Journal of Banking & Finance 67 (2016) 37–52

Contents lists available at ScienceDirect

Journal of Banking & Finance

journal homepage: www.elsevier.com/locate/jbf

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

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ARTICLE INFO

Article history:
Received 24 June 2015
Accepted 17 February 2016
Available online 24 February 2016

JEL classification:
E32
E43
E44
E51
E52

Keywords:
Financial intermediation
Credit spread
Financial friction
Great Recession
Great Moderation

ABSTRACT

This paper identifies the prevailing financial factors that influence credit spread variability and shows how they affected the U.S. business cycle during the 1990–91 and 2001 recessions of the Great Moderation period (1984–2006) and the Great Recession of 2007–09. To do this, we develop and estimate a dynamic general equilibrium model in which financial intermediation and equity assets play a central role. Over the three recession periods, we find that bank market power (sticky rate adjustments and loan rate markups) played a significant role in the credit spread variability that disrupted the U.S. business cycle. Equity prices exacerbate movements in credit spreads through the financial accelerator channel, but cannot be regarded as one of the main driving forces of credit spread variability. Across the three periods, we observe a remarkable decline in the influence of technology and monetary policy shocks. The influence of loan-to-value ratio shocks declined after the 1990–91 recession, while the bank capital requirement shock exacerbated and prolonged credit spread variability over the 2007–09 recession.

1. Introduction

A notable recurring characteristic of financial stress during a recession is the widening of credit spreads. In this paper we identify the prevailing financial factors that influence credit spread variability and investigate whether the financial factors that contributed to credit spread variability in the recent 2007–09 Great Recession differ from those that had this effect in the 1990–91 and 2001 recessions of the Great Moderation period (1984–2006). We examine the mechanisms by which shocks affected credit spread variability over the Great Moderation and Great Recession periods and look at how this variability disrupted the U.S. business cycle. We look specifically at demand- and supply-side credit market frictions, the equity market and bank balance sheet adjustments. Our investigation provides insights into the key financial factors that propagate and amplify financial stress in the real economy.

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. This 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. Farmer (2012) argues that it was the stock market crash of 2008, triggered by a collapse in house prices, that caused the Great Recession.[1] 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 in fact the 1990–91 and 2001 recessions during the Great Moderation exhibited similar financial stress in the form of widening credit spreads and collapsing equity prices.

Collapsing equity prices and widening credit spreads tend to occur at the same time. To illustrate the behavior of credit spread variability and equity prices, Fig. 1 plots the logarithm of the S&P500, two retail credit spreads (the difference between the

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[1] Farmer (2012) identifies 2008 as the start of the Great Recession, although the literature defines the period as *2007–09*.

http://dx.doi.org/10.1016/j.jbankfin.2016.02.008
0378-4266/

mortgage loan rate and the 3-month Treasury Bill rate and the difference between the Baa corporate bond rate and the 3-month Treasury Bill rate) and the interbank credit spread (the difference between the Fed funds rate and the 3-month Treasury Bill rate).[2] Two observations may be made here. Firstly, the recessions (gray columns) of 1990–91, 2001 and 2007–09 coincided with equity price collapses of 14.7% (1990–91), 29.36% (2001) and 50.82% (2007–09), respectively. Secondly, significant credit spread widening occurred during all three recession periods.

Equity plays an important role in bank capital accumulation too. Fig. 2 shows the composition of bank capital over the sample period of 1984–2014.[3] Over the period 1984–2003 the total bank capital structure of all commercial banks in the U.S. consistently comprised, approximately, 55% equity capital stock and 45% retained earnings. However, after 2003Q4 the ratios diverged considerably, with equity capital stock peaking at 81.3% and retained earnings declining to 18.7% by the end of 2009. This simple example shows a significant structural shift towards greater common equity capital leverage in U.S. commercial banks.

Many studies emphasize both demand- and supply-side credit restrictions that affect credit spread variability. 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 cause frictions in financial intermediaries (Gerali et al., 2010; Adrian and Shin, 2011). Some studies focus on how to curtail the effects of credit market frictions or bank balance sheet adjustments on the real economy 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 disruptions of the U.S. credit cycle, their frameworks have yet to be fully adapted to the New-Keynesian framework.[4] Although demand-side factors are important for financial accelerator effects, the consensus of these studies is that financial intermediaries play a significant role in disrupting the financial stability of the real economy-through both the composition of balance sheet aggregates and the widening of credit spreads. It is clear that there have been significant changes in financial intermediation over the past three decades. What is unclear is whether the transmission mechanism of financial intermediation evolved over the Great Moderation and Great Recession periods.

To understand the factors that contribute to credit spread variability and the mechanisms by which they work, we develop a New-Keynesian dynamic stochastic general equilibrium (DSGE) model with a central role for financial intermediation and equity markets.[5] 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 financial accelerator channel (balance sheet channel) is one of the two important mechanisms by which monetary policy affects the size of the external finance premium in credit markets and hence the real economy.[6] On the other hand, the model reveals that equity prices have an important effect on the real economy through the financial accelerator channel and the bank capital channel, where latter describes shocks to the cost or the value of bank capital that can affect bank lending (Markovic, 2006).

The contribution of our paper is threefold. Firstly, by presenting a centralized model of the way nominal, real and financial shocks are transmitted through financial intermediaries, we synthesize recent milestones in the New-Keynesian DSGE literature on financial intermediation (e.g., Cúrdia and Woodford, 2010; Gerali et al., 2010) and the fundamental factors of the Great Recession in the U. S. economy (e.g., Ireland, 2011; Farmer, 2012). Secondly, our model contributes to the DSGE literature by introducing a role for the

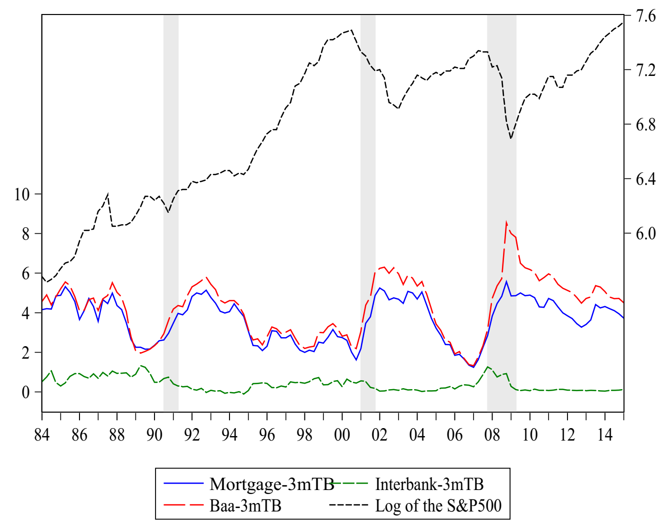

Fig. 1. Financial markets and the U.S. business cycle.

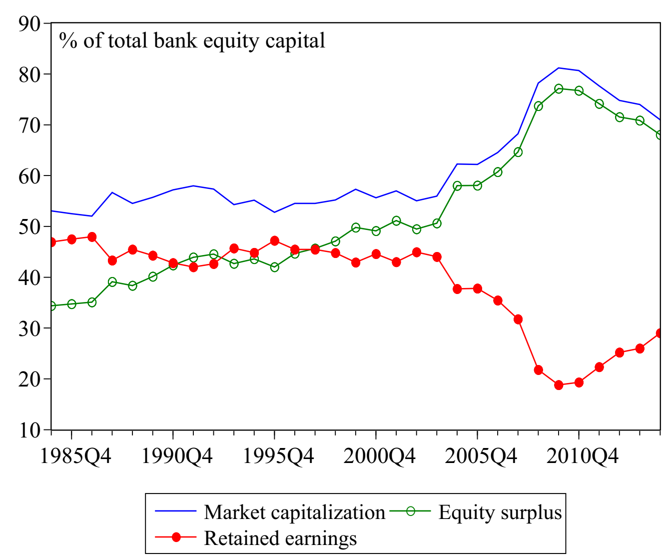

Fig. 2. Composition of bank capital for All U.S. commercial banks.

[2] We refer to the spread between the policy rate and the interbank rate as the interbank credit spread and the spread between the interbank rate and the long-term retail loan rate as the retail credit spread. The net interest spread, referred to by Cúrdia and Woodford (2010) as the 'credit spread', and by Adrian and Shin (2011, p.602) as the 'term spread', is the difference between the rates at which banks borrow and lend. Data source: Federal Reserve Bank of St. Louis's FRED database.

[3] The commercial banking sector's equity capital stock is calculated by the aggregate values of the preferred stock, the common stock at par, and the market value of the common equity surplus. Data source: Federal Deposit Insurance Corporation (FDIC, 2012).

[4] For empirical literature on credit spreads see, for instance, Gemmil and Keswani (2011) and Gencay et al. (2015).

[5] For the role of the equity price channel in a DSGE model see, for instance, Hollander and Liu (2016).

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

equity market in households', firms' and banks' resource allocation. This is critical as collapsing equity prices and widening credit spreads tend to occur at the same tine, and distress the financial sector and the real economy. Finally, we identify the financial factors that influence credit spread variability and whether their behavior changed fundamentally over the Great Moderation and Great Recession periods.

Our estimation 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 (interest-rate policy) has a strong influence on the short-term interbank rate, whereas the influence 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 one of the main driving forces 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), we observe a remarkable decline in the influence of technology and monetary policy shocks over the three recession periods. As far as credit spread variability is concerned, the influence of loan-to-value ratio (LTV hereafter) shocks declined after the 1990–91 recession, while the bank capital requirement shock exacerbated and prolonged credit spread variability during the 2007–09 recession. Moreover, across the three recession periods, we observe an increasing trend for loan markup shocks to contribute to the variability of retail credit spreads.

The rest of the paper is organized as follows. Section 2 defines the transmission mechanisms of credit spread. Section 3 develops the New-Keynesian DSGE model with credit and banking and Section 4 presents the Bayesian estimation results. Sections 5.1 investigates financial factors that affect credit spread variability and Section 5.2 compares the influence of financial factors on credit spread variability over the Great Moderation and Great Recession periods. Section 5.4 provides a robustness analysis of the baseline model. Section 6 concludes.

2. The transmission mechanisms of credit spread

In this section we define the three transmission mechanisms of credit spread 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 adjustment. On the demand side we have the creditworthiness of nonfinancial borrowers (the financial accelerator 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.[7] Investment banks, on the other hand, provide short-term funding to commercial banks in the interbank market, and finance their interbank lending with safe assets (e.g., bank deposits) and bank capital.

In the interbank market, bank capital asset requirements influence the effectiveness of interbank-rate adjustment. Because investment bank assets are subject to bank capital asset requirements, for a given quantity of bank capital, the supply schedule for interbank funds will be upward sloping (Woodford, 2010). 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 safe assets or bank capital) therefore directly affect the supply of credit to nonfinancial borrowers. As a result, financial intermediation in the interbank market and the retail credit market has a direct impact on the efficient allocation of resources in the real economy (Woodford, 2010).

The financial accelerator channel captures the demand-side transmission mechanism of credit spread. Here, household creditworthiness and entrepreneur net worth influence the external finance premium. That is, the ability of borrowers to collateralize their external financing is inversely related to the cost of credit (Bernanke and Gertler, 1995). As a result, low creditworthiness or net worth during recessions causes credit spreads to widen. Conversely, during boom phases improved creditworthiness or net worth causes credit spreads to narrow.

3. Model economy

Households borrow from banks to finance their consumption, safe assets and investment in the equity market. Entrepreneurs demand homogeneous labor to produce wholesale goods. Monopolistically competitive branders in the retail goods sector introduce Calvo-type sticky prices, whereas unions aggregate labor supply and introduce the Calvo-type sticky wages. Banks supply credit to both households and entrepreneurs subject to their balance sheet identity. We close our model by assuming that the monetary authority follows the conventional Taylor-type monetary policy rule.

The price of equity is determined by households' demand for equity investment. To generate the strong correlation between equity prices and credit spreads indicated in Fig. 1, we provide a role for equity in bank capital formation and nonfinancial borrowers' creditworthiness. As a result, the value of equity influences credit spreads through both the bank capital channel and the financial accelerator 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-to-assets ratio, due to the equity price collapse, induces financial distress in over-leveraged banks and this widens the interbank spread.

3.1. Financial intermediation

The banking sector consists of a continuum of bank units, where each bank $j \in [0, 1]$ consists of an investment bank and a commercial bank. We assume that the commercial bank is a wholly owned subsidiary of the investment bank and that the consolidated profits are used as retained earnings at the end of each period.[8]

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] See Gerali et al. (2010) for detailed motivation for market power and sluggish rates in banking.

[8] The structure of the banking sector designed here is purely for modeling purpose. Alternatively, one can consider each bank consists of a wholesale branch, which manages the capital position of the bank, and a retail branch, which raises differentiated deposits and issues differentiated loans (see, Gerali et al., 2010).

$$E_0\sum_{t=0}^{\infty}\beta_B^t\left[i_t^c L_t^c - i_t B_t - \frac{\kappa_k}{2}\left(\frac{K_t^B}{L_t^c} - \tau_t\right)^2 K_t^B\right] \quad (1)$$

subject to the binding balance sheet identity

$$L_t^c = K_t^B + B_t, \quad (2)$$

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-to-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-to-assets 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 widens the interbank credit spread. As banks accumulate larger capital buffers and the capital-to-assets ratio converges towards the target τ_t, the interbank credit spread narrows.

The bank capital accumulation equation is as follows:

$$K_t^B = (1-\delta_B)K_{t-1}^B + \phi_\psi(Q_t^\psi - Q_{t-1}^\psi)\Psi_t^B + \Pi_{\psi,t-1}^B. \quad (3)$$

Q_t^ψ is the equity price and Ψ_t^B is the stock of bank capital. 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 $\left(\Pi_{\psi,t-1}^B\right)$ are bank profits net of dividend payments. We introduce bank equity into bank capital formation in such a way that the market capitalization of the bank equity plays a role in determining the total bank capital. This reflects the recent significant rise in the market value of the common equity surplus on U.S. commercial bank balance sheets indicated in Fig. 2. 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).

We assume there are no frictions between short-term safe asset classes, and that 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,

$$i_t^c - i_t = -\kappa_k\left(\frac{K_t^B}{L_t^c} - \tau_t\right)\left(\frac{K_t^B}{L_t^c}\right)^2. \quad (4)$$

3.1.2. Commercial bank

Commercial bank j differentiates $L_{j,t}^c$ at zero cost and sells it to households and entrepreneurs at their individual markups. All commercial banks apply a symmetrical objective function for all loan types indexed $z = e, h$, described as the following:[9]

$$\max_{\{i_{j,t}^z\}} E_0\sum_{t=0}^{\infty}\beta_B^t\left[i_{j,t}^z L_{j,t}^z - i_t^c L_{j,t}^c - \frac{\kappa_z}{2}\left(\frac{i_{j,t}^z}{i_{j,t-1}^z} - 1\right)^2 i_t^z L_t^z\right]$$

subject to loan demand schedules from households and entrepreneurs:

$$L_{j,t}^z = \left(\frac{i_{j,t}^z}{i_t^z}\right)^{-\varepsilon_t^z} L_t^z. \quad (5)$$

where κ_z is the parameter that captures the quadratic adjustment costs for household and entrepreneur loan rates. We assume that the interbank market determines the feasible total amount of the loans in the retail sector, therefore, $L_{j,t}^c = L_{j,t} = L_{j,t}^h + L_{j,t}^e$ (se also, Gerali et al., 2010; Woodford, 2010). The risk involved in the quality of commercial bank assets enters through a value-at-risk constraint: $(1+i_t^c)L_{j,t}^c \leqslant \nu_B(1+i_{j,t}^z)L_{j,t}^z$, where ν_B is the interbank LTV ratio.[10]

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_t^z are a markup over marginal cost i_t^c:

$$i_t^z = \frac{\varepsilon_t^z}{\varepsilon_t^z - 1} i_t^c. \quad (6)$$

Using the log-linearized equations for loan rate setting, we derive the retail credit spread, between the retail loan rate and the interbank loan rate:

$$\hat{i}_t^z - \hat{i}_t^c = \frac{\kappa_z}{\kappa_z^*}\hat{i}_{t-1}^z + \frac{\beta_B\kappa_z}{\kappa_z^*}E_t\hat{i}_{t+1}^z + \frac{(1+\nu_B)(\varepsilon^z-1) - (1+\beta_B)\kappa_z}{\kappa_z^*}\hat{i}_t^c + \frac{(1-\nu_B)(\varepsilon^z-1)}{\kappa_z^*}\mu_{z,t}, \quad (7)$$

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. (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 $(\hat{i}_t^c)$, which depends on the policy rate and the balance sheet position of the bank. A positive adjustment of the interbank rate puts upward pressure on retail loan rates. 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.

3.2. Households

We 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, leisure, and financial wealth services in the form of safe assets. Households maximize their expected lifetime utility

$$E_0\sum_{t=0}^{\infty}\beta_h^t\left[\frac{(C_t - \phi C_{t-1})^{1-\gamma}}{1-\gamma} - \frac{(H_t)^{1+\eta}}{1+\eta} + \xi_{b,t} ln\frac{B_t}{P_t}\right], \quad (8)$$

where β_h^t is the discount factor. The coefficient of relative risk aversion γ measures the curvature of households' utility with respect to consumption, where habit formation is parameterized by ϕ. η is the Frisch elasticity of labor supply. Households' preferences are subject to a demand shock $\xi_{b,t}$ on real safe assets (B_t/P_t).

The representative household's budget constraint is as follows:

$$C_t + \frac{B_t}{P_t} + \xi_{\psi,t}\frac{Q_t^\psi}{P_t}\Psi_t + \frac{I_{t-1}^h L_{t-1}^h}{P_t} = \frac{W_t}{P_t}H_t + \frac{I_{t-1}B_{t-1}}{P_t} + \frac{L_t^h}{P_t} + \frac{(Q_t^\psi + \Pi_{\psi,t})}{P_t}\Psi_{t-1}. \quad (9)$$

[9] $L_{j,t}^e$ represents entrepreneur loans and $L_{j,t}^h$ represents household loans.

[10] See Woodford (2010, p.32) and Adrian and Shin (2011, p.608-9).

The household allocates periodic wage income (W_tH_t), gross return on safe assets ($I_{t-1}B_{t-1}$), capital gains or losses ($Q_t^{\psi}\Psi_{t-1}$), dividends ($\Pi_{\psi,t}$) and new loans (L_t^h) to current consumption, new asset holdings and the repayment of previous loans ($I_{t-1}^h L_{t-1}^h$). Ψ_t is the aggregate equity held by the household and $\xi_{\psi,t}$ is an equity price shock. For simplicity, 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

$$I_t^h L_t^h \leqslant v_{h,t}\left[\phi_w W_t H_t + (1-\phi_w)Q_t^{\psi}\Psi_t\right]. \tag{10}$$

The household's wage income together with its investment in the equity market represent her creditworthiness and serve as collateral, where $0 \leqslant \phi_w \leqslant 1$ is the weight on wage income.[11] $v_{h,t}$ is a stochastic LTV ratio and, correspondingly, in cases of default $1 - v_{h,t}$ can be interpreted as the proportional transaction cost for the bank's repossession of the borrower's collateral. Following the literature (e.g., Iacoviello, 2005), we assume the size of shocks is small enough 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:

$$\frac{W_t}{P_t} = \frac{\Lambda_t^{-1}(H_t)^{\eta}}{1+\lambda_t\Lambda_t^{-1}v_{h,t}\phi_w}, \tag{11}$$

$$\Lambda_t = \beta_h E_t\left[\Lambda_{t+1}\frac{I_t^h}{\Pi_{t+1}}\right] + \lambda_t I_t^h, \tag{12}$$

$$a\xi_{b,t}\left(\frac{B_t}{P_t}\right)^{-1} = \Lambda_t - \beta_h E_t[\Lambda_{t+1}R_t], \tag{13}$$

$$1 = \beta_h E_t\left[\left(\frac{\Lambda_{t+1}}{\Lambda_t}\right)\frac{Q_{t+1}^{\psi}(1+\zeta_{\psi})}{\xi_{\psi,t}Q_t^{\psi}\Pi_{t+1}}\right] - \lambda_t\Lambda_t^{-1}v_{h,t}(1-\phi_w), \tag{14}$$

where $\Lambda_t = (C_t - \phi C_{t-1})$ is the marginal utility of consumption. The Lagrangian multiplier λ_t is the marginal utility of an additional unit of loans. Eq. (11) is the household's labor supply schedule. Eq. (12) is the consumption Euler equation. Eq. (13) indicates that the demand for safe assets depends on households' consumption and the real gross return to safe assets (R_t), where $R_t < R_t^h\ \forall\ t$.[12] Eq. (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. 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), we 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

$$\max_{\{P_{k,t}^*\}} E_t\sum_{z=0}^{\infty}\theta_R^z\Lambda_{t,z}^R\left[P_{k,t}^*Y_{k,t+z} - P_{j,t+z}^W XY_{k,t+z}\right] \tag{15}$$

subject to the consumer demand schedule for goods

$$Y_{k,t+z} = \left(\frac{P_{k,t}^*}{P_{t+z}}\right)^{-\varepsilon_t^p} Y_{t+z}, \tag{16}$$

where $\Lambda_{t,z}^R$ is the consumption-based relevant discount factor. $P_{k,t}^*$ denotes the optimal 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 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

$$(P_t)^{1-\varepsilon_t^p} = \theta_R\left(\left(\frac{P_{t-1}}{P_{t-2}}\right)^{\gamma_p}P_{t-1}\right)^{1-\varepsilon_t^p} + (1-\theta_R)(P_t^*)^{1-\varepsilon_t^p}, \tag{17}$$

where γ_p determines the degree of price indexation for non-optimizing retailers. Solving and linearizing the optimization problem and combining it with (17) gives the standard forward-looking New-Keynesian Phillips curve.

3.4. Entrepreneurs

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

$$Y_{j,t} = \xi_{z,t}K_{j,t-1}^{\alpha}H_{j,t}^{1-\alpha}, \tag{18}$$

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

$$I_{j,t}^e L_{j,t}^e \leqslant v_{e,jt}\left[\phi_k Q_{j,t}^k K_{j,t-1} + (1-\phi_k)Q_{j,t}^{\psi}\Psi_{j,t}^e\right], \tag{19}$$

where $\phi_k \in (0,1)$ is the weight on physical capital stock. $Q_{j,t}^k$ is the nominal price of physical capital, $v_{e,jt}$ is a stochastic LTV 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 entrepreneur equity ($Q_{j,t}^{\psi}\Psi_{j,t}^e$) serve as a measure of creditworthiness. In other words, they serve as a market-based signal for entrepreneurs' net worth and hence collateral. 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), we assume that in each period the representative entrepreneur chooses the desired amount of physical capital, labor and bank loans to maximize

$$E_0\sum_{t=0}^{\infty}\beta_e^t\left[\frac{(C_{j,t}^e)^{1-\gamma^e}}{1-\gamma^e}\right] \tag{20}$$

subject to the production technology (18), the borrowing constraint (19) and the following flow of funds constraint

$$\frac{Y_{j,t}}{X_{j,t}} + \frac{L_{j,t}^e}{P_t} = C_{j,t}^e + \frac{I_{j,t-1}^e L_{j,t-1}^e}{P_t} + \frac{W_t}{P_t}H_{j,t} + V_{j,t} + Adj_{j,t}^e + \frac{\Pi_{\psi,jt}^e}{P_t}. \tag{21}$$

Adj_t^e captures capital adjustment costs:

$$Adj_{j,t}^e = \kappa_v\left(\frac{V_{j,t}}{K_{j,t-1}} - \delta_e\right)^2\frac{K_{j,t-1}}{(2\delta_e)}, \tag{22}$$

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 capital adjustment cost parameter. $\Pi_{\psi,jt}^e/P_t$ is the real dividend paid out. We assume entre-

[11] To capture the fact that individuals' wage income forms part of the borrowers' creditworthiness in practice we include wage income in the borrowing constraint. Excluding wage income from the borrowing constraint does not affect the quality of the results.

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

preneurs are more impatient than households ($\beta_e^t < \beta_h^t$) 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, we 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:

$$\frac{W_t}{P_t} = \frac{(1-\alpha)Y_{j,t}}{H_{j,t}X_{j,t}}, \tag{23}$$

$$(C_{j,t}^e)^{-\gamma^e} = \beta_e E_t\left[(C_{j,t+1}^e)^{-\gamma}\frac{I_{j,t}^e}{\Pi_{t+1}}\right] + \lambda_{j,t}I_{j,t}^e, \tag{24}$$

$$Q_{j,t}^k = \beta_e E_t\left[\frac{1}{(C_{j,t+1}^e)^{\gamma^e}}\left(\frac{\kappa_v}{\delta_e}\left(\frac{V_{j,t+1}}{K_{j,t}} - \delta_e\right)\frac{V_{j,t+1}}{K_{j,t}} - \frac{\kappa_v}{2\delta_e}\left(\frac{V_{t+1}}{K_{j,t}} - \delta_e\right)^2\right)\right.$$
$$\left. + Q_{j,t+1}^k(1-\delta_e) + \frac{\alpha Y_{j,t+1}}{(C_{j,t}^e)^{\gamma^e}X_{j,t+1}K_{j,t}}\right] + \lambda_{j,t}v_{e,jt}\phi_k Q_{j,t}^k, \tag{25}$$

where $\lambda_{j,t}^e$ is the Lagrangian multiplier of the borrowing constraint. Eq. (23) is the standard labor demand schedule. Eq. (24) gives the entrepreneur consumption Euler equation. Eq. (25) is the investment schedule, where the shadow price of physical capital is defined as $Q_{j,t}^k = (C_{j,t}^e)^{-\gamma^e}(1 + \kappa_v/\delta_e(V_{j,t}/K_{j,t-1} - \delta_e))$. 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.

3.5. Labor supply decisions and the wage-setting equation

Monopolistically competitive unions set the optimal wage at the prevailing labor demand equilibrium. There is a continuum of unions, with each union representing workers of a certain type uniformly distributed across all households.

The unions' problem is to choose $\{W_t^\tau\}_{t=0}^\infty$ to maximize the consumption-weighted wage income of their workers. 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 their 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

$$(W_t)^{1-\varepsilon^w} = \theta_w\left(\left(\frac{P_{t-1}}{P_{t-2}}\right)^{\gamma_w}W_{t-1}\right)^{1-\varepsilon^w} + (1-\theta_w)(W_t^*)^{1-\varepsilon^w}, \tag{26}$$

where γ_w is the degree of wage indexation, and the objective function for the optimal wage is as follows[13]:

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

subject to the the labor demand schedule

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

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

[13] $\widetilde{C}_{t+i} = (C_{t+i} - \phi C_{t+i-1})^\gamma$.

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

where $MRS_{t+i} = \widetilde{C}_{t+i}H_{t+i}^\eta$ 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

$$w_t^* = \frac{(1-\theta_w\beta_h)}{(\varepsilon^w\eta + 1)}E_t\sum_{i=0}^\infty(\theta_w\beta_h)^i(mrs_{t+i} + \varepsilon^w\eta w_{t+i} + p_{t+i}). \tag{27}$$

Combining (27) with the log-linearized aggregate wage index (26) gives the aggregate forward-looking sticky (real) wage equation with price indexation (where $\hat{w}_t = w_t - p_t$)

$$\hat{w}_t = \Phi\beta E_t\hat{w}_{t+1} + \Phi\hat{w}_{t-1} + \Phi\Phi^*(mrs_t - \hat{w}_t) + \Phi\beta E_t\pi_{t+1} - \Phi\pi_t$$
$$- \Phi\theta_w\beta\gamma_w\pi_t + \Phi\gamma_w\pi_{t-1}, \tag{28}$$

where $\Phi^* = \frac{(1-\theta_w)(1-\theta_w\beta)}{\theta_w(1+\varepsilon^w\sigma_n)}$, $\Phi = \frac{1}{(1+\beta)}$, and $mrs_t = \frac{\gamma}{1-\phi}(c_t - \phi c_{t-1}) + \eta h_t$.

3.6. Monetary policy

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

$$I_t = (I_{t-1})^{\kappa_i}\left(\frac{\Pi_t}{\Pi^{target}}\right)^{\kappa_\pi(1-\kappa_i)}\left(\frac{Y_t}{Y_{t-1}}\right)^{\kappa_y(1-\kappa_i)}\xi_{i,t}, \tag{29}$$

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 aggregate resource constraint for the economy is

$$Y_t = C_t + C_t^e + V_t + \delta_B\frac{K_{t-1}^B}{\Pi_t}, \tag{30}$$

where $\delta_B K_{t-1}^B$ represents the banks' management cost in terms of bank capital. In the same way as Iacoviello (2005), we close the model by including the entrepreneur flow of funds constraint (21).

3.7. Market clearing conditions

The market clearing conditions are as follows. 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. In a symmetric equilibrium, all entrepreneurs and banks make identical decisions, so that $Y_{j,t} = Y_t, K_{j,t} = K_t, H_{j,t} = H_t, V_{j,t} = V_t, P_{j,t} = P_t, Q_{j,t}^k = Q_t^k, L_{j,t}^e = L_t^e, L_{j,t}^h = L_t^h$ for $j \in [0,1]$ and $t = 0, 1, 2 \ldots$.

3.8. Exogenous shocks

In our model, there are 10 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_t^p) and the monetary policy shock (ξ_t^i). We introduce seven additional shocks in the financial sector. On the supply side of credit, we have a capital requirement shock (τ_t) in the interbank market and 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 LTV ratio shocks $v_{h,t}$ and $v_{e,t}$, respectively. Households' intertemporal consumption decisions are subject to an exogenous shock to households' safe-asset holdings ($\xi_{b,t}$). Finally, an equity price shock ($\xi_{\psi,t}$) simultaneously affects consumption, production and bank lending activities.

4. Estimation

We estimate the model with Bayesian techniques using U.S. data over the sample period 1984Q1–2014Q4. The full sample covers the recession periods of 1990Q3–1991Q2, 2001Q1–2001Q4 and 2007Q4–2009Q2, and we define the Great Moderation period as of 1984Q1–2006Q4.[14] Since the model has a total of 10 shocks, our data set contains 10 observable variables[15]: output, inflation (GDP deflator), equity price, household loans, entrepreneur loans, household safe assets, 3-month Treasury Bill rate, Fed funds rate, mortgage rate, and Baa corporate bond rate. All the variables except inflation and interest rates are converted into real terms by dividing them by the GDP deflator. Prior to estimation, we take the log-difference of real per capita variables.

Three points are worth noting as regards the observable variables used for estimation. Firstly, monetary authority funds plus household deposits make up aggregate household safe assets. There are two reasons for this aggregation. Firstly, it satisfies the model's arbitrage assumption (Section 3.1.1) that there is unlimited access to monetary authority funds, and, on the empirical side, it accommodates the surge in monetary authority funds that occurred between 2008–2011 as a result of the large-scale recapitalization of the banking sector, which largely offset the significant shortage of household deposits during that period (see also, Woodford, 2010). It would therefore be misleading to view household deposits as the sole measure of bank's available funding when trying to observe the transmission mechanism of financial intermediation. As a consequence of this assumption, we use the 3-month Treasury Bill rate as the short-term safe-asset rate (i.e. the policy rate). Secondly, by the end of 2009 outstanding financial commercial paper stood at \$1.7 trillion. To capture this additional stress that was not present during the Great Moderation period, we derive the interbank rate by averaging the effective Fed funds rate with the 3-month AA financial commercial paper rate.

4.1. Calibrated parameters

Table 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] (see also, Iacoviello, 2005, p.751). We derive the discount factors 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 $(1/R_e - \beta_e) > 0$, we set $\beta_e = 0.955$. 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 retail goods (ε^p) of 11. The price elasticity of demand for different types of labor 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, 2007), we 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.

Table 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 labor	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	1.442
ε^e	Elasticity of substitution for entrepreneur loans	1.348
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	0.655
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

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 1.442 and 1.348, respectively. The target capital requirement ratio τ equals 11%, reflecting the condition of the U.S. banks' recent balance sheet. The bank capital depreciation rate δ_B equals 0.1044.[16] Parameter ϕ_ψ captures the pass-through effect of equity price changes on bank capital accumulation. We set ϕ_ψ to 0.25, based on our preliminary estimations. Shares of household and entrepreneur loans to total bank loans, the consumption-to-output ratio, and the total bank capital-to-output ratio are calculated from the data means over the sample period. We restrict any other steady-state ratios in the banking sector to be consistent with the balance sheet identity and capital requirement. Finally, based on our 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 1% shock to equity prices will directly reduce household and entrepreneur creditworthiness by 0.2%.

4.2. Prior distributions and posterior estimates.

The prior distributions of the structural parameters are reported in columns 3–5 of Tables 2 and 3. We assume that the households' coefficient of relative risk aversion (RRA) γ follows an inverse-gamma distribution with a mean of 2.3 and a standard deviation of 0.15. Meanwhile, the entrepreneurs' RRA ($\gamma_e = 1$) is assumed to be less than the households' RRA, which implies a preference for current period consumption gains. Both RRA values roughly correspond with estimates of their reciprocal (the intertemporal elasticity of substitution in consumption) in the microeconomics literature (e.g., Vissing-Jorgensen, 2002). The prior distribution of habit formation parameter ϕ is set at 0.7 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 (2007) and Christiano et al. (2014). The parameters describing the monetary policy reaction function are chosen within the con-

[14] NBER U.S. recession data are available at www.nber.org/cycles/cyclesmain.html. For the initial structural break of the Great Moderation see, for example, Stock and Watson (2003) and Christiano et al. (2014).

[15] See the Appendix A for data and sources.

[16] We 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 2
Structural parameters.

Parameter		Prior distribution			Posterior distribution			
		Type	Mean	SD	Mean	2.5%	Median	97.5%
Preferences								
γ	Household RRA	Inv.Gamma	2.3	0.15	2.122	1.925	2.114	2.324
γ_e	Entrepreneur RRA	Inv.Gamma	1	0.10	1.077	0.882	1.068	1.252
ϕ	Habit formation	Beta	0.7	0.03	0.739	0.700	0.739	0.777
Prices								
θ_R	Price stickiness	Beta	0.9	0.03	0.924	0.915	0.924	0.931
γ_p	Degree of price indexation	Beta	0.5	0.03	0.523	0.476	0.524	0.568
Monetary policy rule								
κ_i	Coefficient on lagged policy rate	Beta	0.65	0.05	0.645	0.604	0.646	0.687
κ_π	Coefficient on inflation	Gamma	1.5	0.05	1.628	1.546	1.628	1.718
κ_y	Coefficient on output change	Beta	0.25	0.02	0.261	0.228	0.260	0.298
Credit and banking								
ν_h	Households' LTV ratio	Beta	0.65	0.03	0.604	0.555	0.606	0.653
ν_e	Entrepreneurs' LTV ratio	Beta	0.65	0.03	0.742	0.710	0.742	0.776
ν_B	Interbank LTV ratio	Beta	0.4	0.05	0.364	0.298	0.363	0.430
κ_h	HH loan rate adjust. cost	Gamma	10	2	13.12	9.885	13.06	16.67
κ_e	Entrep. loan rate adjust. cost	Gamma	8	2	6.817	5.602	6.805	8.142
κ_k	Leverage deviation cost	Gamma	2	1	0.834	0.663	0.829	0.991
Physical capital								
κ_v	Capital adjust. Costs	Gamma	2	0.05	2.454	2.026	2.439	2.901
K^e/Y	Capital-output ratio	Gamma	10.7	0.20	10.78	10.47	10.77	11.10

Table 3
Exogenous processes.

Parameter		Prior distribution			Posterior distribution			
		Type	Mean	SD	Mean	2.5%	Median	97.5%
AR coefficients								
ρ_z	Technology	Beta	0.95	0.005	0.963	0.957	0.963	0.968
ρ_i	Monetary policy	Beta	0.50	0.05	0.608	0.557	0.609	0.663
ρ_b	Household asset	Beta	0.95	0.005	0.955	0.948	0.955	0.962
ρ_e	Entrep. loan markup	Beta	0.50	0.10	0.569	0.508	0.570	0.638
ρ_h	Household loan markup	Beta	0.50	0.10	0.574	0.463	0.577	0.693
ρ_{ν_h}	Households' LTV	Beta	0.50	0.10	0.792	0.728	0.795	0.863
ρ_{ν_e}	Entrepreneurs' LTV	Beta	0.50	0.10	0.680	0.627	0.683	0.739
ρ_ψ	Equity	Beta	0.75	0.05	0.822	0.779	0.824	0.867
ρ_p	Price markup	Beta	0.50	0.05	0.466	0.404	0.466	0.533
ρ_τ	Capital requirement	Beta	0.75	0.05	0.777	0.724	0.778	0.827
Standard deviations								
ϵ_z	Technology	Inv. gamma	0.01	Inf	0.013	0.012	0.013	0.015
ϵ_i	Monetary policy	Inv. gamma	0.01	Inf	0.005	0.004	0.005	0.006
ϵ_b	Household asset	Inv. gamma	0.01	Inf	0.008	0.007	0.008	0.009
ϵ_e	Entrep. loan markup	Inv. gamma	0.05	Inf	0.080	0.059	0.078	0.101
ϵ_h	Household loan markup	Inv. gamma	0.05	Inf	0.102	0.062	0.100	0.139
ϵ_{ν_h}	Households LTV	Inv. gamma	0.01	Inf	0.019	0.017	0.019	0.021
ϵ_{ν_e}	Entrepreneurs LTV	Inv. gamma	0.01	Inf	0.044	0.035	0.043	0.051
ϵ_ψ	Equity	Inv. gamma	0.01	Inf	0.007	0.005	0.007	0.009
ϵ_p	Price markup	Inv. gamma	0.005	Inf	0.001	0.001	0.001	0.001
ϵ_τ	Capital requirement	Inv. gamma	0.01	Inf	0.016	0.013	0.016	0.019

text of the financial frictions literature (e.g., Christiano et al., 2014). We choose a reasonable value of 0.65 as the prior mean for both the households' LTV ratio (ν_h) and the entrepreneurs' LTV ratio (ν_e). We set the prior mean of the interbank LTV ratio (ν_B) to 0.4 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 means $\{2, 8, 10\}$ and standard deviations $\{1, 2, 2\}$ (see also, Gerali et al., 2010). Analogous to the entrepreneur investment schedule in Iacoviello (2005, p.752), we set the prior mean of the physical capital adjustment cost parameter κ_v to 2. The prior mean of the capital-to-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 to 5 of Table 3.

The estimated posterior statistics for the structural parameters are reported in columns 6 to 9 of Tables 2 and 3. Parameters for preferences, prices and the monetary policy rule all conform well with 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 (0.60) is lower than that for entrepreneurs (0.74), which suggests that entrepreneurs can collateralize their loans more easily (see also, Iacoviello, 2005, p.752). In fact, 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. Corresponding to the observed persistence of retail credit spread movements, large posterior means for the entrepreneur and household loan rate adjustment cost parameters ($\kappa_e = 6.82$ and $\kappa_h = 13.12$) 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 0.834 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 our results in Section 5 show, and contrary to Gerali et al. (2010) for the euro area, we find a clear role for the sticky-rate structure in commercial banking for both business cycle dynamics and credit spread variability.

4.3. Cyclical properties of the model

This section studies the cyclical properties of the key variables in the model. Firstly, we compare the standard deviations of a variable relative to that of output from the data and those from the model. Thereafter, we compare correlations of output with interested variables from the data and those from the model.

The model successfully mimics the cyclical properties of the data. Panel A of Table 4 reports the results for the U.S. data. Over the sample period 1984Q01–2014Q04, equity prices are ten times as volatile as output, while investment and bank capital are slightly over three and two times as volatile as output, respectively. The relative variation of consumption to output is slightly less than one. Output is persistent at one-step and two-step autocorrelations, and are positively correlated with all the variables, except for the retail credit spreads and bank market capitalization. Panel B of Table 4 reports the corresponding results from the model. Firstly, the generated volatilities of the variables are consistent with those from the data. Secondly, except market capitalization, the model successfully replicates the correlation of the key variables with output observed from the U.S. data. The model overestimates the negative correlation of market capitalization with output.

Table 4
Cyclical properties.

Variable	$\frac{\sigma(X)}{\sigma(Y)}$	Correlation of output with				
		X_{t-2}	X_{t-1}	X_t	X_{t+1}	X_{t+2}
Panal A: US economy						
Output	1	0.51	0.71	0.87	0.71	0.51
Consumption	0.84	0.67	0.81	0.89	0.82	0.71
Investment	3.24	0.63	0.79	0.90	0.88	0.80
Equity price	10.0	0.60	0.67	0.65	0.56	0.43
Bank capital	2.33	0.17	0.40	0.59	0.63	0.64
Bank capital	3.26	0.19	0.12	0.07	0.02	−0.01
Market capitalization	5.60	−0.06	−0.07	−0.07	−0.06	−0.02
Retained earnings	9.11	0.38	0.33	0.28	0.23	0.14
Interbank spread	0.32	0.23	0.31	0.42	0.47	0.48
Household spread	1.15	−0.53	−0.58	−0.64	−0.67	−0.65
Entrepreneur spread	1.52	−0.61	−0.67	−0.69	−0.66	−0.59
Panal B: model economy						
Output (Y_t)	1	0.89	0.93	0.97	0.93	0.89
Consumption (C_t)	0.89	0.71	0.68	0.64	0.58	0.52
Investment (V_t)	2.72	0.67	0.74	0.80	0.81	0.81
Equity price (Q_t^ψ)	7.04	0.82	0.81	0.79	0.75	0.69
Bank capital (K_t^B)	3.15	0.58	0.63	0.68	0.68	0.67
Market cap. ($K_t^B - \omega_B$)	3.84	−0.41	−0.46	−0.51	−0.53	−0.54
Retained earnings (ω_B)	5.72	0.59	0.65	0.72	0.73	0.73
Interbank spread S_t^c	0.35	0.10	0.13	0.16	0.17	0.17
Household spread S_t^h	1.24	−0.45	−0.47	−0.49	−0.48	−0.46
Entrepreneur spread S_t^e	1.64	−0.49	−0.50	−0.50	−0.47	−0.42

Note: For the U.S. data, all series are detrended using the HP filter. For the model, we use the smoothed variables predicted from the posterior estimates.

5. Results

In this section, we use the DSGE model developed in Section 3 (hereafter, the baseline model) to determine the main financial factors that affected credit spread variability over the Great Moderation and Great Recession periods. Firstly, we establish the prevailing financial factors responsible for credit spread variability over the full sample period (1984Q1–2014Q4). Using the historical shock decomposition of each credit spread, we show how structural shocks predict the cyclical pattern of credit spreads in the U.S. business cycle. Secondly, we compare U.S. recession episodes during the Great Moderation and Great Recession periods. To do this, we re-estimate the baseline model with three sub-sample periods covering the 1990–91, 2001 and 2007–09 recessions. We determine whether the factors that affect credit spreads changed over these periods, and whether there were any clear differences in the transmission mechanisms of credit spread during these periods. We conclude this section with a robustness analysis of the baseline model.

5.1. Factors affecting credit spread variability

Fig. 3 provides the historical shock decomposition of the interbank and retail credit spreads. Here, we focus on how the structural shocks predict cyclical patterns of credit spreads over the Great Moderation and Great Recession periods. 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-to-assets 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 that the bank capital requirement shock has a significant impact on interbank credit spread variability during the 2007–09 recession. Furthermore, the collapse of the equity market during the 2001 and 2007–09 recessions causes some additional financial stress. The monetary policy shock does not contribute significantly to interbank credit spread variability over the Great Moderation and Great Recession periods, where the technology shock only contributes 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 claim that monetary authorities kept the policy rate too low from 2002 to 2005, inadvertently creating the incentive for banks to seek larger profit margins by increasing risky portfolios (Taylor, 2007; Adrian and Shin, 2011). The widening of retail credit spreads occurs at the peak of each recession period (1990Q3–1991Q2, 2001Q1–2001Q4 and 2007Q4–2009Q2). This 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, in particular the 2007Q4–2009Q2 recession. Although a technology shock produces a negative correlation between equity prices and net credit spreads (see Fig. 6), it is unlikely that a single

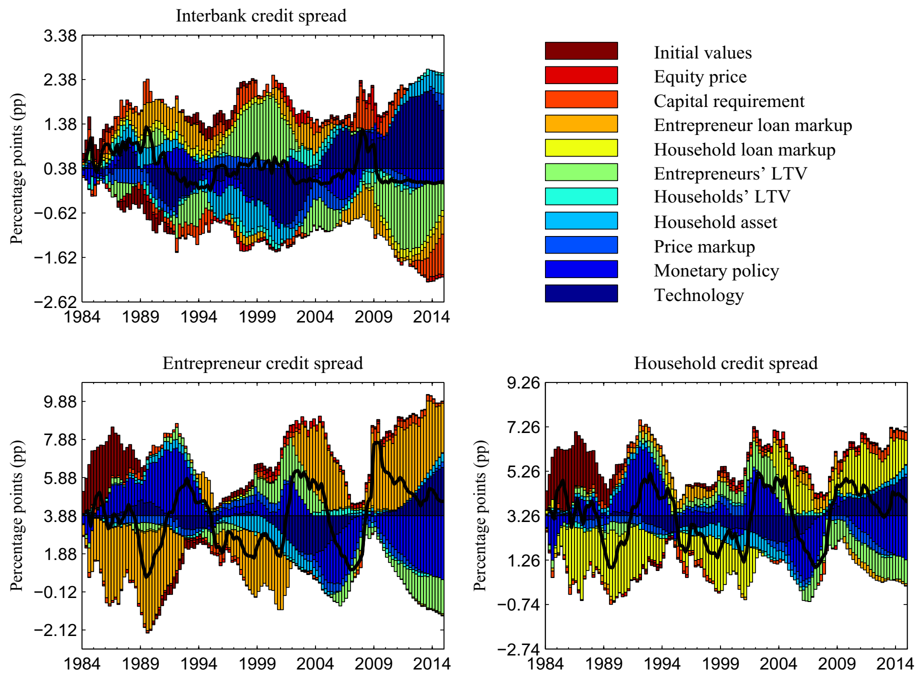

Fig. 3. Historical decomposition of credit spreads (full-sample).

large fundamental shock could generate systemic financial stress in both equity and credit markets—the cause is more likely to be a combination of financial shocks and real shocks.[17]

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 benefit from large profit-making margins. Financial intermediaries exert their 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 shock exacerbates movements in credit spreads, but cannot be regarded as one of the main driving forces of credit spread variability.

5.2. Great Moderation versus Great Recession

In this section we investigate first whether the factors that influenced the variability of credit spreads are different in the three recession periods and second whether there are any clear shifts in the forces driving credit spread variability across the three periods. To do this we re-estimate the baseline model with three sub-sample periods. Each sub-sample period includes a maximum of 20 quarters before and after each recession's peak and trough: 1985Q3–1996Q2, 1996Q1–2006Q4 and 2002Q4–2014Q2.

Although the recessions of 1990–91 and 2001 were milder than that of 2007–09, a comparative study by Ireland (2011) shows that the pattern of shocks did not change 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 demand and supply shocks, with the notable difference in the Great Recession being that these adverse shocks were deeper and lasted longer. He argues that while expansionary monetary policy helped to cushion 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 the depth 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 to a reduction in the volatility of a similar combination of exogenous shocks.

Table 5 reports the contribution of the structural shocks to the variance of credit spreads at 1-quarter, 1-year and 5-year horizons and Fig. 4 provides the historical shock decomposition of the entrepreneur credit spread.[18] Capital requirement shocks have the largest influence (approximately 35% and 29% over the forecast horizon) on interbank credit spread variability for both the 2007–09 and 1990–01 recession periods. On the demand side, the influence of the households' LTV shock (ϵ_{v_h}) is strong over 1-quarter and 1-year horizons for each of the three periods, and has the largest influence in the 2001 recession period. The entrepreneurs' LTV shock (ϵ_{v_e}) is consistent over the forecast horizon for each period, but plays a less significant role in explaining interbank credit spread variability. The interbank credit spread in the 2001 recession period therefore seems to be less rooted in supply-side factors. Comparing all three periods, we find that the impact of technology shocks falls steadily over shorter 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 periods, we see an increasing trend in the contribution of loan markup shocks (ϵ_e and ϵ_h) to the variability of both retail credit spreads

[17] The posterior theoretical moments show that output has a strong positive correlation with equity prices and a strong negative correlation with credit spreads (Results are not reported here, but are available upon request).

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

Table 5
Variance decomposition of credit spreads for the U.S. recession periods.

	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
Interbank spread									
ϵ_z	0.097	0.063	0.358	0.075	0.070	0.275	0.170	0.152	0.328
ϵ_i	0.052	0.061	0.022	0.060	0.075	0.044	0.028	0.034	0.023
ϵ_p	0.034	0.031	0.251	0.017	0.017	0.158	0.016	0.018	0.212
ϵ_b	0.001	0.001	0.020	0.001	0.001	0.023	0.001	0.001	0.022
ϵ_{v_h}	0.197	0.135	0.040	0.359	0.344	0.175	0.250	0.199	0.083
ϵ_{v_e}	0.106	0.110	0.114	0.069	0.081	0.096	0.069	0.096	0.097
ϵ_h	0.006	0.021	0.006	0.003	0.016	0.011	0.003	0.021	0.016
ϵ_e	0.060	0.048	0.033	0.071	0.055	0.059	0.044	0.036	0.046
ϵ_τ	0.403	0.492	0.145	0.262	0.284	0.129	0.338	0.384	0.133
ϵ_ψ	0.043	0.037	0.011	0.082	0.058	0.028	0.080	0.059	0.040
Household credit spread									
ϵ_z	0.021	0.010	0.058	0.029	0.022	0.123	0.090	0.087	0.396
ϵ_i	0.173	0.120	0.134	0.265	0.174	0.212	0.153	0.084	0.100
ϵ_p	0.019	0.030	0.098	0.012	0.018	0.061	0.021	0.023	0.055
ϵ_b	0.001	0.001	0.002	0.001	0.000	0.002	0.000	0.000	0.002
ϵ_{v_h}	0.038	0.014	0.009	0.063	0.026	0.019	0.045	0.017	0.007
ϵ_{v_e}	0.049	0.020	0.017	0.029	0.011	0.013	0.022	0.009	0.027
ϵ_h	0.637	0.782	0.648	0.518	0.713	0.529	0.589	0.742	0.351
ϵ_e	0.024	0.009	0.006	0.035	0.016	0.017	0.024	0.015	0.036
ϵ_τ	0.035	0.013	0.026	0.032	0.012	0.018	0.039	0.015	0.016
ϵ_ψ	0.003	0.001	0.001	0.015	0.007	0.007	0.017	0.008	0.010
Entrepreneur credit spread									
ϵ_z	0.028	0.029	0.154	0.025	0.025	0.141	0.107	0.123	0.433
ϵ_i	0.133	0.091	0.135	0.185	0.116	0.173	0.156	0.085	0.096
ϵ_p	0.014	0.024	0.095	0.008	0.012	0.047	0.021	0.023	0.050
ϵ_b	0.001	0.000	0.002	0.001	0.000	0.002	0.000	0.000	0.002
ϵ_{v_h}	0.033	0.013	0.008	0.044	0.018	0.016	0.048	0.018	0.007
ϵ_{v_e}	0.037	0.015	0.026	0.020	0.007	0.014	0.021	0.011	0.031
ϵ_h	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.001
ϵ_e	0.722	0.813	0.548	0.683	0.807	0.586	0.586	0.714	0.355
ϵ_τ	0.029	0.012	0.029	0.023	0.009	0.014	0.042	0.016	0.015
ϵ_ψ	0.003	0.002	0.002	0.011	0.005	0.006	0.019	0.009	0.010

Note: see Table 3 for shock parameter descriptions.

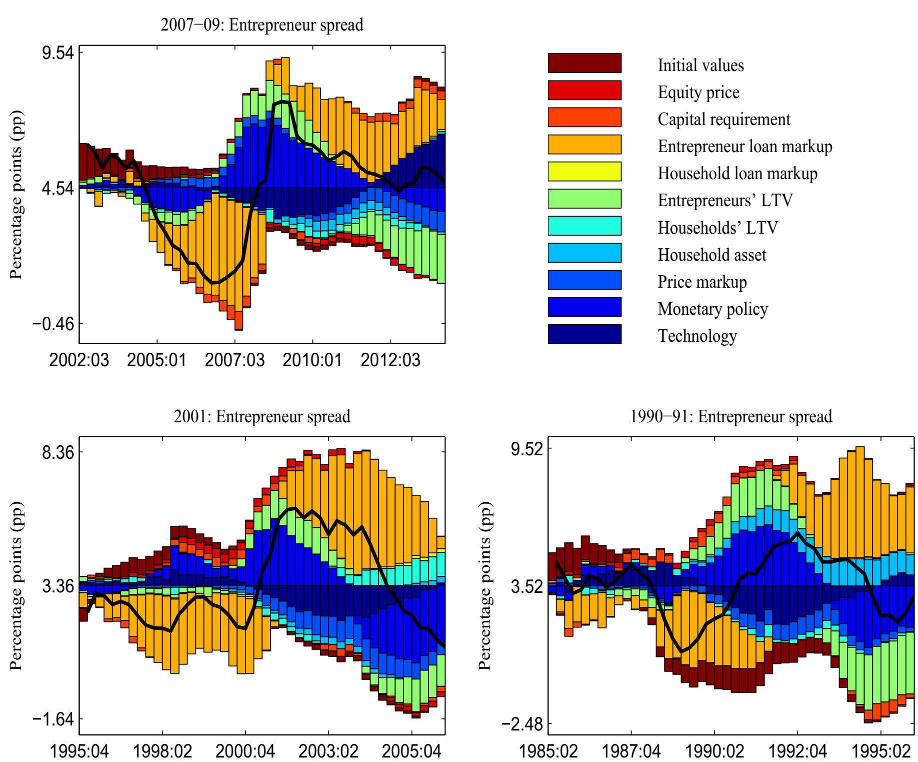

Fig. 4. Historical decomposition for entrepreneur credit spread: 2007–09 recession (top-left); 2001 recession (bottom-left); 1990–91 recession (bottom-right).

at all horizons. In contrast, the contribution of LTV shocks (ϵ_{v_h} and ϵ_{v_e}) is small and ambiguous across the three periods. Analogous to the interbank credit spread, we observe a remarkable decline in the influence of technology and monetary policy shocks over three 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 with regard to the historical shock decomposition of the entrepreneur credit spread in Fig. 4. Firstly, from the demand side of the credit market, the influence of LTV shocks declines after the 1990–91 recession, while the bank capital requirement shock exacerbates and prolongs credit spread variability over the 2007–09 recession. Secondly, 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.

5.3. Monetary policy and the U.S. recessions: credit spreads and interest rate smoothing

In this section we first investigate whether the Fed should take into consideration of credit spread when making monetary policy decisions. This exercise is motivated by the increasing focus on credit spread by the FOMC members after the recent financial crisis. We re-estimate the baseline model with an augmented Taylor-type interest rate rule, in which besides output and inflation the Fed also adjusts the policy rate in response to credit spread:

$$I_t = (I_{t-1})^{\kappa_{i1}} \left(\frac{\Pi_t}{\Pi^{target}}\right)^{\kappa_\pi(1-\kappa_{i1})} \left(\frac{Y_t}{Y_{t-1}}\right)^{\kappa_y(1-\kappa_{i1})} (S_t)^{-\kappa_s(1-\kappa_{i1})} \xi_{i,t} \tag{31}$$

where κ_s is the weight on the relevant credit spread(retail[19] or interbank) and κ_{i1} is the weight on the first-order lagged policy rate. Following Cúrdia and Woodford (2010, p.16) we assume $0 < \kappa_s < 1$, which implies that the policy rate should be lowered when credit spread widens and the size of the adjustment in the policy rate should be less than the size of the increase in credit spreads.[20] This augmented Taylor rule attenuates any "effective tightening" of widening spreads that are not linked to excess output and inflation.

In addition, we consider an alternative augmented Taylor rule, in which we include interest rate smoothing – the second-order lagged policy rate:

$$I_t = (I_{t-1})^{\kappa_{i1}} (I_{t-2})^{\kappa_{i2}} \left(\frac{\Pi_t}{\Pi^{target}}\right)^{\kappa_\pi(1-\kappa_{i1}-\kappa_{i2})} \left(\frac{Y_t}{Y_{t-1}}\right)^{\kappa_y(1-\kappa_{i1}-\kappa_{i2})} \xi_{i,t}, \tag{32}$$

where κ_{i2} is the weight on the second-order lagged policy rate.

Table 6 reports the parameter estimates from the baseline model (full-sample period), but with three variant augmented Taylor rules: a standard Taylor rule with the retail credit spread, with the interbank credit spread, and with interest rate smoothing. Firstly, adding the retail credit spread or interest rate smoothing (AR(2)) improves the log marginal data density of the model, where including the interbank credit spread does not improve the fit of the model. For the model with interest rate smoothing, the estimated κ_{i1} and κ_{i2} together give a value of 0.72. This is slightly above the parameter estimates from other models, suggesting that an interest-rate-smoothing Taylor rule of order two provides a better description of the policy rate persistence in the U.S. (see, Coibion and Gorodnichenko, 2012).

Since adding the retail credit spread in the Taylor rule improves the fit of the model over the full-sample period, we now take one step further, investigating whether the Fed adjusted its monetary policy in response to credit spread variations in a different manner during different recession periods. Table 7 reports the parameter estimates for each sub-sample period. It is worth noting that the estimated κ_s increases from 0.124 for the 1990–91 recession period to 0.346 for the recent 2007–09 recession period. This finding suggests that the Fed adjusted the policy rate more heavily in response to retail credit spread widening leading up to, and over the Great Recession. It is worth pointing out that there are no significant changes in the estimated adjustment coefficients κ_y and κ_π across the three sub-samples, but only significant changes in κ_s. In addition, for each sub-sample period the marginal density of the augmented retail–credit–spread Taylor rule model is higher than that of the baseline model. This indicates that including the retail credit spread in the Taylor rule improves the fit of model, the same as reported in the full-sample estimation results.

5.4. Robustness analysis

In this section, we perform a robustness analysis for the model developed in the paper. We compare the baseline model with three variant versions of the model. We compare first the dynamics of variant models in response to monetary and technology shocks and then the parameter estimates across models. These exercises provide more valuable insights for analysis of credit spread variability.

The three variants serve to highlight three key issues. For the first variant (FI hereafter) we assume flexible interest 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 between the baseline model and this flexible interest rate variant highlights the role of bank market power through sticky retail rate adjustment. For the second variant (TB hereafter) we use the 10-year Treasury Bill rate 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 on long-term interest rates. We are thus able to test the robustness of the credit spread transmission mechanisms. For the third variant (NI hereafter), we re-estimate the model without the observed variable for the interbank rate.[21] As this NI model is in line with the models with multiple interest rates in the literature (e.g., Gerali et al., 2010), it serves as a useful reference for comparing our baseline model with those models.

5.4.1. Nominal and real shocks

Fig. 5 shows the impulse responses of the observed variables to a contractionary monetary policy shock.[22] The dynamics of the TB model and the NI model follow a similar pattern as that of the baseline model. The differences between the impact of the monetary policy in the three models are negligible. There are, however, some uninformative differences in credit spreads and equity prices. When we compare the baseline model with the FI model, we find an important role for sticky rate adjustments: during a recession (or boom), imperfect bank competition stifles the 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 more severe in response to a con-

[19] Given that the share of the entrepreneur and household credit markets are approximately the same, we equally weight the household and entrepreneur retail spreads to give an average measure of retail spread.

[20] We also estimate the model with gamma and inverse-gamma distributions and vary prior means and standard deviations for κ_s and the estimated results are consistent with those reported here and supporting the assumption that $0 < \kappa_s < 1$.

[21] We drop the capital requirement shock to match nine shocks with the remaining nine observed variables.

[22] For simplicity, we aggregate household loans and entrepreneur loans, and label it total loans. We also include the response of the capital-asset ratio. Here we focus on robustness analysis. Interest rates and credit spreads are expressed in percentage points.

Table 6
Parameter estimates for augmented Taylor-rule models.

	Posterior distribution means					Posterior distribution means			
	Baseline	AR(2)	Retail spread	Interbank spread		Baseline	AR(2)	Retail spread	Interbank spread
Marginal density	4515	4541	4527	4510					
Parameters					Parameters				
γ	2.122	2.149	2.107	2.134	ρ_z	0.963	0.963	0.963	0.962
γ_e	1.077	1.019	1.064	1.047	ρ_i	0.608	0.493	0.627	0.608
ϕ	0.739	0.732	0.740	0.741	ρ_b	0.955	0.955	0.956	0.956
θ_R	0.924	0.926	0.922	0.923	ρ_e	0.569	0.411	0.547	0.570
γ_p	0.523	0.542	0.511	0.518	ρ_h	0.574	0.558	0.518	0.562
κ_{i1}	0.645	1.222	0.660	0.644	ρ_{v_h}	0.792	0.810	0.793	0.788
κ_{i2}	–	−0.501	–	–	ρ_{v_e}	0.680	0.704	0.674	0.686
κ_π	1.628	1.650	1.608	1.632	ρ_ψ	0.822	0.821	0.840	0.827
κ_y	0.261	0.266	0.263	0.261	ρ_p	0.466	0.459	0.457	0.461
κ_s	–	–	0.123	0.050	ρ_τ	0.777	0.774	0.782	0.784
v_h	0.604	0.605	0.504	0.599	ϵ_z	0.013	0.013	0.013	0.013
v_e	0.742	0.729	0.824	0.747	ϵ_i	0.005	0.005	0.005	0.005
v_B	0.364	0.424	0.344	0.368	ϵ_b	0.008	0.008	0.008	0.008
κ_k	0.834	0.798	0.829	0.857	ϵ_e	0.080	0.124	0.087	0.081
κ_e	6.817	8.304	7.155	6.796	ϵ_h	0.102	0.096	0.121	0.106
κ_h	13.12	11.52	14.61	13.25	ϵ_{v_h}	0.019	0.018	0.019	0.019
κ_v	2.454	2.553	2.146	2.451	ϵ_{v_e}	0.044	0.036	0.052	0.044
K^e/Y	10.78	10.72	10.75	10.75	ϵ_ψ	0.007	0.007	0.006	0.007
					ϵ_p	0.001	0.001	0.001	0.001
					ϵ_τ	0.016	0.017	0.016	0.016

Note: κ_{i1} and κ_{i2} are the parameters of the first- and second-order lagged policy rate. κ_s refers to the parameter of relevant spread. See Tables 2 and 3 for the remaining parameter descriptions. We exclude prior distributions and statistic confidence intervals in the table due to limited space.

Table 7
U.S. recessions: retail–credit–spread augmented Taylor rule.

	Posterior distribution means				Posterior distribution means		
	2007–09	2001	1990–91		2007–09	2001	1990–91
Marginal density	1743 (1724)	1658 (1635)	1603 (1578)				
Parameters				AR(1) processes			
γ	2.308	2.196	2.317	ρ_z	0.95	0.95	0.95
γ^e	1.046	1.044	1.048	ρ_i	0.55	0.52	0.50
ϕ	0.714	0.716	0.735	ρ_b	0.95	0.95	0.95
θ_R	0.921	0.933	0.915	ρ_e	0.43	0.57	0.57
γ_p	0.489	0.478	0.501	ρ_h	0.38	0.57	0.50
κ_i	0.601	0.621	0.576	ρ_{v_h}	0.53	0.89	0.47
κ_π	1.536	1.518	1.538	ρ_{v_e}	0.70	0.61	0.61
κ_y	0.258	0.254	0.248	ρ_ψ	0.79	0.82	0.73
κ_s	0.346	0.186	0.124	ρ_p	0.45	0.41	0.43
v_h	0.542	0.540	0.645	ρ_τ	0.81	0.78	0.73
v_e	0.796	0.784	0.684	ϵ_z	0.011	0.010	0.013
v_B	0.392	0.391	0.390	ϵ_i	0.003	0.004	0.004
κ_k	1.132	1.331	1.449	ϵ_b	0.008	0.006	0.007
κ_e	4.766	7.374	6.028	ϵ_e	0.105	0.066	0.059
κ_h	12.95	13.03	9.90	ϵ_h	0.128	0.080	0.106
κ_v	1.656	1.973	2.747	ϵ_{v_h}	0.015	0.015	0.018
K^e/Y	10.73	10.75	10.75	ϵ_{v_e}	0.021	0.024	0.028
				ϵ_ψ	0.008	0.006	0.008
				ϵ_p	0.001	0.001	0.001
				ϵ_τ	0.011	0.008	0.011

Note: See Tables 2 and 3 for parameter descriptions. Prior means and standard deviations used here are the same as those in the baseline model (full-sample) estimation. Numbers in the parentheses are the estimated marginal densities of the baseline model.

tractionary monetary policy. Even though the influence of monetary policy on the interbank spread in the TB model is larger, this provides no distinct advantage in the results. The retail credit spreads decline more in the baseline model than those in the TB model. In other words, the influence of the conventional monetary policy on long-term interest rates is not robust.

Fig. 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). The bullish equity market improves both the demand and supply of the credit market. On the demand side, borrowers' creditworthiness increases the feasible amount of loans. The improved credit demand and wider bank profit margins propagate the dynamics of the model through both financial accelerator and bank capital channels. On the supply side, the 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 between the dynamics of the three variant models in response to the technology shock, except for retail credit spreads. For the FI model and the TB model, the responses of retail credit spreads are exacerbated. This once again emphasizes the importance of sticky retail rate adjustment in the banking sector.

In summary, based on the model comparison, we find that the baseline model is robust to alternative versions. The dynamics of the model in response to both monetary and technology shocks are in conformity with the evidence in the established literature. Indeed, as shown in Section 5.4.2 below, comparing the estimated parameters of the variant models reinforces these findings.

5.4.2. Alternative model parameter estimates

Table 8 compares the posterior estimates of the structural parameters for the three variant models. Overall, the parameter estimates are consistent across models, indicating that our results are robust. The most notable variations occur in some of the parameters in the banking sector. 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 in the estimated

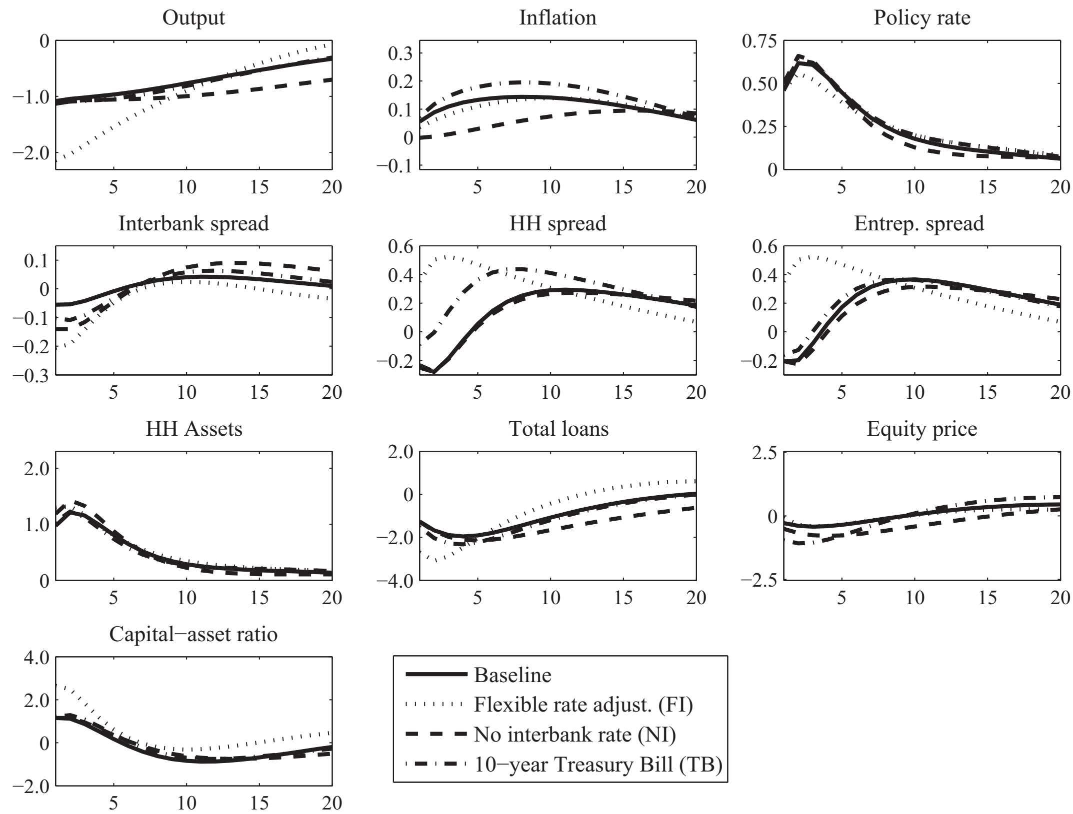

Fig. 5. IRFs to a contractionary monetary policy shock.

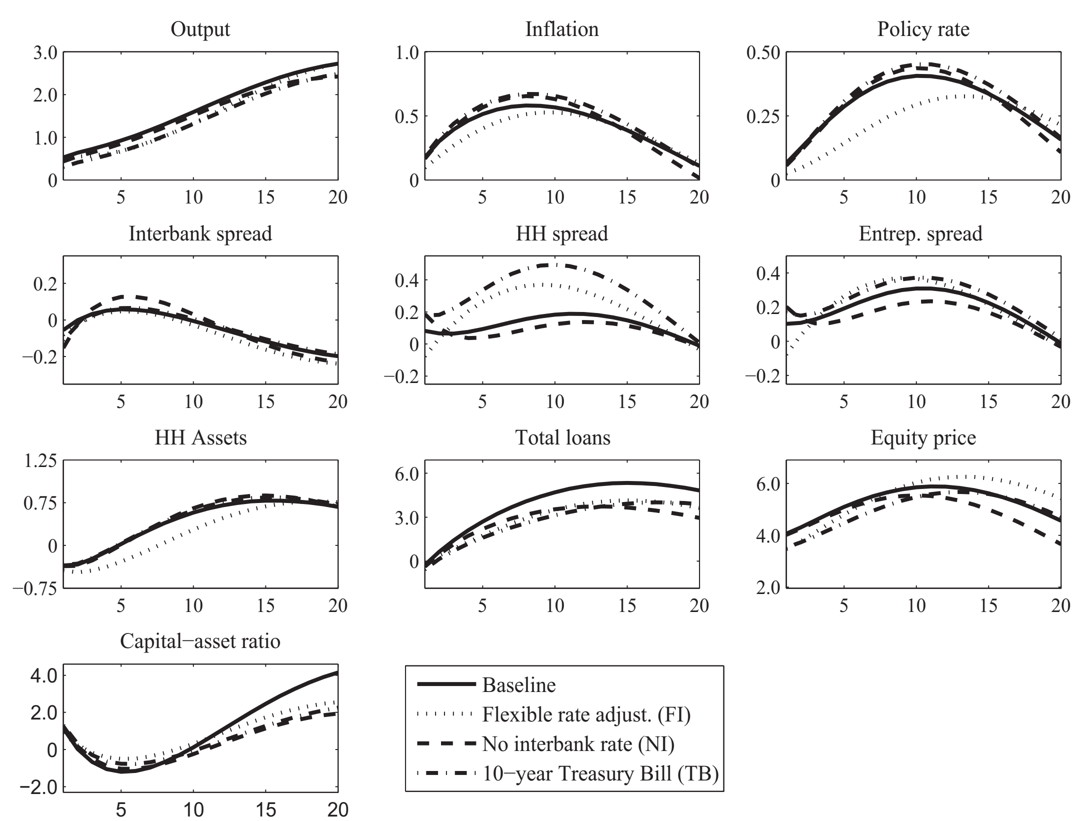

Fig. 6. IRFs to a positive technology shock.

Table 8
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	4515	4343	3885	4453					
Parameters					Parameters				
γ	2.122	2.239	2.086	2.128	ρ_z	0.963	0.988	0.960	0.960
γ_e	1.077	0.990	1.017	1.006	ρ_i	0.608	0.358	0.598	0.570
ϕ	0.739	0.743	0.729	0.735	ρ_b	0.955	0.971	0.956	0.956
θ_R	0.924	0.929	0.908	0.916	ρ_e	0.569	0.863	0.591	0.552
γ_p	0.523	0.536	0.539	0.546	ρ_h	0.574	0.928	0.598	0.799
κ_i	0.7902	0.790	0.658	0.654	ρ_{ν_h}	0.792	0.951	0.849	0.825
κ_π	1.6027	1.603	1.587	1.586	ρ_{ν_e}	0.680	0.641	0.670	0.650
κ_y	0.27	0.270	0.260	0.260	ρ_ψ	0.822	0.889	0.834	0.824
ν_h	0.604	0.618	0.609	0.617	ρ_p	0.466	0.371	0.531	0.501
ν_e	0.742	0.729	0.703	0.700	ρ_τ	0.777	0.876	–	0.830
ν_B	0.364	0.160	0.308	0.237	ϵ_z	0.013	0.013	0.013	0.013
κ_k	0.834	1.338	2.146	1.468	ϵ_i	0.005	0.005	0.006	0.005
κ_e	6.817	–	7.878	10.53	ϵ_b	0.008	0.008	0.009	0.008
κ_h	13.12	–	13.85	11.77	ϵ_e	0.080	0.014	0.082	0.045
κ_ν	2.454	1.402	2.479	2.464	ϵ_h	0.102	0.012	0.100	0.018
K^e/Y	10.78	10.80	10.77	10.78	ϵ_{ν_h}	0.019	0.019	0.019	0.018
					ϵ_{ν_e}	0.044	0.021	0.040	0.033
					ϵ_ψ	0.007	0.004	0.006	0.007
					ϵ_p	0.001	0.001	0.001	0.001
					ϵ_τ	0.016	0.011	–	0.025

Note: We exclude parameter descriptions, prior means and standard deviations (see Tables 2 and 3), and statistic confidence intervals in the table due to the limited space.

interbank LTV ratio (ν_B) from 0.364 to 0.160.[23] At the same time, zero sticky retail rate adjustment is now compensated by a significant jump in the persistence of stochastic markup shocks (ρ_e, ρ_h). If we compare all three variants of the model to the baseline model, we find that a larger leverage deviation cost parameter (κ_k) creates additional imperfect rate adjustment by magnifying the influence of the capital-to-assets ratio on the interbank rate and hence on long-term retail loan rates. This suggests that the baseline model represents the influence of leverage deviation costs more accurately than the three variants do.

6. Conclusion

This paper develops a New-Keynesian DSGE model with a central role of 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 are hence seen as an indicator of financial market stress. Overall, we find that supply-side financial factors are the primary source of credit spread variability, which is along the lines of Gilchrist and Zakrajšek (2012). That is, retail loan markup shocks 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 it has a much weaker effect on long-term nonfinancial loan rates. Imperfect bank competition attenuates the effect of monetary policy through both sticky rate adjustments and a counter-cyclical bank capital-to-assets ratio. Equity prices exacerbate movements in credit spreads through the financial accelerator channel, but cannot be regarded as one of the main driving forces 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 demand and supply shocks, with the notable difference for the Great Recession being 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. As far as credit spread variability is concerned, the influence of LTV shocks has declined since the 1990–91 recession, while the bank capital requirement shock exacerbated and prolonged 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.

Acknowledgement

The financial assistance of the National Research Foundation (NRF) of South Africa towards this research is hereby acknowledged (Grant number: 90577). Financial support from Economic Research Southern Africa (ERSA) is also greatly acknowledged. Opinions expressed and conclusions arrived at, are those of the authors and are not necessarily to be attributed to the NRF and ERSA. Hylton Hollander would like to acknowledge that part of the work was done at AIFRM, UCT whilst a postdoc.

Appendix A. Data and sources

Data source from the Federal Reserve Bank of St. Louis (FRED):

1. RGDP: Real Gross Domestic Product, 1 Decimal (GDPC1), Billions of Chained 2009 Dollars, Quarterly, Seasonally Adjusted Annual Rate
2. Inflation: GDP Implicit Price Deflator (GDPDEF), Index 2009 = 100, Quarterly, Seasonally Adjusted
3. Nominal short-term interest rates: 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) (Percent, Quarterly, Not Seasonally Adjusted.)

[23] As discussed in Section 3.1.2, $1 - \nu_B$ captures the weight of the stochastic markup in retail loan rate setting.

4. Treasury rate: 10-Year Treasury Constant Maturity Rate (GS10), Percent, Quarterly, Not Seasonally Adjusted
5. Loan rate to entrepreneurs: Moody's Seasoned Baa Corporate Bond Yield (BAA), Percent, Quarterly, Not Seasonally Adjusted
6. Loan rate to households: 30-Year Conventional Mortgage Rate (MORTG), Percent, Quarterly, Not Seasonally Adjusted
7. 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)
8. Loans to entrepreneurs: Total Liabilities – Balance Sheet of Non-farm Nonfinancial Corporate Business (TLBSNNCB), Billions of Dollars, Quarterly, Not Seasonally Adjusted
9. Deposits: Deposits – Assets – Balance Sheet of Households and Nonprofit Organizations (DABSHNO), Billions of Dollars, Quarterly, Not Seasonally Adjusted
10. Monetary authority funds: Total Credit Market Assets Held by Domestic Financial Sectors –Monetary Authority (MATCMAHDFS), Billions of Dollars, Quarterly, Not Seasonally Adjusted
11. Equity: Standard and Poor 500 Index (SP500), Index, Quarterly, Not Seasonally Adjusted
12. Consumption. Real Personal Consumption Expenditures (PCECC96), Billions of Chained 2009 Dollars, Quarterly, Seasonally Adjusted Annual Rate.
13. Investment. Gross Fixed Capital Formation in United States© (USAGFCFQDSMEI),[24] Billions of United States Dollars, Seasonally Adjusted.
14. US population: Civilian Noninstitutional Population (CNP16OV), Thousands of Persons, Quarterly, Not Seasonally Adjusted.

Appendix B. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jbankfin.2016.02.008.

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