channel in models with financial frictions. Figure 2.2 illustrates the importance of capturing the market capitalization of bank equity capital.[3] Over the period 1992Q04−2003Q04, the bank capital structure of all commercial banks in the U.S. consistently comprised, on average, 46.7% equity surplus and 44.6% retained earnings. However, since 2003Q04 the ratios diverged considerably, with equity surplus peaking at 77.3% and retained earnings declining to 18.7% by the end of 2009. Finally, regulatory authorities are increasingly emphasizing common equity as a safety-net to adverse bank shocks. Figure 2.3 shows the minimum capital requirements for banks according to the proposed Basel III regulations (BIS, 2012). By 2015, tier 1 common equity must reach a minimum of 4.5% of risk-weighted assets (RWA). By 2019, two additional common equity requirements must be met: a 2.5% capital conservation buffer and a 0 − 2.5% country-specific discretionary counter-cyclical buffer. This implies a potential 7 − 9.5% common equity requirement out of a possible 10.5 − 13% of RWA. The requirement for retained earnings falls from 2% to 1.5% of RWA. Both Figure 2.2 and Figure 2.3 show the significant structural shift towards greater common equity capital leveraging in U.S. commercial

[3] Data source: Federal Deposit Insurance Corporation (FDIC, 2012).

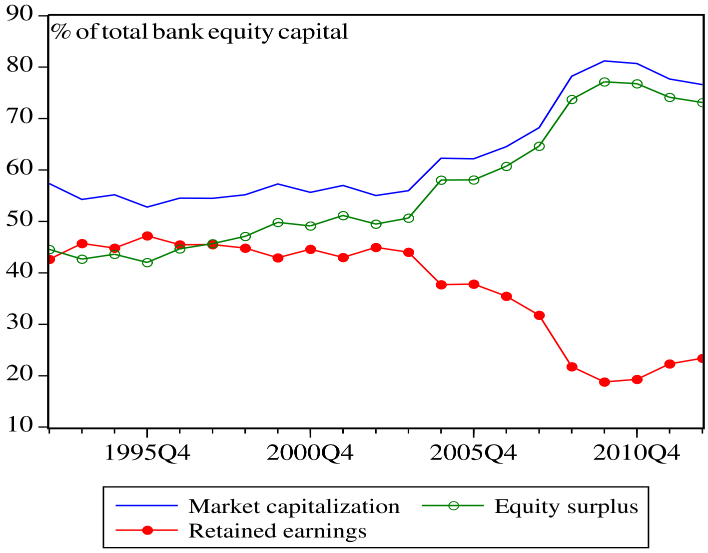

Figure 2.2: Bank capital structure for all U.S. commercial banks (1992Q04−2012Q01)

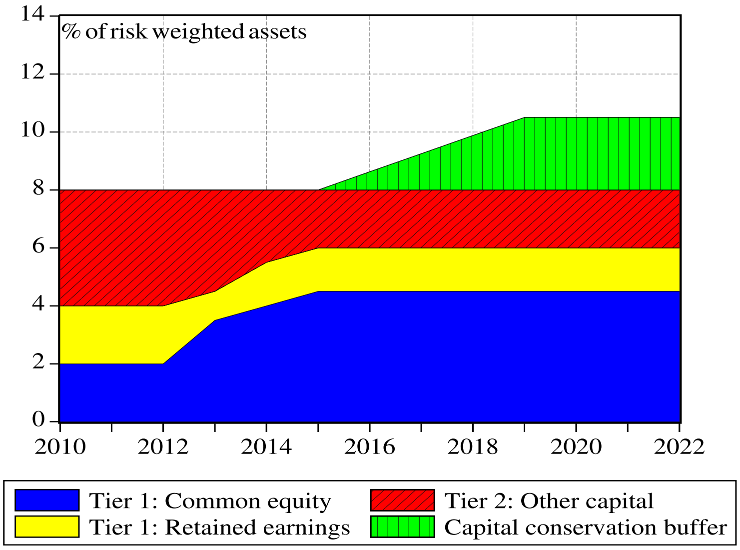

Figure 2.3: Basel III minimum capital requirements

banks.

This paper is related to the literature on the interaction between equity prices and macroeconomic fundamentals. More specifically, the interaction between equity prices and the real economy, through the household wealth effect, specifies an active role for the demand-side effect of the equity market in a standard dynamic New-Keynesian business cycle analysis. Wei (2010) points out that this expanding literature has not been widely studied within the New-Keynesian framework. He goes on to show that a New-Keynesian sticky-price model is well able to generate the positive correlation between real dividend yields and inflation observed in the data. That is, because inflation makes shareholders more risk averse the required equity premium and the real discount rate rise. As a result, the sticky-price structure of New-Keynesian models highlight the influence of monetary policy rules on the relationship between equity prices, inflation and the real economy.

Indeed, previous studies often fell short of including both an explicit demand-side equity market interaction and a coherent way for allowing equity prices to directly impact consumption, production and banking activities. On the one hand, Castelnuovo and Nisticò (2010) show how the demand-side interaction between heterogenous investors produces a strong financial wealth effect on consumption. However, the stock market wealth effect on households serves as the sole financial market mechanism to study the relationship between equity markets and monetary policy.[4] On the other hand, Christiano et al. (2010) establish an economic link between bank funding and bank lending in which equity plays a role. Their analysis validates the important contribution of the credit market and the equity market for replicating the U.S. business cycle. However, to capture crucial equity market information in production activities, equity price data serves as a proxy for the price of capital. Whereby a financial wealth shock (i.e., a shock to the value of equity) has a contemporaneous impact on entrepreneurs' net worth, and hence creditworthiness. This mechanism is distinct from that of bank funding: for the reason that banks issue short-term marketable securities to households to finance their loans to entrepreneurs. As a result, the model overlooks a tractable and micro-founded framework for equity pricing, by which equity prices directly influence consumption, production and banking activities.[5]

This paper is also related to the bank capital literature. Markovic (2006) and Meh and Moran (2010) provide evidence on the importance of bank capital for bank lending and funding, and the need to entrench the bank capital channel in the financial frictions paradigm. Markovic (2006) shows how households' investment in bank equity shares influences the cost and value of bank capital. Although no financial frictions arise from within the banking sector and the representative bank is non-optimizing, he finds a significant role for the bank capital channel in propagating shocks to bank lending and, subsequently, the real economy. Meh and Moran (2010) show how bank capital arises to mitigate the moral hazard problem between banks and their creditors. As a result, the bank capital channel greatly amplifies and propagates both real and financial shocks on economic activity. In addition, Van den Heuvel (2008) finds that bank capital requirements limit the ability of banks to satisfy households' liquidity preferences which, in turn, significantly hinder real economic activity. Indeed, only recently did Markovic (2006), Van den Heuvel (2008)

[4]Castelnuovo and Nisticò (2010, p.1724-5) therefore highlight the need to extend their baseline model to include, e.g., a non-trivial role for financial intermediaries. Here, they also discuss the implications of not considering a wider range of macroeconomic factors such as endogenous physical capital accumulation and asset-price fluctuations on investment.

[5]See Christiano et al. (2010, p.5−10) for comments on the counterfactual responses from the model.

and Christiano et al. (2010) support the idea of including equity in bank capital accumulation. However, none of these studies consider the demand-side effect of the equity market on banking operations. In this study, I introduce an equity price channel to close these gaps in the interaction between equity prices and the real economy in the literature.

The contribution of the paper is two-fold. Firstly, by addressing the gaps in the literature I highlight the equity price channel as a different aspect to general equilibrium models with financial frictions. This equity price channel links consumption, production and banking activities, whereby equity prices affect both households' and entrepreneurs' financial wealth, and bank assets are partially financed by equity. Secondly, I estimate the model with Bayesian techniques, using U.S. data over the sample period 1982Q01−2012Q01. I show that a New-Keynesian DSGE model with an equity price channel well mimics the U.S. business cycle over the sample period. The model also does well in terms of reproducing the strong procyclicality of the equity price.

The main findings of this paper are as follows. The equity price channel amplifies and propagates shocks to the real economy through both financial accelerator and bank capital channels. Equity plays a significant role in amplifying the financial accelerator effect on interest rates, inflation and household loans. Due to the direct wealth effect, a negative equity price shock decreases households' consumption and, hence, output. The equity price channel weakens the countercyclicality of bank capital-asset ratios, which reflects the increasing emphasis on common equity capital in Basel regulations. This is beneficial in terms of financial stability, but amplifies and propagates shocks to the real economy.

The rest of the paper proceeds as follows. Section 2.2 defines the equity price channel. Section 2.3 develops the New-Keynesian DSGE model with financial frictions and the equity price channel. Section 2.4 presents the Bayesian estimation results. Section 2.5 discusses the role of the equity price channel in business cycle fluctuations, performs the robustness analysis and reports the cyclical properties of the equity price. Section 2.6 concludes.

2.2 The equity price channel in business cycles

The nexus of the equity price channel in the model economy is as follows. Equity prices are endogenously determined by the aggregation of buying and selling shares between market participants. That is, households can adjust their portfolio (bank and entrepreneur) equity investment to either liquidate shares to finance current consumption or increase their equity holdings for future consumption. This is the direct wealth effect on consumption. As a result, the demand-side determination of equity prices will affect financial contracts between creditors and debtors. Specifically, the extension of credit to households is based on their ability to service debt with wage income and their financial wealth (equity investment), whereas entrepreneurs obtain loans based on their market capitalization and their redeemable physical capital assets. Hence, the market value of entrepreneur equity affects their ability to finance production with loans.

Not only does the equity price channel affect real economic activity through the financial accelerator channel, it also influences credit supply through bank capital requirements and bank funding. Firstly, banks finance assets with deposits and bank capital (equity and retained earnings), where bank equity capital functions as a shock-absorber for loan defaults or deficiencies. Secondly, I adopt the quadratic adjustment cost structure from Gerali et al. (2010) as the core framework for credit supply frictions in financial intermediation: a monopolistically competitive banking sector with quadratic adjustment costs for the interbank and retail loan rates.

2.3 The model economy

The basic framework of the model is a medium-scale New Keynesian DSGE model, in which a monopolistically competitive retail goods sector introduces Calvo-type sticky prices. For simplicity purposes, wages are flexible in the model. I augment the model with a heterogeneous banking sector along the lines of Gerali et al. (2010). The model is closed by assuming that the monetary authority follows a Taylor-type interest rate rule.

I introduce the equity price channel in the model as follows. Both borrower and saver households invest in the equity market, where equity serves, in part, as a measure of creditworthiness for borrower households. Analogously the market value of the initial stock of entrepreneur equity serves, in part, as a measure of net worth when entrepreneurs borrow bank loans. For banks, bank capital is accumulated through previous bank capital, bank equity and retained earnings.

2.3.1 Households

There are two types of representative households, namely saver and borrower households. Both types of households, indexed by $\Gamma = b, s$ for borrowers and savers, maximize their expected lifetime utility function:

$$E_0 \sum_{t=0}^{\infty} \beta_\Gamma^t \Big[\frac{(C_t^\Gamma - \phi C_{t-1}^\Gamma)^{1-\gamma^\Gamma}}{1-\gamma^\Gamma} - \frac{(H_t^\Gamma)^{1+\eta}}{1+\eta} + aln(\frac{D_t^\Gamma}{P_t}) + \xi_{\psi,t} ln(\frac{Q_t^\psi \Psi_t^\Gamma}{P_t}) \Big], \tag{2.1}$$

where the discount factor $\beta_b^t < \beta_s^t$. The coefficient of relative risk aversion γ^Γ measures the curvature of the utility function with respect to its argument $C_t^\Gamma - \phi C_{t-1}^\Gamma$, where C_t^Γ is real consumption at time t and habit formation is parameterized by ϕ. η is the Frisch elasticity of labour supply with respect to hours worked H_t. Households' financial wealth is made up of deposits D_t^Γ and equity investments Ψ_t^Γ. Q_t^Ψ is the equity price at time t and $\xi_{\psi,t}$ is an exogenous demand shock on real equity balances. Parameter a equals 0 for borrowers and 1 for savers. That is, only savers hold deposits.[6]

[6]The assumption of liquidity services in the utility function can be traced back to Sidrauski (1967a,b). Similar to Van den Heuvel (2008) and Christiano et al. (2010), I allow financial instruments (both deposits and equity) to provide

2.3.2 Savers

Compared with borrowers, savers have a lower marginal propensity to consume, hold risk-free deposits $(a = 1)$, and do not borrow from banks at all. Savers allocate periodic income from wages (W_t), deposits $(I^d_{t-1}D^s_{t-1})$, capital gains/losses $(Q^\psi_t \Psi^s_{t-1})$ and dividends $(\Pi_{\psi,t})$ to current consumption and new financial wealth holdings. Eq. 2.2 gives the budget constraint for savers:

$$C^s_t + \frac{D^s_t}{P_t} + \frac{Q^\psi_t}{P_t}\Psi^s_t = \frac{W_t}{P_t}H^s_t + \frac{I^d_{t-1}D^s_{t-1}}{P_t} + \frac{(Q^\psi_t + \Pi_{\psi,t})}{P_t}\Psi^s_{t-1}. \tag{2.2}$$

The dividend policy is characterized by periodic rebated profits from entrepreneurs and banks to shareholders. For banks, dividend payments are endogenously determined, whereas for entrepreneurs the dividend policy follows rule defined as a proportion r^ψ (the steady-state net dividend yield) of each household's equity holdings.

$\Psi_t = \Psi^s_t + \Psi^b_t$ is the total aggregate equity stock. The total aggregate equity stock equals the total supply of equity from banks Ψ^B_t and entrepreneurs Ψ^e_t, which is constant (i.e., no new equity shares are issued). Therefore, in equilibrium $\Psi \equiv \Psi^B + \Psi^e = \Psi^s_t + \Psi^b_t$.

The representative saver household's first-order conditions for deposits, labour and equity holdings are the following:

$$\frac{P_t}{D^s_t} = U^s_{c,t} - \beta_s E_t\left[U^s_{c,t+1}\frac{I^d_t}{P_{t+1}/P_t}\right], \tag{2.3}$$

$$\frac{W_t}{P_t} = \frac{(H^s_t)^\eta}{U^s_{c,t}}, \tag{2.4}$$

$$\xi_{\psi,t}\frac{P_t}{Q^\psi_t\Psi^s_t} = U^s_{c,t} - \beta_s E_t\left[U^s_{c,t+1}\left(\frac{Q^\psi_{t+1} + \Pi_{\psi,t+1}}{Q^\psi_t}\right)\frac{P_t}{P_{t+1}}\right], \tag{2.5}$$

where $U^s_{c,t} = (C^s_t - \phi C^s_{t-1})^{-\gamma}$ is the marginal utility of consumption and the Lagrangian multiplier of the household's budget constraint. Eq. 2.3 indicates that the demand for deposits depends on households' consumption and the real return to deposits. Eq. 2.4 gives the standard real wage equation: the real wage equals the marginal rate of substitution of leisure for consumption. Eq. 2.5 gives the demand for equity holdings. Assuming no direct utility from equity holdings, the first order condition for equity holdings collapses to the standard consumption-based asset pricing equation,

$$1 = \beta_s E_t\left[\frac{U^s_{c,t}}{U^s_{c,t+1}}\left(\frac{Q^\psi_{t+1} + \Pi_{\psi,t+1}}{Q^\psi_t}\right)\frac{P_t}{P_{t+1}}\right]. \tag{2.6}$$

2.3.3 Borrowers

Borrowers do not invest in risk-free deposits $(a = 0)$ and, instead, borrow bank loans to finance their current consumption and investment in equity. Borrowers' budget constraint is given by:

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this service. As a result, this modeling device drives a wedge between the return on equity and the return on bank deposits.

$$C_t^b + \frac{I_{t-1}^h L_{t-1}^h}{P_t} + \frac{Q_t^\psi}{P_t}\Psi_t^b = \frac{W_t}{P_t}H_t^b + \frac{L_t^h}{P_t} + \frac{(Q_t^\psi + \Pi_{\psi,t})}{P_t}\Psi_{t-1}^b. \tag{2.7}$$

Borrower households allocate periodic income from wages, capital gains/losses, dividends and new loans (L_t^h) to current consumption, new financial wealth holdings and the repayment of previous loans $(I_{t-1}^h L_{t-1}^h)$. In addition to the budget constraint, borrowers also face the following borrowing constraint:

$$I_t^h L_t^h \leq \nu_{h,t}\big[\phi_w W_{t+1} H_t^b + (1-\phi_w)(Q_{t+1}^\psi + \Pi_{\psi,t+1})\Psi_t^b\big]. \tag{2.8}$$

The representative borrower's wage income together with her investment in the equity market serve as a measure of creditworthiness, where $0 \leq \phi_w \leq 1$ is the weight on wage income. $\nu_{h,t}$ is the stochastic loan-to-value ratio and, correspondingly, $1-\nu_{h,t}$ can be interpreted as the proportional transaction cost for bank's repossession of collateral assets in cases of borrower defaults. Following the literature (eg. Iacoviello, 2005), I assume the size of shocks is small enough so that the borrowing constraint is always binding.

The representative borrower household's first-order conditions for labour, household loans and equity holdings are the following:

$$(H_t^b)^\eta = U_{c,t}^b \frac{W_t}{P_t} + \lambda_t^h \nu_{h,t}\phi_w E_t\left[\frac{W_{t+1}}{P_t}\right], \tag{2.9}$$

$$U_{c,t}^b = \beta_b E_t\left[U_{c,t+1}^b \frac{I_t^h}{P_{t+1}/P_t}\right] + \lambda_t^h I_t^h, \tag{2.10}$$

$$\begin{aligned} \xi_{\psi,t}\frac{P_t}{Q_t^\psi \Psi_t^b} &= U_{c,t}^b - E_t\left[\beta_b\left(U_{c,t+1}^b \frac{R_{t+1}^\psi}{P_{t+1}/P_t}\right)\right. \\ &\quad \left. + \lambda_t^h \nu_{h,t}(1-\phi_w)\frac{R_{t+1}^\psi}{P_{t+1}/P_t}\right], \end{aligned} \tag{2.11}$$

where $U_{c,t}^b$ and λ_t^h are the Lagrangian multipliers of the budget constraint and borrowing constraint, respectively. $R_{t+1}^\psi = (Q_{t+1}^\psi + \Pi_{\psi,t+1})/Q_t^\psi$ is the gross nominal return to equity. Eq. 2.9 is the first-order condition for borrowers' labour supply. Eq. 2.9 and Eq. 2.4 give the aggregate labour supply schedule. Eq. 2.10 is the borrower household consumption Euler equation. Eq. 2.11 gives borrowers' demand for equity holdings.

By introducing heterogeneity in households and equity holdings in the households' utility function, I am able to model the demand-side interplay in the equity market. Indeed, given the assumption of a constant total stock of equity, the net effect of the realized demand for equity holdings for different types of households is equivalent, $|\triangle\ \Psi_t^b| = |\triangle\ \Psi_t^s|$.

2.3.4 Retailers

The retail sector is characterized by monopolistically competitive branders and acts as a modelling device to introduce Calvo-type sticky prices into the model (see, Bernanke et al., 1999; Iacoviello, 2005). Retailers purchase intermediate goods $Y_{j,t}$ from entrepreneurs at the wholesale price $P^W_{j,t}$ in a competitive market, and differentiate them at no cost into $Y_{k,t}$. Each retailer sells with a markup over $P^W_{j,t}$ at price $P_{k,t}$, taking into account their individual demand curves from consumers. Following Calvo (1983), I assume that the retailer can only adjust the retail price with probability $1-\theta_R$ in each period. Therefore, the decision problem for the retailer is

$$\max_{\{P^*_{k,t}\}} E_t \sum_{z=0}^{\infty} \theta^z_R \Lambda_{t,z} \left[P^*_{k,t} Y_{k,t+z} - P^W_{j,t+z} X Y_{k,t+z} \right] \tag{2.12}$$

subject to the consumer demand schedule for goods

$$Y_{k,t+z} = (\frac{P^*_{k,t}}{P_{t+z}})^{-\varepsilon^p_t} Y_{t+z}, \tag{2.13}$$

where $\Lambda_{t,z}$ is the consumption-based relevant discount factor. $P^*_{k,t}$ denotes the price set by the retailers, who are able to adjust the price in period t. $X_t \equiv \frac{P_t}{P^W_t}$ is the aggregate markup of the retail price over the wholesale price. In steady-state, $X = \frac{\varepsilon^p}{(\varepsilon^p - 1)}$, where ε^p is the steady-state price elasticity of demand for intermediate good $Y_{j,t}$.

The aggregate price level is determined by

$$P_t^{1-\varepsilon^p_t} = \theta_R \left((\frac{P_{t-1}}{P_{t-2}})^{\gamma_p} P_{t-1} \right)^{1-\varepsilon^p_t} + (1-\theta_R)(P^*_t)^{1-\varepsilon^p_t}, \tag{2.14}$$

where γ_p determines the degree of price indexation. Combining and linearizing Eq. 2.12 and Eq. 2.14 gives the forward-looking Phillips Curve, where current inflation is positively related to expected inflation and negatively related to the markup.

2.3.5 Entrepreneurs

Entrepreneurs produce the wholesale good using a standard Cobb-Douglas production function described by

$$Y_{j,t} = \xi_{z,t} K^{\alpha}_{j,t-1} H^{1-\alpha}_{j,t}, \tag{2.15}$$

where $K_{j,t-1}$ is physical capital, $H_{j,t}$ is labour, and $\xi_{z,t}$ is the technology.

In each period the representative entrepreneur chooses the desired amount of physical capital, bank loans and labour to maximize

$$E_0 \sum_{t=0}^{\infty} \beta^t_e \left[\Omega^e_{j,t} \right] \tag{2.16}$$

subject to the production technology (Eq. 2.15) and the flow of funds constraint

$$\Omega^e_{j,t} = \frac{Y_{j,t}}{X_{j,t}} + \frac{L^e_{j,t}}{P_t} - \frac{I^e_{j,t-1} L^e_{j,t-1}}{P_t} - \frac{W_t}{P_t} H_{j,t} - (K_{j,t} - (1-\delta_e) K_{j,t-1}) - Adj^e_{j,t} - \Pi^e_{\psi,jt}. \tag{2.17}$$

$Adj^e_{j,t}$ captures the adjustment cost of capital installation:

$$Adj^e_{j,t} = \kappa_v (\frac{V_{j,t}}{K_{j,t-1}} - \delta_e)^2 \frac{K_{j,t-1}}{(2\delta_e)}, \tag{2.18}$$

where $V_{j,t}$ is the investment used to accumulate capital and κ_v is the capital adjustment cost parameter. $\Pi^e_{\psi,jt} = (r^\psi Q^\psi_{j,t} \Psi^e_j)/P_t$ is the real dividend paid out. I assume entrepreneurs are more impatient than saver households ($\beta^t_e < \beta^t_s$), as in Iacoviello (2005).[7]

In addition to the flow of funds constraint, the representative entrepreneur also faces the following borrowing constraint:

$$I^e_{j,t} L^e_{j,t} \leq \nu_{e,jt}[\phi_k Q^k_{j,t+1} K_{j,t} + (1-\phi_k) Q^\psi_{j,t+1} \Psi^e_j], \tag{2.19}$$

where $Q^k_{j,t}$ is the nominal price of physical capital, $\nu_{e,jt}$ is the exogenous stochastic loan-to-value ratio, and $I^e_{j,t}$ is the gross nominal interest rate on entrepreneur bank loans ($L^e_{j,t}$). The value of physical capital ($Q^k_{j,t} K_{j,t}$) and the market value of the initial stock of entrepreneur equity ($Q^\psi_{j,t} \Psi^e_j$) serve as a measure of creditworthiness, where $\phi_k \in [0,1]$ is the weight on physical capital stock.

The first order conditions for labour, bank loans and physical capital are the following:

$$\frac{W_t}{P_t} = \frac{(1-\alpha) Y_{j,t}}{H_{j,t} X_{j,t}}, \tag{2.20}$$

$$\lambda^e_{j,t} = \frac{1}{I^e_{j,t}} - \beta_e E_t \left[\frac{P_t}{P_{t+1}} \right], \tag{2.21}$$

$$\begin{aligned} \frac{Q^k_{j,t}}{P_t} = \; & \beta_e E_t \Bigg[\left(\frac{\kappa_v}{\delta_e} \left(\frac{V_{j,t+1}}{K_{j,t}} - \delta_e \right) \frac{V_{j,t+1}}{K_{j,t}} - \frac{\kappa_v}{2\delta_e} \left(\frac{V_{j,t+1}}{K_{j,t}} - \delta_e \right)^2 \right) \\ & + \frac{Q^k_{j,t+1}}{P_{t+1}} (1-\delta_e) + \frac{\alpha Y_{j,t+1}}{X_{j,t+1} K_{j,t}} + \lambda^e_{j,t} \nu_{e,jt} \phi_k \frac{Q^k_{j,t+1}}{P_{t+1}} \Bigg], \end{aligned} \tag{2.22}$$

where $\lambda^e_{j,t}$ is the Lagrangian multiplier of the borrowing constraint. Eq. 2.20 is the standard labour demand schedule. Eq. 2.22 is the investment schedule, indicating that the shadow price of capital must equal the expected marginal product of capital plus the discounted expected shadow price and capital adjustment costs.

2.3.6 Loan and deposit demand

Following Gerali et al. (2010), I adopt a Dixit-Stiglitz framework for the credit market. The retail branch of bank j provides a basket of differentiated deposits ($D_{j,t}$) and loan contracts with households ($L^h_{j,t}$) and entrepreneurs ($L^e_{j,t}$). The deposit and loan demand schedules are

$$D_{j,t} = \left(\frac{i^d_{j,t}}{i^d_t} \right)^{-\varepsilon^d_t} D_t, \tag{2.23}$$

$$L^h_{j,t} = \left(\frac{i^h_{j,t}}{i^h_t} \right)^{-\varepsilon^h_t} L^h_t, \qquad L^e_{j,t} = \left(\frac{i^e_{j,t}}{i^e_t} \right)^{-\varepsilon^e_t} L^e_t, \tag{2.24}$$

[7] The usual binding constraint conditions apply (see Iacoviello, 2005, p. 743-4), while $(1/R^e - \beta_e) > 0$ must hold.

where $D_t = D_t^s \; \forall \; j \in [0,1]$. ε_t^d, ε_t^h and ε_t^e are the stochastic elasticities of substitution for deposits, household loans and entrepreneur loans respectively. The interest rates are set by bank j. When setting interest rates the stochastic elasticities influence the aggregate markups for deposits and loans, which in turn, attenuate or exacerbate the pass-through effect of monetary policy.

2.3.7 Banking sector

The banking sector setup is along the lines of Gerali et al. (2010), in which there is a continuum of monopolistically competitive commercial banks. Each bank $j \in [0,1]$ consists of a perfectly competitive wholesale branch and two monopolistically competitive retail branches, namely a loan branch and a deposit branch. Banks issue loans to households and entrepreneurs. Assets (both household and entrepreneur loans) are funded by deposits and bank capital. Banks have the market power to set interest rates subject to a quadratic cost.

I introduce the equity price channel into the banking sector in the following way: bank capital is accumulated through previous period bank capital, changes in market capitalization of bank equity and retained earnings (see Eq. 2.27). The equity price channel therefore plays a key role in determining credit supply through bank capital requirements and bank funding (i.e., the bank capital channel). For instance, a negative equity price shock worsens the capital-asset ratio. In order to bring the capital-asset ratio back to the target, banks have to reduce credit extension. One way to do this is to raise the cost of credit, resulting in a downward pressure on credit demand. Moreover, the binding bank balance sheet automatically reduces the feasible supply of credit—equivalent to a leftward shift in the credit supply schedule which, in turn, adversely affects household consumption and entrepreneur production.

It is worth noting that in the model developed here, bank deposits are not only one form of financial wealth for households, but also one form of bank funds on the liability side of banks' balance sheets. Therefore, changes in deposits affect households' utility and banks' ability to extend credit.

Wholesale branch

The mandate of the wholesale branch is to manage the consolidated balance sheet of bank j. The movement of funds between the branches of bank j are as follows. The wholesale branch accepts deposits from the retail deposit branch at the wholesale deposit rate i_t^d. The retail loan branch receives wholesale loans and remunerates the wholesale branch at i_t^l. The wholesale branch therefore chooses wholesale loans (L_t) and deposits (D_t) to maximize

$$E_0 \sum_{t=0}^{\infty} \beta_B^t \left[i_t^l L_t - i_t^D D_t - \frac{\kappa_k}{2} \left(\frac{K_t^B}{L_t} - \tau \right)^2 K_t^B \right] \tag{2.25}$$

subject to the binding balance sheet identity

$$L_t = K_t^B + D_t, \tag{2.26}$$

where K_t^B is the total bank capital. The coefficient κ_k captures the quadratic adjustment cost of the deviation of the current capital-to-asset ratio (K_t^B/L_t) from a target minimum capital requirement ratio (τ), according to the Basel regulations.

The bank capital accumulation equation is as follows:

$$K_t^B = (1-\delta_B)K_{t-1}^B + \phi_B(Q_t^{\psi} - Q_{t-1}^{\psi})\Psi^B + (1-\phi_{\psi})\omega_{B,t-1}, \tag{2.27}$$

where, analogous to entrepreneurs, the initial stock of bank equity (Ψ^B) remains unchanged. What matters here is the market capitalization of bank equity $(Q_t^{\psi}\Psi^B)$. The higher the market capitalization of bank equity is, the more bank capital will be accumulated and, in turn, the more credit banks will be able to supply. ϕ_B measures the pass-through effect of equity price changes on total bank capital. Retained earnings are the consolidated profits $(\omega_{B,t-1})$ of bank j net of dividend payments, where ϕ_{ψ} is the share of bank profits paid out as dividends to households. δ_B captures sunk costs for bank capital management.

Combining the first-order conditions for loans and deposits gives the spread between the competitive wholesale loan rate and the wholesale deposit rate,

$$i_t^l = i_t^d - \kappa_k\left(\frac{K_t^B}{L_t} - \tau\right)\left(\frac{K_t^B}{L_t}\right)^2. \tag{2.28}$$

The banking sector is closed by assuming that wholesale branches have access to unlimited funds from the central bank at the policy rate i_t. Arbitrage in the interbank market will then drive the wholesale deposit rate i_t^d towards i_t.

Retail branches

The retail loan branch of bank j differentiates wholesale loans L_t at zero cost. These loans are then sold to households and entrepreneurs at their individual rates. The coefficients κ_h and κ_e capture the quadratic adjustment costs for household and entrepreneur loan rates. The retail loan branch's objective function is

$$\max_{\{i_t^h, i_t^e\}} E_0 \sum_{t=0}^{\infty} \beta_B^t \left[i_t^h L_t^h + i_t^e L_t^e - i_t^l L_t - \frac{\kappa_h}{2}\left(\frac{i_t^h}{i_{t-1}^h} - 1\right)^2 i_t^h L_t^h - \frac{\kappa_e}{2}\left(\frac{i_t^e}{i_{t-1}^e} - 1\right)^2 i_t^e L_t^e \right] \tag{2.29}$$

subject to demand schedules (2.24), with $L_t^h + L_t^e = L_t$.

In the symmetric equilibrium (for all loan types indexed $z = e, h$ and banks $j \in [0,1]$), the first-order conditions give the borrower households' and entrepreneurs' bank loan rates. The log-linearized equation for the loan rate can be written as

$$\begin{aligned} \hat{i}_t^z \;=\; & \frac{\kappa_z}{\varepsilon^z - 1 + (1+\beta_B)\kappa_z}\hat{i}_{t-1}^z + \frac{\beta_B\kappa_z}{\varepsilon^z - 1 + (1+\beta_B)\kappa_z}E_t\hat{i}_{t+1}^z \\ & + \frac{\varepsilon^z - 1}{\varepsilon^z - 1 + (1+\beta_B)\kappa_z}\hat{i}_t^l - \frac{\varepsilon_t^z}{\varepsilon^z - 1 + (1+\beta_B)\kappa_z}. \end{aligned} \tag{2.30}$$

Eq. 2.30 shows that loan rate setting depends on the stochastic markup, the past and expected future loan rates, and the marginal cost of the loan branch (the wholesale loan rate $\hat{i}^l_t$), which depends on the policy rate and the balance sheet position of the bank.[8]

The log-linearized equation for the deposit rate is

$$\hat{i}^d_t = \frac{\kappa_d}{1-\varepsilon^d+(1+\beta_B)\kappa_d}\hat{i}^d_{t-1} + \frac{\beta_B\kappa_d}{1-\varepsilon^d+(1+\beta_B)\kappa_d}E_t\hat{i}^d_{t+1} + \frac{1-\varepsilon^d}{1-\varepsilon^d+(1+\beta_B)\kappa_d}\hat{i}_t. \quad (2.31)$$

With flexible interest rates, Eq. 2.31 implies $\hat{i}^d_t = \hat{i}_t$. Gerali et al. (2010) show that the deposit rate is a markdown of the policy rate. However, based on the inspection of U.S. deposit rate data over the sample period 1982Q01−2012Q01, I find an aggregate steady-state markup of 0.16 percentage points over the federal funds rate. This implies that the retail deposit branch is indeed making a negligible loss based on the model's setup.

2.3.8 Monetary policy and market clearing conditions

The monetary authority follows a Taylor-type interest rate rule

$$I_t = (I_{t-1})^{\kappa_i}\left(\frac{\Pi_t}{\Pi^{target}}\right)^{\kappa_\pi(1-\kappa_i)}\left(\frac{Y_t}{Y_{t-1}}\right)^{\kappa_y(1-\kappa_i)}\xi_{i,t}, \quad (2.32)$$

where κ_i is the weight on the lagged policy rate, κ_π is the weight on inflation (Π_t), and κ_y is the weight on output growth. $\xi_{i,t}$ is the monetary policy shock following an AR(1) stochastic process.

The aggregate resource constraint for the economy is

$$Y_t = C_t + V_t + \delta_B\frac{K^B_{t-1}}{\Pi_t}, \quad (2.33)$$

where $C_t = C^s_t + C^b_t$ is aggregate consumption. In the equity market, as discussed in Section 2.3.2, $\Psi \equiv \Psi^B + \Psi^e = \Psi^s_t + \Psi^b_t$. The usual market aggregation applies for loans $(L_t = L^h_t + L^e_t)$ and labour $(H_t = H^s_t + H^b_t)$.

In a symmetric equilibrium, all entrepreneurs and bank retail branches make identical decisions, so that $Y_{j,t} = Y_t$, $K_{j,t} = K_t$, $H_{j,t} = H_t$, $V_{j,t} = V_t$, $P_{j,t} = P_t$, $Q^k_{j,t} = Q^k_t$, $D_{j,t} = D_t$, $L^e_{j,t} = L^e_t$, $L^h_{j,t} = L^h_t$ for j ∈ [0,1] and $t = 0, 1, 2 \ldots$.

2.4 Estimation

The model is estimated with Bayesian techniques using U.S. data over the sample period 1982Q01 −2012Q01.[9] Since the model has a total of nine shocks, the data set contains nine observable variables: output, inflation (GDP deflator), equity price, household loans, entrepreneur loans, deposits,

[8] With flexible interest rates, the loan rate is a markup over the marginal cost: $i^z_t = \frac{\varepsilon^z_t}{\varepsilon^z_t - 1} i^l_t$.

[9] The estimation is done using Dynare, developed by Michel Juillard and his collaborators at CEPREMAP.

Table 2.1: Calibrated parameters

Parameter	Description	Value
β_s	Discount factor for saver households	0.99
β_b	Discount factor for borrower households	0.96
β_e	Discount factor for entrepreneurs	0.95
η	Inverse of the Frisch elasticity	1
α	Capital share in the production function	0.33
δ_e	Capital depreciation rate	0.025
κ_v	Capital installation costs	2
ε^p	Price elasticity of demand for goods	11
R^ψ	Steady-state gross dividend yield	1.026
ε^e	Elasticity of substitution for entrepreneur loans	1.352
ε^h	Elasticity of substitution for household loans	1.436
τ	Capital requirement ratio	0.11
δ_B	Sunk costs for bank capital management	0.4
ϕ_ψ	Share of bank profits paid out in dividends	0.68
L^h/L	Households' share of total loans	0.45
L^e/L	Entrepreneurs' share of total loans	0.55
L/Y	Total loans-output ratio	1.5
C/Y	Consumption-output ratio	0.679
$Q^\psi\Psi/Y$	Total equity-output ratio	0.849

Note: Bank and retailer discount factors are equal to the saver household discount factor.

the Fed funds rate, the mortgage rate, and the Baa corporate rate. All variables except inflation and interest rates are converted in real terms using the GDP deflator. I take the log-difference of real variables prior to estimation.

2.4.1 Calibrated parameters

Table 2.1 lists the parameters that are calibrated prior to estimation. In the first block, the discount factor for saver households (β_s) is the reciprocal of the benchmark steady-state rate ($R = 1.01$). To guarantee that the borrowing constraints are binding, the discount factors for borrower households (β_b) and entrepreneurs (β_e) are calibrated to 0.96 and 0.95, respectively. As in Gerali et al. (2010), I assume that the bank's discount factor (β_B) and the retailer's discount factor (β_R) equal β_s. The inverse of the Frisch elasticity (η) is set to 1. The capital-output share α is set to 0.33, and the physical capital depreciation rate δ_e is set to 0.025. The parameter governing capital installation costs (κ_v) is set to 2 (see, for example, Iacoviello, 2005). A steady-state gross markup of $X = 1.10$ implies a price elasticity of demand for retail goods of $\varepsilon^p = 11$. The steady-state return to equity is calibrated from S&P500 dividend yield data (see, Shiller, 2005, updated).

The second block in Table 2.1 reports the relevant conditions of the U.S. banking sector and the steady-state ratios of the main aggregates. The elasticities of substitution for entrepreneur loans (ε^e) and household loans (ε^h) equal 1.352 and 1.436 respectively. The target capital requirement ratio τ equals 11%, reflecting the recent U.S. commercial banks' balance sheet condition. Based on Eq. 2.27, δ_B equates with the steady-state ratio of retained earnings to bank capital over the sample period 1982−2012 (FDIC, 2012). From 1982 to 2012, the average dividend to net income ratio for all U.S. commercial banks $\phi_\psi = 0.68$ (FDIC, 2012). Shares of household and entrepreneur loans to total bank loans, the total loans-output ratio, the consumption-output ratio, and the equity-output ratio are calculated using the data means over the sample period. I restrict any other steady-state ratios in the banking sector to be consistent with the balance sheet identity and the capital requirement.

2.4.2 Prior distributions and posterior estimates

The prior distributions of the structural parameters are reported in columns 3-5 in Tables 2.2 and 2.3. I assume that the coefficients of relative risk aversion (RRA) for savers and borrowers $\{\gamma^s, \gamma^b\}$ follow an inverse-gamma distribution with a mean of 3 and a standard deviation of 0.5. The prior on habit formation parameter ϕ is set at 0.5 with a standard deviation of 0.1. Prior means and standard deviations of the parameters in the Phillips Curve and the monetary policy rule are based on the estimates from Smets and Wouters (2007) and Christiano et al. (2010). The interest rate adjustment cost parameters $\{\kappa_k, \kappa_h, \kappa_e\}$ are assumed to follow a gamma distribution with a mean of 4 and a standard deviation of 2 (see also, Gerali et al., 2010). Based on recent data from the Federal Housing Finance Board, I choose a reasonable value of 0.75 as the prior mean for households' LTV (ν_h) and a more modest prior mean of 0.55 for entrepreneurs' LTV (ν_e) (see also, Gerali et al., 2010; Iacoviello and Neri, 2010). The weight on wages (ϕ_w) in the household borrowing constraint is set to 0.5 with a standard deviation of 0.05. This implies that the amount households can borrow depends equally on their wage income and on the market value of their equity holdings. A relatively higher weight on physical capital assets ($\phi_k = 0.8$) is imposed in the entrepreneur borrowing constraint. The prior mean of ϕ_B is set to 0.35 with a standard deviation of 0.05. Lastly, the prior distributions for the AR(1) coefficients and the standard deviations of the shocks are reported in columns 3-5 in Table 2.3.

The estimated posterior means and standard deviations for the structural parameters are reported in columns 6-9 in Tables 2.2 and 2.3. The estimated relative risk aversion coefficient for saver households (4.21) is higher than that for borrower households (2.69). This implies that saver households are less sensitive to financial market conditions and have a stronger preference for smoothing their lifetime consumption. The estimated consumption habit formation parameter ($\phi = 0.75$) is consistent with those in the literature (e.g., Uhlig, 2007; Christiano et al., 2010). The estimated parameters for price-setting and the monetary policy rule all conform well to the literature.

Table 2.2: Structural parameters

	Parameter	Prior distribution Type	Mean	Std.dev	Posterior distribution Mean	2.5%	Median	97.5%
Preferences								
γ_s	Saver RRA	Inv.Gamma	3	0.5	4.21	3.08	4.17	5.27
γ_b	Borrower RRA	Inv.Gamma	3	0.5	2.69	2.06	2.64	3.27
ϕ	Habit formation	Beta	0.5	0.1	0.75	0.70	0.75	0.79
Prices and wages								
θ_R	Price stickiness	Beta	0.7	0.05	0.86	0.84	0.86	0.88
γ_p	Degree of price indexation	Beta	0.5	0.05	0.62	0.54	0.62	0.70
Monetary policy rule								
κ_i	Coefficient on lagged policy rate	Beta	0.5	0.05	0.49	0.42	0.49	0.56
κ_π	Coefficient on inflation	Gamma	2	0.05	2.07	1.99	2.07	2.16
κ_y	Coefficient on output change	Beta	0.25	0.05	0.25	0.18	0.25	0.33
Credit and banking								
κ_h	HH loan rate adjust. cost	Gamma	4	2	3.59	1.58	3.40	5.84
κ_e	Entrep. loan rate adjust. cost	Gamma	4	2	0.87	0.45	0.83	1.23
κ_k	Leverage deviation cost	Gamma	4	2	9.11	6.44	8.93	12.1
ν_h	Households' LTV ratio	Beta	0.75	0.05	0.73	0.64	0.73	0.80
ν_e	Entrepreneurs' LTV ratio	Beta	0.55	0.05	0.51	0.42	0.51	0.60
ϕ_w	Weight on wages	Beta	0.5	0.05	0.43	0.38	0.43	0.48
ϕ_k	Weight on phys. capital	Beta	0.8	0.05	0.91	0.87	0.91	0.94
ϕ_B	Equity price pass-through	beta	0.35	0.05	0.35	0.28	0.35	0.42

The estimated parameter capturing the entrepreneur loan rate adjustment cost (0.87) is smaller than that of the household loan rate adjustment cost (3.59), reflecting more frequent adjustments of the Baa corporate rate to the changes in credit market condition, compared to that of the mortgage rate. Interestingly, both estimates in this paper for the U.S. economy are lower than those in Gerali et al. (2010) for the Euro area. The estimated parameter measuring the cost of deviating from targeted leverage is 9.11. The estimated LTV ratio for entrepreneurs (0.51) is lower than that of households (0.73), which suggests that households can more easily collateralize their loans. In fact, high estimates for ν_h and ν_e imply that changes to household creditworthiness and entrepreneur net worth have strong effects on aggregate demand and output. An estimated pass-through of equity price changes on bank capital accumulation $\phi_B = 0.35$ implies that, *ceteris paribus*, a 1% decrease in the equity price leads to a 0.35% decline in bank equity capital.

2.5 Results

In this section, I first assess the baseline New-Keynesian DSGE model with the equity price channel (BEP hereafter) by examining the dynamics of the model in response to a technology shock, a monetary policy shock, an equity price shock and a price markup shock. The main focus here

Table 2.3: Exogenous processes

	Parameter	Prior distribution Type	Mean	Std.dev	Posterior distribution Mean	2.5%	Median	97.5%
AR(1) coefficients								
ρ_z	Technology	beta	0.5	0.1	0.975	0.964	0.976	0.985
ρ_i	Monetary policy	beta	0.5	0.1	0.487	0.402	0.489	0.567
ρ_d	Deposit	beta	0.5	0.1	0.977	0.961	0.978	0.991
ρ_e	Entrep. loan markup	beta	0.5	0.1	0.672	0.598	0.677	0.746
ρ_h	Household loan markup	beta	0.5	0.1	0.558	0.451	0.555	0.675
ρ_{ν_h}	Households' LTV	beta	0.5	0.1	0.922	0.892	0.922	0.951
ρ_{ν_e}	Entrepreneurs' LTV	beta	0.5	0.1	0.972	0.957	0.973	0.988
ρ_ψ	Equity	beta	0.5	0.1	0.938	0.921	0.938	0.953
ρ_p	Price markup	beta	0.5	0.1	0.584	0.495	0.589	0.666
*S*tandard deviations								
ϵ_z	Technology	Inv.Gamma	0.01	inf	0.024	0.019	0.023	0.028
ϵ_i	Monetary policy	Inv.Gamma	0.01	inf	0.009	0.008	0.009	0.011
ϵ_d	Deposit	Inv.Gamma	0.01	inf	0.007	0.007	0.007	0.008
ϵ_e	Entrep. loan markup	Inv.Gamma	0.01	inf	0.006	0.004	0.005	0.007
ϵ_h	Household loan markup	Inv.Gamma	0.01	inf	0.014	0.007	0.014	0.021
ϵ_{ν_h}	Households' LTV	Inv.Gamma	0.01	inf	0.012	0.010	0.012	0.013
ϵ_{ν_e}	Entrepreneurs' LTV	Inv.Gamma	0.01	inf	0.013	0.011	0.013	0.015
ϵ_ψ	Equity	Inv.Gamma	0.01	inf	0.003	0.002	0.003	0.004
ϵ_p	Price markup	Inv.Gamma	0.01	inf	0.001	0.001	0.001	0.001

is on how the equity price channel affects the business cycle through the direct wealth effect on consumption, the financial accelerator channel and the bank capital channel. I then study the role of equity in borrower creditworthiness and bank capital accumulation. Finally, in order to complement the quantitative analysis, I carry out the robustness analysis for the model, and report the cyclical properties of the equity price.

In order to draw more valuable insights from the model, I compare the BEP model with two alternative versions of the model: the model without the equity price channel (NEP hereafter) and the flexible interest rate model (FI hereafter). For the NEP model, the equity market is taken out of the model completely. That is, equity assets are no longer part of households' financial wealth and no longer serve as a measure of creditworthiness for borrower households and entrepreneurs. In addition, bank equity is not being used to accumulate bank capital. For the FI model, there are no quadratic interest rate adjustment costs, i.e. $\kappa_h = \kappa_e = 0$.

2.5.1 The equity price channel

As shown in Figures 2.4 and 2.5, it is clear that the equity price channel amplifies and propagates shocks to the real economy through both financial accelerator and bank capital channels.[10]

[10]Figure 2.4 reports the impulse responses of output, policy rate, equity price and inflation to each shock listed from column one to four, whereas Figure 2.5 reports the impulse responses of the banking sector variables. As the impulse

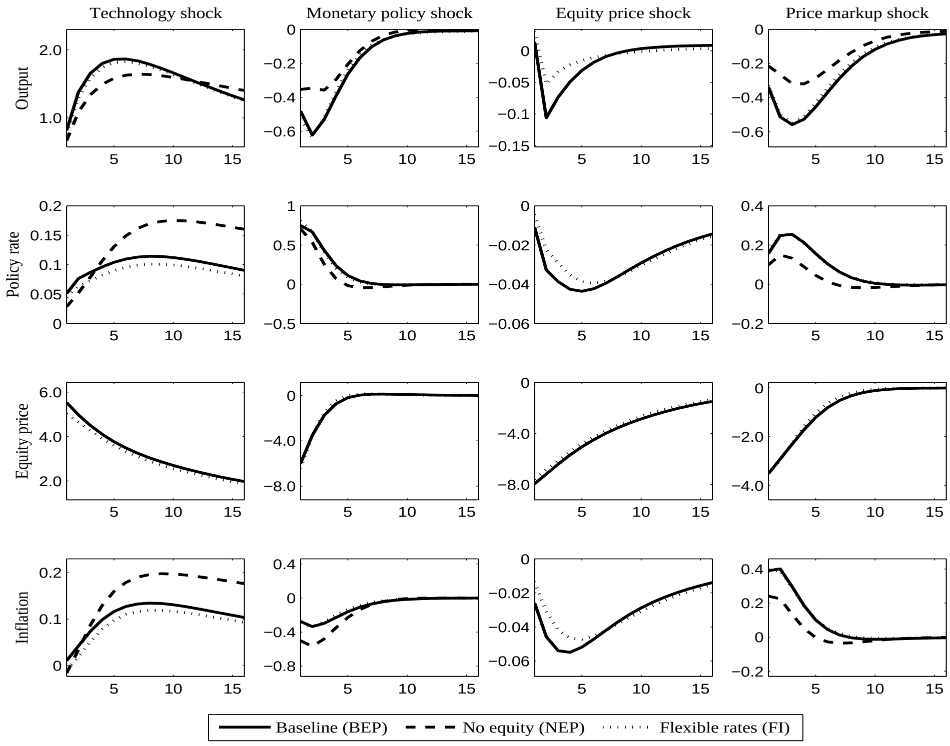

Figure 2.4: Impulse responses for the main macroeconomic aggregates

In response to a positive technology shock, the equity price rises. On the one hand, a bullish equity market increases the creditworthiness of borrower households and entrepreneurs and, in turn, increases credit demand (the financial accelerator channel). On the other hand, banks are able to meet the increase in credit demand because the bullish equity market raises bank capital and, hence, the feasible quantity of credit supply (the bank capital channel). The upward shift of the credit demand and supply schedules increases total loans, which stimulates entrepreneurs' investment in production activities and allows households to increase their current consumption.

The equity price channel weakens the counter-cyclicality of the capital-asset ratio. The technology shock produces a counter-cyclical capital-asset ratio for the U.S. economy (see also, Meh and Moran, 2010). As the capital-asset ratio falls below the capital requirement over-leveraged banks put upward pressure on retail loan rates, which raises the cost of credit and, at the same time, increases the profitability of the marginal loan (that is, a widening of credit spreads). Banks therefore adjust their capital-asset ratios back to the regulatory requirement, dampening the credit expansion. Including common equity in bank capital accumulation weakens the counter-cyclicality

responses of household loans are qualitatively similar to those of entrepreneur loans, I report the results for entrepreneur loans only.

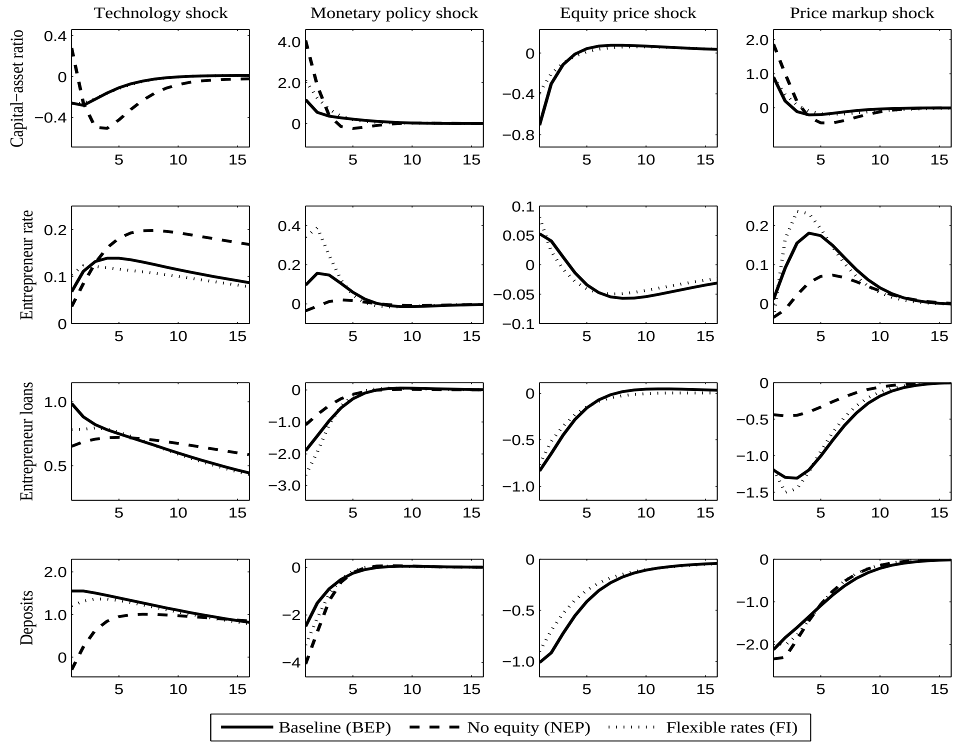

Figure 2.5: Impulse responses for the banking sector variables

of the capital-asset ratio (BEP versus NEP, first row in Figure 2.5). This reflects the increasing emphasis on common equity capital in Basel regulations, whereby equity serves as a shock absorber for capital deficiencies. The equity price channel is therefore beneficial in terms of financial stability, but amplifies and propagates shocks to the real economy.

Similarly, the dynamics of the model in response to a negative equity price shock mimics that of a negative technology shock (see also, Castelnuovo and Nisticò, 2010). Due to the direct wealth effect, a negative equity price shock decreases households' consumption and, hence, output. The deterioration of banks and borrowers' balance sheets exacerbates the decline in real economic activity. As a result, the decline in both output and inflation leads to a reduction of the policy rate. But, at the same time, the decline in the value of common equity reduces bank capital, which causes banks to become over-leveraged. A decrease in the capital-asset ratio therefore drives a positive wedge between long-term retail loan rates and the policy rate—as a result, the attempt to reduce the cost of credit is curtailed.

For a positive monetary policy shock and price markup shock, we observe similar dynamics for the real economy: a decline in output. Moreover, the decline in output is greater with the BEP model than that with the NEP model. For the credit market, on the demand side, the equity price channel significantly influences the creditworthiness of borrowers. On the supply side, equity price movements have a strong influence on bank funding through bank equity capital. As a result, the equity price channel amplifies and propagates shocks to bank loans: the decrease in entrepreneur loans is more severe with the BEP model than that with the NEP model.

2.5.2 The role of equity in borrower creditworthiness and bank capital accumulation

In this section I investigate the role of equity in borrower creditworthiness and bank capital accumulation. To do so, I estimate and compare two alternative models to the baseline BEP model. In the first alternative model (ALT1 hereafter) I take equity out of the household's and entrepreneur's borrowing constraints (i.e., $\phi_k = \phi_w = 1$). In the second alternative model (ALT2 hereafter) there is no equity in bank capital accumulation (i.e., $\phi_B = 0$). Figure 2.6 displays the estimated impulse response to a negative equity price shock for ALT1, ALT2 and BEP models.

Based on the results, we can conclude that the equity price channel amplifies and propagates the shock to the real economy mainly through the bank capital channel: the responses of output with the ALT1 and BEP models are qualitatively and quantitatively the same, and are stronger than that with the ALT2 model, in which equity plays no role in bank capital accumulation. This conclusion is supported by the results for both entrepreneur and household loans: their decline in response to the shock with the BEP model is larger than that with the ALT2 model. Without equity in bank capital accumulation, the response of loan rates is much stronger than that with the BEP model. As a result, there is a less severe decline in bank loans.

Equity plays a critical role in determining the impact of a negative equity price shock on the capital-asset ratio through the bank capital channel. Without equity in bank capital accumulation (in ALT2), the capital-asset ratio increases in response to a negative equity price shock, as opposed to a decline with the ALT1 and BEP models. This is because a decrease in equity prices results in a decline in bank assets through the role of equity in borrower creditworthiness, while the shock does not have a direct impact on bank capital. In order to bring the capital-asset ratio back to its target, banks have to adjust loan rates more heavily than otherwise (ALT2 versus BEP). The same applies to the monetary authority in adjusting the policy rate in response to the shock. Compared to the ALT2 model, the opposite responses of policy and loan rates with the ALT1 model are due to both the increase in inflation and the decline in the capital-asset ratio.

Equity plays a significant role in borrower creditworthiness in affecting interest rates and inflation. In other words, the equity price channel amplifies and propagates the shock to the policy rate, both loan rates and inflation mainly through the financial accelerator channel. It is worth noting that, compared to entrepreneur loans, equity plays a more significant role in amplifying the financial accelerator effect on household loans. This is due to the estimated weight on equity assets in the household's borrowing constraint, which is much higher than that in the entrepreneur's

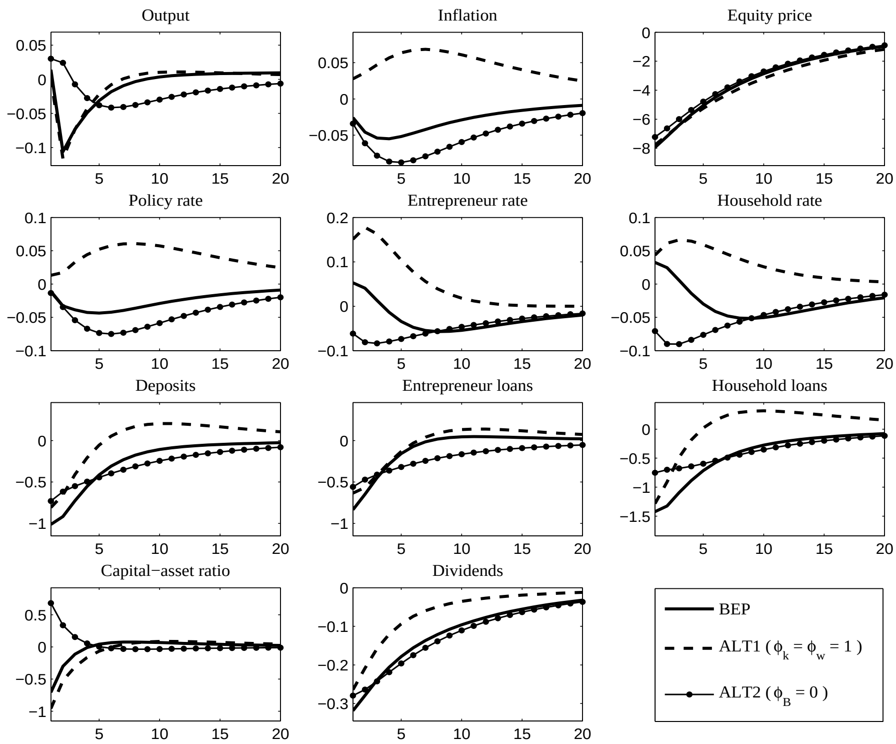

Figure 2.6: Impulse response to a negative equity price shock

borrowing constraint.[11]

To provide an additional frame of reference, I estimate a vector autoregression (VAR) with the same data set and sample period used in the DSGE model estimation.[12] Figure 2.7 displays the VAR impulse responses to a negative equity price shock. The responses of output, interest rates and loans from the estimated BEP model are all quantitatively and qualitatively similar to those from the estimated VAR. A few points are worth noting here. Firstly, in response to a negative equity price shock, the contraction of loans to households and entrepreneurs reflects an important role of equity in borrower creditworthiness. Secondly, the strong positive correlation between output and equity prices highlights the direct financial wealth effect on consumption and, hence, output. Thirdly, the impulse responses of deposits from the estimated DSGE models are inconsistent with that from the estimated VAR. Neither the BEP model nor the two alternative models capture the initial substitution effect between deposits and equity.[13] This is because, in the DSGE model setup, the binding bank balance sheet identity constrains the substitutability of

[11] See Table 2.2.

[12] The VAR contains two lags of each variable.

[13] That is, in response to a collapse in equity prices, households initially shift from equity assets to risk-free deposit holdings.

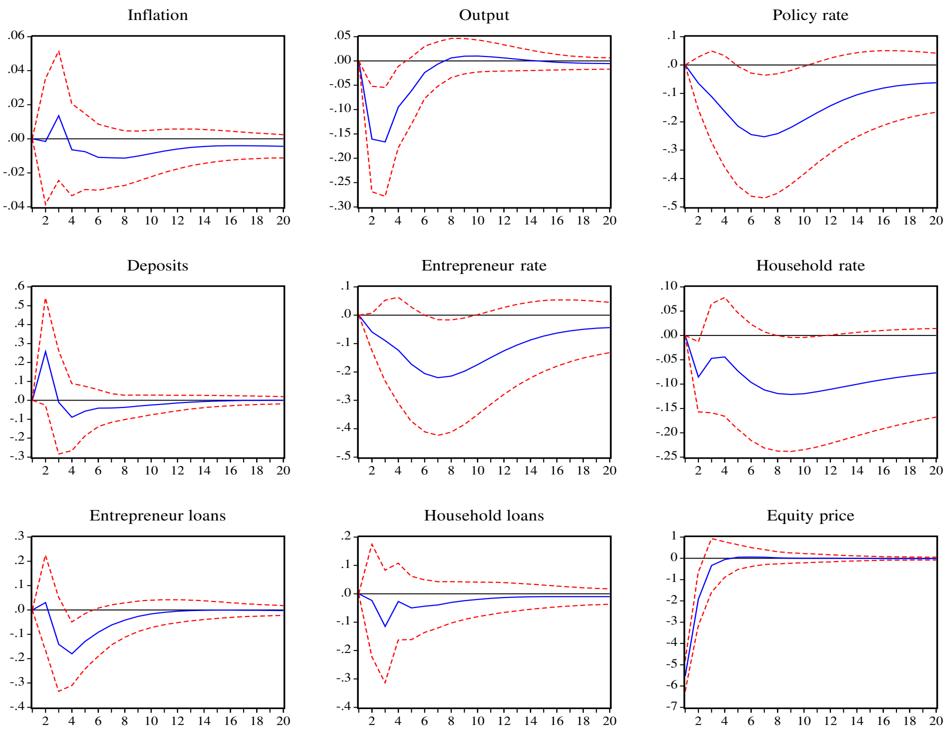

Figure 2.7: VAR impulse response to a negative equity price shock

equity assets with deposit holdings.

2.5.3 Robustness analysis

To perform the robustness analysis, I compare the posterior estimates of the parameters of the BEP, NEP and FI models. Overall, as reported in Table 2.4, most of the parameter estimates are consistent across models. Some interesting points are worth noting here. The estimated relative risk aversion coefficients for both borrowers and savers for the BEP model are greater than those for the NEP model. This reflects the fact that households are more risk averse if they invest in the equity market. As argued by Cochrane (2008), a high degree of risk aversion is needed to explain the high risk premium. The estimated κ_k for the NEP model is 5.27, whereas the estimate is 9.11 for the BEP model. This decline in the capital adjustment cost parameter in the NEP model reflects the significance of the equity price channel on bank capital. The same is observed in the FI model. The estimated LTV ratios for entrepreneurs (ν_e) and households (ν_h) are consist with the findings in the literature, and vary slightly across the models.

The dynamics of the model reported in Section 2.5.1 also shows that the model developed here (BEP) is robust. Overall, the BEP model with the equity price channel performs well. The responses of the main macroeconomic variables to each of the shocks are intuitive, and conform

Table 2.4: Alternative model estimated parameter comparisons

	Posterior distribution means				Posterior distribution means		
	Benchmark BEP	No equity NEP	Flexible rates FI		Benchmark BEP	No equity NEP	Flexible rates FI
Parameters				AR(1) processes			
γ_s	4.215	3.881	3.349	ρ_z	0.975	0.976	0.952
γ_b	2.691	2.000	2.458	ρ_i	0.487	0.463	0.464
ϕ	0.746	0.707	0.693	ρ_d	0.977	0.935	0.946
θ_R	0.861	0.819	0.867	ρ_e	0.672	0.451	0.724
γ_p	0.623	0.691	0.644	ρ_h	0.558	0.533	0.747
κ_i	0.493	0.496	0.446	ρ_{ν_h}	0.922	0.928	0.905
κ_π	2.071	2.088	2.082	ρ_{ν_e}	0.972	0.935	0.936
κ_y	0.253	0.247	0.260	ρ_ψ	0.938	-	0.899
κ_h	3.592	3.617	-	ρ_p	0.584	0.545	0.533
κ_e	0.869	2.939	-	ϵ_z	0.024	0.016	0.019
κ_k	9.111	5.274	4.095	ϵ_i	0.009	0.010	0.010
ν_h	0.728	0.739	0.781	ϵ_d	0.007	0.008	0.008
ν_e	0.508	0.295	0.526	ϵ_e	0.006	0.013	0.003
ϕ_w	0.428	-	0.430	ϵ_h	0.014	0.014	0.003
ϕ_k	0.907	-	0.897	ϵ_{ν_h}	0.012	0.022	0.010
ϕ_B	0.352	-	0.228	ϵ_{ν_e}	0.013	0.008	0.012
				ϵ_ψ	0.003	-	0.004
				ϵ_p	0.001	0.001	0.001

Note: I exclude parameter descriptions, prior means and standard deviations, and statistical confidence intervals in the table, due to the limited space. (see Tables 2.2 and 2.3)

to the findings in the literature (eg. Castelnuovo and Nisticò, 2010).

2.5.4 Cyclical properties of the equity price channel

This section studies the cyclical properties of equity price. First, I compare the standard deviations of a variable, $\sigma(X)$, relative to that of output from the data and those from the model. Thereafter, I compare correlations of equity price with interested variables from the data and those from the model.

Panel A in Table 2.5 reports the results for the U.S. data. Over the sample period 1982Q01–2012Q01, equity prices are nine times as volatile as output, while investment and bank capital are four and two times as volatile. The relative variation of consumption to output is slightly less than one. Equity prices are persistent at one-step and two-step autocorrelations, and are positively correlated with all the variables. In addition, equity prices tend to be a leading indicator of the other variables.

Panel B reports the results from the model. Firstly, the generated volatilities of the variables are consistent with those from the data. Secondly, for all the variables the model replicates the strong positive correlation with equity price observed from the U.S. data.

Table 2.5: Cyclical properties of equity price

Variable	$\frac{\sigma(X)}{\sigma(Y)}$	*Correlation of equity price with*				
		X_{t-2}	X_{t-1}	X_t	X_{t+1}	X_{t+2}
Panel A: U.S. data						
Equity price	9.29	0.59	0.83	1	0.83	0.59
Consumption	0.79	0.28	0.42	0.57	0.60	0.56
Investment	4.04	0.21	0.33	0.47	0.57	0.61
Bank Capital	2.01	0.23	0.15	0.31	0.37	0.38
GDP	1	0.27	0.41	0.55	0.61	0.56
Panel B: Model economy						
Equity price (Q_t^{ψ})	6.87	0.87	0.94	1	0.94	0.87
Consumption (C_t)	1.14	0.68	0.75	0.82	0.80	0.77
Investment (V_t)	2.64	0.42	0.45	0.48	0.48	0.49
Bank Capital (K_t^B)	1.43	0.46	0.56	0.66	0.61	0.58
Output (Y_t)	1	0.68	0.76	0.83	0.82	0.79

Notes: For the U.S. data, all series are detrended using the HP filter. For the model, I use the smoothed variables predicted from the posterior estimates. Equity price and output are observable variables in estimation though.

Overall, the model does well in terms of reproducing the strong procyclicality of the equity market. Furthermore, for both the data and the model equity price is shown to be a leading indicator of the other variables. These results reaffirm the relevance of the equity price channel in a general equilibrium model.

2.6 Concluding remarks

This paper highlights the equity price channel as a different aspect to general equilibrium models with financial frictions. Indeed, as with other general equilibrium models in the literature, the model developed here lacks a comprehensive description of complex stock price dynamics. Rather, the focus here is on the implication of introducing the equity price channel into a general equilibrium model: how the equity price channel affects consumption, production and banking activities. I show that a New-Keynesian DSGE model with an equity price channel reproduces the U.S. business cycle well. The model also does well in terms of reproducing the strong procyclicality of the equity market.

The equity price channel amplifies and propagates shocks to the real economy through both the financial accelerator channel and the bank capital channel. Equity plays a significant role in amplifying the financial accelerator effect on interest rates, inflation and household loans. Due to the direct wealth effect, a negative equity price shock decreases households' consumption and, hence, output. The equity price channel weakens the counter-cyclicality of bank capital-asset ratios. Equity serves as a shock absorber for capital deficiencies, which reflects the increasing emphasis on common equity capital in Basel regulations. This is beneficial in terms of financial stability, but amplifies and propagates shocks to the real economy.

Chapter 3

Credit spread variability in U.S. business cycles: the Great Moderation versus the Great Recession

3.1 Introduction

The objective of this paper is to establish the prevailing financial factors that influence credit spread variability, and the mechanisms through which shocks impact credit spread variability over the Great Moderation and Great Recession periods. I specifically look at demand- and supply-side credit market frictions, the equity market and bank balance sheet adjustments. Furthermore, I investigate whether there are any contributing financial factors to credit spread variability in the recent 2007−09 Great Recession that can be distinguished from the 1990−91 and 2001 recessions during the Great Moderation. By answering these questions we gain insight into the key financial factors that propagate and amplify financial stress to the real economy.

One notable recurring characteristic of financial stress in recessions is the widening of credit spreads. Since the financial crisis reared its head in August 2007, systemic disruptions to financial intermediation have shown how large variations in credit spreads dislocate the interaction between short-term interest rates and real economic activity. The recent crisis has also called into question the lack of a prominent role for financial intermediation and multiple interest rates in dynamic macroeconomic models, and subsequently, the effectiveness of the interest-rate policy of central banks (Woodford, 2010; Gertler and Kiyotaki, 2011). Similarly, the role of the equity market cannot be ignored. As pointed out by Brunnermeier (2009) and Adrian and Shin (2011), both credit spreads and equity markets exhibited significant financial stress during the Great Recession of 2007−09, and both significantly affected real economic activity and the business cycle (see, Castelnuovo and Nisticò, 2010; Gilchrist and Zakrajšek, 2012). In fact, the 1990−91 and 2001 recessions during the Great Moderation exhibited similar financial stress through widening credit spreads and collapsing equity prices. Farmer (2012b) goes further and argues that it is the stock

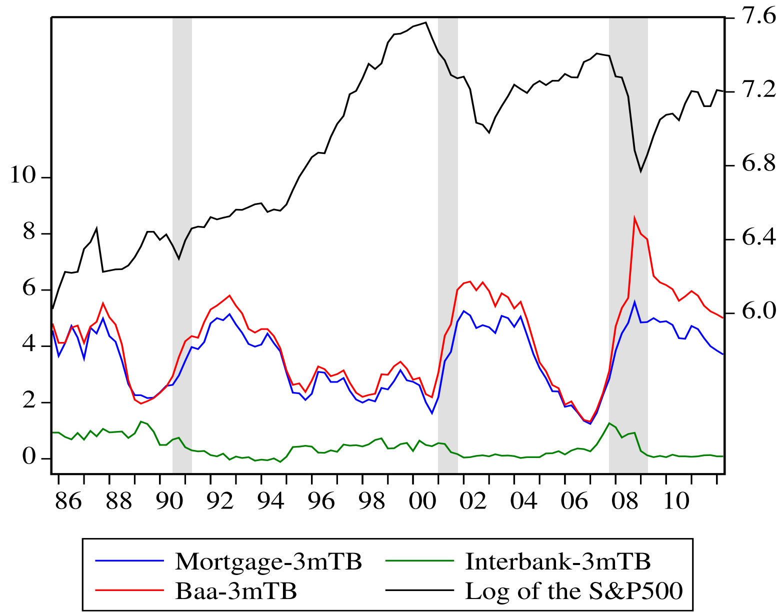

Figure 3.1: Financial markets and the U.S. business cycle

market crash of 2008, triggered by a collapse in house prices, that caused the Great Recession.

Collapsing equity prices and widening credit spreads tend to occur at the same time. To illustrate the behaviour of credit spread variability and equity prices, Figure 3.1 plots the logarithm of the S&P500, two retail credit spreads (the difference of the mortgage loan rate and the 3-month Treasury Bill rate and the difference of the Baa corporate bond rate and the 3-month Treasury Bill rate) and the interbank credit spread (the difference of the interbank rate and the 3-month Treasury Bill rate).[1] Two observations are worth noting here. Firstly, the recessions (grey areas) of 1990−91, 2001 and 2007−09 coincided with equity price collapses (from recession peak to S&P500 trough) of 14.7% (1990−91), 11.91% (2001) and 48.82% (2007−09), respectively.[2] Secondly, significant credit spread widening occurred during all three recession periods.

Equity plays an important role in bank capital accumulation too. Figure 3.2 shows the composition of bank capital over the sample period of 1982−2012.[3] Over the period 1982Q2−2003Q4 the total bank capital structure of all commercial banks in the U.S. consistently comprised of, approximately, 55% equity capital stock and 45% retained earnings.[4] However, since 2003Q4 the ratios diverged considerably, with equity surplus peaking at 77.3% and retained earnings declin-

[1]Data source: Federal Reserve Bank of St. Louis's FRED database. See Section 3.4 for the definition of the interbank rate.

[2]The total equity price collapses were: 14.78% (Jun '90−Oct '90), 29.68% (Aug '00−Sept '01), and 50.82% (Oct '07−Mar '09).

[3]Data source: Federal Deposit Insurance Corporation (FDIC, 2012).

[4]The commercial banking sector's equity capital stock is calculated by summing the aggregate values of the preferred stock, the common stock at par, and the market value of the common equity surplus.

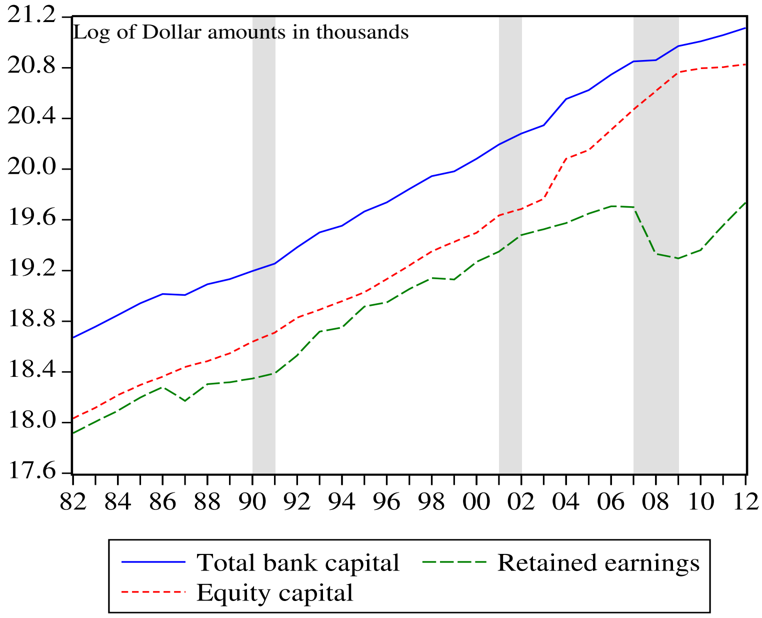

Figure 3.2: Composition of bank capital for all U.S. commercial banks

ing to 18.7% by the end of 2009. This simple exercise shows a significant structural shift towards greater common equity capital leverage in U.S. commercial banks.

A volume of research on financial factors emphasizes both credit demand- and supply-side restrictions that exacerbate the business cycle. For example, creditworthiness and net worth constrain the borrowing ability of households and firms (Bernanke et al., 1999; Iacoviello, 2005), while bank capital requirements, interest rate stickiness and value-at-risk constraints impose frictions in financial intermediaries (Gerali et al., 2010; Adrian and Shin, 2011). Although demand-side factors are important for financial accelerator effects, the consensus highlights the importance of financial intermediaries in propagating financial instability to real economic activity—through both the composition of balance sheet aggregates and the widening of credit spreads. Some studies focus on how to curtail the effects of credit market frictions or bank balance sheet adjustments on real economic activity through either conventional or unconventional monetary policies. Cúrdia and Woodford (2010) use a basic New-Keynesian model with credit frictions and minimal financial intermediary structures to investigate the interaction between credit spread variability and monetary policy. Adrian and Shin (2011) and Gertler and Kiyotaki (2011) centralize the role of financial intermediation in macroeconomic models to conform more closely to current institutional realities. While these two studies successfully highlight potential causes and consequences of the recent U.S. credit cycle, their frameworks have yet to be fully adapted to the New-Keynesian framework. It is clear though, there have been significant changes in financial intermediation over the last three decades. What is unclear is whether the transmission mechanism of financial intermediation has evolved over the Great Moderation and Great Recession periods (Ireland, 2011, p.52).

To understand the sources of credit spread variability, and the mechanisms through which they impact credit spread variability, I develop a New-Keynesian dynamic stochastic general equilibrium (DSGE) model with a central role for financial intermediation and equity markets. On the one hand, the model captures how financial intermediaries adjust interest rates in response to their own balance sheet adjustments and that of nonfinancial borrowers. This is along the lines of Bernanke and Gertler (1995), in which the authors argue that the balance sheet channel (financial accelerator channel) is one of the two important mechanisms through which monetary policy affects the size of the external finance premium in credit markets and, hence, real economic activity.[5] On the other hand, the model reveals an important role for equity prices in affecting real economic activity through the financial accelerator channel and the bank capital channel.

The contribution of the paper is two-fold. Firstly, it synthesizes recent milestones in the New-Keynesian DSGE literature on financial intermediation (e.g., Cúrdia and Woodford, 2009; Gerali et al., 2010) and the fundamental factors of the Great Recession in the U.S. economy (e.g., Ireland, 2011; Farmer, 2012b). That said, I present a centralized framework of financial intermediaries' interest rate setting behaviour in the transmission of nominal, real and financial shocks. In terms of the model setup, this paper contributes to the DSGE literature by introducing a role for the equity market in households, firms and banks' resource allocation. For the second contribution, I investigate whether financial factors that affect credit spread variability and their behaviour have fundamentally changed over the the Great Moderation and the Great Recession periods.

The results show that supply-side factors are the primary source of credit spread variability, which is along the lines of Gilchrist and Zakrajšek (2012). That is, retail loan markups account for more than half of the variability of retail credit spreads and sticky rate adjustments significantly alter the path of retail loan rates relative to the policy rate. Monetary policy has a strong influence on the short-term interbank rate, whereas the effectiveness of interest-rate policy on long-term nonfinancial loan rates is much weaker. Equity prices exacerbate movements in credit spreads through the financial accelerator channel, but cannot be regarded as a main driving force of credit spread variability. Both the financial accelerator and bank capital channels play a significant role in propagating the movements of credit spreads. In contrast to Ireland (2011), I observe a remarkable decline in the influence of technology and monetary policy shocks over three recession periods. From the demand-side of the credit market, the influence of LTV shocks has declined since the 1990−91 recession, while the bank capital requirement shock exacerbates and prolongs credit spread variability over the 2007−09 recession period. Moreover, across the three recession periods, there is an increasing trend in the contribution of loan markup shocks to the variability of retail credit spreads.

[5] The other mechanism is the bank lending channel.

The rest of the paper is organized as follows. Section 3.2 defines the credit spread transmission mechanism of financial intermediation. Section 3.3 develops the New-Keynesian DSGE model with financial market interactions, and Section 3.4 presents the Bayesian estimation results. Sections 3.5.1 investigates financial factors that affect credit spread variability, and Section 3.5.2 compares the influence of financial factors on credit spread variability over the Great Moderation and Great Recession periods. Section 3.5.3 provides a robustness analysis of the baseline model. Section 3.6 concludes.

3.2 The transmission mechanisms of credit spread variability

In this section I define the four transmission mechanisms of credit spread variability in the DSGE model with credit and banking. On the supply side of the credit market we have bank market power and bank balance sheet adjustments. On the demand side, we have the creditworthiness of nonfinancial borrowers (the financial accelerator channel). The fourth transmission mechanism is the equity price channel.

Credit supply factors fall under two types of banking operations. On the one hand, commercial banks are monopolistically competitive, and supply long-term loans to nonfinancial borrowers (households and entrepreneurs) in the retail market. Credit spread variability arises from interest-rate stickiness and stochastic retail rate markups. This bank market power is the mechanism by which long-term retail loan rates adjust disjointedly to short-term interest rates. Investment banks, on the other hand, provide short-term funding to commercial banks in the interbank market, and finance their interbank lending with deposits and bank capital.

In the interbank market, bank capital-asset requirements influence the adjustment of the effective interbank rate. Because investment bank assets are subject to a bank capital-asset requirement, for a given quantity of bank capital, the supply schedule for interbank funds will be upward sloping (Woodford, 2010, p.31-32). In contrast, the downward sloping demand schedule for interbank funding depends on the quantity of available interbank funds at any given retail credit spread. The intersection of the supply and demand schedules determines the equilibrium quantity of interbank funds and the prevailing credit spreads. Shocks to bank funding (either deposits or bank capital) therefore directly affect the supply of liquidity to nonfinancial borrowers. As a result, financial intermediation in the interbank market and in the retail credit market has a direct impact on the efficient allocation of resources in real economic activity (Woodford, 2010, p.29-35).

The financial accelerator channel captures the demand side transmission mechanism of credit spread variability. Here, household creditworthiness and entrepreneur net worth influence the external finance premium.[6] That is, the ability of borrowers to collateralize their external financing is inversely related to the cost of credit (Bernanke and Gertler, 1995, p.35). As a result, low net

[6] The external finance premium is the difference between the cost of external financing (equity or debt) and internal financing (retained earnings).

worth or collateral during recessions causes credit spreads to widen. Conversely, during boom phases improved creditworthiness causes credit spreads to narrow.

I identify the equity price channel as a separate transmission mechanism in credit spread variability. The price of equity is determined by households' demand for equity investment. To generate the strong correlation between equity prices and credit spreads (Figure 3.1) I provide a role for equity in nonfinancial borrowers' creditworthiness and bank capital. As a result, the equity price channel influences credit spreads through both the financial accelerator channel and the bank capital channel. For example, an equity price collapse reduces borrower creditworthiness which puts upward pressure on retail credit spreads from the demand side. On the supply side, a fall in the bank capital-asset ratio induces financial distress in over-leveraged banks, which widens the interbank spread.

3.3 The model economy

To begin with, the credit spreads in this study are defined as follows. The spread between the policy rate and the interbank rate is the interbank credit spread, whereas the spread between the interbank rate and the long-term retail loan rate is the retail credit spread.[7]

Households borrow bank loans to finance their consumption, hold safe assets (e.g., bank deposits and government bonds), and invest in the equity market. Entrepreneurs demand homogenous labour to produce wholesale goods. Monopolistically competitive branders in the retail goods sector introduce Calvo-type sticky prices, whereas unions aggregate labour supply and introduce the Calvo-type sticky wages in the model. The model is closed by assuming that the monetary authority follows the conventional Taylor-type monetary policy rule.

3.3.1 Financial intermediation

There is a continuum of bank units, where each bank $j \in [0, 1]$ consists of an investment bank and a commercial bank. The commercial bank is assumed to be a wholly-owned subsidiary of the investment bank, and the consolidated profits are used as retained earnings at the end of each period (see, Gerali et al., 2010).

3.3.1.1 Investment Bank

The investment bank chooses household safe assets (B_t) and the amount of interbank lending to commercial banks (L_t^c) to maximize periodic discounted cash-flows:

[7] In the literature, the net interest spread is the difference between the rates at which banks borrow and lend. Cúrdia and Woodford (2009) refer to the net interest spread as the credit spread, while Adrian and Shin (2011, p.602) refer to it as the term spread.

$$E_0 \sum_{t=0}^{\infty} \beta_B^t \left[i_t^c L_t^c - i_t B_t - \frac{\kappa_k}{2} \left(\frac{K_t^B}{L_t^c} - \tau_t \right)^2 K_t^B \right] \tag{3.1}$$

subject to the binding balance sheet identity

$$L_t^c = K_t^B + B_t, \tag{3.2}$$

where K_t^B is the total bank capital. The coefficient κ_k captures the quadratic adjustment cost of the deviation of the current capital-assets ratio (K_t^B/L_t^c) from a target capital requirement ratio (τ_t), according to the Basel regulations. τ_t follows an exogenous AR(1) process. This banking sector setup allows for interbank credit spread variability emanating from capital-asset ratio adjustments relative to exogenous innovations in τ_t. For example, when financial stress hits the interbank market banks raise their desired capital requirement, which immediately raises the interbank spread. As banks are accumulating larger capital buffers and the capital-asset ratio is converging towards the target τ_t, the interbank credit spread becomes narrower.

The bank capital accumulation equation is as follows:

$$K_t^B = (1 - \delta_B) K_{t-1}^B + \phi_\psi (Q_t^\psi - Q_{t-1}^\psi) \Psi^B + \Pi_{\psi,t-1}^B. \tag{3.3}$$

I assume that the initial stock of bank equity (Ψ^B) remains unchanged. What matters here is the market capitalization of bank equity ($Q_t^\psi \Psi^B$). As the market value of bank equity increases, bank capital accumulates and, in turn, the feasible credit supply increases (i.e. a rightward shift of the credit supply schedule). ϕ_ψ measures the pass-through effect of equity price changes on total bank capital. δ_B is the bank capital depreciation rate, capturing management costs for banks. Retained earnings ($\Pi_{\psi,t-1}^B$) are bank profits net of dividend payments.

I assume no frictions between short-term safe asset classes, and the investment bank has access to unlimited funds from the central bank at the policy rate i_t. Therefore, arbitrage implies that investment banks remunerate household safe assets at i_t. Conversely, for the supply of interbank funds, the commercial bank remunerates investment bank assets at i_t^c. Combining the first order conditions for B_t and L_t^c gives the interbank credit spread between the interbank loan rate and the policy rate,

$$i_t^c = i_t - \kappa_k \left(\frac{K_t^B}{L_t^c} - \tau_t \right) \left(\frac{K_t^B}{L_t^c} \right)^2. \tag{3.4}$$

3.3.1.2 Commercial bank

Commercial bank j differentiates $L_{j,t}^c$ at zero cost and sells them to households and entrepreneurs at their individual markups. All commercial banks $j \in [0, 1]$ apply a symmetrical objective function for all loan types indexed $z = e, h$, described as the following:

$$\max_{\{i^z_{j,t}\}} E_0 \sum_{t=0}^{\infty} \beta_B^t \left[i^z_{j,t} L^z_{j,t} - i^c_t L^c_{j,t} - \frac{\kappa_z}{2} \left(\frac{i^z_{j,t}}{i^z_{j,t-1}} - 1 \right)^2 i^z_t L^z_t \right]$$

subject to loan demand schedules (indexed $z = e, h$) from households and entrepreneurs

$$L^z_{j,t} = \left(\frac{i^z_{j,t}}{i^z_t} \right)^{-\varepsilon^z_t} L^z_t. \tag{3.5}$$

I assume that the interbank market determines the feasible quantity of loans in the retail sector, therefore, $L^c_{j,t} = L_{j,t} = L^h_{j,t} + L^e_{j,t}$ (see also, Gerali et al., 2010; Woodford, 2010). Risk on the quality of commercial bank assets enters through a value-at-risk constraint: $(1 + i^c_t)L^c_{j,t} \leq \nu_B(1 + i^z_{j,t})L^z_{j,t}$. Where ν_B is the interbank loan-to-value ratio.[8]

In the symmetric equilibrium the first order conditions give household and entrepreneur loan rates. Under flexible interest rates $(\kappa_z = 0)$ and no value-at-risk constraint, retail loan rates i^z_t are a markup over marginal cost i^c_t:

$$i^z_t = \frac{\varepsilon^z_t}{\varepsilon^z_t - 1} i^c_t. \tag{3.6}$$

Subsequently, the retail rate markup over i^c_t is defined as the retail credit spread. Therefore, for each loan type z, the sum of the interbank credit spread and retail credit spread gives the net interest spread (as in Cúrdia and Woodford (2009)) between i^z_t and i_t.

Using the log-linearized equations for loan rate setting, we derive the retail credit spread S^z_t:

$$\begin{aligned} S^z_t \;=\; & \frac{\kappa_z}{\kappa^*_z}\hat{i}^z_{t-1} + \frac{\beta_B\kappa_z}{\kappa^*_z} E_t \hat{i}^z_{t+1} + \frac{(1+\nu_B)(\varepsilon^z - 1) - (1+\beta_B)\kappa_z}{\kappa^*_z}\hat{i}^c_t \\ & + \frac{(1-\nu_B)(\varepsilon^z - 1)}{\kappa^*_z}\mu_{z,t}, \end{aligned} \tag{3.7}$$

where $\mu_{z,t}$ is the stochastic process for retail rate markups imposed by commercial banks, and $\kappa^*_z = (1 - \nu_B)(\varepsilon^z - 1) + (1 + \beta_B)\kappa_z$. Eq. 3.7 shows that entrepreneur and household loan rate setting depends on: the stochastic markup, past and expected future loan rates, and the marginal cost of the loan branch $(\hat{i}^c_t)$ which depends on the policy rate and the balance sheet position of the bank. Firstly, the stochastic markup moves independently from $\hat{i}^c_t$. As ν_B tends to one, the influence of the interbank rate over retail rate setting increases, while the influence of the stochastic markup decreases. In contrast, a higher adjustment cost (κ_z) smoothes the adjustment of retail loan rates and, hence, retail credit spreads. Furthermore, a positive adjustment of the interbank rate puts upward pressure on retail loan rates, yet the pass-through effect becomes smaller for higher values of κ_z.

[8] See Woodford (2010, p.32) and Adrian and Shin (2011, p.608-9). Appendix C discusses the setup in more detail.

3.3.2 Households

I adopt the conventional consumption-based asset pricing framework for equity. The demand driven equity price is market determined by contemporaneous wealth effects on households' intertemporal consumption choices, capital gains (or losses) and dividend payments. Moreover, equity is redeemable as collateral for bank loans.

The representative household derives utility from consumption and leisure choices, and financial wealth services in the form of safe assets (see also, Iacoviello, 2005; Christiano et al., 2010). Households maximize expected lifetime utility

$$E_0 \sum_{t=0}^{\infty} \beta_h^t \left[\frac{(C_t - \phi C_{t-1})^{1-\gamma}}{1-\gamma} - \frac{(H_t)^{1+\eta}}{1+\eta} + \xi_{b,t} ln \frac{B_t}{P_t} \right], \tag{3.8}$$

where β_h^t is the discount factor. The coefficient of relative risk aversion γ measures the curvature of the household's utility function with respect to its argument $C_t - \phi C_{t-1}$, where C_t is real consumption at time t and habit formation is parameterized by ϕ. η is the Frisch elasticity of labour supply with respect to hours worked (H_t). Households' preferences are subject to a demand shock $\xi_{b,t}$ on real safe asset balances (B_t/P_t).

The representative household's budget constraint is as follows:

$$C_t + \frac{B_t}{P_t} + \xi_{\psi,t} \frac{Q_t^{\psi}}{P_t} \Psi_t + \frac{I_{t-1}^h L_{t-1}^h}{P_t} = \frac{W_t}{P_t} H_t + \frac{I_{t-1} B_{t-1}}{P_t} + \frac{L_t^h}{P_t} + \frac{(Q_t^{\psi} + \Pi_{\psi,t})}{P_t} \Psi_{t-1}. \tag{3.9}$$

The household allocates periodic wage income $(W_t H_t)$, gross return on safe assets $(I_{t-1} B_{t-1})$, capital gains/losses $(Q_t^{\psi} \Psi_{t-1})$, real dividends $(\Pi_{\psi,t})$ and new loans (L_t^h) to current consumption, new asset holdings and the repayment of previous loans $(I_{t-1}^h L_{t-1}^h)$. $\xi_{\psi,t}$ is an equity price shock. The dividend policy is defined as a proportion ζ_{ψ} (the steady-state dividend yield) of the value of each household's equity holdings. In addition to the budget constraint, the household also faces a borrowing constraint

$$I_t^h L_t^h \leq \nu_{h,t} \big[\phi_w W_t H_t + (1 - \phi_w) Q_t^{\psi} \Psi_t \big]. \tag{3.10}$$

The household's wage income together with her investment in the equity market serve as a measure of creditworthiness, where $0 \leq \phi_w \leq 1$ is the weight on wage income. $\nu_{h,t}$ is a stochastic loan-to-value ratio and, correspondingly, in cases of default $1 - \nu_{h,t}$ can be interpreted as the proportional transaction cost for bank's repossession of borrower's collateral. Following the literature (e.g., Iacoviello, 2005), I assume the size of shocks is small enough so that the borrowing constraint is always binding.

The representative household's first order conditions for hours worked, household loans, safe assets and equity are as follows:

$$\frac{W_t}{P_t} = (U_{c,t})^{-1}(H_t)^{\eta} - \lambda_t (U_{c,t})^{-1}\nu_{h,t}\phi_w \frac{W_t}{P_t}, \tag{3.11}$$

$$U_{c,t} = \beta_h E_t\left[U_{c,t+1}\frac{I_t^h}{\Pi_{t+1}}\right] + \lambda_t I_t^h, \tag{3.12}$$

$$\xi_{b,t}\left(\frac{B_t}{P_t}\right)^{-1} = U_{c,t} - \beta_h E_t\left[U_{c,t+1}R_t\right], \tag{3.13}$$

$$1 = \beta_h E_t\left[\left(\frac{U_{c,t+1}}{U_{c,t}}\right)\left(\frac{Q_{t+1}^{\psi} + \Pi_{\psi,t+1}}{\xi_{\psi,t}Q_t^{\psi}}\right)\frac{1}{\Pi_{t+1}}\right] - \lambda_t (U_{c,t})^{-1}\nu_{h,t}(1-\phi_w), \tag{3.14}$$

where $U_{c,t} = (C_t - \phi C_{t-1})^{-\gamma}$ is the marginal utility of consumption and the Lagrangian multiplier of the household's budget constraint. The Lagrangian multiplier λ_t is the marginal utility of an additional unit of loans. Eq. 3.11 is the household's labour supply schedule. Eq. 3.12 is the consumption Euler equation. Eq. 3.13 indicates that the demand for assets depends on households' consumption and the real return to safe assets (R_t), where $R_t < R_t^h \;\forall\, t$.[9] Eq. 3.14 gives the consumption-based asset pricing equation for equity investment. Specifically, the resulting equilibrium market price for equity incorporates demand-side wealth effects on consumption.

3.3.3 Retailers

The retail sector, characterized by monopolistically competitive branders, introduces Calvo-type sticky prices into the model (see, Bernanke et al., 1999; Iacoviello, 2005). Retailers purchase intermediate goods $Y_{j,t}$ from entrepreneurs at the wholesale price $P_{j,t}^W$ in a competitive market, and differentiate them at no cost into $Y_{k,t}$. Each retailer sells $Y_{k,t}$ with a mark-up over $P_{j,t}^W$ at price $P_{k,t}$, taking into account their individual demand curves from consumers. Following Calvo (1983), I assume that the retailer can only adjust the retail price with probability $(1-\theta_R)$ in each period. Therefore, the decision problem for the retailer is

$$\max_{\{P_{k,t}^*\}} E_t \sum_{z=0}^{\infty} \theta_R^z \Lambda_{t,z}\left[P_{k,t}^* Y_{k,t+z} - P_{j,t+z}^W X Y_{k,t+z}\right] \tag{3.15}$$

subject to the consumer demand schedule for goods

$$Y_{k,t+z} = \left(\frac{P_{k,t}^*}{P_{t+z}}\right)^{-\varepsilon_t^p} Y_{t+z}, \tag{3.16}$$

where $\Lambda_{t,z}$ is the consumption-based relevant discount factor. $P_{k,t}^*$ denotes the optimal sales price set by the retailers, who are able to adjust the price in period t. $X_t \equiv P_t/P_t^W$ is the aggregate

[9] $R_t^h = I_t^h/\Pi_{t+1}$ is the real return on household loans.

markup of the retail price over the wholesale price. In steady state, $X = \varepsilon^p/(\varepsilon^p - 1)$, where ε^p is the steady state price-elasticity of demand for intermediate good $Y_{j,t}$.

The aggregate price level is determined by

$$(P_t)^{1-\varepsilon_t^p} = \theta_R(\left(\frac{P_{t-1}}{P_{t-2}}\right)^{\gamma_p} P_{t-1})^{1-\varepsilon_t^p} + (1-\theta_R)(P_t^*)^{1-\varepsilon_t^p}, \tag{3.17}$$

where γ_p determines the degree of price indexation for non-optimizing retailers. Solving and linearizing the optimization problem and combining it with Eq. 3.17 gives the forward-looking New-Keynesian Phillips curve, as in the literature.

3.3.4 Entrepreneurs

The representative entrepreneur produces the intermediate good $Y_{j,t}$ using a standard Cobb-Douglas production function

$$Y_{j,t} = \xi_{z,t} K_{j,t-1}^{\alpha} H_{j,t}^{1-\alpha}, \tag{3.18}$$

where $0 < \alpha < 1$. $K_{j,t-1}$ is physical capital and $\xi_{z,t}$ is an exogenous technology shock for total factor productivity. The representative entrepreneur faces the following borrowing constraint

$$I_{j,t}^e L_{j,t}^e \leq \nu_{e,jt}[\phi_k Q_{j,t}^k K_{j,t-1} + (1-\phi_k) Q_{j,t}^{\psi} \Psi_j^e], \tag{3.19}$$

where $\phi_k \in (0,1)$ is the weight on physical capital stock. $Q_{j,t}^k$ is the nominal price of physical capital, $\nu_{e,jt}$ is an exogenous stochastic loan-to-value ratio, and $I_{j,t}^e$ is the gross nominal interest rate on entrepreneur bank loans ($L_{j,t}^e$). The market value of physical capital ($Q_{j,t}^k K_{j,t-1}$) and the initial stock of entrepreneur equity ($Q_{j,t}^{\psi} \Psi_j^e$) serve as a measure of creditworthiness.[10] The equity market is introduced into the production sector in such a way that it has an impact on the entrepreneur's resource allocation and, in turn, the productivity of the economy.

Following Iacoviello (2005), I assume that in each period the representative entrepreneur chooses the desired amount of physical capital, labour and bank loans to maximize

$$E_0 \sum_{t=0}^{\infty} \beta_e^t \left[\frac{(C_{j,t}^e)^{1-\gamma^e}}{1-\gamma^e}\right] \tag{3.20}$$

subject to the production technology (Eq. 3.18), borrowing constraint (Eq. 3.19) and the following flow of funds constraint

$$\frac{Y_{j,t}}{X_{j,t}} + \frac{L_{j,t}^e}{P_t} = C_{j,t}^e + \frac{I_{j,t-1}^e L_{j,t-1}^e}{P_t} + \frac{W_t}{P_t} H_{j,t} + V_{j,t} + Adj_{j,t}^e + \Pi_{\psi,jt}^e. \tag{3.21}$$

Adj_t^e captures capital adjustment costs:

$$Adj_{j,t}^e = \kappa_v (\frac{V_{j,t}}{K_{j,t-1}} - \delta_e)^2 \frac{K_{j,t-1}}{(2\delta_e)}, \tag{3.22}$$

[10] In other words, they serve as a market-based signal for entrepreneurs' net worth and hence collateral.

where $V_{j,t}$ is the investment used to accumulate capital, $K_{j,t} = (1-\delta_e)K_{j,t-1} + V_{j,t}$, and κ_v is the variable capital adjustment cost parameter. $\Pi^e_{\psi,t} = (\zeta_\psi Q^\psi_t \Psi^e_j)/P_t$ is the real dividend paid out. I assume entrepreneurs are more impatient than households ($\beta^t_e < \beta^t_h$) and, therefore, γ^e should be less than γ. Iacoviello (2005) adopts log utility ($\gamma^e = 1$) for entrepreneurs. This implies that entrepreneurs are not risk neutral, but rather lie between being extremely risk averse and risk neutral. Here, I add the risk aversion coefficient to capture the degree of impatience of entrepreneurs, while the usual binding constraint conditions must hold $(1/I^e - \beta_e) > 0)$.

The first order conditions for hours worked, bank loans and physical capital are the following:

$$\frac{W_t}{P_t} = \frac{(1-\alpha)Y_{j,t}}{H_{j,t}X_{j,t}}, \tag{3.23}$$

$$(C^e_{j,t})^{-\gamma^e} = \beta_e E_t\left[(C^e_{j,t+1})^{-\gamma}\frac{I^e_{j,t}}{\Pi_{t+1}}\right] + \lambda_{j,t}I^e_{j,t}, \tag{3.24}$$

$$\begin{aligned} Q^k_{j,t} &= \beta_e E_t\Bigg[\frac{1}{(C^e_{j,t+1})^{\gamma^e}}\left(\frac{\kappa_v}{\delta_e}\left(\frac{V_{j,t+1}}{K_{j,t}} - \delta_e\right)\frac{V_{j,t+1}}{K_{j,t}} - \frac{\kappa_v}{2\delta_e}\left(\frac{V_{t+1}}{K_{j,t}} - \delta_e\right)^2\right) \\ &\quad + Q^k_{j,t+1}(1-\delta_e) + \frac{\alpha Y_{j,t+1}}{(C^e_{j,t})^{\gamma^e}X_{j,t+1}K_{j,t}}\Bigg] + \lambda_{j,t}\nu_{e,jt}\phi_k Q^k_{j,t}, \end{aligned} \tag{3.25}$$

where $\lambda^e_{j,t}$ is the Lagrangian multiplier of the borrowing constraint. Eq. 3.25 is the investment schedule, where the shadow price of physical capital is defined as $Q^k_{j,t} = (C^e_{j,t})^{-\gamma^e}(1 + \kappa_v/\delta_e$ $(V_{j,t}/K_{j,t-1} - \delta_e))$. The investment schedule states that the shadow price of capital must equal the expected marginal product of capital plus the discounted expected shadow price and capital adjustment costs. Eq. 3.23 is the standard labour demand schedule. Eq. 3.24 gives the entrepreneur consumption Euler equation.

3.3.5 Labour supply decisions and the wage-setting equation

The wage-setting equilibrium stems from the work of Gali et al. (2007). Monopolistically competitive unions set the optimal wage at the prevailing labour demand equilibrium. There is a continuum of unions, each union represents workers of a certain type τ uniformly distributed across all households.

The unions' problem is to choose $\{W^\tau_t\}^\infty_{t=0}$ to maximize the consumption-weighted wage income of their workers. However, following Calvo (1983), in each time period only a random fraction $1-\theta_w$ of unions have the opportunity to reset the optimal wage (W^*_t) for its workers, whereas those unions that cannot reset wages simply index to the lagged wage rate, as in Christiano et al. (2005) and Smets and Wouters (2007). Therefore, the wage index is given by

$$(W_t)^{1-\varepsilon^w} = \theta_w(\left(\frac{P_{t-1}}{P_{t-2}}\right)^{\gamma_w} W_{t-1})^{1-\varepsilon^w} + (1-\theta_w)(W^*_t)^{1-\varepsilon^w}, \tag{3.26}$$

where γ_w is the degree of wage indexation, and the objective function for the optimal wage is as follows:

$$\max_{\{W_t^*\}} E_t \sum_{i=0}^{\infty} (\theta_w \beta_h)^i \left[\left(\frac{W_t^* H_{t+i}^\tau}{P_{t+i} \tilde{C}_{t+i}} - \frac{(H_{t+i}^\tau)^{1+\eta}}{1+\eta} \right) \right]$$

subject to the the labour demand schedule

$$H_{t+i}^\tau = \left(\frac{W_t^*}{W_{t+i}} \right)^{-\varepsilon_t^w} H_{t+i}.$$

Here $\tilde{C}_{t+i}$, defined as $\tilde{C}_{t+i} = (C_{t+i} - \phi C_{t+i-1})^\gamma$, captures households' consumption preferences.

Assuming a constant wage elasticity of substitution ($\varepsilon_{t=0}^w$), the first order condition for W_t^* is

$$E_t \sum_{i=0}^{\infty} (\theta_w \beta_h)^i \left[\frac{W_t^*}{P_{t+i}} \left(\frac{1}{MRS_{t+i}} \right) \right] = E_t \sum_{i=0}^{\infty} (\theta_w \beta_h)^i \left[\mu^w \left(\frac{W_t^*}{W_{t+i}} \right)^{-\varepsilon^w \eta} \right],$$

where $MRS_{t+i} = \tilde{C}_{t+i} H_{t+i}^\eta$ is the marginal rate of substitution between consumption and leisure for households and $\mu^w = \varepsilon^w / (\varepsilon^w - 1)$ is the steady-state wage markup.

Log-linearizing and solving for w_t^* gives the optimal wage equation

$$w_t^* = \frac{(1-\theta_w \beta_h)}{(\varepsilon^w \eta + 1)} E_t \sum_{i=0}^{\infty} (\theta_w \beta_h)^i \Big(\chi mrs_{t+i} + \varepsilon^w \eta w_{t+i} + p_{t+i} \Big), \tag{3.27}$$

where $\chi \equiv W/MRS\mu^w$.

Combining Eq. 3.27 with the log-linearized aggregate wage index (3.26) gives the aggregate sticky wage equation

$$\begin{aligned} w_t &= \Phi w_{t-1} + \Phi \beta_h E_t w_{t+1} + \Phi^* (\varepsilon^w \eta w_t + \chi mrs_t) \\ &\quad + \Phi \beta_h E_t \pi_{t+1} - \Phi \pi_t - \Phi \theta_w \beta_h \gamma_w \pi_t + \Phi \gamma_w \pi_{t-1}, \end{aligned} \tag{3.28}$$

where $\Phi^* = (1-\theta_w)(1-\theta_w \beta_h)/(1+\theta_w^2 \beta_h)(1+\varepsilon^w \eta)$ and $\Phi = \theta_w/(1+\theta_w^2 \beta_h)$.

3.3.6 Monetary policy and market clearing conditions

The monetary authority follows a Taylor-type interest-rate policy

$$I_t = (I_{t-1})^{\kappa_i} \left(\frac{\Pi_t}{\Pi^{target}} \right)^{\kappa_\pi (1-\kappa_i)} \left(\frac{Y_t}{Y_{t-1}} \right)^{\kappa_y (1-\kappa_i)} \xi_{i,t}, \tag{3.29}$$

where κ_i is the weight on the lagged policy rate, κ_π is the weight on inflation, and κ_y is the weight on output growth. $\xi_{i,t}$ is the monetary policy shock following an AR(1) stochastic process.

The market clearing conditions are as follows. The aggregate resource constraint for the economy is

$$Y_t = C_t + C_t^e + V_t + \delta_B \frac{K_{t-1}^B}{\Pi_t}, \tag{3.30}$$

where $\delta_B K^B_{t-1}$ represents the banks' management cost in terms of bank capital. Similar to Iacoviello (2005), I close the model by including the entrepreneur flow of funds constraint (3.21).

In the equity market, the aggregate demand for equity shares across a continuum of households implies that $\Psi_t \equiv \Psi$. Market clearing in the equity market therefore requires the assumption of a constant total stock of equity shares in the whole economy. Given this assumption, entrepreneurs and banks do not issue new shares and $\Psi^e + \Psi^b = \Psi$. The usual market clearing aggregation applies for consumption and loans.

3.3.7 Exogenous shocks

In the model, there are ten exogenous shocks that follow AR(1) processes with independent and identically distributed standard deviations. The three core New-Keynesian shocks are the technology shock ($\xi_{z,t}$), the price markup shock (ε^p_t) and the monetary policy shock (ξ^i_t). I introduce seven additional shocks in the financial sector. On the supply side of credit, there is a capital requirement shock (τ_t) in the interbank market and there are two retail loan rate markup shocks to household loans ($\mu_{h,t}$) and entrepreneur loans ($\mu_{e,t}$). On the demand side of credit, household loans and entrepreneur loans are subject to loan-to-value shocks $\nu_{h,t}$ and $\nu_{e,t}$, respectively. Households' intertemporal consumption decisions are subject to an exogenous shock to households' safe-asset holdings ($\xi_{b,t}$). Finally, an equity price shock ($\xi_{\psi,t}$) contemporaneously affects consumption, production and bank lending activities.

3.4 Estimation

The model is estimated with Bayesian techniques using U.S. data over the sample period 1982Q2−2012Q3. The full sample covers the recession periods of 1990Q3−1991Q2, 2001Q1−2001Q4 and 2007Q4−2009Q2, and the Great Moderation period of 1982Q2−2006Q4.[11] Since the model has a total of 10 shocks, the data set contains 10 observable variables: output, inflation (GDP deflator), equity price, household loans, entrepreneur loans, household assets, 3-month Treasury Bill rate, Fed funds rate, mortgage rate, and Baa corporate bond rate. All variables except inflation and interest rates are converted into real terms by dividing the GDP deflator. Prior to estimation, I take the log-difference of real per capita variables.

A few points are worth noting in terms of the observable variables used for estimation. Firstly, monetary authority funds plus household deposits (similar to the monetary base plus M2 money supply) make up aggregate household safe assets. The motivation for this aggregation is two-fold. This satisfies the arbitrage assumption in the model setup (Section 3.3.1.1) from unlimited access to monetary authority funds. On the empirical side, it accommodates the recent surge in monetary

[11]NBER U.S. recession data is available at http://www.nber.org/cycles/cyclesmain.html. For the initial structural break of the Great Moderation see, for example, Stock and Watson (2003, p.173) and Farmer (2012b, p.697). The model is estimated using Dynare developed by Michel Juillard and his collaborators at CEPREMAP.

authority funds between 2008−2011, resulting from the large-scale recapitalization of the banking sector, which largely offset the significant shortage of household deposits during that time (see also, Woodford, 2010). Therefore, it would be misleading to view household deposits as the sole measure of bank liabilities (or available bank funding) when trying to observe the transmission mechanism of financial intermediation. Secondly, as a consequence of this assumption, I use the 3-month Treasury Bill rate as the short-term safe-asset rate (i.e., the policy rate). Lastly, by the end of 2009, outstanding financial commercial paper stood at \$1.7 trillion. To capture this additional financial stress on the effective interbank rate, which was not exhibited in the Great Moderation period, I derive the interbank rate by averaging the effective Fed funds rate with the 3-month AA financial commercial paper rate.

3.4.1 Calibrated parameters

Table 3.1 lists the parameters that are calibrated prior to estimation. In the first block, discount factors $\{\beta_h, \beta_e, \beta_B\}$ fall in the interval $[0.95, 0.99]$, where $\beta_h = 0.97$ is the mean of saver and borrower household discount factors 0.99 and 0.95 (see also, Iacoviello, 2005, p.751). I derive the entrepreneur and bank discount factors (β_e, β_B) from the reciprocal of their relevant steady-state markups over the steady-state quarterly safe asset rate $(R = 1.01)$. For example, using a steady-state quarterly gross real return to entrepreneur loans $R_e = 1.0383$, and satisfying the binding borrowing constraint condition $(1/R_e - \beta_e) > 0$, I set $\beta_e = 0.955$. This ensures a similar value for both the household and entrepreneur binding constraint conditions. The inverse of the Frisch elasticity η is set to 1. The capital-output share α is set to 0.33, and the physical capital depreciation rate δ_e is set to 0.025. A steady-state gross markup of $X = 1.10$ implies a price elasticity of demand for differentiated retail goods (ε^p) of 11. The price elasticity of demand for different types of labour ε^w is fixed at 5, implying a steady-state wage markup (μ^w) of 25%. Lastly, based on well-established estimates (e.g., Smets and Wouters, 2003, 2007), I assume a high degree of wage indexation (0.8) and let the probability of resetting an optimal wage $(1 - \theta_w)$ approximate an average length of wage contracts of one year.

The second block reports the steady-state aggregate ratios and the relevant U.S. banking sector conditions. The elasticities of substitution for household loans (ε^h) and entrepreneur loans (ε^e) equal 1.441 and 1.353, respectively. The target capital requirement ratio τ equals 11%, reflecting the recent U.S. banks' balance sheet condition. The bank capital depreciation rate δ_B equals 0.1044.[12] Parameter ϕ_ψ captures the pass-through effect of equity price changes on bank capital accumulation. I set ϕ_ψ to 0.25, based on preliminary estimations. Shares of household and entrepreneur loans to total bank loans, the consumption-output ratio, and the total bank capital-to-output ratio are calculated from the data means over the sample period. I restrict any other

[12] I assume that there are no undivided profits in the steady-state equilibrium, and therefore derive the value from the net income data of all U.S. commercial banks (FDIC, 2012).

Table 3.1: Calibrated parameters

Parameter	Description	Value
β_h	Household discount factor	0.97
β_e	Entrepreneur discount factor	0.955
β_B	Bank discount factor	0.986
η	Inverse of the Frisch elasticity	1
α	Capital share in the production function	0.33
δ_e	Capital depreciation rate	0.025
ε^p	Price elasticity of demand for goods	11
ε^w	Price elasticity of demand for labour	5
θ_w	Wage stickiness	0.75
γ_w	Degree of wage indexation	0.8
τ	Capital requirement ratio	0.11
ε^h	Elasticity of substitution for household loans	1.441
ε^e	Elasticity of substitution for entrepreneur loans	1.353
δ_B	Sunk costs for bank capital management	0.1044
ϕ_ψ	Equity price pass-through on total bank capital	0.25
L^h/L	Households' share of total loans	0.46
L^e/L	Entrepreneurs' share of total loans	0.54
C/Y	Consumption-output ratio	0.679
K^B/Y	Total bank capital-output ratio	0.171
ϕ_w	Weight on wages in borr. constraint	0.8
ϕ_k	Weight on physical capital in borr. constraint	0.8

steady-state ratios in the banking sector to be consistent with the balance sheet definition and capital requirement. Finally, based on stable preliminary estimations, the weights on wages (ϕ_w) and physical capital (ϕ_k) in the borrowing constraints are set to 0.8. This implies that, for example, a negative 10% shock to equity prices will directly reduce household and entrepreneur creditworthiness by 2%.

3.4.2 Prior distributions and posterior estimates

The prior distribution of the structural parameters are reported in columns $3-5$ in Tables 3.2 and 3.3. I assume that the household's coefficient of relative risk aversion (RRA) γ follows an inverse-gamma distribution with a mean of 3 and a standard deviation of 0.5. Meanwhile, the entrepreneur's RRA is assumed to be much less than the household's RRA ($\gamma_e = 0.9$), which implies a preference for current period consumption gains. Both RRA values roughly correspond with estimates of its reciprocal (the intertemporal elasticity of substitution in consumption) in the micro literature (e.g., Vissing-Jorgensen, 2002). The prior on habit formation parameter ϕ is set at 0.65 with a standard deviation of 0.03 (e.g., Christiano et al., 2005). Parameters in the Phillips curve are based on the estimates from Smets and Wouters (2003) and Christiano et al. (2010). The parameters describing the monetary policy reaction function are chosen within the context of fi-

Table 3.2: Structural parameters

		Prior Distribution			Posterior Distribution			
	Parameter	Type	Mean	Std.dev	Mean	2.5%	Median	97.5%
Preferences								
γ	Household RRA	Inv.Gamma	3	0.5	4.910	4.088	4.866	5.659
γ_e	Entrepreneur RRA	Inv.Gamma	0.9	0.1	1.087	0.888	1.073	1.279
ϕ	Habit formation	Beta	0.65	0.03	0.708	0.672	0.707	0.749
Prices								
θ_R	Price stickiness	Beta	0.8	0.03	0.923	0.914	0.924	0.932
γ_p	Degree of price indexation	Beta	0.5	0.03	0.511	0.464	0.510	0.554
Monetary policy rule								
κ_i	Coefficient on lagged policy rate	Beta	0.65	0.05	0.615	0.570	0.616	0.661
κ_π	Coefficient on inflation	Gamma	1.5	0.05	1.612	1.529	1.612	1.697
κ_y	Coefficient on output change	Beta	0.25	0.02	0.261	0.228	0.260	0.292
Credit and banking								
ν_h	Households' LTV ratio	Beta	0.6	0.03	0.580	0.531	0.580	0.630
ν_e	Entrepreneurs' LTV ratio	Beta	0.6	0.03	0.722	0.693	0.722	0.752
ν_B	Interbank LTV ratio	Beta	0.5	0.05	0.424	0.361	0.423	0.485
κ_h	HH loan rate adjust. cost	Gamma	5	2	15.22	11.87	15.07	18.51
κ_e	Entrep. loan rate adjust. cost	Gamma	5	2	6.890	5.720	6.890	8.072
κ_k	Leverage deviation cost	Gamma	5	2	1.255	1.038	1.254	1.443
Physical capital								
κ_v	Capital adjust. costs	Gamma	2	0.5	2.292	1.847	2.263	2.689
K^e/Y	Capital-output ratio	Gamma	10.7	0.2	10.78	10.46	10.78	11.11

nancial frictions literature, based on the estimates of Christiano et al. (2010). I choose a reasonable value of 0.6 as the prior mean for both the households' LTV ratio (ν_h) and the entrepreneur's LTV ratio (ν_e). I set the prior mean of the interbank LTV ratio (ν_B) to 0.5 with a standard deviation of 0.05. The interest rate adjustment cost parameters $\{\kappa_k, \kappa_h, \kappa_e\}$ are assumed to follow a gamma distribution with a mean of 5 and a standard deviation of 2 (see also, Gerali et al., 2010). Analogous to the entrepreneur investment schedule in Iacoviello (2005, p.752), I set the prior mean of the physical capital adjustment cost parameter κ_v to 2. The prior mean of the capital-output ratio is set to 10.7 based on its steady-state value. Lastly, the prior distributions for the AR(1) coefficients and the standard deviations of the shocks are reported in columns 3−5 in Table 3.3.

The estimated posterior statistics for the structural parameters are reported in columns 6−9 in Tables 3.2 and 3.3. Parameters for preferences, prices, and the monetary policy rule all conform well within the literature consensus. Shocks for monetary policy, loan rate markups to households and entrepreneurs, and the price markup are not persistent, while the rest are strongly persistent. The LTV ratio for households (0.58) is lower than that of entrepreneurs (0.72), which suggests that entrepreneurs can more easily collateralize their loans (see also, Iacoviello, 2005, p. 752). In fact,

Table 3.3: Exogenous processes

		Prior Distribution			Posterior Distribution			
	Parameter	Type	Mean	Std.dev	Mean	2.5%	Median	97.5%
AR coefficients								
ρ_z	Technology	beta	0.98	0.005	0.981	0.979	0.981	0.984
ρ_i	Monetary policy	beta	0.2	0.05	0.431	0.347	0.433	0.513
ρ_b	Household asset	beta	0.97	0.005	0.970	0.967	0.971	0.973
ρ_e	Entrep. loan markup	beta	0.3	0.05	0.422	0.352	0.423	0.493
ρ_h	Household loan markup	beta	0.2	0.05	0.269	0.180	0.268	0.347
ρ_{ν_h}	Households' LTV	beta	0.95	0.005	0.951	0.943	0.951	0.960
ρ_{ν_e}	Entrepreneurs' LTV	beta	0.55	0.05	0.618	0.561	0.620	0.680
ρ_ψ	Equity	beta	0.8	0.05	0.871	0.835	0.872	0.906
ρ_p	Price markup	beta	0.3	0.05	0.373	0.292	0.373	0.461
ρ_t	Capital requirement	beta	0.85	0.05	0.782	0.722	0.782	0.843
Standard deviations								
ϵ_z	Technology	Inv.Gamma	0.02	inf	0.016	0.014	0.016	0.017
ϵ_i	Monetary policy	Inv.Gamma	0.01	inf	0.008	0.007	0.008	0.009
ϵ_b	Household asset	Inv.Gamma	0.01	inf	0.008	0.007	0.008	0.009
ϵ_e	Entrep. loan markup	Inv.Gamma	0.08	inf	0.114	0.086	0.114	0.144
ϵ_h	Household loan markup	Inv.Gamma	0.08	inf	0.210	0.153	0.206	0.273
ϵ_{ν_h}	Households' LTV	Inv.Gamma	0.03	inf	0.021	0.019	0.021	0.024
ϵ_{ν_e}	Entrepreneurs' LTV	Inv.Gamma	0.03	inf	0.029	0.023	0.028	0.034
ϵ_ψ	Equity	Inv.Gamma	0.01	inf	0.005	0.004	0.005	0.006
ϵ_p	Price markup	Inv.Gamma	0.002	inf	0.001	0.001	0.001	0.001
ϵ_t	Capital requirement	Inv.Gamma	0.015	inf	0.012	0.010	0.012	0.014

high estimates for ν_h and ν_e imply that changes to household creditworthiness and entrepreneur net worth have strong and persistent effects on aggregate demand and output. An estimated interbank LTV of 0.42 highlights the importance of bank market power by giving a large weight to retail loan rate markups (see Eq. 3.7). Corresponding to the observed persistence of retail credit spread movements, large posterior means for the entrepreneur and household loan rate adjustment cost parameters ($\kappa_e = 6.89$ and $\kappa_h = 15.22$) imply a large degree of retail loan rate stickiness. Furthermore, $\kappa_e < \kappa_h$ confirms the recent relatively sharper changes to the entrepreneur credit spread in the data (see also, Gerali et al., 2010, p.124). A value of 1.255 for the leverage deviation cost, on the other hand, is significantly smaller. However, this value is based on the close relationship between the short-term policy rate and the short-term interbank rate. As shown in the results in Section 3.5, and contrary to Gerali et al. (2010) for the Euro area, I find a clear role for the sticky-rate structure in commercial banking for both business cycle dynamics and credit spread variability.

3.5 Results

In this section, I use the DSGE model developed in Section 3.3 (hereafter, the baseline model) to determine the main financial factors that impact credit spread variability over the Great Moderation and Great Recession periods. Firstly, I establish the prevailing financial factors in credit spread variability over the full sample period (1982Q2−2012Q3). Using the historical shock decomposition of each credit spread I show how structural shocks predict the cyclical pattern of credit spreads in the U.S. business cycle. Secondly, I compare U.S. recession episodes over the Great Moderation and Great Recession periods. To do this, I re-estimate the baseline model with three sub-sample periods covering the 1990−91, 2001 and 2007−09 recessions. I determine whether factors that impact credit spreads have changed over time; and whether there are any clear differences in the transmission mechanisms of credit spread variability during the Great Moderation and Great Recession periods. I conclude this section with a robustness analysis of the baseline model.

3.5.1 Impact factors on credit spread variability

Figure 3.3 provides the historical shock decomposition of the interbank and retail credit spreads. Here, I focus on how the structural shocks predict cyclical patterns of credit spreads over the Great Moderation and Great Recession periods. Both supply- and demand-side factors explain the historical interbank credit spread well. On the demand side, LTV shocks contribute significantly to interbank credit spread variability. For instance, a negative entrepreneur LTV shock reduces bank assets, and raises the capital-asset ratio—narrowing the interbank credit spread. This clearly corresponds with the post-recession credit slumps of 1992−1995, 2002−2004 and 2009−2012, observed in the data. Conversely, we see a similar effect for the large credit boom period between 1997 and 2001. On the supply-side, we observe a significant impact of the bank capital requirement shock on interbank credit spread variability in 2007−09 recession. Furthermore, the collapse of the equity market during the 2001 and 2007−09 recession periods created some additional financial stress. The monetary policy shock did not contribute significantly to interbank credit spread variability over the Great Moderation and Great Recession periods. Whereas, the technology shock only contributed significantly to the 2007-09 recession and subsequent credit slump.

The persistence of retail credit spread widening or narrowing is driven by bank market power over retail loan rate markups. There is, however, one exception. Leading up to the August 2007 crisis, monetary policy has an extremely persistent effect on narrowing retail credit spreads—more than offsetting the loan rate markups. This observation gives credence to the evidence that monetary authorities kept the policy rate too low from 2002Q3 to 2006Q3 (Taylor, 2007, p.2-3), inadvertently creating the incentive for banks to seek larger profit margins by increasing risky portfolios (Adrian and Shin, 2011; Borio and Zhu, 2012). The widening of retail credit spreads occurs at the peak of each recession period (1990Q3−1991Q2, 2001Q1−2001Q4 and 2007Q4−2009Q2). This

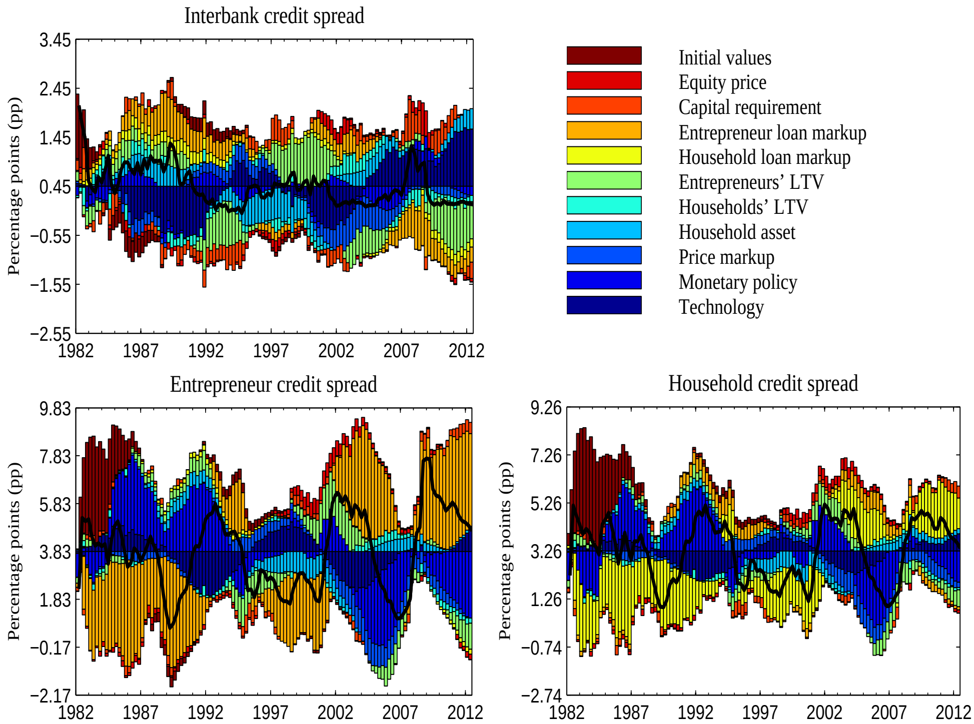

Figure 3.3: Historical decomposition of credit spreads (full-sample)

reflects the observation from the interest rate data that credit spreads become increasingly narrow towards the end of boom phases of the business cycle, and conversely widen in recession periods (see, Gilchrist and Zakrajšek, 2012, p.1696).

In terms of the relationship between equity prices and credit spread variability, the impact of the equity price shock on credit spread variability is small. Yet, we observe the recurring pattern of falling equity prices and widening credit spreads during U.S. recessions, the 2007Q4−2009Q2 recession in particular. Although a technology shock produces the negative correlation between equity prices and net credit spreads (see Figure 3.6), it is unlikely that a single large fundamental shock is able to generate systemic financial stress in both equity and credit markets. Rather, it is more likely due to a combination of financial shocks and real shocks.[13]

In summary, we observe bank market power as the primary source of credit spread variability. This is along the lines of Gilchrist and Zakrajšek (2012), in which the authors find that it is the supply-side factors of financial intermediation that dominate the demand-side factors in driving credit spread variability. By borrowing on short-term rates and lending on long-term rates banks carry balance sheet risk, but also large profit-making margins. Financial intermediaries exert their

[13]From the DSGE model, the posterior theoretical moments show that output has a strong positive correlation with equity and a strong negative correlation with net credit spreads (see Table C.1 in the Appendix).

market power over net interest margins between their assets and liabilities, to the extent that they impose a measure of risk or desired profitability on interest rates charged. On the demand side, the financial accelerator channel plays a significant role in driving interbank credit spread variability only. Finally, the equity price channel exacerbates movements in credit spreads, but cannot be regarded as a main driving force of credit spread variability.

3.5.2 Great Moderation verse Great Recession

In this section, I investigate: first, whether factors that impact the variability of credit spreads differs in the three recession periods; and second, whether there are any clear shifts in the driving forces behind credit spread variability across the three recession periods. To do so, I re-estimate the baseline model with three sub-sample periods. Each sub-sample period includes a maximum of twenty quarters before and after each recession's peak and trough: 1985Q3−1996Q2; 1996Q1−2006Q4; and 2002Q4−2012Q3.

Although the recessions of 1990−91 and 2001 were milder than the 2007−09 one, a comparative study by Peter Ireland (2011) shows that the pattern of shocks has not changed significantly throughout the Great Moderation and Great Recession periods. In fact, Ireland (2011) finds that all three recessions were caused by a similar combination of exogenous demand and supply shocks, where the notable difference for the Great Recession is that these adverse shocks were deeper, and lasted longer. The author argues that while expansionary monetary policy helped in cushioning the 1990−91 and 2001 recessions, the zero lower bound on the policy rate created a *de facto* contractionary policy in 2009. This constraint contributed to both the duration and deepness of the recession. Similarly, Stock and Watson (2003), Sims and Zha (2006) and Smets and Wouters (2007) find that the start of the Great Moderation cannot be attributed to changes in structural parameters—that is, the endogenous transmission mechanism of shocks—but rather a reduction in the volatility of a similar combination of exogenous shocks.

Table 3.4 reports the contribution of the structural shocks to the variance of credit spreads at 1-quarter, 1-year, and 5-year horizons. Here, supply-side financial factors account for a great part of credit spread variability in the 2007−09 recession period. In addition, the impact of technology shocks and monetary policy shocks has fallen considerably during all three recession periods. The parameter estimates for each of the U.S. recession sub-samples (see Table C.2 in the Appendix) reveal little evidence of significant changes in the structural parameters. In contrast, the posterior means for the standard deviations of household's and entrepreneur's LTV shocks (ϵ_{ν_h} and ϵ_{ν_e}) have declined since the 1990−91 recession, while the standard deviation for the entrepreneur loan markup shock (ϵ_e) has steadily increased. This indicates a shift from demand-side to supply-side credit market shocks.

Capital requirement shocks have the largest influence (approximately 30% over the forecast horizon) on interbank credit spread variability for both the 2007−09 and 1990−91 recession peri-

Table 3.4: Variance decomposition of credit spreads for the U.S. recession periods

Interbank spread

	2007−09: Horizons			2001: Horizons			1990−91: Horizons		
Shocks	1-quart.	1-year	5-years	1-quart.	1-year	5-years	1-quart.	1-year	5-years
ϵ_z	0.086	0.063	0.613	0.110	0.109	0.521	0.120	0.107	0.384
ϵ_i	0.039	0.046	0.015	0.055	0.072	0.032	0.065	0.091	0.057
ϵ_p	0.007	0.007	0.055	0.003	0.004	0.028	0.001	0.002	0.023
ϵ_b	0.001	0.003	0.023	0.001	0.002	0.034	0.000	0.001	0.027
ϵ_{ν_h}	0.288	0.233	0.070	0.244	0.236	0.088	0.317	0.292	0.183
ϵ_{ν_e}	0.086	0.070	0.061	0.208	0.181	0.145	0.054	0.055	0.069
ϵ_h	0.003	0.013	0.006	0.001	0.012	0.010	0.001	0.007	0.008
ϵ_e	0.073	0.068	0.022	0.097	0.094	0.032	0.020	0.019	0.013
ϵ_t	0.320	0.403	0.107	0.209	0.235	0.088	0.325	0.353	0.178
ϵ_ψ	0.099	0.093	0.030	0.073	0.055	0.020	0.097	0.072	0.057

Household credit spread

	2007−09: Horizons			2001: Horizons			1990−91: Horizons		
Shocks	1-quart.	1-year	5-years	1-quart.	1-year	5-years	1-quart.	1-year	5-years
ϵ_z	0.024	0.011	0.041	0.038	0.021	0.095	0.087	0.096	0.374
ϵ_i	0.245	0.154	0.148	0.311	0.195	0.179	0.412	0.284	0.255
ϵ_p	0.002	0.004	0.026	0.001	0.003	0.010	0.001	0.001	0.006
ϵ_b	0.001	0.001	0.001	0.001	0.001	0.002	0.000	0.000	0.002
ϵ_{ν_h}	0.080	0.038	0.025	0.050	0.025	0.018	0.088	0.049	0.027
ϵ_{ν_e}	0.048	0.021	0.015	0.091	0.039	0.028	0.024	0.013	0.017
ϵ_h	0.495	0.721	0.697	0.420	0.674	0.632	0.270	0.488	0.262
ϵ_e	0.035	0.016	0.011	0.038	0.018	0.013	0.011	0.008	0.007
ϵ_t	0.055	0.026	0.031	0.034	0.017	0.017	0.073	0.041	0.031
ϵ_ψ	0.015	0.007	0.005	0.016	0.008	0.007	0.034	0.020	0.018

Entrepreneur credit spread

	2007−09: Horizons			2001: Horizons			1990−91: Horizons		
Shocks	1-quart.	1-year	5-years	1-quart.	1-year	5-years	1-quart.	1-year	5-years
ϵ_z	0.023	0.018	0.096	0.033	0.023	0.128	0.100	0.134	0.444
ϵ_i	0.152	0.088	0.120	0.232	0.147	0.155	0.423	0.305	0.254
ϵ_p	0.001	0.002	0.027	0.001	0.002	0.009	0.001	0.001	0.006
ϵ_b	0.001	0.000	0.001	0.001	0.000	0.002	0.000	0.000	0.003
ϵ_{ν_h}	0.053	0.024	0.018	0.038	0.019	0.016	0.091	0.054	0.028
ϵ_{ν_e}	0.031	0.013	0.012	0.069	0.031	0.026	0.024	0.016	0.020
ϵ_h	0.000	0.000	0.001	0.000	0.000	0.001	0.000	0.000	0.000
ϵ_e	0.693	0.833	0.692	0.588	0.758	0.641	0.248	0.421	0.197
ϵ_t	0.035	0.016	0.028	0.026	0.013	0.015	0.076	0.045	0.031
ϵ_ψ	0.011	0.005	0.004	0.013	0.007	0.006	0.037	0.023	0.018

Note: see Table 3.3 for shock parameter descriptions.

ods. Compared to the 1990−91 recession period, however, the results show that over 20-quarters the entrepreneur loan markup shock accounts for 5% more of the 2007−09 interbank spread variance. On the demand-side, the influence of the household's LTV shock (ϵ_{ν_h}) is strong over 1-quarter and 1-year horizons for each U.S. recession period. The entrepreneur's LTV shock (ϵ_{ν_e}) only plays a significant role in explaining interbank credit spread variability during the 2001 recession. As such, the interbank credit spread in the 2001 recession period seems to be less rooted in supply-side factors. Comparing all three recession periods, I find that the impact of technol-

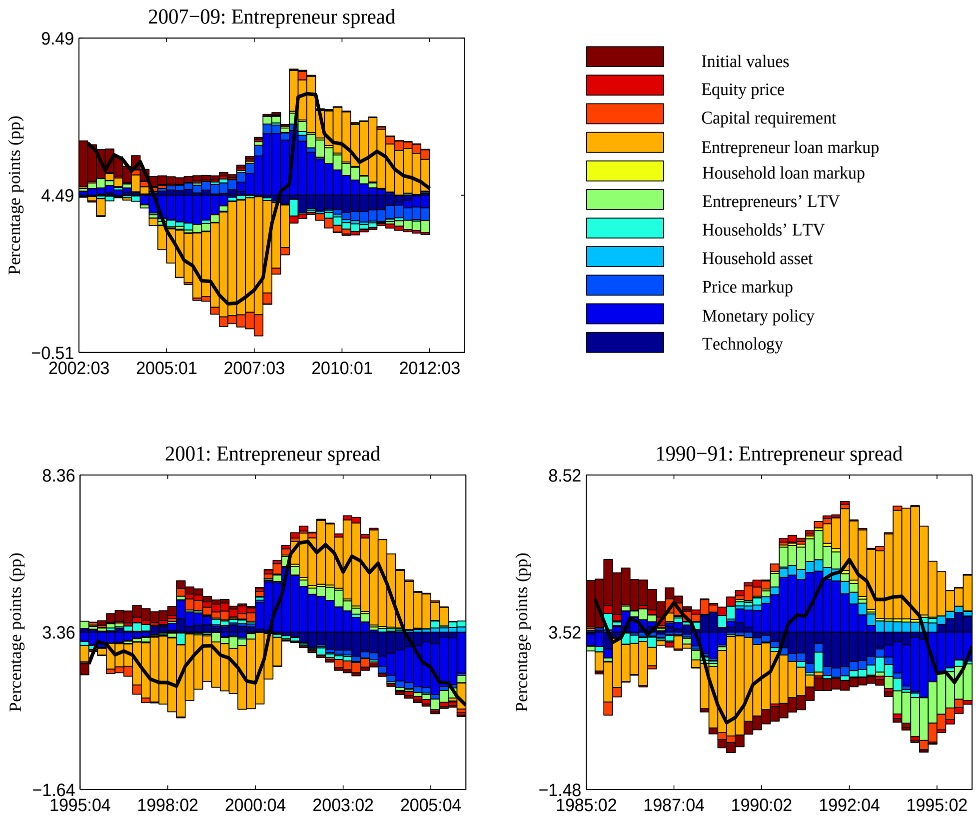

Figure 3.4: Historical decomposition for entrepreneur credit spread: 2007−09 recession (top-left); 2001 recession (bottom-left); 1990−91 recession (bottom-right)

ogy shocks has fallen steadily over shorter horizons, while the impact of monetary policy has fallen significantly over all horizons. As a result, interbank credit spread variability in the recent recession is more strongly rooted in supply-side financial factors.

Bank market power plays a dominant role in explaining the variability of both retail credit spreads. Across the three recession periods, there is an increasing trend in the contribution of loan markup shocks (ϵ_e and ϵ_h) to the variability of both retail credit spreads at all horizons. In contrast, the contribution of LTV shocks (ϵ_{ν_h} and ϵ_{ν_e}) are small and ambiguous across the three recession periods. Analogous to the interbank credit spread, there is a remarkable decline in the influence of technology and monetary policy shocks over the three recession periods. These findings suggest a shift towards a greater influence of supply-side financial factors in the 2007−09 recession.

Two important observations are worth noting in the historical shock decomposition of the entrepreneur credit spread in Figure 3.4.[14] Firstly, from the demand-side of the credit market, the influence of LTV shocks has declined since the 1990−91 recession, while the bank capital requirement shock exacerbates and prolongs credit spread variability over the 2007−09 recession period. Secondly, for each recession period, policy rate adjustments consistently lead movements in the spread, which are prolonged by entrepreneur loan markups (bank market power). For the 1990−91 and 2001 recessions, the entrepreneur credit spread returns to its steady state after approximately three years, whereas it takes much longer to converge to steady state during the 2007−09 recession. After the 1990−91 and 2001 recessions the policy rate continues to fall for a number of quarters, which sharply reduces the spread. However, from 2010 onwards, we see that the zero lower bound prevents the policy rate from counteracting the persistence of retail loan markups and higher capital requirements. As a result, the direct influence of the policy rate on nonfinancial long-term rates is completely ineffective over the 2007−09 recession period.[15]

3.5.3 Robustness analysis

For the robustness analysis, I compare the baseline model with three variant versions of the model developed in the paper. I first compare the impulse responses to monetary and technology shocks, and then the parameter estimates across models. The robustness analysis also provides more valuable insights for analysis on credit spread variability.

The three variant models serve to highlight three key issues. For the first variant model (FI hereafter) I assume flexible rate adjustments on retail loan rate setting. That is, there are no quadratic retail loan rate adjustment costs ($\kappa_h = \kappa_e = 0$). The comparison analysis between the baseline model and the flexible interest rate model highlights the role of bank market power through sticky retail rate adjustment. For the second variant version (TB hereafter) I use the 10-year Treasury Bill as the observed data for the interbank rate. Introducing the interbank spread between the 3-month and 10-year Treasury Bill rates highlights the influence of monetary policy over long-term interest rates. By doing so, I am able to test the robustness of the credit spread transmission mechanisms, as defined in Section 3.2. For the third variant version (NI hereafter), I re-estimate the model without the observed variable for the interbank rate. In addition, I drop the capital requirement shock to match nine shocks with the remaining nine observed variables. As this NI model is in line with the estimated models with multiple interest rates in the literature (e.g., Gerali et al., 2010), it serves a useful reference for the baseline model.

[14]For the sake of space, I only report the results for the entrepreneur credit spread here. Results for the household credit spread follow a similar pattern, and are available upon request.

[15]With the use of impulse response functions, Appendix C.3 provides a supplementary discussion on the role of monetary policy shocks and financial shocks across the U.S. recession periods.

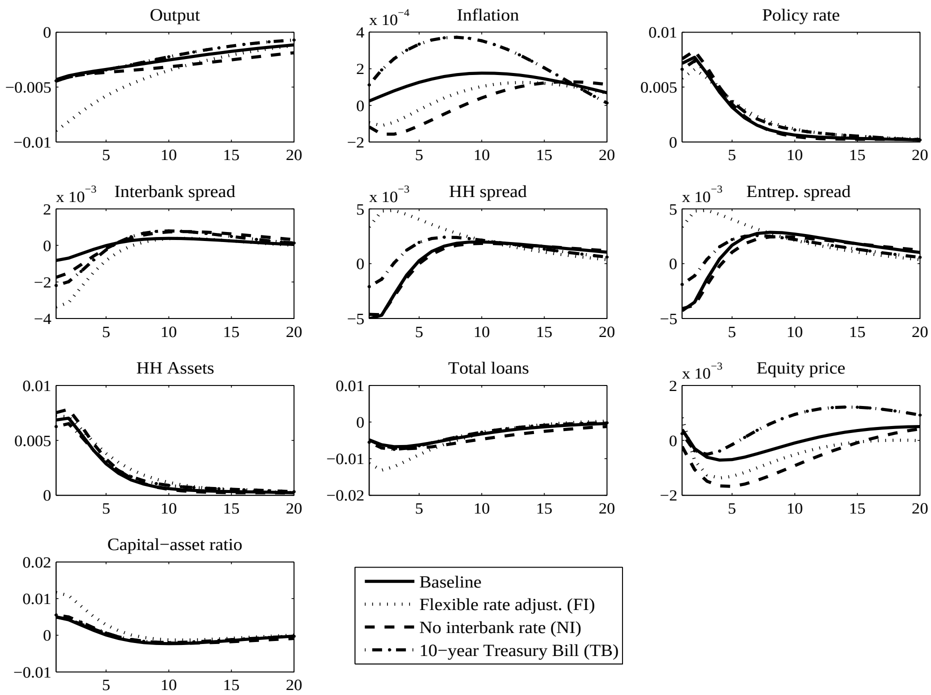

Figure 3.5: Impulse response to a contractionary monetary policy shock

3.5.3.1 Nominal and real shocks

Figure 3.5 shows the impulse responses of the observed variables to a contractionary monetary policy shock.[16] Comparing the baseline model to the FI model, reveals an important role for sticky rate adjustments: during a recession (or boom), imperfect bank competition will stifle efforts of monetary authorities to stimulate (or attenuate) aggregate demand through the conventional interest-rate policy. Without sticky rate adjustments, the decline in total loans and output is much more severe in response to a contractionary monetary policy. The dynamics of the TB model and the NI model follow a similar pattern as that of the baseline model. There are some uninformative differences in credit spreads and equity prices though; as the difference in the impact of monetary policy on output, inflation and balance sheet quantities is negligible among the three models. More importantly, the influence of monetary policy on the interbank spread in the TB model (i.e., the 10-yr Treasury Bill) provides no distinct advantage in the results. Similarly, compared to the baseline model and the NI model, the pass-through onto retail credit spreads is only slightly improved. In other words, the influence of the conventional monetary policy on long-term interest rates is not

[16]For simplicity, I aggregate household loans and entrepreneur loans, and label it total loans. I also include the response of the capital-asset ratio. The dynamics of the baseline model in response to a contractionary monetary policy shock are discussed in Appendix C.3. Here I focus on robustness analysis.

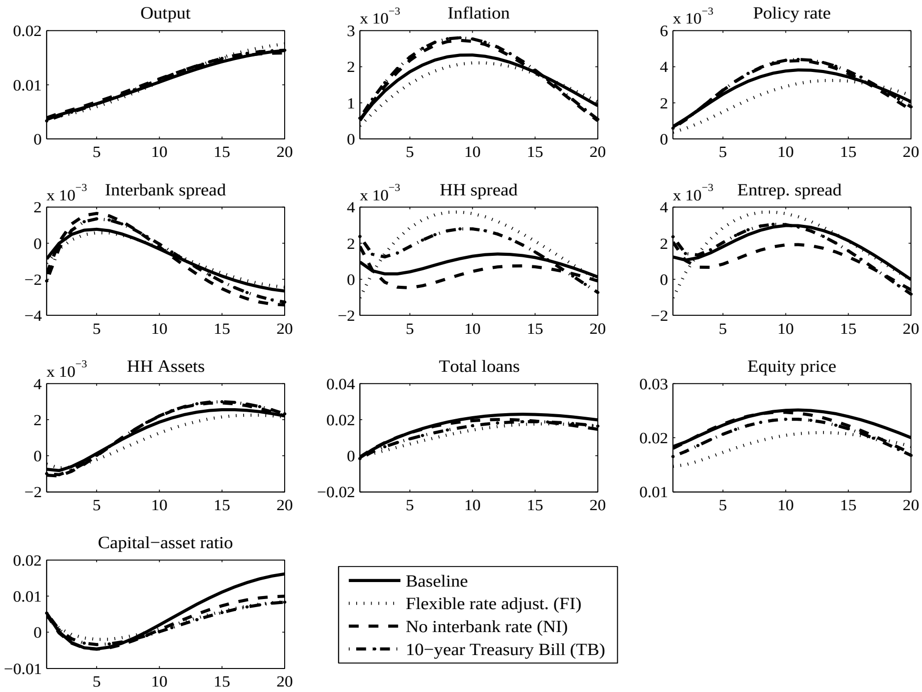

Figure 3.6: Impulse response to a positive technology shock

robust.

Figure 3.6 shows the impulse responses of the observed variables to a positive technology shock. For the baseline model, the effect of the technology shock on output is strong and persistent. The positive financial wealth effect on household consumption subsequently fuels the equity price boom (see also, Castelnuovo and Nisticò, 2010, p.1720). The bullish equity market improves both the demand and supply of the credit market. On the demand side, borrower's creditworthiness increases the feasible amount of loans. The improved credit demand and widen bank profit margins propagate the dynamics of the model through both financial accelerator and bank capital channels (see, Christiano et al., 2010, p.55-58). On the supply side, increased market value of bank equity increases bank funding and, therefore, shifts the credit supply schedule upward. Conversely, the policy rate increases in response to higher output and inflation. Higher interest rates dampen credit demand, and raise households' demand for safe assets in the medium- to long-term. There is little variation in the dynamics among variant models in response to the technology shock, except for retail credit spreads. For the FI model, responses of retail credit spreads are exacerbated. This reiterates the importance of sticky retail rate adjustment in the banking sector.

In summary, based on the model comparison, the baseline model is found to be robust to alternative versions of the model. Moreover, compared the the TB model, the baseline model

Table 3.5: Alternative model parameter estimates

	Posterior distribution means					Posterior distribution means			
	Baseline	Flexible (FI)	No interbank rate (NI)	10-yr Treasury Bill (TB)		Baseline	Flexible (FI)	No interbank rate (NI)	10-yr Treasury Bill (TB)
Marginal density	4357	4155	3765	4332					
Parameters					Parameters				
γ	4.910	4.578	4.806	4.543	ρ_z	0.981	0.987	0.981	0.981
γ^e	1.087	0.878	1.117	0.872	ρ_i	0.431	0.337	0.433	0.409
ϕ	0.708	0.713	0.705	0.708	ρ_b	0.970	0.973	0.970	0.970
θ_R	0.923	0.924	0.907	0.908	ρ_e	0.422	0.868	0.449	0.549
γ_p	0.511	0.500	0.520	0.523	ρ_h	0.269	0.919	0.276	0.583
κ_i	0.615	0.765	0.642	0.669	ρ_{ν_h}	0.951	0.952	0.951	0.952
κ_π	1.612	1.580	1.598	1.591	ρ_{ν_e}	0.618	0.617	0.609	0.591
κ_y	0.261	0.272	0.264	0.262	ρ_ψ	0.871	0.896	0.881	0.877
ν_h	0.580	0.581	0.584	0.487	ρ_p	0.373	0.377	0.440	0.411
ν_e	0.722	0.701	0.690	0.682	ρ_t	0.782	0.861	-	0.847
ν_B	0.424	0.158	0.321	0.063	ϵ_z	0.016	0.016	0.015	0.015
κ_k	1.255	2.176	2.629	3.005	ϵ_i	0.008	0.006	0.008	0.007
κ_e	6.890	-	8.024	6.208	ϵ_b	0.008	0.008	0.008	0.008
κ_h	15.22	-	16.32	12.96	ϵ_e	0.114	0.016	0.105	0.027
κ_v	2.292	1.530	2.199	2.519	ϵ_h	0.210	0.014	0.197	0.026
K^e/Y	10.78	10.89	10.77	10.79	ϵ_{ν_h}	0.021	0.021	0.021	0.021
					ϵ_{ν_e}	0.029	0.013	0.027	0.019
					ϵ_ψ	0.005	0.004	0.005	0.005
					ϵ_p	0.001	0.001	0.001	0.001
					ϵ_t	0.012	0.009	-	0.015

Note: I exclude parameter descriptions, prior means and standard deviations (see Tables 3.2 and 3.3), and statistic confidence intervals in the table due to the limited space.

conforms more closely to the implied results of the NI model. The dynamics of the baseline model in response to both monetary and technology shocks conform with the established literature evidence. Indeed, as shown in Section 3.5.3.2 below, the comparison of the estimated parameters between variant models reinforces these findings.

3.5.3.2 Alternative model parameter estimates

Table 3.5 compares the posterior estimates of the structural parameters for each alternative model. Overall, the parameter estimates are mostly consistent across models, indicating the results are robust. The most notable variations occur in some of the parameters in the banking sector, which reiterates the importance of the supply-side factors in determining credit spread variability. Compared to the baseline model, the FI model predictably gives more weight to stochastic markup shocks in retail loan rate setting since sticky retail loan rate adjustment falls away. This is indicated by a decline of the estimated interbank LTV ratio (ν_B) from 0.424 to 0.158. As discussed in Section 3.3.1.2, $1 - \nu_B$ captures the weight of the stochastic markup in retail loan rate setting. At the same time, zero sticky retail rate adjustment is now compensated for by a significant jump in the persistence of stochastic markup shocks (ρ_e, ρ_h). Compared to all three alternative versions of the model, a larger leverage deviation cost parameter (κ_k) in the baseline model creates additional imperfect rate adjustment by magnifying the influence of the capital-asset ratio on the interbank rate and, hence, long-term retail loan rates. This suggests that the baseline model represents the influence of leverage deviation costs more accurately.

The shocks and frictions considered in each estimated model determine its ability to fit the data. The relative importance of the baseline model can therefore be measured by comparing its marginal data density (measured in log points) to that of each alternative model.[17] For flexible rate adjustment, the marginal density of the FI model falls from 4357 to 4155. This highlights the importance of sticky retail rate adjustment for capturing credit spread data. For the TB model, the marginal density falls from 4357 to 4332. This suggests that the model setup is less suited to explain variability between the 3-month and 10-year Treasury Bill rates and, hence, misspecification due to the capital requirement shock is less likely in the baseline model. Therefore, the structural relationship in the baseline model (between bank balance sheet adjustments and the short-term interbank rate) is empirically preferable to that of the TB model.

3.6 Concluding remarks

This paper develops a New-Keynesian DSGE model with a central role for financial intermediation and equity assets to assess the influence of financial factors on credit spread variability. Large movements in credit spreads are closely linked to U.S. recessions over the Great Moderation and Great Recession periods and, hence, seen as an indicator of financial market stress. Overall, we observe supply-side factors as the primary source of credit spread variability, which is along the lines of Gilchrist and Zakrajšek (2012). That is, retail loan markups account for more than half of the variability of retail credit spreads. Moreover, sticky rate adjustments significantly alter the path of retail loan rates relative to the policy rate. Monetary policy has a strong influence on the short-term interbank rate, whereas the effectiveness of interest-rate policy on long-term nonfinancial loan rates is much weaker. Imperfect bank competition attenuates the effect of monetary policy through both sticky rate adjustments and a counter-cyclical bank capital-asset ratio. Equity prices exacerbate movements in credit spreads through the financial accelerator channel, but cannot be regarded as a main driving force of credit spread variability. Both financial accelerator and bank capital channels play a significant role in propagating the movements of credit spreads.

Ireland (2011) finds that all three recessions were caused by a similar combination of exogenous demand and supply shocks, where the notable difference for the Great Recession is that these adverse shocks were deeper, and lasted longer. In contrast, we observe a remarkable decline in the influence of technology and monetary policy shocks over three recession periods. From the demand-side of the credit market, the influence of LTV shocks has declined since the 1990−91

[17] The exception being the NI model: given the same prior distributions, one less observable variable means that the marginal data density will always be lower than the baseline model.

recession, while the bank capital requirement shock exacerbates and prolongs credit spread variability over the 2007−09 recession period. Moreover, across the three recession periods, there is an increasing trend in the contribution of loan markup shocks to the variability of both retail credit spreads.

Chapter 4

The effectiveness of countercyclical capital requirements and contingent convertible capital: a dual approach to macroeconomic stability

4.1 Introduction

The purpose of macroprudential policy is to limit systemic financial distress, with the ultimate objective of curtailing macroeconomic costs associated with that financial instability. One such instrument relied on by the Basel Committee on Banking Supervision is that of countercyclical capital requirements (as in Basel III). Indeed, both financial institutions and regulatory authorities are increasingly looking into a dual role for contingent convertible capital instruments (CoCos) and countercyclical capital adequacy (CA) ratios (Avdjiev et al., 2013; Calomiris and Herring, 2013; Galati and Moessner, 2013).[1] Although CoCos are primarily designed to re-capitalize individual bank balance sheets, its adoption within the macroprudential toolkit provides a role for CoCos—alongside Tier 1 equity capital—in mitigating systemic financial distress.

This paper studies the effectiveness of CA ratios and CoCos in limiting financial instability, and its associated influence on the real economy. Moreover, this paper assesses whether CoCos complement the objectives of a Basel III macroprudential policy. To do this, I augment both features into a standard real business cycle (RBC) framework with an equity market and a banking sector. Regulatory capital requirements enter through a quadratic adjustment cost on bank leverage, which includes a time-variant capital adequacy rule. The corporate finance model of Jaffee et al. (2013) provides the core framework to introduce CoCos into the general equilibrium model. The model is calibrated to real U.S. data and used for simulations. To assess the effectiveness of

[1] Both the Basel Committee on Banking Supervision and the Federal Reserve are in the process of formalizing the standards for contingent capital within Basel III regulatory requirements.

countercyclical capital requirements, a comparison analysis of alternative Basel regimes is done. Here, adopting an RBC framework provides a useful benchmark to observe the dynamic interactions between the financial system and the real economy.

While a capital adequacy rule provides a coherent framework for macroprudential policy, it neglects the barriers to external equity financing. Borio and Zhu (2012, p.238) identify a number of reasons for why banks are reluctant to issue new equity or reduce dividends. For example, the tax shield on debt financing discourages equity financing; and equity issuances may signal weak performance (i.e., adverse selection). The authors also identify distortions related to asymmetric information, agency problems and deposit insurance. Moreover, the return on equity for banks—the maximizing objective for its shareholders—is lowered when new equity is issued or dividends are cut. Conversely, in times of financial distress, the willingness of private investors to *supply* external equity capital can quickly dissipate. As a result, when the banking sector is over-leveraged, a weak macroeconomic outlook will exacerbate financial instability.

That said, contingent convertible debt provides an answer to equity issuances during banking crises and recessions (Avdjiev et al., 2013). CoCos are debt instruments which automatically convert into common equity when, for example, the bank's capital-asset ratio falls below a predetermined level. At this point of financial distress, equity shares are issued to CoCo holders at their current market price, commensurate to the face value of the original debt instrument. The main objective of CoCos is to therefore replace the lost capital of a financial institution in a timely manner (Calomiris and Herring, 2013). This addresses, in particular, two important financial distress phenomena: one, the amplification of asset fire sales can be curtailed or attenuated; two, the capital-asset ratios of financial institutions are stabilized in a timely manner at the prescribed market value of equity. For example, in the case of systemically important financial institutions (SIFIs), a negative shock to capital-asset ratios (induced by a freeze in the interbank market) results in a fire sale of assets as these SIFIs attempt to stabilize their capital positions. However, the role of CoCos would be to automatically convert into common equity at a prescribed trigger value. As a result, the soundness of bank balance sheets are more readily restored.

The main findings of the paper are as follows. First, a Basel III macroprudential policy improves the balance sheet position of banks and attenuates the effects of shocks on the real economy. That is, relative to simulations of the Basel I and Basel II regimes (akin to fixed and procyclical capital requirements, respectively), a countercyclical CA rule reduces business cycle fluctuations. Second, CoCos effectively re-capitalize the banking sector and foster the objectives of countercyclical capital requirements. Under financial shocks, CoCos provide an effective automatic stabilization effect on the financial cycle and the real economy. Whereas, technology shocks produce little variability in bank capital-asset ratios. As a result, a countercyclical CA rule dominates CoCos in the stabilization of real shocks. These findings suggests that CA ratios and CoCos provide an effective dual approach to macroprudential policy. On the one hand, a capital adequacy rule mitigates the build-up of systemic risk through a capital buffer. On the other hand, CoCos are able to reduce the impact of a sudden decline in bank capital. Another result of the paper highlights the robust cyclical properties of the model with respect to the data. Here, financial shocks play a key role in matching financial data variability and reducing the correlation of variables with output.

This paper is related to an expanding literature on the impact of various macroprudential policy tools on the broader economy. Currently, most dynamic stochastic general equilibrium (DSGE) models study either the interaction between monetary policy and macroprudential policy (e.g., Angelini et al., 2012; Angeloni and Faia, 2013; Quint and Rabanal, 2014) or the performance of loan-to-value rules and capital adequacy rules—i.e., the balance sheet channel and the bank lending channel, respectively (e.g., Funke and Paetz, 2012; Brzoza-Brzezina et al., 2013; Lambertini et al., 2013).[2] Although the balance sheet channel forms an important part of the transmission mechanism of financial instability, this paper highlights the bank lending channel in the propagation of shocks to the real economy (e.g., Markovic, 2006; Meh and Moran, 2010). In other words, to satisfy regulatory requirements banks can either raise new capital or reduce their supply of loans. This paper also focuses on the dynamic interactions between the financial system and the real economy, to which two papers are closely related. Firstly, the model setup in Van den Heuvel (2008) is closely related to the one developed here. That is, both models derive a role for debt and equity financing, where firms and banks maximize the return on shareholders' equity. However, in Van den Heuvel (2008), banks and firms only last for one period, and a minimum capital requirement arises to mitigate the moral hazard problem from deposit insurance. Secondly, de Walque et al. (2010) augment an RBC model with a banking sector and similarly study the effects of capital requirements on the business cycle. But instead of incorporating an interbank market with liquidity injections, the model developed here introduces a role for contingent convertible capital.

Lastly, although macroprudential policies are designed to mitigate financial instability, the lack of consensus on a clear definition for financial stability is well-documented (Galati and Moessner, 2013, p.848). Following Borio (2011, p.17), I measure the success of macroprudential policy by its ability to "mitigate the financial cycle"—that is, to reduce the procyclicality of the financial system. On the one hand, the equity premium, the bank capital-asset ratio and the credit spread serve as a measure of financial stability. On the other hand, output, consumption and investment serve as a measure of macroeconomic stability. The "risk" of financial instability is related to the deviation of bank leverage from a target leverage ratio (e.g., Christensen et al., 2011), while the countercyclical CA rule adjusts to output growth (e.g., Angelini et al., 2012; Brzoza-Brzezina et al., 2013).[3]

The remainder of this paper is organized as follows. Section 4.2 describes the model and

[2] Galati and Moessner (2013) provide an extensive literature review on macroprudential policy. Borio and Zhu (2012) also provide an overview of the theoretical studies on the role of bank capital in monetary transmission, and specifically highlight the importance of the "risk-taking channel" of monetary policy.

[3] A number of studies promote the credit-to-GDP ratio as a more robust early warning indicator (e.g., Drehmann and Tsatsaronis, 2014). Within the DSGE framework, however, deviations of output from steady-state simplifies the solution of the model, without loss of generality.

introduces a role for contingent convertible capital. Section 4.3 discusses the calibration of the model and its implied steady-state values. Section 4.4 compares the model's numerical simulations with U.S. data and presents the main findings. Section 4.5 concludes.

4.2 The model economy

This model departs from the standard one-sector, representative agent RBC model in two ways. First, introducing a banking sector creates a market for financial intermediation. More precisely, banks convert household deposits into loanable funds, from which nonfinancial firms borrow to finance their capital input. Second, both nonfinancial firms and banks can raise external equity financing by issuing shares to households. For simplicity, firms and banks are assumed to be wholly-owned by households, and therefore maximize the return on shareholders' equity. Meanwhile, only banks hold contingent convertible debt as a means to satisfy their capital adequacy ratios.

To ensure that the Modigliani and Miller (1958) theorem no longer holds, frictions arise between the rates of return on deposits, loans and equity. In the real sector, firms face a borrowing constraint and households have a liquidity preference for holding deposits.[4] As a result, the credit spread and the equity premium are linked to the marginal value of installed capital and the marginal utility of liquidity services. In the financial sector, banks face quadratic costs for deviating from a target leverage ratio, such that higher levels of leverage increase the return on equity relative to debt. Here, the target leverage ratio follows a capital adequacy rule, which is either independent from the business cycle (Basel I), or endogenous (Basel II and Basel III). In addition, introducing a capital requirement and a borrowing constraint implies that some proportion of external funding, for both banks and firms, will always comprise of equity.

4.2.1 Households

The representative household maximizes its expected lifetime utility function given by:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{(C_t - \phi C_{t-1})^{1-\gamma}}{1-\gamma} - \frac{(H_t)^{1+\eta}}{1+\eta} + ln(D_t) \right], \tag{4.1}$$

where β^t is the discount factor. Utility depends positively on the consumption of goods C_t relative to habit formation, and negatively on the supply of labour hours H_t. ϕ measures the habit persistence based on aggregate past consumption. Households' financial wealth is made up of risk-free deposits D_t and equity investments E_t. Similar to Van den Heuvel (2008) and Christiano et al. (2010) I assume households derive direct utility from the liquidity services of deposits.

[4]Given that households are risk averse and utility maximizing, the latter case is motivated by the greater risk and larger transaction costs associated with stocks compared to deposits. (see, e.g., Van den Heuvel, 2008; Brunnermeier et al., 2012)

This drives a positive wedge in the spread between the return on equity and the return on bank deposits. η measures the inverse of the Frisch elasticity of labour supply. γ captures the inverse of the intertemporal elasticity of substitution in consumption.

Eq. 4.2 gives the household budget constraint:

$$C_t + D_t + Q_t E_t = W_t H_t + R_{t-1} D_{t-1} + (Q_t + V_t) E_{t-1}. \tag{4.2}$$

The household allocates periodic income from wages (W_t), gross real returns on deposits $(R_{t-1}D_{t-1})$, real capital gains/losses $(Q_t E_{t-1})$ and real dividend income $(V_t E_{t-1})$ to current consumption and new financial wealth holdings. In aggregate, the total equity stock E_t equals the total supply of equity from banks E_t^b and firms E_t^f.[5] Q_t is the equity price in current period t.

The representative household's first-order conditions for deposits, labour and equity holdings are the following:

$$\frac{1}{D_t} = U_{c,t} - \beta E_t \Big[U_{c,t+1} R_t \Big], \tag{4.3}$$

$$W_t = (U_{c,t})^{-1} (H_t)^{\eta}, \tag{4.4}$$

$$U_{c,t} = \beta E_t \Big[U_{c,t+1} R^e_{t+1} \Big], \tag{4.5}$$

where $R^e_{t+1} = (Q_{t+1} + V_{t+1})/Q_t$ is the gross real return on equity and $U_{c,t} = (C_t - \phi C_{t-1})^{-\gamma}$ is the marginal utility of consumption. Eq. 4.3 is the household's demand for deposits. Eq. 4.4 gives the standard real wage equation: that is, the real wage equals the marginal rate of substitution between consumption and labour. Eq. 4.5 gives the consumption Euler equation, based on the standard asset-pricing equation for equity.

Combining Eq. 4.5 and Eq. 4.3 illustrates the spread between R^e_{t+1} and R_t, based on household liquidity preferences for deposits:

$$\frac{U_{d,t}}{U_{c,t}} = \beta E_t \Big[R^e_{t+1} - R_t \Big]. \tag{4.6}$$

Here Eq. 4.6 states that the marginal utility of the liquidity services $(U_{d,t} = D_t^{-1})$, expressed in units of consumption, equals the equity premium.

4.2.2 Nonfinancial firms

Nonfinancial firms manage the goods producing sector, and are owned by households. A firm's objective is to therefore maximize the value of its shareholders equity.[6] Analogous to Bernanke et al. (1999, p.1349) and Van den Heuvel (2008, p.304), I assume that the firm must borrow an amount L_t to finance the difference between the value of capital goods and shareholders' equity

[5] $E_t = E_t^f + E_t^b$ and $V_t E_t = V_t^f E_t^f + V_t^b E_t^b$. Later on we see that $V_t = V_t^f = V_t^b$.

[6] Equivalent to maximizing the return on shareholders' equity (ROSE).

(net worth): $L_t = K_t - Q_t E_t^f$. In other words, the firm finances its new physical capital purchases in the beginning of the period by issuing equity to households $(Q_t E_t^f)$ and by borrowing from banks (L_t). Firms will continue to issue shares only if the expected return on equity financing is positive.[7]

Firms produce goods using a standard Cobb-Douglas production function described by

$$Y_t = \xi_{z,t} K_{t-1}^{\alpha} H_t^{1-\alpha}, \tag{4.7}$$

where K_{t-1} is physical capital, H_t is the demand of labour hours, and $\xi_{z,t}$ is the technology. In addition, nonfinancial firms face a borrowing constraint:

$$R_t^l L_t \leq \nu K_t, \tag{4.8}$$

where ν is the nonfinancial firm's loan-to-value (LTV) ratio.

Therefore, in each period, the firm chooses the desired amount of physical capital, labour and equity issuance to maximize

$$E_0 \sum_{t=0}^{\infty} \beta_f^t \left[\frac{\Omega_t^f}{R_t^e} \right] \tag{4.9}$$

subject to the production technology, Eq. 4.7, the borrowing constraint, Eq. 4.8, and the flow of funds constraint

$$\Omega_t^f = Y_t - W_t H_t - I_t + Q_t E_t^f + L_t - R_{t-1}^l L_{t-1} - (Q_t + V_t^f) E_{t-1}^f - \Phi_t^i. \tag{4.10}$$

$\Phi_t^i = (\kappa_i / 2\delta)(I_t / K_{t-1} - \delta)^2 K_{t-1}$ captures the capital installation costs, where $I_t = K_t - (1 - \delta) K_{t-1}$ is investment and δ is the rate of depreciation. Using the capital financing identity, $L_t = K_t - Q_t E_t^f$, and dividing Eq. 4.10 by the return on equity, $R_t^e = (Q_t + V_t^f)/Q_{t-1}$, gives the maximization problem of the firm:

$$\frac{\Omega_t^f}{R_t^e} = \frac{Y_t - W_t H_t + (1-\delta) K_{t-1} - R_{t-1}^l (K_{t-1} - Q_{t-1} E_{t-1}^f) - \Phi_t^i}{R_t^e} - Q_{t-1} E_{t-1}^f, \tag{4.11}$$

defined as the value of shareholders equity (net income over the return on equity) minus the initial equity investment (see, e.g., Van den Heuvel, 2008, p.304).

The first order conditions for labour, physical capital, and equity issuances are the following:

$$W_t = \frac{(1-\alpha) Y_t}{H_t}, \tag{4.12}$$

$$\begin{aligned} R_t^l &= E_t \left[\frac{\alpha Y_{t+1}}{K_t} + Q_{t+1}^I (1-\delta) + \frac{\kappa_i}{\delta} \left(\frac{I_{t+1}}{K_t} - \delta \right) \frac{I_{t+1}}{K_t} - \frac{\kappa_i}{2\delta} \left(\frac{I_{t+1}}{K_t} - \delta \right)^2 \right] \\ &- \frac{1}{\beta^f} (Q_t^I - 1) - \frac{\lambda_t^f}{\beta^f} (1 - \frac{\nu}{R_t^l}) R_{t+1}^e, \end{aligned} \tag{4.13}$$

$$\lambda_t^f = \beta^f \left(\frac{R_{t+1}^e - R_t^l}{R_{t+1}^e} \right). \tag{4.14}$$

[7] That is, if the expected real income from production covers the expected wage, the gross loan repayment and the initial equity investment plus the dividend.

$Q_t^I = 1 + \kappa_i/\delta(I_t/K_{t-1} - \delta)$ is the shadow value of capital. Eq. 4.12 is the standard labour demand schedule. Eq. 4.13 states that the return on loans must equal the expected marginal product of capital plus capital installation costs, taking account for the marginal product of an additional loan λ_t^f. Eq. 4.14 shows that the marginal product of an additional loan is positively related to the discounted equity financing premium, such that the following holds: if $R_{t+1}^e > R_t^l$ then $0 < \lambda_t^f < 1$; if $R_{t+1}^e < R_t^l$ then $\lambda_t^f < 0$.

In the frictionless case there are no constraints on credit, and the rates of return on debt and equity are equalized. This implies that both rates of return equal the marginal product of capital. Two important frictions arise from introducing the borrowing constraint: one, a standard Bernanke et al. (1999) financial accelerator effect arises, and two, an increase in the equity financing premium increases the margin product of an additional loan. In addition, the borrowing constraint ensures that the firm must maintain a proportion of capital, $(R_t^l - \nu)/R_t^l$, as equity. Combining Eq. 4.13 with Eq. 4.14, and ignoring capital installation costs, gives the equity financing margin for nonfinancial firms:

$$R_{t+1}^e = \frac{\alpha Y_{t+1}}{K_t} + (1-\delta) + \left(\frac{R_{t+1}^e - R_t^l}{R_t^l}\right)\nu. \tag{4.15}$$

The return on equity is therefore procyclical and linked to the marginal value of installed capital (see also, Christiano and Fisher, 2003).

4.2.3 Banks

Analogous to nonfinancial firms, banks are owned by households and therefore maximize the return on shareholders' equity. Banks issue loans to nonfinancial firms, and fund these assets with deposits and bank capital ($K_t^b = Q_t E_t^b$). Following a recent string of macroprudential studies, banks face a non-binding capital requirement (e.g., Angelini et al., 2012; Angeloni and Faia, 2013; Brzoza-Brzezina et al., 2013). In this paper, quadratic costs arise when the bank's leverage ratio (L_t/K_t^b) deviates from the macroprudential instrument: the target leverage ratio τ_t. This introduces two important conditions of financial intermediation. Firstly, it drives a wedge between bank lending and funding rates. Secondly, the target leverage ratio can be governed by a macroprudential policy rule to mimic the effects of alternative Basel regimes. Because banks are subject to a binding balance sheet identity, $L_t = K_t^b + D_t$, deposits are taken as given. In other words, given households' demand for liquidity services from deposits, the bank will adjust L_t and E_t^b to maximize the return on shareholders' equity.

Therefore, the bank chooses loans (L_t) and equity (E_t^b) to maximize

$$E_0 \sum_{t=0}^{\infty} \beta_b^t \left[\frac{\Omega_t^b}{R_t^e}\right] \tag{4.16}$$

subject to the balance sheet identity and the flow of funds constraint

$$\Omega_t^b = R_{t-1}^l L_{t-1} - R_{t-1}D_{t-1} - L_t + D_t + Q_t E_t^b - \digamma(E,L) - (Q_t + V_t^b)E_{t-1}^b, \quad (4.17)$$

where $\digamma(E,L) = \kappa/2(L_t/K_t^b - \tau_t)^2 D_t$ is the regulatory cost of intermediation measured by deviations of bank leverage around a target leverage ratio τ_t. As with nonfinancial firms, using the balance sheet identity and the return on equity, $R_t^e = (Q_t + V_t^b)/Q_{t-1}$, Eq. 4.17 can be written as follows:

$$\frac{\Omega_t^b}{R_t^e} = \frac{R_{t-1}^l L_{t-1} - R_{t-1}D_{t-1} - \digamma(E,L)}{R_t^e} - Q_{t-1}E_{t-1}^b. \quad (4.18)$$

The first-order conditions for loans and equity are:

$$R_t^l - R_t = \digamma^l(E,L), \quad (4.19)$$

$$R_{t+1}^e - R_t = -\digamma^e(E,L)\frac{1}{Q_t}, \quad (4.20)$$

where $\digamma^l(E,L) > 0$ and $-\digamma^e(E,L) > 0$. In the frictionless equilibrium $(\kappa = 0)$ $R_{t+1}^e = R_t^l = R_t$. This implies that households derive zero utility from the liquidity provision of deposits, and that firms do not face a borrowing constraint.

Combining Eqs. 4.19 and 4.20 gives the equity financing margin:

$$R_{t+1}^e - R_t^l = \kappa\left(\frac{L_t}{K_t^b} - \tau_t\right)\left(\frac{D_t}{K_t^b}\right)^2. \quad (4.21)$$

Eq. 4.21 states that when bank leverage rises above the target leverage ratio, τ_t, the required return on equity increases relative to the return on loans. Comparing Eqs. 4.14 and 4.21 implies that the discounted marginal product of an additional loan is proportional to the marginal cost from increasing bank leverage. Subsequently, $R_t^e \gg R_t^l$ when bank leverage and the marginal product of installed capital are increasing.[8] This captures two key empirical features of the U.S. banking sector. One, as leverage rises the cost of equity financing increases relative to debt financing (Hanson et al., 2010, 2011). Two, in an environment of expanding bank balance sheets and a widening equity premium, bank leverage is procyclical (Adrian and Shin, 2010b, 2013). That is, leverage rises during booms and falls during busts.

Additional empirical evidence provided by Adrian and Shin (2010b, 2013) shows that U.S. banks tend to adjust debt, rather than equity, to actively manage leverage. In other words, bank capital accumulation is persistent. As it stands in the model setup, leverage requirements create a wedge between the rates of return on equity and loans; however, banks are able to adjust their balance sheet quantities to make this cost negligible. It is therefore necessary to derive a law of motion for bank capital accumulation.

[8] To be consistent with nonfinancial firms, the bank should face a fixed proportional cost to both equity and debt financing such that the spread, $R^e - R^l > 0$. This, however, is not an issue for the log-linearized system of equations.

To begin with, from the optimizing Eqs. 4.19 and 4.20, we can re-write the bank's flow of funds constraint as

$$R^l_t L_t - R_t D_t - R^e_{t+1} K^b_t - F(E, L) = 0, \tag{4.22}$$

where $K^b_t = Q_t E^b_t$.[9] Substituting in the balance sheet identity $L_t = D_t + K^b_t$ and using $R^e_{t+1} = (Q_{t+1} + V^b_{t+1})/Q_t$ gives

$$r^l_t L_t - r_t D_t = (Q_{t+1} + V^b_{t+1})E^b_t - Q_t E^b_t. \tag{4.23}$$

Eq. 4.23 states that the net interest margin between the bank's assets and liabilities must cover the expected real capital gains $(\Delta Q_{t+1} E^b_t)$ plus the expected real dividend paid to households $(V^b_{t+1} E^b_t)$. To introduce a law of motion for bank capital accumulation, we let the RHS of Eq. 4.23 equal $K^b_{t+1} - (1 - \delta)K^b_t$:

$$(Q_{t+1} + V^b_{t+1})E^b_t - Q_t E^b_t = Q_{t+1} E^b_{t+1} - (1 - \delta_b) Q_t E^b_t \tag{4.24}$$

$$\therefore\ Q_{t+1}(E^b_{t+1} - E^b_t) = -(\delta_b Q_t E^b_t - V_{t+1} E^b_t). \tag{4.25}$$

Therefore, Eq. 4.25 assumes an implicit cost for issuing new shares at price Q_{t+1}. This cost is equal to a fraction δ_b of the initial equity investment less the expected dividend payment. Given this assumption, we can write the law of motion for bank capital accumulation, from Eq. 4.23, as follows:

$$K^b_{t+1} = (1 - \delta_b)K^b_t + (r^l_t L_t - r_t D_t). \tag{4.26}$$

4.2.4 Macroprudential policy

Similar to Angelini et al. (2012) and Brzoza-Brzezina et al. (2013), the Basel III target leverage ratio τ_t follows a countercyclical capital adequacy rule:

$$\tau_t = \bar{\tau}^{(1-\rho_\tau)} \tau_{t-1}^{\rho_\tau} \left(\frac{Y_t}{\bar{Y}} - 1 \right)^{-\kappa_\tau (1-\rho_\tau)} e^{\epsilon_{\tau,t}}, \tag{4.27}$$

where $\epsilon_{\tau,t}$ is an i.i.d shock to the target leverage ratio. The countercyclical policy rule is parameterized by $\kappa_\tau > 0$ and $1 > \rho_\tau \geq 0$. Under a Basel III countercyclical regime, banks accumulate a capital buffer when output deviates above steady-state. This implies that the required leverage ratio of banks is tapered during booms and elevated during busts. Alternatively, when the target leverage ratio is reduced (raised) banks become overleveraged (underleveraged). When banks are overleveraged (underleveraged), the return on equity increases (decreases) relative to the return on loans.

[9] For simplicity, the regulatory cost term, $F(E, L)$, will hereafter be ignored as it falls away in the log-linearized equation.

4.2.5 Closing the model

To close the model, the dynamic adjustment path of the risk-free real rate of interest, R_t, must be specified. As documented by King and Watson (1996, p.48), RBC models tend to fail at reproducing the negative correlation between the real rate of interest and output for U.S data (see also, Begum, 1998; Christiano and Fisher, 2003; Garnier and Wilhelmsen, 2005).[10] That said, King and Watson (1996, p.48) find that generating a negative correlation is possible at the expense of counterfactual business cycle moments for labour input (see also Table 4.3 below).

Based on the model setup, it is important to disentangle the influence of the banking sector from the risk-free rate R_t for two reasons. Firstly, if banks are able to control R_t, given their optimal responses for loans and equity, the impact of capital requirements on the real economy becomes negligible.[11] Secondly, as the bank capital accumulation equation is derived from the flow of funds constraint, it rules out specifying an equation for the dynamic adjustment of deposits. Therefore, deviations of the risk-free real rate from its steady-state are characterized by the following dynamic rule:

$$R_t = \bar{R}^{(1-\rho_r)} R_{t-1}^{\rho_r} (\frac{Y_t}{\bar{Y}} - 1)^{-\kappa_r(1-\rho_r)}, \tag{4.28}$$

where, for simplicity, ρ_r is assumed to equal 0.

The aggregate resource constraint for the economy is

$$Y_t = C_t + I_t + F(E, L). \tag{4.29}$$

4.2.6 Introducing contingent convertible capital (CoCos)

Prior to conversion, CoCos are issued as debt instruments at a fixed rate of return. When the bank's capital-asset ratio falls below a predetermined level CoCos will automatically convert into equity. At this trigger value, defined as the target leverage ratio τ_t, CoCo holders' receive a certain value of common equity in exchange for the original debt instrument D_t. Equity is issued at the current market price, and can be issued up to the face value of the original debt instrument ($Q_t E_t^{\chi} \leq \mu D_t$). To introduce CoCos into the model developed here requires three assumptions. First, deposits convert into equity with a probability θ at any given value of L_t/K_t^b above the trigger value τ_t. In other words, θ is uniformly distributed above τ_t. Second, the assumption of perfect markets is relaxed, in which arbitrage implies that the real dividend yield must equal the real rate of return on deposits. As a result, no arbitrage implies that the payoffs of debt and equity instruments (carried over from period $t-1$) may not equate. Third, given the CoCo constraint $Q_{t-1}E_{t-1}^{\chi} \leq \mu D_{t-1}$ the bank must first settle the optimal combination of debt and equity, given the probability θ of debt converting into equity. That said, the bank's balance sheet is still binding in period t.

[10] These studies also show that the negative correlation of the real rate of interest is both a leading indicator and contemporaneous.

[11] That is, deriving a rate of returns margin from the bank's first-order conditions: see Eq. D.26 in the Appendix.

The bank therefore maximizes the following return on shareholders equity:

$$\frac{\Omega_t^b}{R_t^e} = \frac{R_{t-1}^l L_{t-1} - R_{t-1}(1-\theta\mu)D_{t-1} - F(E,L)}{R_t^e} - Q_{t-1}(E_{t-1}^b + \theta E_{t-1}^\chi), \tag{4.30}$$

Combining the first-order conditions for L_t and E_t^b gives:

$$R_{t+1}^e - R_t^l = \frac{1}{\beta_b}\left[\kappa\left(\frac{L_t}{K_t^B} - \tau_t\right)\frac{D_t}{K_t^B}(\frac{L_t}{K_t^B} - 1)\right], \tag{4.31}$$

where total bank capital K_t^B now comprises of the original bank capital K_t^b plus the value of newly converted CoCo instruments, $K_t^\chi = Q_t E_t^\chi$. If $\theta = 0$ then $K_t^B = K_t^b$, and Eq. 4.31 becomes the original Eq. 4.21 in the model without CoCos.

Combining the first-order conditions for D_t and E_t^χ gives:

$$(1-\theta\mu)R_t + \theta\mu R_{t+1}^e = \frac{\theta\mu}{\beta_b}\left[\kappa\left(\frac{L_t}{K_t^B} - \tau_t\right)\frac{D_t}{K_t^B}\frac{L_t}{K_t^B}\right]. \tag{4.32}$$

Eq. 4.32 states that the marginal cost of leverage deviations is proportional to the expected payoff of debt converting into equity at any given leverage ratio (L_t/K_t^B) above the trigger value τ_t. Conversely, when $L_t/K_t^B < \tau_t$ then $\theta = 0$. Substituting Eq. 4.32 into Eq. 4.31 then gives the new marginal cost of leverage deviations in financial intermediation.

The bank capital accumulation equation for K_t^b can be written as follows:

$$K_{t+1}^b = (1-\delta)K_t^b + (r_t^l L_t - r_t D_t) + (R_t - R_{t+1}^e)\theta K_t^\chi. \tag{4.33}$$

The final equation affected from introducing CoCos is the household's demand for deposits, given as:

$$\frac{1}{D_t} = U_{c,t} - \beta E_t\left[U_{c,t+1}((1-\theta\mu)R_t + \theta\mu R_{t+1}^e)\right]. \tag{4.34}$$

4.3 Calibration

Households' preferences and nonfinancial firm technology are calibrated in line with the literature. Bank balance sheets are calibrated to represent current U.S. banking conditions, whereas the real rates of return on loans and equity are based on average real quarterly data from 1985Q1−2013Q4. Tables 4.1 and 4.2 summarize the calibrated parameters and the implied steady-state values based on the model setup.[12]

The seven preference and technology parameters are calibrated as follows. The inverse of the intertemporal elasticity of substitution in consumption (γ) and the inverse of the Frisch elasticity of labour supply (η) are set to 2. Habit formation ϕ equals 0.75. The capital-output share α is

[12] In the log-linearized equation, the bank's steady-state balance sheet condition offsets the influence of κ in the dynamic adjustment. Rather, the leverage ratio τ governs the degree of influence of balance sheet adjustments.

Table 4.1: Calibrated parameters

Parameter	Description	Value
Households		
γ	Coefficient of relative risk aversion	2
ϕ	Habit persistence	0.75
η	Inverse of the Frisch elasticity	2
Nonfinancial firms		
α	Capital share in the production function	0.3
δ	Capital depreciation rate	0.025
κ_i	Capital installation costs	0.5
ν	Loan-to-value ratio for firms	0.75
Steady-state rates		
R	Steady-state return on deposits	1.005
R^l	Steady-state return on loans	1.015
R^e	Steady-state return on equity	1.035
Banks		
τ	Target leverage ratio	6.67
μ	Ratio of CoCos to total debt	0.015
θ	Debt to equity conversion rate	0.1
κ_r	Real (natural) rate deviation rule	0.25

Table 4.2: Implied steady-state values from the model

Parameter	Description	Value
β	Discount factor	0.966
U_d/U_c	Liquidity services provided by deposits	0.029
$\alpha Y/K$	Marginal production of capital	0.045
K/Y	Capital-output ratio	6.634
I/Y	Investment-output ratio	0.166
C/Y	Consumption-output ratio	0.834
δ_b	Fixed costs for bank capital management	0.072
K^X/K^B	Ratio of CoCos to total bank capital	0.1

Note: the steady-state equations based on the model are provided in the appendix.

set to 0.3, and the physical capital depreciation rate δ is set to 0.025. The parameter governing capital installation costs (κ_i) is set to 0.5 (see, for example, Bernanke et al., 1999). Lastly, the loan-to-value ratio for firms is set to 0.75.

Based on S&P500 data for equity prices and dividends, the average quarterly real return on equity is 3.5% (Shiller, 2005, updated). $R^e = 1.035$ matches a 15% annualized real return on bank equity for the period 1985Q1−2008Q1 (Meh and Moran, 2010, p.565). Similar to the value chosen in the RBC setup of de Walque et al. (2010, p.1244), the steady-state values for the quarterly real risk-free rate R and the real borrowing rate are set to 1.005 and 1.015, respectively.

For the banking sector, the steady-state target leverage ratio τ is set to 6.67, which corresponds to an average bank capital-asset ratio of 15%. This is slightly above the average total equity to total assets ratio of 11% for all U.S. commercial banks in 2013, but is similar to the 14% capital adequacy ratio motivated by Meh and Moran (2010) and the 15% effective capital-asset ratio in de Walque et al. (2010). Since 2009, the ratio of CoCos issued to that of non-CoCo subordinated debt plus senior unsecured debt is 1.5% (Avdjiev et al., 2013). μ is therefore set equal to 0.015. A reasonable assumption of 1.5% serves the purpose of this paper to study the mitigating effects of CoCos under negative shocks to bank capital. Similarly, given a decline in bank capital, the conversion probability from debt to equity (θ) is fixed at 0.1. A value of 0.25 for κ_r implies that the real interest rate deviates 25 basis points below its steady-state when the output gap increases 1% (e.g., Laubach and Williams, 2003; Garnier and Wilhelmsen, 2005).

The remaining implied steady state values are reported in Table 4.2. In relation to the RBC literature, the implied steady state values for the capital-output ratio (6.63) and the investment-output ratio (0.17) are slightly below their normally observed values, $K/Y = 8$ and $I/Y = 0.2$ (de Walque et al., 2010). As a result, the consumption-output ratio (0.83), is slightly higher than what is observed in the data between 1985Q1 and 2013Q4 (0.66). The discount factor β is the reciprocal of the steady-state return on equity (see Eq. 4.5). The bank capital management costs parameter δ equals 0.072. Based on the approximate estimate for μ and given τ, the ratio of contingent convertible capital to total bank capital is set at 10%. All autoregressive parameters for exogenous shock processes are standardized to equal 0.75, and innovations are independent and normally distributed. A degree of persistence of 0.75 implies a lifespan of approximately four years for technology and financial shocks.

4.4 Findings

Firstly, Section 4.4.1 explains the business cycle effects of bank capital regulation, from Basel I through to Basel III. Subsequently, Section 4.4.2 looks at the effectiveness of CoCos in mitigating negative shocks to bank capital, and whether there is potential for CoCos to complement the Basel III regime with countercyclical capital requirements. Section 4.4.3 concludes with a comparison of the business cycle moments produced by the model to those observed in the data. This exercise also highlights the key role of financial shocks in reproducing business cycle characteristics.

4.4.1 Business cycle dynamics of the Basel regimes

The purpose of this subsection is to establish the business cycle effects of minimum capital requirements under alternative Basel regimes. Similar to Angelini et al. (2012) and Brzoza-Brzezina et al. (2013), the Basel III target leverage ratio τ_t follows a countercyclical capital adequacy rule (Eq. 4.27) where $\kappa_\tau = 2.14$ is the standard deviation of the capital-asset ratio relative to output. This means that the target leverage ratio of banks is tapered during booms and elevated during recessions. In other words, banks accumulate a capital buffer when output deviates above steady-state. Conversely, Basel II procyclicality can be emulated by inverting the sign for κ_τ (e.g., Angeloni and Faia, 2013, p.321). This generates the procyclical leverage observed for minimum capital requirements under Basel II. For the Basel I regime, bank capital requirements are exogenous, where $\kappa_\tau = 0$ and τ_t becomes an exogenous AR(1) process. Figures 4.1 and 4.2 show the impulse responses to a productivity shock and a target leverage ratio shock, for each Basel regime.

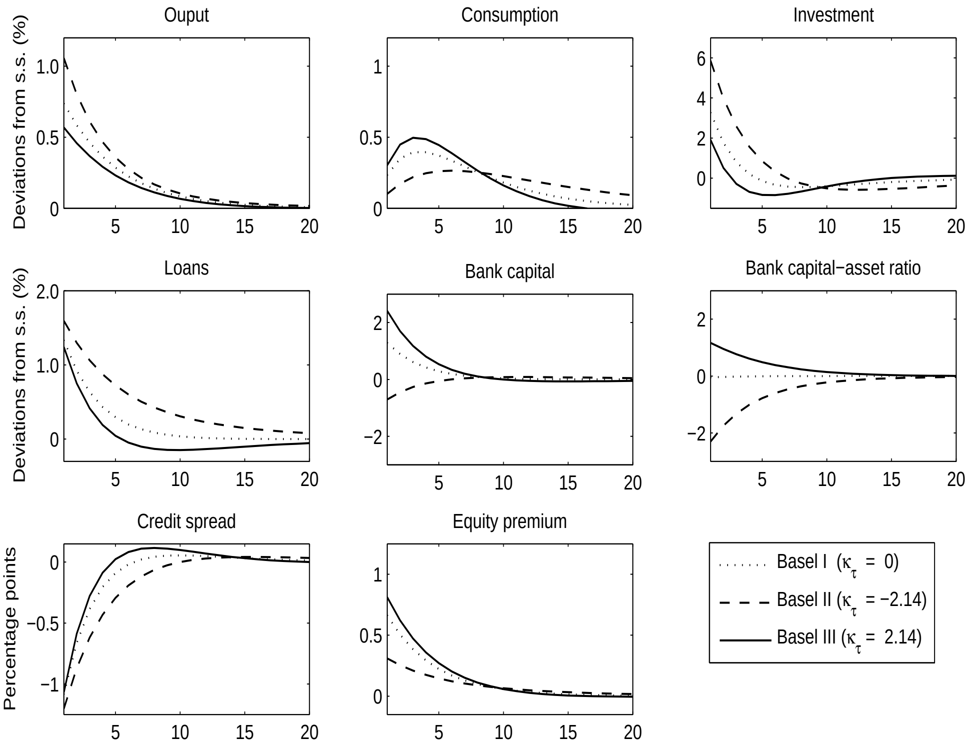

Figure 4.1: Impulse response to a positive technology shock. From Basel I to Basel III.

In Figure 4.1 we immediately see the exacerbating effect of a procyclical Basel II regime. A positive technology shock raises output, consumption and investment causing banks to expand their balance sheets by taking on deposits and extending loans to firms. The demand for loans is spurred on by the narrowing credit spread, whilst the rising equity premium reflects the bullish market and the profitability of nonfinancial firms and banks. On the one hand, compared to Basel

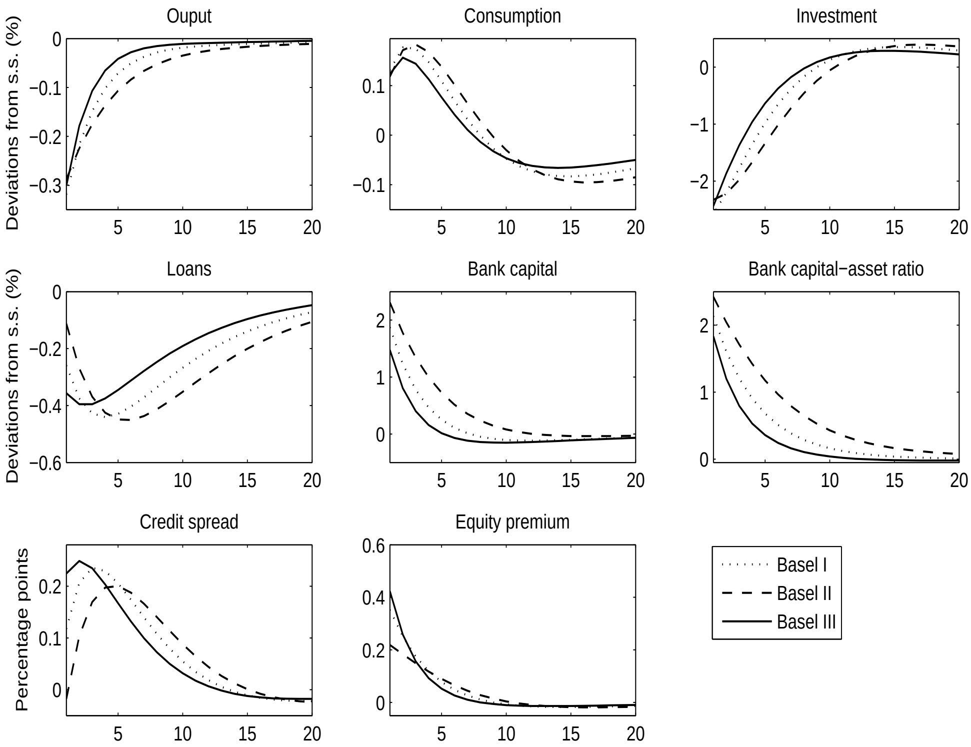

Figure 4.2: Impulse response to a reduced target leverage ratio. From Basel I to Basel III.

I, Basel II increases the volatility of bank balance sheets as well as the real economy. In particular, banks become overextended in an environment of higher financing costs and lower returns on assets, causing real investment and production to expand. Households' smooth their consumption paths by increasing savings, whilst a lower return on equity initially dampens consumption. On the other hand, in a Basel I regime banks are required to raise capital to stabilize their leverage ratios, which minimizes adverse bank balance sheet adjustments.[13]

For Basel III, countercyclical capital requirements effectively stabilize bank balance sheets and business cycle fluctuations. By raising a capital buffer, in addition to the Basel I requirements, credit extension is tapered and an overexpansion of the real economy is prevented. In fact, the credit market stabilizes after seven quarters, with the real economy reverting to steady-state within fifteen quarters. Overall, the results for the Basel regimes in Figure 4.1 confirm the findings in de Walque et al. (2010), Christensen et al. (2011) and Angeloni and Faia (2013).

Figure 4.2 shows similar results for each alternative Basel regime under the banking sector shock. Basel II is procyclical, and Basel III is countercyclical. Reducing the target leverage ratio

[13]With exogenous capital requirements the target leverage ratio remains constant, i.e., Basel I is time-invariant.

of banks, analogous to requiring banks to hold more capital, impacts the business cycle as follows. For Basel II, the effect on loans and the credit premium becomes more amplified than Basel I and Basel III after five quarters. In addition, an overcapitalization of bank balance sheets crowds out liquidity supply to and from banks. The result of a worsening credit market and increasing liquidity shortages strengthens the negative effect of higher capital requirements on the real economy. The converse is true for the Basel III regime.

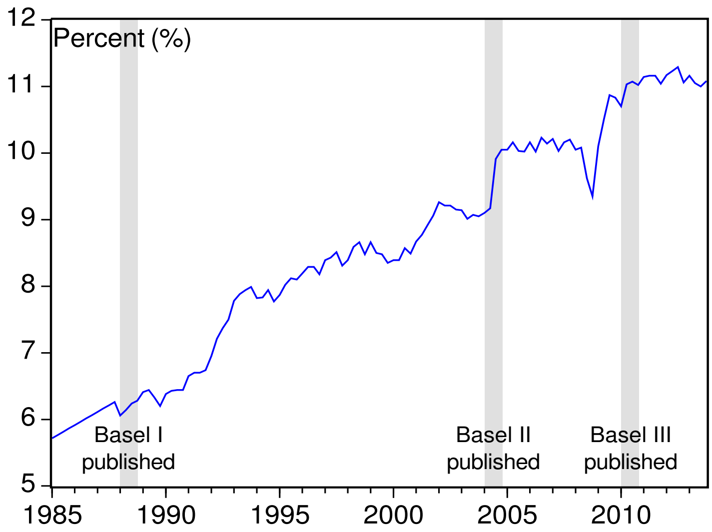

Figure 4.3: Equity-to-assets ratio for all U.S. banks

Moreover, the impact of minimum capital requirements is more clearly observed when the *steady-state* target leverage ratio, and not only the dynamic adjustment thereof, changes. This can be interpreted as the effect of an incremental increase in the level of minimum capital requirements from Basel I to Basel III. Figure 4.3 shows the total equity to total assets ratio for all U.S. banks from 1985Q1 to 2013Q4. The shaded areas correspond with the published dates of each Basel Accord. The idea here is to roughly illustrate the incremental increase in the steady-state *level* of bank capital-asset ratios after each Basel Accord. Figure 4.4 shows the impulse response to a reduced target leverage ratio for a low versus a high steady-state capital requirement. Here, I keep the target leverage ratio exogenous, and simply raise the steady-state capital-asset ratio from 10% to 15% (i.e., $\tau = 10$ and $\tau = 6.67$, respectively). The increase in the steady-state capital-asset ratio has a strong exacerbating effect on bank loans and the cost of credit. As a result, investment in production activities declines, further reducing output. Although consumption initially rises because of a better return on equity, it becomes negative after eight quarters.

The reasoning from the model setup is as follows. Based on the bank's optimizing Eqs. 4.19 and 4.20, we can re-write the flow of funds constraint to derive the implied steady-state rate of

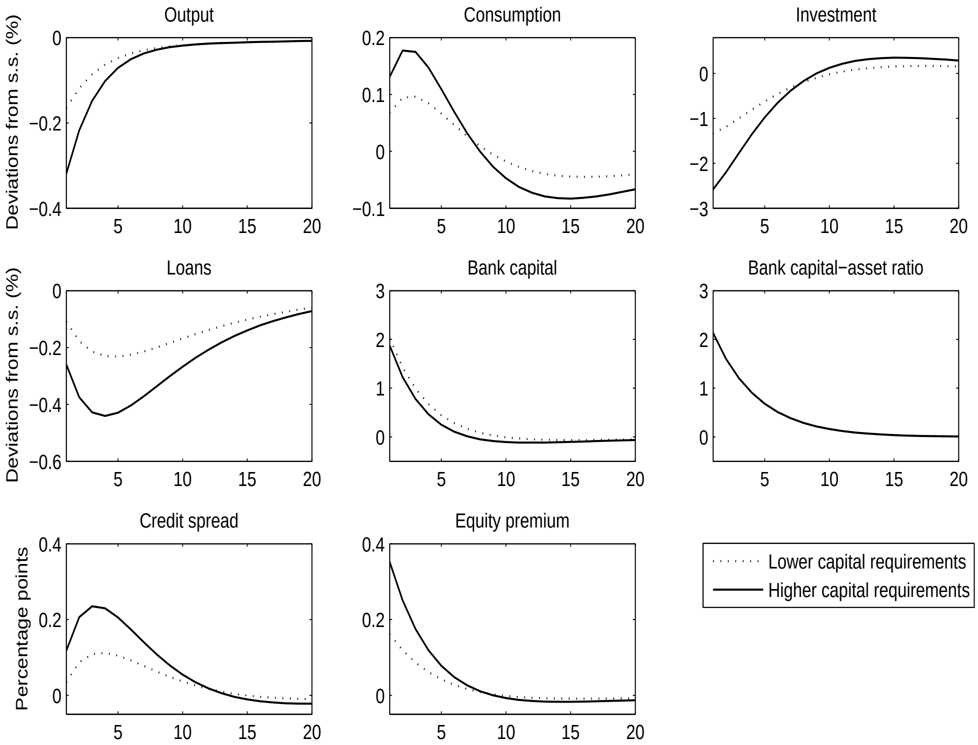

Figure 4.4: Impulse response to a reduced target leverage ratio for low versus high capital requirements.

returns margin

$$R^l = \frac{1}{\tau}R^e + \frac{(\tau - 1)}{\tau}R. \tag{4.35}$$

Given $R = 1.005$, $R^l = 1.015$ and $R^e = 1.035$, the implied steady-state value for the leverage ratio τ equals 3. Its reciprocal gives a 33% bank capital-asset ratio. Therefore, as τ tends to 3 (i.e., reducing τ from 10 to 6.67) the bank approaches its optimal maximization point. Conversely, given R^e and R, the higher the leverage ratio the narrower the steady-state rate of returns margin becomes. In the dynamic equation (4.21), this also means that the variability of the credit spread and the equity premium is smaller for a given adjustment to the bank capital-asset ratio.

4.4.2 Contingent convertible capital

This subsection shows how contingent convertible capital complements the objectives of a Basel III macroprudential policy. From the above analysis, it is clear that the shift from Basel II to Basel III should reduce the impact of shocks on both the real economy and the financial sector. However, two important drawbacks are observed. One, shocks to the business cycle are exacerbated by higher steady-state levels of minimum capital requirements. Two, the Basel III regime is not designed to counteract sudden negative shocks to bank capital. Here, contingent convertible capital becomes a useful instrument for bank capital requirements. In that, once the debt instrument converts into common equity the conversion is permanent. State contingent CoCos therefore address permanent shifts in bank capital needs—without requiring banks to hold higher levels of common equity to preempt episodes of financial distress. More importantly, the role of CoCos is to automatically re-capitalize banks, reduce financial distress (in a timely manner), and mitigate knock-on effects to the real economy.

To highlight this role, I compare impulse responses of the model with contingent convertible capital to the one without (hereafter No CoCos). Figures 4.5 and 4.6 show the attenuating effect of CoCos under a negative target leverage ratio shock and a negative bank capital shock. Figure 4.7 shows the impulse response to a technology shock. For the leverage shock and the technology shock the target leverage ratio is kept exogenous.[14] For the bank capital shock, the Basel III regime combines with CoCos to highlight the comparative advantage of CoCos over countercyclical capital requirements, in periods of financial distress. In each case, banks are required to raise their capital-asset ratios to satisfy the target leverage ratio. Based on the model setup, CoCos will convert into equity with probability 0.1 when the trigger value (L_t/K_t^b) is above the target level (τ_t).

Figure 4.5 clearly shows the effectiveness of CoCos in mitigating financial distress. On the one hand, for the No CoCos model, a positive shock to capital requirements causes a contraction in loan supply and a widening credit spread. As a result, investment in production activities declines. Although household consumption initially increases due to the positive wealth effect of equity, output falls 0.32%. On the other hand, allowing for banks to hold contingent convertible capital (see CoCos 1) significantly reduces the adverse effect of higher capital requirements, on both the financial sector and the real economy. Firstly, the triggering of CoCos from debt to equity raises overall bank capital and reduces the amount of debt on bank balance sheets. As a result, the contraction in loan supply and the rise in the cost of capital halves. The knock-on effect to the real economy is subsequently mitigated, with output now falling only 0.16%. Furthermore, increasing the steady-state ratio of CoCos to total bank capital (K^{χ}/K^{B}) from 10% to 25% further reduces the instability caused by the shock (see CoCos 2). Although illustrative, this result clearly shows a significant stabilization role for CoCos.

Indeed, an exogenous shock to capital requirements may reflect either a market response for holding a capital buffer or a response to Basel regulatory requirements; but as shown for a positive technology shock, an increase in bank leverage signals an overleveraged financial sector with

[14] When the Basel III regime combines with CoCos, the target leverage ratio becomes time-variant and endogenous for all shocks. For this reason, I abstract from showing the combined results in Figures 4.5 and 4.7. That said, comparing the impulse responses for Basel III and CoCos (i.e., Fig. 4.1 with Fig. 4.7; and Fig. 4.2 with Fig.4.5) is indicative of the combined result for both shocks.

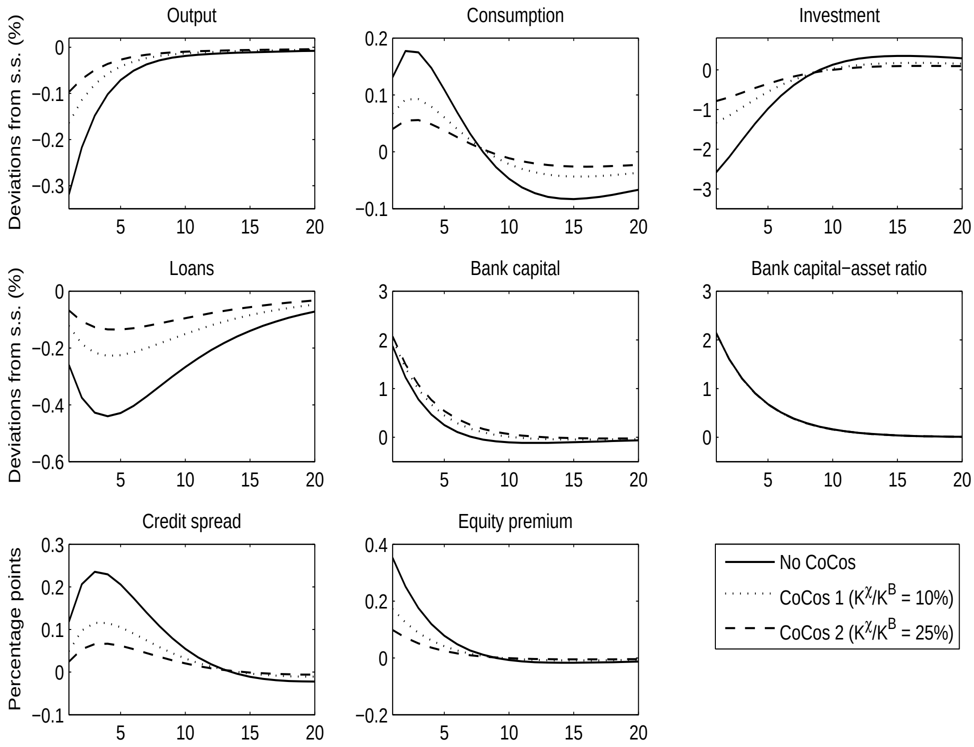

Figure 4.5: Impulse response to a reduced target leverage ratio. Introducing contingent convertible capital.

excess credit supply (i.e., a build-up of systemic risk). To therefore test the flexibility of CoCos, Figure 4.6 illustrates the effectiveness of CoCos under a negative shock to bank capital. Here, we can interpret the trigger value to be linked to bank capital, and not the leverage ratio. In addition, CoCos combine with the Basel III regime to show its relative dominance against financial shocks.

The results in Figure 4.6 follows closely to that observed for the target leverage ratio shock. But instead of requiring banks to *raise* their capital-asset ratios, they must now attenuate the *costs of a fall* in bank capital. CoCos effectively reduce the collapse in bank equity by half, and reduce the effect of the shock on all the variables. More importantly, when the Basel III regime combines with CoCos the stabilization effect only marginally improves. In particular, when the shock to bank capital reduces credit supply and causes a fall in output, capital requirements are automatically tapered. This means that banks are not required to raise bank capital immediately and, as a result, leverage deviation costs are not transmitted onto the credit spread and the equity premium. This mechanism, however, is not strong enough to improve on the stabilization effect of CoCos.

For the positive technology shock (Figure 4.7), introducing CoCos raises the aggregate bank capital-asset ratio, but the adjustment is too small to influence the broader economy. Therefore,

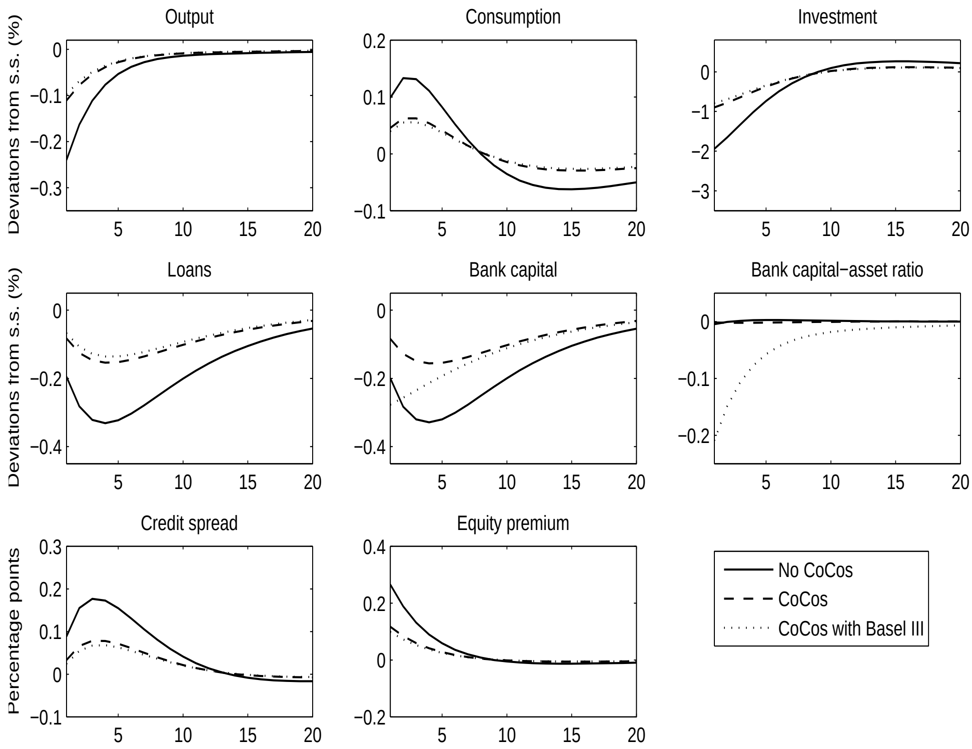

Figure 4.6: Impulse response to a negative bank capital shock. Introducing contingent convertible capital.

when banks become overleveraged because of a positive supply shock, a countercyclical capital adequacy rule dominates. That is, the Basel III regime increases the bank capital-asset ratio significantly more, thereby reducing business cycle fluctuations (see Figure 4.1). This, in fact, is a desirable outcome for the following reasons. Firstly, CoCos are designed to react to negative financial shocks, and not shocks to the real economy. For example, if the trigger value was tied to the share price of common bank equity—and not the leverage ratio—then a positive technology shock will not trigger a conversion of CoCos. Secondly, as positive supply shocks to the real economy tend to be more gradual and persistent, a countercyclical capital adequacy rule dampens the build-up of excess credit supply. Conversely, over shorter horizons, CoCos effectively counteract negative financial shocks.

4.4.3 Business cycle moments

Table 4.3 presents the cyclical properties of the data and the model. The standard deviations and correlations of the U.S. data are calculated from the sample period 1985Q1−2013Q4. Model 1 shows the second moments produced by the model from a productivity shock, whereas, model 2

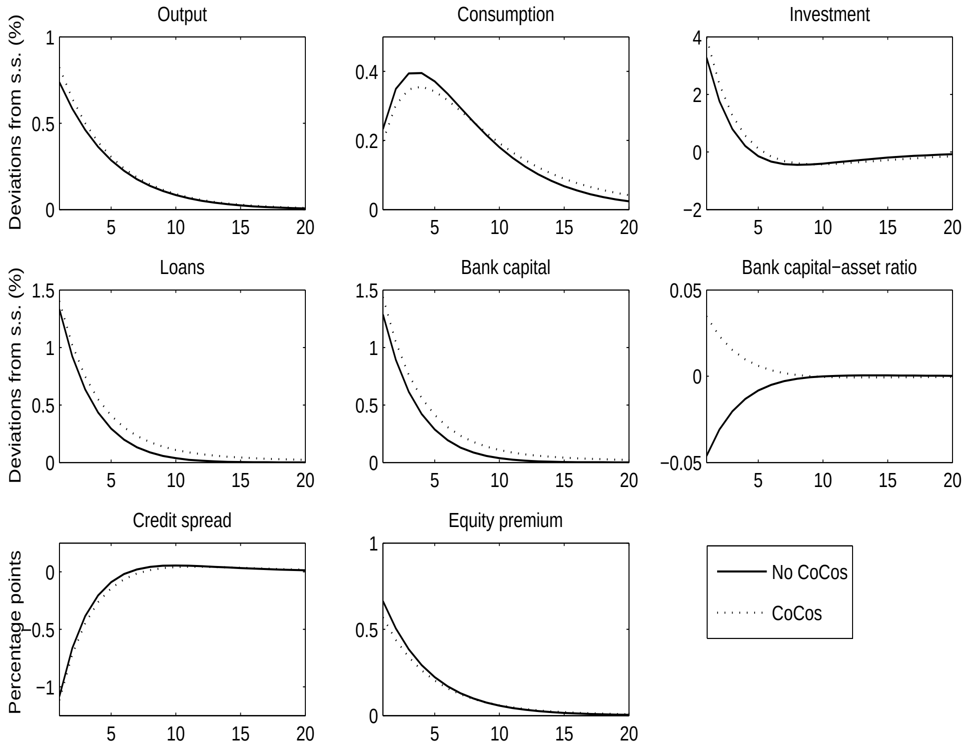

Figure 4.7: Impulse response to a positive technology shock. Introducing contingent convertible capital.

includes a target leverage ratio shock and an equity premium shock in order to capture financial market properties of the data, not explained by the traditional RBC theory. The productivity shock (1%) and leverage shock (2.14%) correspond to one standard deviation observed in the data. The equity premium shock is set to half a standard deviation (2.7%).

Model 1 reproduces the cyclical moments of the real sector fairly well: consumption is slightly less volatile than output, while investment is over three times as volatile. Although the relative standard deviation of hours worked is consistent with the data, its correlation with output is strongly negative. This counterfactual statistic is a result of the labour market setup being fully-flexible in the model. For the financial sector, model 1 does reasonably well to capture the relative standard deviations of firm loans and the credit spread, but their correlations with output are significantly overestimated. For the equity premium and the bank capital-asset ratio, however, model 1 poorly reproduces both business cycle moments.

Including two uncorrelated financial sector shocks (model 2) improves almost all the results of relative standard deviations and correlations. Similar to the results in de Walque et al. (2010), adding the financial shocks raises the volatility of all the variables and reduces their correlation

Table 4.3: Cyclical properties

	standard deviation relative to output			correlation with output		
Variable	data	mod.1	mod.2	data	mod.1	mod.2
Output (Y_t)	1	1	1	1	1	1
Consumption (C_t)	0.86	0.85	0.88	0.91	0.85	0.61
Investment (V_t)	4.97	3.32	4.81	0.93	0.73	0.69
Hours (H_t)	0.35	0.46	0.66	0.73	-0.99	-0.35
Firm loans (L_t)	2.08	1.53	1.94	0.38	0.97	0.72
Credit spread ($R_t^l - R_t$)	1.35	1.12	1.51	-0.66	-0.88	-0.55
Equity premium ($R_t^e - R_t$)	5.30	0.85	3.53	0.02	0.998	0.04
bank capital-asset ratio (K_t^b/L_t)	2.14	0.05	2.51	-0.28	-0.95	-0.35

Note: all variables, except for rates, are in log real terms and are detrended using the HP filter (data list: see Appendix E).

with output. In particular, the statistics for all the financial variables are greatly improved at the expense of lower correlations for consumption and investment.

4.5 Concluding remarks

Using a standard RBC model with an equity market and a banking sector, this paper shows that countercyclical capital requirements (as in Basel III) and contingent convertible capital provide an effective dual approach to macroprudential policy. On the one hand, a countercyclical capital adequacy rule dominates CoCos in the stabilization of real shocks. That is, by raising a capital buffer the Basel III regime mitigates the build-up of excess credit supply and, as a result, constrains the expansion of overleveraged banks. On the other hand, CoCos have a strong advantage over the Basel III regime against negative financial shocks. Here, CoCos effectively re-capitalize banks, reduce financial distress in a timely manner, and mitigate knock-on effects to the real economy. Countercyclical capital requirements and contingent convertible capital instruments therefore limit financial instability, and its associated influence on the real economy.

The introduction of contingent convertible capital into the general equilibrium framework comes with two clear shortcomings. One, alternative states cannot be an outcome of the model, but rather imposed through exogenous shocks. Two, the technique used in the model setup to combine bank deposits with subordinated debt (i.e., CoCos) is highly stylized. Given these shortcomings, however, the model does well to capture the mechanism for which CoCos are designed. Furthermore, it is fairly straightforward to include nominal rigidities in the RBC framework, and to observe how monetary policy interacts with macroprudential policy. As it stands, the model does well to capture the cyclical properties of U.S. data, and further research adopting this framework looks promising.

Chapter 5

Summary

This dissertation emphasizes the financial instability inherent in modern financial markets and the real economy, and provides a framework to study the financial factors that give rise to financial instability. More specifically, it provides a deeper understanding of how financial intermediation modifies the transmission mechanism of monetary policy and other macroeconomic shocks; and includes new insights on limiting financial instability, and its associated influence on the real economy.

To do this, I introduce a different aspect to dynamic stochastic general equilibrium (DSGE) models with financial frictions. Namely, I develop a role for the equity market in financial intermediation, firm production and household consumption—termed the equity price channel. The idea here is to capture the systemic interconnection between the financial system and the real economy. This innovative model forms the foundation of three research papers which successively incorporates: the systemic and pro-cyclical effect of equity, the sources of credit spread variability over the Great Moderation and Great Recession periods, and the role of contingent convertible capital in Basel III macroprudential regulation.

The main findings of the study in chapter two are as follows. The equity price channel amplifies and propagates shocks to the real economy through both the financial accelerator channel and the bank capital channel. Equity plays a significant role in amplifying the financial accelerator effect on interest rates, inflation and household loans. Due to the direct wealth effect, a negative equity price shock decreases households' consumption and, hence, output. The equity price channel weakens the counter-cyclicality of bank capital-asset ratios, which reflects the increasing emphasis on common equity capital in Basel regulations. This is beneficial in terms of financial stability, but amplifies and propagates shocks to the real economy.

The results of the study in chapter three show that supply-side factors are the primary source of credit spread variability. That is, retail loan markups account for more than half of the variability of retail credit spreads and sticky rate adjustments significantly alter the path of retail loan rates relative to the policy rate. Monetary policy has a strong influence on the short-term interbank rate, whereas the effectiveness of interest-rate policy on long-term nonfinancial loan rates is much weaker. Equity prices exacerbate movements in credit spreads through the financial accelerator channel, but cannot be regarded as a main driving force of credit spread variability. Both the financial accelerator and bank capital channels play a significant role in propagating the movements of credit spreads. Across the last three U.S. recession periods (1990−91, 2001, and 2007−09) I observe a remarkable decline in the influence of technology and monetary policy shocks. Whereas, there is an increasing trend in the contribution of loan rate markup shocks to the variability of retail credit spreads. From the demand-side of the credit market, the influence of LTV shocks has declined since the 1990−91 recession, while the bank capital requirement shock exacerbates and prolongs credit spread variability over the 2007−09 recession period.

In chapter four, I find that countercyclical capital requirements (as in Basel III) and contingent convertible capital (CoCos) provide an effective dual approach to macroprudential policy. On the one hand, a countercyclical capital adequacy rule dominates CoCos in the stabilization of real shocks. That is, by raising a capital buffer the Basel III regime mitigates the build-up of excess credit supply and, as a result, constrains the expansion of overleveraged banks. On the other hand, CoCos have a strong advantage over the Basel III regime against negative financial shocks. Here, CoCos effectively re-capitalize banks, reduce financial distress in a timely manner, and mitigate knock-on effects to the real economy. Countercyclical capital requirements and contingent convertible capital instruments therefore limit financial instability and its associated influence on the real economy.

Appendices

Appendix A

Note on the core DSGE framework

General equilibrium models capture the simultaneous decisions that jointly determine economic outcomes, including the short to medium term pathology we know as the business cycle. It attempts, in addition, to explain crucial transmission mechanisms, particularly on the monetary side. The specification and estimation of DSGE models specifically provides for analysis on: sources of business cycle fluctuations, questions about structural changes, counterfactual scenarios, and the link between structural features and reduced form parameters of the economy.

The current suite of DSGE models synthesise elements of new Keynesian economics and real business cycle (RBC) theory, to form the benchmark framework widely used.[1] The framework is an open or closed economy based on micro-foundations and heterogeneous decision makers, through which real and nominal rigidities arise (e.g., Smets and Wouters, 2003; Christiano et al., 2005). In this model, the representative household consumes goods, supplies labour, holds money and decides how much to invest in both the capital stock and bonds. The expected lifetime utility function can be either separable or non-separable in consumption, leisure, and real money balances, and household types can be distinguished by their preferences.[2] Habit formation in consumption and investment adjustment costs generate the hump-shaped responses of aggregate demand. The model also features variable capital utilisation and fixed costs in the endogenous accumulation of capital.[3] Firms, in turn, hire labour and rent capital to produce goods. To close the real economy, fiscal policy is usually restricted to a Ricardian setting (see Elmendorf and Mankiw, 1998). The equilibrium conditions for this benchmark model without nominal rigidities are as follows: the real wage equals the marginal rate of substitution between consumption and labour; the real rate of return on risk-free bonds drives intertemporal consumption; and the rate of return on

[1]See Kydland and Prescott (1982) and Prescott (1986) for the real business cycle approach and Clarida et al. (1999) and Woodford (2003) for the new Keynesian economics.

[2]Depending on the research topic, real money balances will be excluded or substituted with a cash-in-advance constraint (Walsh, 2010). More recently, however, other financial variables such as the housing stock have been included in the utility function (Iacoviello, 2005).

[3]The modeling assumption of variable capital utilisation for households gives the same first-order conditions that would arise if the firms own the capital stock.

capital equals the marginal value of installed capital.

To introduce the elements of new Keynesian economics, the model can be extended so that both households and firms face nominal rigidities. Specifically, the monopolistic supply of differentiated consumption goods (or types of labour) implies price (or wage) setting behaviour. As a result, nominal price and wage stickiness limits the ability of households and firms to respond to new information in the economy. The most prominent method for capturing this is the Calvo (1983) model of price and wage setting with partial indexation (e.g., Erceg et al., 2000).[4] With inflation expectations comes a role for monetary policy, in which an interest rate rule responds to the deviations of inflation and output from their respective steady-states (Taylor, 1993a). Finally, various orthogonal structural shocks—often assumed to follow first-order autoregressive processes—drive the stochastic nature of the dynamic general equilibrium model. The model has the capacity to deal with supply side shocks such as total factor productivity and labour supply shocks, demand side shocks such as investment-specific and exogenous spending shocks, mark-up shocks on prices, wages and risk premiums, and monetary policy shocks.

[4]Other price-setting models have been introduced by Rotemberg (1982) and Taylor (1993b)

Appendix B

The equity price channel

B.1 System of equilibrium conditions

This appendix summarizes the complete nonlinear model. The baseline (BEP) model includes all 32 endogenous variables and all 9 exogenous AR(1) shock processes. To go from the BEP model to the model without equity (the NEP model), we set $\phi_w = \phi_k = 1$ and $\phi_B = \phi_\psi = 0$, remove Eqs. B.17−B.21 below, and ignore the following six endogenous variables: $\Psi_t^s, \Psi_t^b, \Pi_{\psi,t}, \Pi_{\psi,t}^e$, $\Pi_{\psi,t}^B, Q_t^\psi$ (note that in the NEP model $\xi_{\psi,t} = 0$). To go from the BEP model to the flexible retail rate (FI) model we simply set $\kappa_h = \kappa_e = 0$. For the ALT1 model we set $\phi_w = \phi_k = 1$, and for the ALT2 model we set $\phi_B = 0$. The 32 endogenous variables are as follows:

Y_t, C_t, C_t^s, C_t^b, K_t, H_t, H_t^s , H_t^b, V_t, D_t, L_t, L_t^e, L_t^h, K_t^B, Ψ_t^s, Ψ_t^b, P_t, P_t^*, Q_t^k, X_t, W_t, I_t, I_t^l, I_t^h, I_t^e, Q_t^ψ , $\Pi_{\psi,t}$, $\Pi_{\psi,t}^e$, $\Pi_{\psi,t}^B$, $\omega_{B,t}$, λ_t^h , λ_t^e.

Those variables jointly solve the following 32 equations:[1]

- Definitions:

$$\begin{aligned}
U_{c,t}^s &= (C_t^s - \phi C_{t-1}^s)^{-\gamma}, \\
U_{c,t}^b &= (C_t^b - \phi C_{t-1}^b)^{-\gamma}, \\
\Lambda_{t,z} &= \beta^R \frac{C_t^s}{C_{t+z}^s}.
\end{aligned}$$

[1]Note that Eq. B.11 and Eq. B.12 combine P_t and P_t^* to solve for inflation (Π_t) in the usual log-linearized forward looking Phillips Curve.

- Output and market clearing:

$$\begin{aligned} Y_t &= \xi_{z,t} K_{t-1}^{\alpha} H_t^{1-\alpha}, && \text{(B.1)} \\ Y_t &= C_t + V_t + \delta_B \frac{K_{t-1}^B}{\Pi_t}, && \text{(B.2)} \\ \Psi_t^s + \Psi_t^b &= \Psi^B + \Psi^e, && \text{(B.3)} \\ C_t &= C_t^s + C_t^b, && \text{(B.4)} \\ L_t &= L_t^h + L_t^e, && \text{(B.5)} \\ H_t &= H_t^s + H_t^b. && \text{(B.6)} \end{aligned}$$

- Capital:

$$\begin{aligned} K_t &= (1-\delta_e) K_{t-1} + V_t, && \text{(B.7)} \\ \frac{Q_t^k}{P_t} &= (1 + \frac{\kappa_v}{\delta_e}(\frac{V_t}{K_{t-1}} - \delta_e), && \text{(B.8)} \\ \frac{Q_t^k}{P_t} &= \beta_e E_t \Bigg[\left(\frac{\kappa_v}{\delta_e} \left(\frac{V_{t+1}}{K_t} - \delta_e \right) \frac{V_{t+1}}{K_t} - \frac{\kappa_v}{2\delta_e} \left(\frac{V_{t+1}}{K_t} - \delta_e \right)^2 \right) \\ &\quad + \frac{Q_{t+1}^k}{P_{t+1}}(1-\delta_e) + \frac{\alpha Y_{t+1}}{X_{t+1} K_t} + \lambda_t^e \nu_{e,t} \phi_k \frac{Q_{t+1}^k}{P_{t+1}} \Bigg], && \text{(B.9)} \\ \lambda_t^e &= \frac{1}{I_t^e} - \beta_e E_t \left[\frac{P_t}{P_{t+1}} \right]. && \text{(B.10)} \end{aligned}$$

- Price dynamics:

$$\frac{P_t^*}{P_t} = \left(\frac{\varepsilon_t^y}{\varepsilon_t^y - 1} \right) \frac{E_t \sum_{z=0}^{\infty} \theta_R^z \Lambda_{t,z} \left[\frac{X}{X_{t+z}} \left(\frac{P_{t+z}}{P_t} \right)^{\varepsilon_t^y} Y_{t+z} \right]}{E_t \sum_{z=0}^{\infty} \theta_R^z \Lambda_{t,z} \left[\left(\frac{P_{t+z}}{P_t} \right)^{(\varepsilon_t^y - 1)} Y_{t+z} \right]}, \quad \text{(B.11)}$$

$$1 = \theta_R \left((\frac{P_{t-1}}{P_{t-2}})^{\gamma_p} \frac{P_{t-1}}{P_t} \right)^{1-\varepsilon_t^p} + (1-\theta_R) \left(\frac{P_t^*}{P_t} \right)^{1-\varepsilon_t^p}. \quad \text{(B.12)}$$

- Wage dynamics:

$$\begin{aligned} (H_t^s)^{\eta} &= U_{c,t}^s \frac{W_t}{P_t}, && \text{(B.13)} \\ (H_t^b)^{\eta} &= U_{c,t}^b \frac{W_t}{P_t} + \lambda_t^h \nu_{h,t} \phi_w E_t \left[\frac{W_{t+1}}{P_t} \right], && \text{(B.14)} \\ \frac{W_t}{P_t} &= \frac{(1-\alpha) Y_t}{H_t X_t}, && \text{(B.15)} \\ \lambda_t^h &= \frac{U_{c,t}^b}{I_t^h} - \beta_b E_t \left[U_{c,t+1}^b \frac{P_t}{P_{t+1}} \right]. && \text{(B.16)} \end{aligned}$$

- Equity dynamics:

$$\xi_{\psi,t}\frac{P_t}{Q_t^{\psi}\Psi_t^s} = U_{c,t}^s - \beta_s E_t\left[U_{c,t+1}^s\left(\frac{Q_{t+1}^{\psi}+\Pi_{\psi,t+1}}{Q_t^{\psi}}\right)\frac{P_t}{P_{t+1}}\right], \quad (B.17)$$

$$\xi_{\psi,t}\frac{P_t}{Q_t^{\psi}\Psi_t^b} = U_{c,t}^b - \beta_b E_t\left[U_{c,t+1}^b\left(\frac{Q_{t+1}^{\psi}+\Pi_{\psi,t+1}}{Q_t^{\psi}}\right)\frac{P_t}{P_{t+1}}\right] - \lambda_t^h \nu_{h,t}(1-\phi_w)\left(\frac{Q_{t+1}^{\psi}+\Pi_{\psi,t+1}}{Q_t^{\psi}}\right)\frac{P_t}{P_{t+1}}, \quad (B.18)$$

$$P_t\Pi_{\psi,t}^e = r^{\psi}Q_t^{\psi}\Psi^e, \quad (B.19)$$

$$\Pi_{\psi,t}^B = \phi_{\psi}\omega_{B,t}, \quad (B.20)$$

$$\Pi_{\psi,t} = \frac{P_t\Pi_{\psi,t}^e}{\Psi^e}+\frac{\Pi_{\psi,t}^B}{\Psi^B}. \quad (B.21)$$

- Borrowing constraints and deposit demand:

$$L_t^h = \frac{\nu_{h,t}}{I_t^h}[\phi_w W_{t+1}H_t^b + (1-\phi_w)(Q_{t+1}^{\psi}+\Pi_{\psi,t+1})\Psi_t^b], \quad (B.22)$$

$$L_t^e = \frac{\nu_{e,t}}{I_t^e}[\phi_k Q_{t+1}^k K_t + (1-\phi_k)Q_{t+1}^{\psi}\Psi^e], \quad (B.23)$$

$$\frac{P_t}{D_t^s} = U_{c,t}^s - \beta_s E_t\left[U_{c,t+1}^s\frac{I_t^d}{P_{t+1}/P_t}\right]. \quad (B.24)$$

- Interest rate setting and bank balance sheet quantities:[2]

$$i_t^l = i_t - \kappa_k\left(\frac{K_t^B}{L_t}-\tau\right)\left(\frac{K_t^B}{L_t}\right)^2, \quad (B.25)$$

$$0 = 1-\varepsilon_t^e+\varepsilon_t^e\frac{i_t^l}{i_t^e}-\kappa_e\left(\frac{i_t^e}{i_{t-1}^e}-1\right)\frac{i_t^e}{i_{t-1}^e} + \beta_B E_t\left[\kappa_e\left(\frac{i_{t+1}^e}{i_t^e}-1\right)\left(\frac{i_{t+1}^e}{i_t^e}\right)^2\frac{L_{t+1}^e}{L_t^e}\right], \quad (B.26)$$

$$0 = 1-\varepsilon_t^h+\varepsilon_t^h\frac{i_t^l}{i_t^h}-\kappa_h\left(\frac{i_t^h}{i_{t-1}^h}-1\right)\frac{i_t^h}{i_{t-1}^h} + \beta_B E_t\left[\kappa_h\left(\frac{i_{t+1}^h}{i_t^h}-1\right)\left(\frac{i_{t+1}^h}{i_t^h}\right)^2\frac{L_{t+1}^h}{L_t^h}\right], \quad (B.27)$$

$$K_t^B = (1-\delta_B)K_{t-1}^B + \phi_B(Q_t^{\psi}-Q_{t-1}^{\psi})\Psi^B + (1-\phi_{\psi})\omega_{B,t-1}, \quad (B.28)$$

$$L_t = K_t^B + D_t. \quad (B.29)$$

[2] In the log-linearized version we include a shock to deposits ξ_t^d to avoid near stochastic singularity (see, e.g., Gerali et al., 2010, p.116). Lower case net interest rates correspond with their respective upper case rates.

- Flow of funds:

$$C_t^s = \frac{W_t}{P_t}H_t^s + \frac{I_{t-1}^d D_{t-1}^s}{P_t} + \frac{(Q_t^\psi + \Pi_{\psi,t})}{P_t}\Psi_{t-1}^s - \frac{D_t^s}{P_t} - \frac{Q_t^\psi}{P_t}\Psi_t^s, \tag{B.30}$$

$$\omega_{B,t} = i_t^h L_t^h + i_t^e L_t^e - i_t^d D_t - \frac{\kappa_K}{2}\left(\frac{K_t^B}{L_t} - \tau\right)^2 K_t^B - \frac{\kappa_h}{2}\left(\frac{i_t^h}{i_{t-1}^h} - 1\right)^2 i_t^h L_t^h$$
$$-\frac{\kappa_e}{2}\left(\frac{i_t^e}{i_{t-1}^e} - 1\right)^2 i_t^e L_t^e - \Pi_{\psi,t}^B. \tag{B.31}$$

- Monetary policy rule and shock processes:

$$I_t = (I_{t-1})^{\kappa_i}\left(\frac{\Pi_t}{\Pi^{target}}\right)^{\kappa_\pi(1-\kappa_i)}\left(\frac{Y_t}{Y_{t-1}}\right)^{\kappa_y(1-\kappa_i)}\xi_{i,t}, \tag{B.32}$$

$$\varepsilon_t^p = \rho_p \varepsilon_{t-1}^p + \epsilon_{p,t}, \tag{B.33}$$

$$\xi_{z,t} = \rho_z \xi_{z,t-1} + \epsilon_{z,t}, \tag{B.34}$$

$$\xi_{i,t} = \rho_z \xi_{i,t-1} + \epsilon_{i,t}, \tag{B.35}$$

$$\xi_{d,t} = \rho_d \xi_{d,t-1} + \epsilon_{d,t}, \tag{B.36}$$

$$\varepsilon_t^h = \rho_h \varepsilon_{t-1}^h + \epsilon_{h,t}, \tag{B.37}$$

$$\varepsilon_t^e = \rho_e \varepsilon_{t-1}^e + \epsilon_{e,t}, \tag{B.38}$$

$$\nu_{h,t} = \rho_{\nu_h} \nu_{h,t-1} + \epsilon_{\nu h,t}, \tag{B.39}$$

$$\nu_{e,t} = \rho_{\nu_e} \nu_{e,t-1} + \epsilon_{\nu e,t}, \tag{B.40}$$

$$\xi_{\psi,t} = \rho_\psi \xi_{\psi,t-1} + \epsilon_{\psi,t}. \tag{B.41}$$

Appendix C

Credit spread variability

C.1 Value-at-risk (VaR) constraint

As the investment bank runs the commercial bank operations, it must ensure that the commercial bank's capital buffer is large enough to cover the Value-at-Risk constraint in each period $t = 0, 1, 2, 3, ...$ (see also, Adrian and Shin, 2010b, p.609). The following condition must therefore hold for the commercial bank $j \in [0, 1]$:

$$k(1 + i^c_t)L^c_{j,t} - s(1 + i^l_{j,t})L_{j,t} \leq \Xi^c_{j,t}, \tag{C.1}$$

where, for simplicity, $i^l_{j,t}$ is the effective retail loan rate for households and entrepreneurs, and s/k is the interbank LTV ratio ν_B.[1] $\Xi^c_{j,t}$ is the quantity of cash balances (capital) transferred to (or withdrawn from) the commercial bank's balance sheet in the *beginning* of each period. As a result, the following balance sheet condition must hold for bank $j \in [0, 1]\ \forall\ t = 0, 1, 2, 3, ...$: $\Xi^c_{j,t} = (k)L^c_{j,t} - (s)L_{j,t}$. We can therefore re-write Eq. C.1 as

$$k(i^c_t)L^c_{j,t} \leq s(i^l_{j,t})L_{j,t}, \tag{C.2}$$

$$\nu_B \frac{i^l_{j,t}}{i^c_t} \geq \frac{L^c_{j,t}}{L_{j,t}}. \tag{C.3}$$

The VaR equation states that the markup of the commercial bank's net interest spread times ν_B must be at least as large as its debt-to-asset ratio. If we further assume that $L^c_{j,t} = L_{j,t} = L^h_{j,t} + L^e_{j,t}$, it implies that the interbank LTV ratio must be bigger than or equal to the inverse of the markup over marginal cost $(i^c_t/i^l_{j,t})$. Note that $\Xi^c_{j,t}$ will be a constant proportion $(k - s)$ of the feasible quantity of loans $(L_{j,t})$; but it is uninformative as it falls away in the consolidated bank balance sheet.

C.2 Log-linearized system of equilibrium conditions

• Households

[1] See Woodford (2010, p.32) for the interpretation of s and k.

Labour demand

$$w_t = aa\frac{\gamma}{1-\phi}(c_t - \phi c_{t-1}) + \eta h_t - aa(\frac{1}{R^h} - \beta_h)\nu_h \phi_w (\lambda_t^h + \nu_{h,t}), \quad \text{(C.4)}$$

where aa is $\frac{1}{(1-(\frac{1}{R^h}-\beta_h)\nu_h\phi_w)}$.

Households' Euler equation

$$(\frac{1}{R^h} - \beta_h)\lambda_t^h = \beta_h(\frac{\gamma}{1-\phi}(c_{t+1} - \phi c_t) + \pi_{t+1}) - \frac{1}{R^h}(\frac{\gamma}{1-\phi}(c_t - \phi c_{t-1}) + i_t^h). \quad \text{(C.5)}$$

Safe-assets demand

$$b_t = \frac{\gamma}{(1-\phi)(1-\beta_h R)}(c_t - \phi c_{t-1}) + \frac{\beta_h R}{1-\beta_h R}(i_t - \pi_{t+1} - \frac{\gamma}{1-\phi}(c_{t+1} - \phi c_t)) - \xi_{b,t}, \quad \text{(C.6)}$$

where $\frac{1}{1-\beta_h R}$ is the asset-consumption ratio of households and is calibrated from the data as 0.856.

Equity price

$$\begin{aligned} q_t^{\psi} &= E_t[q_{t+1}^{\psi} - \frac{\gamma}{1-\phi}(c_{t+1} - \phi c_t)] + \frac{\gamma}{(1-\Gamma_\psi)(1-\phi)}(c_t - \phi c_{t-1}) \\ &+ \frac{\Gamma_\psi}{1-\Gamma_\psi}(\lambda_t + \nu_{h,t}) - \xi_{\psi,t}, \end{aligned} \quad \text{(C.7)}$$

where $\Gamma_\psi = ((1/R^h) - \beta_h)\nu_h(1-\phi_w)$.

Borrowing constraint

$$l_t^h = \frac{\phi_w}{R^h}(w_t + h_t) + \frac{(1-\phi_w)}{R^h}q_t^{\psi} - i_t^h + \frac{1}{R^h}\nu_{h,t}. \quad \text{(C.8)}$$

- Entrepreneurs

Labour demand

$$h_t = y_t - x_t - w_t,$$

Entrepreneurs' Euler equation

$$(\frac{1}{R^e} - \beta_e)\lambda_t^e = \beta_e(\gamma^e(c_{t+1}^e) + \pi_{t+1}) - \frac{1}{R^e}(\gamma^e(c_t^e) + i_t^e),$$

Investment schedule

$$\begin{aligned} v_t - k_{t-1} = \frac{\beta_e}{(1-\Upsilon_k)}E_t[v_{t+1} - k_t] + \frac{(1-\beta_e(1-\delta_e)-\Upsilon_k)}{(1-\Upsilon_k)\kappa_v}(y_{t+1} - x_{t+1} - k_t) \\ + \frac{\Upsilon_k}{(1-\Upsilon_k)\kappa_v}(\lambda_t^e + \nu_{e,t}) + \frac{\beta_e(1-\delta_e)\gamma^e}{(1-\Upsilon_k)\kappa_v}(c_t^e - c_{t+1}^e). \end{aligned} \quad \text{(C.9)}$$

The shadow price of capital:

$$q_t^k = \kappa_v(v_t - k_{t-1}) - \gamma^e c_t^e, \quad \text{(C.10)}$$

where $\Upsilon_k = 0$ is the same as Iacoviello (2005, p. 760 (A3)).

Production function

$$y_t = \alpha k_{t-1} + (1-\alpha)h_t + \xi_{z,t} \tag{C.11}$$

Borrowing constraint

$$l_t^e = \frac{\phi_k}{R^e}(q_t^k + k_{t-1}) + \frac{(1-\phi_k)}{R^e}q_t^{\psi} - i_t^e + \frac{1}{R^e}\nu_{e,t} \tag{C.12}$$

Capital accumulation

$$k_t = (1-\delta_e)k_{t-1} + \delta_e v_t \tag{C.13}$$

The entrepreneur flow of funds constraint

$$\frac{C^e}{Y}c_t^e = \frac{\alpha}{X}(y_t - x_t) + \frac{L^e}{Y}(l_t^e - R^e i_{t-1}^e - R^e l_{t-1}^e + R^e \pi_t) - \frac{\delta_e K}{Y}v_t - \frac{Q^{\psi}\Psi^e}{Y}\zeta_{\psi} q_t^{\psi} \tag{C.14}$$

- Retailers

The log-linearized forward-looking Phillips curve with price indexation

$$\pi_t = \frac{\beta_R}{(1+\beta_R\gamma_p)}E_t\pi_{t+1} + \frac{\gamma_p}{(1+\beta_R\gamma_p)}\pi_{t-1} - \frac{(1-\theta_R)(1-\theta_R\beta_R)}{(1+\beta_R\gamma_p)\theta_R}x_t + \varepsilon_t^p. \tag{C.15}$$

- Unions and the wage-setting equation

The forward-looking sticky wage equation with price indexation

$$\begin{aligned} w_t = \Phi w_{t-1} + \Phi\beta E_t w_{t+1} + \Phi^*(\varepsilon^w \eta \hat{w}_t + \chi(\frac{\gamma}{1-\phi}(c_t - \phi c_{t-1}) + \eta h_t)) \\ + \Phi\beta E_t \pi_{t+1} - \Phi\pi_t - \Phi\theta_w\beta\gamma_w\pi_t + \Phi\gamma_w\pi_{t-1}, \end{aligned} \tag{C.16}$$

where $\Phi^* = \frac{(1-\theta_w)(1-\theta_w\beta)}{(1+\theta_w^2\beta)(1+\varepsilon^w\eta)}$ and $\Phi = \frac{\theta_w}{(1+\theta_w^2\beta)}$; $\chi = \frac{1}{\mu_w(1+\lambda\tilde{C}\nu_h\phi_w)}$; $\lambda\tilde{C} = (\frac{1}{R^h} - \beta_h)$.

- Banking sector

Interbank rate

$$i_t^c = i_t - \frac{\kappa_k}{r}\tau^3(k_t^B - l_t - \xi_{\tau,t}) \tag{C.17}$$

Bank capital accumulation

$$k_t^B = (1-\delta_B)k_{t-1}^B + \delta_B\omega_{B,t-1} + \phi_{\psi}(q_t^{\psi} - q_{t-1}^{\psi}) - (1-\phi_{\psi})\pi_t \tag{C.18}$$

Profit function

$$\frac{\omega_B}{L}\omega_{B,t} = r^h\frac{L^h}{L}(i_t^h + l_t^h) + r^e\frac{L^e}{L}(i_t^e + l_t^e) - r\frac{B}{L}(i_t + b_t) - \frac{Q^{\psi}\Psi_B}{L}\zeta_{\psi}(q_t^{\psi}) \tag{C.19}$$

Retail loan rate setting to households

$$\begin{aligned} \hat{i}_t^h = \frac{\kappa_h}{(1-\nu_B)(\varepsilon^h-1)+(1+\beta_B)\kappa_h}\hat{i}_{t-1}^h + \frac{\beta_B\kappa_h}{(1-\nu_B)(\varepsilon^h-1)+(1+\beta_B)\kappa_h}E_t\hat{i}_{t+1}^h \\ + \frac{2(\varepsilon^h-1)}{(1-\nu_B)(\varepsilon^h-1)+(1+\beta_B)\kappa_h}\hat{i}_t^c + \frac{(1-\nu_B)(\varepsilon^h-1)}{(1-\nu_B)(\varepsilon^h-1)+(1+\beta_B)\kappa_h}\mu_{h,t}, \end{aligned} \tag{C.20}$$

where $\mu_{h,t} = \frac{\varepsilon_t^h}{\varepsilon_t^h - 1}$ is the stochastic markup shock.

Retail loan rate setting to entrepreneurs

$$\hat{i}_t^e = \frac{\kappa_e}{(1-\nu_B)(\varepsilon^e - 1) + (1+\beta_B)\kappa_e}\hat{i}_{t-1}^e + \frac{\beta_B \kappa_e}{(1-\nu_B)(\varepsilon^e - 1) + (1+\beta_B)\kappa_e} E_t \hat{i}_{t+1}^e$$
$$+ \frac{2(\varepsilon^e - 1)}{(1-\nu_B)(\varepsilon^e - 1) + (1+\beta_B)\kappa_e}\hat{i}_t^c + \frac{(1-\nu_B)(\varepsilon^e - 1)}{(1-\nu_B)(\varepsilon^e - 1) + (1+\beta_B)\kappa_e}\mu_{e,t}, \quad \text{(C.21)}$$

where $\mu_{e,t} = \frac{\varepsilon_t^e}{\varepsilon_t^e - 1}$ is the stochastic markup shock.

Interbank spread and retail spread definitions (indexed by $z = h, e$)

$$s_t = i_t^c - i_t, \quad \text{(C.22)}$$
$$s_t^z = i_t^z - i_t^c. \quad \text{(C.23)}$$

• Monetary policy and market clearing conditions

$$i_t = \kappa_i i_{t-1} + \kappa_\pi (1-\kappa_i)\pi_t + \kappa_y (1-\kappa_i)(y_t - y_{t-1}) + \xi_{i,t}, \quad \text{(C.24)}$$
$$y_t = \frac{C}{Y}c_t + \frac{C^e}{Y}c_t^e + \delta_e \frac{K}{Y}v_t + \frac{K^B}{Y}\delta_B k_{t-1}^B, \quad \text{(C.25)}$$
$$l_t = \frac{L^h}{L}l_t^h + \frac{L^e}{L}l_t^e. \quad \text{(C.26)}$$

C.3 Tables and figures

Figure C.1 shows the impulse responses of the observed variables to a contractionary monetary policy shock, for each recession period.[2] It is clear that the impact of monetary policy shocks is very similar in each sub-sample period. This suggests that the credit channel of monetary policy behaved no differently during each recession. Monetary policy has a strong influence on the short-term interbank rate, even though a narrower interbank credit spread (due to the increase in the capital-asset ratio) somewhat dampens the policy shock. On the other hand, the effectiveness of interest-rate policy on long-term nonfinancial loan rates is much weaker.

For all three recession periods, imperfect bank competition attenuates the effect of monetary policy through both sticky rate adjustments and a counter-cyclical bank capital-asset ratio (see also, Goodfriend and McCallum, 2007; Gerali et al., 2010). Retail loan rates increase sluggishly compared to the policy rate, causing retail credit spreads to narrow. In fact, for all three sub-samples, the initial 50 basis point increase in the policy rate results in a 30 basis point reduction in each retail credit spread. Banks initially increase retail loan rates less than the policy rate to minimize the reduction in credit demand. It curbs the fall of future retained earnings from

[2]For simplicity, I aggregate household loans and entrepreneur loans, and label it total loans. I also include the impulse response function of the capital-asset ratio.

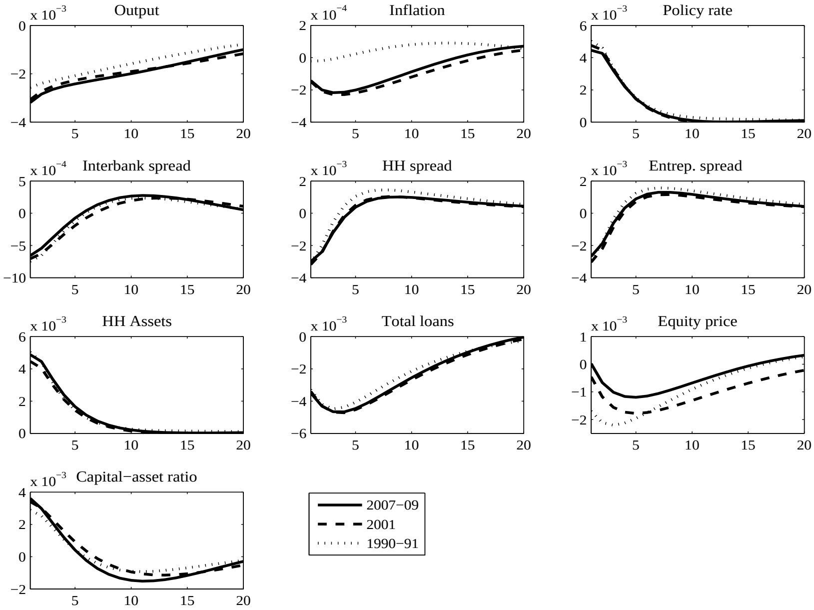

Figure C.1: Impulse response to a contractionary monetary policy shock. U.S. recessions.

the decrease in the supply of total loans. The increase of the policy rate raises the demand for safe assets, and reduces credit extension. This reduces production and consumption, leading to a decline in output. The effect on inflation in all three sub-samples is negligible.

Figure C.2 sheds more light on the issue raised here. A positive bank capital requirement shock raises the target capital-asset ratio to which banks stabilize. Subsequently, the shock transmits through two channels: one, a wider credit spread minimizes the loss of retained earnings; two, to stabilize their balance sheets, banks retract credit supply significantly. A positive capital requirement shock produces qualitatively similar responses to that of the monetary policy shock, with the exception of the interbank spread and the policy rate. Finally, compared to the 1990−91 and 2001 recessions, bank capital-asset adjustments exacerbate output in the 2007−09 recession.

The results above show that monetary policy cannot explain the severity or persistence of the recent 2007−09 recession, whereas a financial shock to bank capital requirements presents one alternative source for the severeness and persistence of the Great Recession.

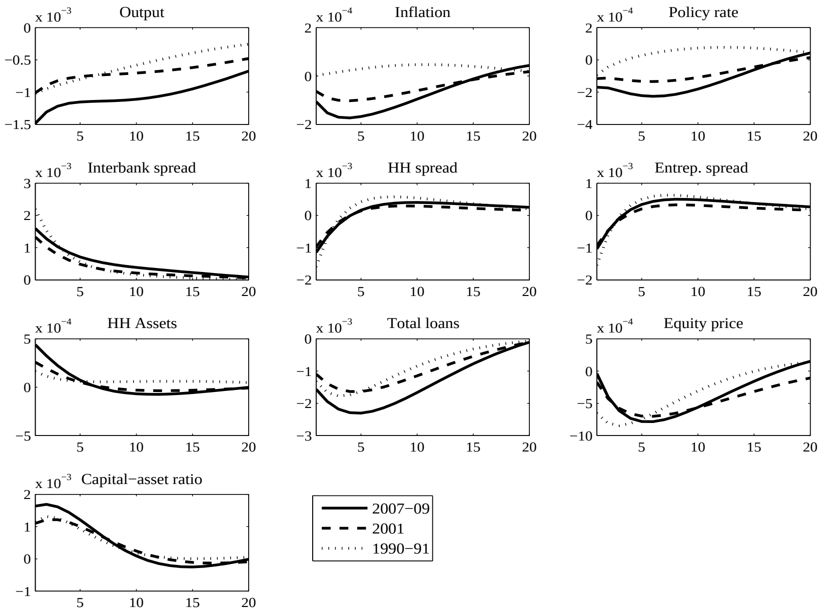

Figure C.2: Impulse response to a positive bank capital requirement shock. U.S. recessions.

Table C.1: Correlation of output with credit spreads and equity price

Variable	Interbank spread (S_t)	Household spread (S_t^h)	Entrepreneur spread (S_t^e)	Equity price (Q_t^ψ)
Output (Y_t)	-0.63	-0.16	-0.16	0.65

Table C.2: U.S. recessions estimated parameter comparisons

	Posterior distribution means				Posterior distribution means		
	2007−09	2001	1990−91		2007−09	2001	1990−91
Parameters				AR(1) processes			
γ	4.023	3.983	4.250	ρ_z	0.98	0.98	0.98
γ^e	1.035	0.930	0.930	ρ_i	0.28	0.27	0.27
ϕ	0.672	0.691	0.671	ρ_b	0.97	0.97	0.97
θ_R	0.917	0.922	0.913	ρ_e	0.32	0.34	0.36
γ_p	0.487	0.481	0.493	ρ_h	0.31	0.34	0.31
κ_i	0.685	0.676	0.637	ρ_{ν_h}	0.79	0.89	0.80
κ_π	1.511	1.509	1.534	ρ_{ν_e}	0.63	0.59	0.58
κ_y	0.254	0.253	0.255	ρ_ψ	0.82	0.85	0.78
ν_h	0.743	0.739	0.747	ρ_p	0.32	0.30	0.31
ν_e	0.789	0.795	0.786	ρ_t	0.83	0.82	0.75
ν_B	0.365	0.368	0.383	ϵ_z	0.014	0.012	0.017
κ_k	1.382	1.575	1.955	ϵ_i	0.005	0.005	0.005
κ_e	4.965	8.435	6.096	ϵ_b	0.008	0.006	0.006
κ_h	11.06	13.31	8.29	ϵ_e	0.117	0.095	0.083
κ_v	2.073	1.588	2.008	ϵ_h	0.114	0.115	0.118
K^e/Y	10.71	10.76	10.77	ϵ_{ν_h}	0.019	0.016	0.022
				ϵ_{ν_e}	0.020	0.023	0.036
				ϵ_ψ	0.007	0.005	0.007
				ϵ_p	0.001	0.001	0.001
				ϵ_t	0.010	0.008	0.010

Note: I exclude parameter descriptions, prior means and std. dev., and statistic confidence intervals in the table due to the limited space. However, Tables 3.2 and 3.3 are a good guide.

Appendix D

CoCos and Basel III

D.1 Log-linearized system of equilibrium conditions

• Households

Deposit demand

$$(1-\beta R)d_t = \frac{\gamma}{(1-\phi)}(c_t - \phi c_{t-1}) - (\beta R)E_t\left[\frac{\gamma}{(1-\phi)}(c_{t+1} - \phi c_t) - r_t\right] \tag{D.1}$$

Wages

$$w_t = \frac{\gamma}{(1-\phi)}(c_t - \phi c_{t-1}) + \eta h_t \tag{D.2}$$

Equity Euler equation

$$c_t = \frac{\phi}{(1+\phi)}c_{t-1} + \frac{1}{(1+\phi)}E_t[c_{t+1}] + \frac{(1-\phi)}{\gamma(1+\phi)}r^e_{t+1} \tag{D.3}$$

Steady-state condition: $\beta = 1/R^e$

• Firms

Labor demand

$$w_t = y_t - h_t \tag{D.4}$$

The equity financing premium

$$R^e r^e_{t+1} = \frac{\alpha Y}{K}(y_{t+1} - k_t) + \nu\frac{R^e}{R^l}(r^e_{t+1} - r^l_t) + \nu(\frac{R^e}{R^l} - 1)\nu_t + \kappa_i(i_{t+1} - k_t) - \frac{\kappa_i}{\beta_f}(i_t - k_{t-1}), \tag{D.5}$$

where $(\alpha Y/K) = R^l - (1-\delta) - ((R^e - R^l)\nu)/R^l$ and $R^e > R^l$.

Borrowing constraint

$$l_t = \nu_t + k_t - r^l_t, \tag{D.6}$$

where ν_t is an AR(1) stochastic shock.

Production function

$$y_t = \alpha k_{t-1} + (1-\alpha)h_t + \xi_{z,t}, \tag{D.7}$$

where $\xi_{z,t}$ is an AR(1) stochastic shock.

• Banks

The equity financing margin

$$R^e r^e_{t+1} - R^l r^l_t = \tau(\tau - 1)\kappa(l_t - k^b_t - \tau_t), \tag{D.8}$$

where $R^e > R^l$; $\kappa \approx [\frac{1}{10}; \frac{1}{3}]$; $\tau = (L/K^b) > 1$ and $(\tau - 1) = (D/K^b)$.

• Market clearing

Aggregate resource constraint

$$y_t = \frac{C}{Y}c_t + \frac{I}{Y}i_t \tag{D.9}$$

Evolution of state variables

$$k_t = (1 - \delta)k_{t-1} + \delta i_t \tag{D.10}$$

$$k^b_{t+1} = (1 - \delta_b)k^b_t + r^l\tau(r^l_t + l_t) - r(1 - \tau)(r_t + d_t) \tag{D.11}$$

Risk-free real rate of return rule

$$r_t = \rho_r r_{t-1} - \kappa_r(1 - \rho_r)y_t \tag{D.12}$$

• Shock processes

$$\xi_{z,t} = \rho_z \xi_{z,t-1} + \epsilon_{z,t}, \tag{D.13}$$

$$\tau_t = \rho_\tau \tau_{t-1} - \kappa_\tau(1 - \rho_\tau)y_t + \epsilon_{\tau,t}, \tag{D.14}$$

$$\xi_{e,t} = \rho_e \xi_{e,t-1} + \epsilon_{e,t}, \tag{D.15}$$

$$\xi_{k^b,t} = \rho_{k^b}\xi_{k^b,t-1} + \epsilon_{k^b,t}. \tag{D.16}$$

D.2 Model steady states

$$\beta = \beta_f = \beta_b = \frac{1}{R^e} \tag{D.17}$$

$$\frac{\alpha Y}{K} = R^e - (1 - \delta) - ((R^e - R^l)/R^l)\nu \tag{D.18}$$

$$\frac{K}{Y} = \frac{\alpha}{\alpha Y/K} \tag{D.19}$$

$$\frac{I}{Y} = \delta\frac{K}{Y} \tag{D.20}$$

$$\frac{C}{Y} = 1 - \delta\frac{K}{Y} \tag{D.21}$$

$$\frac{U_d}{U_c} = (1 - \beta R) \tag{D.22}$$

$$\delta_b = r^l\tau - r(\tau - 1), \tag{D.23}$$

where U_d and U_c are the marginal utilities of deposits and consumption.

After introducing contingent convertible debt, we include the following steady-state condition:

$$\mu = \frac{K^{\chi}}{K^{B}} \frac{1}{(\tau - 1)}, \tag{D.24}$$

and Eq. D.22 becomes:

$$\frac{U_d}{U_c} = (1 - \beta((1 - \theta\mu)R + \theta\mu R^{e})). \tag{D.25}$$

D.3 The rate of returns margin

Based on the optimizing Eqs. 4.19 and 4.20, we can re-write the flow of funds constraint to derive the rate of returns margin

$$R_t^{l} = \frac{K_t^{b}}{L_t} R_{t+1}^{e} + (1 - \frac{K_t^{b}}{L_t}) R_t + \frac{F(E, L)}{L_t}. \tag{D.26}$$

Therefore, if $R_t \ll R_t^{l}$ and $R_t \ll R_t^{e}$, then from Eq. D.26 $R_t^{l} \ll R_t^{e}$.

Appendix E

Data and sources

Data source from the St. Louis Federal Reserve Economic Data (FRED).

1. RGDP: Real Gross Domestic Product, 1 Decimal (GDPC1), Billions of Chained 2005 Dollars, Quarterly, Seasonally Adjusted Annual Rate.

2. Consumption: Real Personal Consumption Expenditures (PCECC96), Billions of Chained 2009 Dollars, Quarterly, Seasonally Adjusted Annual Rate.

3. Investment: Real Gross Private Domestic Investment (GPDIC96), 3 decimal, Billions of Chained 2009 Dollars, Quarterly, Seasonally Adjusted Annual Rate

4. Hours: Average Weekly Hours Of Production And Nonsupervisory Employees (AWHNONAG), Total private, Hours, Quarterly, Seasonally Adjusted.

5. Inflation: GDP Implicit Price Deflator (GDPDEF), Index 2005=100, Quarterly, Seasonally Adjusted.

6. Nominal short-term interest rates (Percent, Quarterly, Not Seasonally Adjusted.): 3-Month Treasury Bill: Secondary Market Rate (TB3MS); 3-month average of the daily Effective Federal Funds Rate (FEDFUNDS); 3-Month AA Financial Commercial Paper Rate (CPF3M).

7. Deposit rate: US CD secondary market – 1-month, 3-month, 6-month middle rate, arithmetic average of DCD1M, CD3M and CD6M respectively (see also, Pesaran and Xu, 2011, p.46).

8. Treasury rate: 10-Year Treasury Constant Maturity Rate (GS10), Percent, Quarterly, Not Seasonally Adjusted.

9. Loan rate to entrepreneurs: Moody's seasoned Baa corporate bond yield (BAA), Percent, Quarterly, Not Seasonally Adjusted.

10. Loan rate to households: 30-Year Conventional Mortgage Rate (MORTG), Percent, Quarterly, Not Seasonally Adjusted.

11. Loans to households: Total Liabilities – Balance Sheet of Households and Nonprofit Organizations (TLBSHNO), Billions of Dollars, Quarterly, Not Seasonally Adjusted - includes mortgage sector and consumer credit sector (equivalent to CMDEBT).

12. Loans to entrepreneurs: Total Liabilities – Balance Sheet of Non-farm Nonfinancial Corporate Business (TLBSNNCB), Billions of Dollars, Quarterly, Not Seasonally Adjusted.

13. Deposits: Deposits – Assets – Balance Sheet of Households and Nonprofit Organizations (DABSHNO), Billions of Dollars, Quarterly, Not Seasonally Adjusted (closely related to M2SL).

14. Monetary authority funds: Total Credit Market Assets Held by Domestic Financial Sectors - Monetary Authority (MATCMAHDFS), Billions of Dollars, Quarterly, Not Seasonally Adjusted.

15. Equity: Standard and Poor 500 Index (SP500), Index, Quarterly, Not Seasonally Adjusted.

16. Loans to nonfinancial firms: Commercial and Industrial Loans (BUSLOANS), All Commercial Banks, Billions of Dollars, Quarterly, Seasonally Adjusted plus Real Estate Loans, All Commercial Banks (REALLN), Billions of Dollars, Quarterly, Seasonally Adjusted.

17. Bank capital-asset ratio: Total Equity to Total Assets for Banks (EQTA), Percent, Quarterly, Not Seasonally Adjusted.

18. Return on equity: Return on Average Equity for all U.S. Banks (USROE), Percent, Quarterly, Not Seasonally Adjusted.

19. US population: Civilian Noninstitutional Population (CNP16OV), Thousands of Persons, Quarterly, Not Seasonally Adjusted.

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