The Equity Price Channel in a New-Keynesian DSGE Model with Financial Frictions and Banking

Hylton Hollander and Guangling Liu

ERSA working paper 360

July 2013

Economic Research Southern Africa (ERSA) is a research programme funded by the National Treasury of South Africa.

The views expressed are those of the author(s) and do not necessarily represent those of the funder, ERSA or the author's affiliated institution(s). ERSA shall not be liable to any person for inaccurate information or opinions contained herein.

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

Hylton Hollander*and Guangling Liu †‡

July 20, 2013

Abstract

This paper studies the role of the equity price channel in business cycle fluctuations, and highlights its systemic risk across all sectors of the economy. We develop a canonical New-Keynesian dynamic stochastic general equilibrium model with a tractable role for the equity market in banking, entrepreneur and household economic interactions. The model is estimated with Bayesian techniques using U.S. data over the sample period $1982Q01 - 2012Q01$. We show that a New-Keynesian DSGE model with an equity price channel well mimics the U.S. business cycle. Moreover, the equity price channel significantly exacerbates business cycle fluctuations through both the financial accelerator and bank funding channels. This study highlights the equity price channel as a different aspect to general equilibrium models with financial frictions, and emphasizes the consequences of the (in)stability of financial markets on the real economy.

JEL codes: E32, E43, E44, E51, G12

Keywords: Equity price channel, asset pricing, financial frictions, bank capital, New-Keynesian, Bayesian

*Department of Economics, University of Stellenbosch, Stellenbosch, 7602, South Africa. E-mail address: hollander03@gmail.com

†Corresponding author: Department of Economics, University of Stellenbosch, Stellenbosch, 7602, South Africa. Tel: +27 21 808 2238 fax: +27 21 808 4637. E-mail address: davegliu@gmail.com

‡We thank Economic Research Southern Africa (ERSA) and the National Research Foundation (NRF) for their financial support of this project. The usual disclaimer applies.

1 Introduction

This paper studies the role of the equity price channel in business cycle fluctuations and highlights its systemic risk across all sectors of the economy. To do so, we 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 funding channel (see Christiano et al., 2010). Moreover, we introduce a tractable role for the equity market in banking, entrepreneur and household economic interactions. 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 intends to elucidate any salient features that equity market cycles attribute to financial (in)stability. The study also provides the macroeconomic implications of the equity price channel in a general equilibrium model: contagion from unrelated self-fulfilling pessimism in the stock market; the stock market wealth effect on bank capital, liquidity and the borrower's balance sheet; and mark-to-market inefficiencies when equity capital is not accurately represented.

There are at least two reasons for including the equity market in a general equilibrium model with financial frictions. Firstly, equity prices absorb and react to market expectations and macroeconomic conditions and, therefore, contain important market information. Secondly, modern financial integration and intermediation have prevalent consequences on the financial wealth of households, entrepreneurs and banks. The 2007/2008 financial crisis and the subsequent persistent global economic recession have thrust banks and monetary authorities into the spotlight, and indeed, have even been seen as propagating and aggravating financial shocks to the real economy (Taylor, 2009; Mishkin, 2011; Woodford, 2012). Moveover, Christiano et al. (2008) and Farmer (2012) show how self-fulfilling asset price expectations can induce equity market collapses and macroeconomic instability. The evidence suggests that, within a short period, the inherent financial fragility can exacerbate small changes in asset prices, resulting in systemic equity market collapses.

The interaction between financial markets and the rest of the economy can be critical in explaining business cycles, and this works through the following channels. Firstly, the financial accelerator channel is characterized by the bank and borrower balance-sheet effect. Specifically, household and entrepreneur borrowing constraints constitute the demand side of credit (Kiyotaki and Moore, 1997; Bernanke et al., 1999), while bank lending frictions and regulatory bank capital requirements represent the supply side dynamics of credit (Gerali et al., 2010). Secondly, as in Christiano et al. (2010), we specifically address the funding of assets through deposits and bank capital by distinguishing the bank funding channel from the usual credit supply and demand dynamics. Conceptually, the bank funding channel encompasses the accounting and economic links between lending and funding in banks. It emphasizes the demand for deposits and equity investment, in conjunction with the banks' liquidity-supply ability. Finally, the equity price channel propagates the bank capital channel in a way similar to Markovic (2006), in which bank capital is accumulated through bank equity and retained earnings.[1] However, *ceteris paribus*, in the event of a sharp decline in the capital-to-asset ratio, bank market power is restricted to adjusting interest rates in order to raise retained earnings (or equivalently, widen interest rate spreads) so that capital requirements are met

[1] For convenience, we view the bank capital channel defined in BCBS (2011, p.10) as part of the bank funding channel.

and adjustment costs are minimized.[2]

The role of the equity market and bank capital in business cycle dynamics are the two key areas being incorporated in the recent New-Keynesian financial frictions literature (Markovic, 2006; Christiano et al., 2008; Van den Heuvel, 2008; Castelnuovo and Nistico, 2010; de Walque et al., 2010; Meh and Moran, 2010; Wei, 2010). 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 within the financial frictions paradigm. Castelnuovo and Nistico (2010) emphasize the significant role of equity prices in affecting the real economy and business cycle, and find a significant relationship between monetary policy and equity price fluctuations.

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) highlights that the expanding literature on the interaction between equity pricing and the macroeconomy has not been widely studied within the New-Keynesian framework.[3] 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 production, consumption and financial activities. For instance, Christiano et al. (2010) incorporate both the bank funding channel and equity prices (as a proxy for the price of capital) in their study. Their analysis validates the important contribution of these two mechanisms for the performance of the out-of-sample prediction of the model. However, the ad hoc way of capturing the crucial information from equity prices – without a tractable, micro-founded framework for equity pricing – is a significant shortcoming of the model.[4] On the other hand, Castelnuovo and Nistico (2010) use the stock market wealth effect on households as the sole propagating channel to study the relationship between equity markets and monetary policy, without considering a wider range of macroeconomic factors such as endogenous physical capital accumulation and asset-price fluctuations on investment. In our study, we 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, the paper aims to develop a fully-fledged DSGE model with financial frictions, including a tractable role for the equity market in different sectors of the economy. In the model, the equity price is determined endogenously by the aggregation of buying and selling shares between market participants (borrower and saver households). Equity prices affect both households' and entrepreneurs' financial wealth through the financial accelerator channel. The market value of equity investment, along with wage income, serves as the collateral for household borrowing, whereas the market value of the initial stock of equity and physical capital assets serve as the redeemable collateral for entrepreneur borrowing. For banks, assets are partially financed by bank equity. Therefore, equity prices affect banks' liquidity supply through the bank funding channel. In addition, banks need to adjust their balance sheets in reaction to the changes in equity prices so that regulatory bank capital requirements are met. Secondly, we

[2]Note that we assume banks cannot raise equity funds by issuing new shares. Specifically, banks respond to shocks to bank profits (loan defaults or nominal interest rate shocks) or exogenous changes in market capitalization (equity price shocks) by adjusting their balance sheets.

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

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

estimate the model with Bayesian techniques, using U.S. data over the sample period $1982Q01 - 2012Q01$. We show that a New-Keynesian DSGE model with an equity price channel well mimics the U.S. business cycle over the sample period. Moreover, the equity price channel exacerbates business cycle fluctuations through both the financial accelerator and bank funding channels. The study highlights the equity price channel as a different aspect to general equilibrium models with financial frictions, and emphasizes the consequences of the (in)stability of financial markets for the real economy.

The rest of the paper proceeds as follows. Section 2 defines the equity price channel and gives the motivation for the introduction of the equity price channel in the model. Section 3 develops the New-Keynesian DSGE model with financial frictions and the equity price channel. Sections 4-6 present the Bayesian estimation results, and discuss the implications of the equity price channel and its interplay with the financial accelerator and bank funding channels. Section 7 concludes.

2 The equity price channel in business cycles

The nexus of the equity price channel in the real 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 equity investment to either liquidate shares to finance current consumption or increase their equity holdings for future consumption. This endogenous equity price determination has implications for 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 current market value of the entrepreneur initial stock of 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 liquidity supply through the bank funding channel. 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. Moreover, regulatory authorities are increasingly emphasizing common equity as a safety-net to adverse bank shocks. Fig. 1 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 minimum bank capital requirement. The requirement for retained earnings falls from 2% to 1.5% of RWA. To our knowledge, the existing financial frictions paradigm has drawn little attention to the disaggregated accounting for bank capital. Only recently did Markovic (2006), Van den Heuvel (2008), and Christiano et al. (2010) support the idea of including equity in bank capital accumulation, in addition to retained earnings.

Thus far, we have formulated the conceptual framework and transmission mechanisms of the equity price channel in a tractable way that can be incorporated in the DSGE modeling paradigm. Empirical evidence

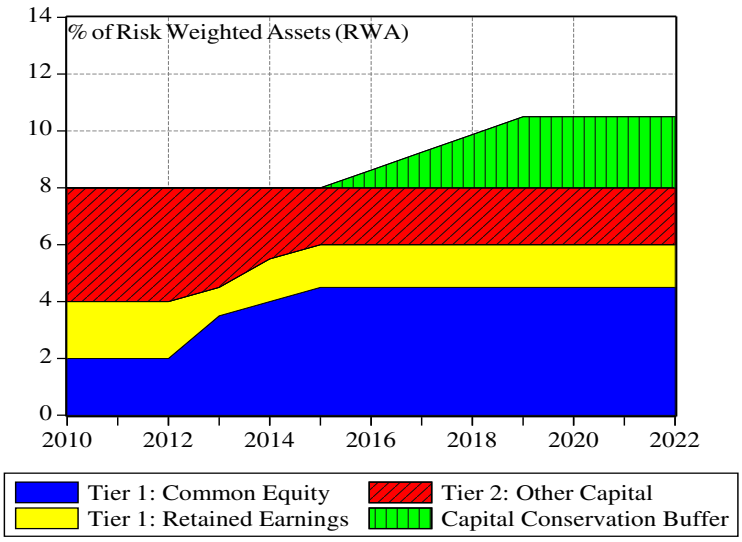

Figure 1: Basel III minimum capital requirements

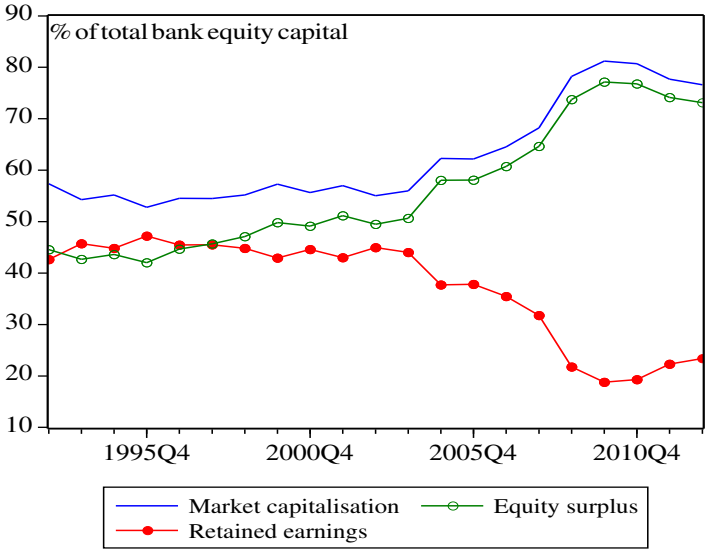

Figure 2: Bank equity capital structure: all commercial banks (1992Q04 - 2012Q01)

also supports the necessity of including the equity price channel in models with financial frictions. Fig. 2 illustrates the importance of capturing the market capitalization of bank equity capital, the mark-to-market capital surplus in particular.[5] Over the period $1992Q04 - 2003Q04$, the total bank capital structure of all commercial banks in the U.S. consistently comprised, on average, 46.7% capital surplus and 44.6% retained earnings. However, since $2003Q04$ the ratios diverged considerably, with capital surplus peaking at 77.2% and retained earnings declining to 18.8% by the end of 2009. This simple exercise shows the significant structural shift towards greater common equity capital leveraging in U.S. commercial banks.

3 The model economy

3.1 Households

We adopt the conventional consumption-based asset pricing framework. The model setup of partial equity market equilibrium between borrower and saver households requires, without loss of generality, the adoption of financial wealth in the utility function. Therefore, the demand-driven equity price is market-determined by the contemporaneous wealth effect on households' intertemporal consumption choices, the direct utility service, capital gains (or losses) and dividend returns. Moreover, in the case of borrower households, equity is redeemable as collateral for bank loans.

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 given by:

$$\max E_0 \sum_{t=0}^{\infty} \beta_{\Gamma}^{t} \left[\frac{(\tilde{C}_t^{\Gamma})^{1-\gamma^{\Gamma}}}{1-\gamma^{\Gamma}} - \frac{(H_t^{\Gamma})^{1+\eta}}{1+\eta} + a\xi_{d,t} ln \frac{D_t^{\Gamma}}{P_t} + (1-a)\xi_{\psi,t} ln(\frac{Q_t^{\psi}\Psi_t^{\Gamma}}{P_t}) \right] \tag{1}$$

where the discount factor $\beta_b^t < \beta_s^t$. Consumption ($\tilde{C}_t^{\Gamma} = C_t^{\Gamma} - \phi C_{t-1}^{\Gamma}$) includes habit formation parameterized by ϕ. Households' financial wealth is made up of deposits (D_t^{Γ}) and equity investments (Ψ_t^{Γ}). Q_t^{Ψ} is the equity price in current period t. Preferences are subject to two disturbances: one is on deposit demand ($\xi_{d,t}$), and the other one is on equity holdings ($\xi_{\psi,t}$). η measures the Frisch elasticity of labor supply. γ^{Γ} is the coefficient of relative risk aversion for each household type ($\Gamma = b, s$), and a is the weight of households' financial wealth in deposits.

3.2 Savers

Compared with borrowers, savers have a lower marginal propensity to consume and do not borrow from banks at all. Eq 2 is the budget constraint for savers,

$$C_t^s + \frac{D_t^s}{P_t} + \frac{Q_t^{\psi}\Psi_t^s}{P_t} = \frac{W_t}{P_t} H_t^s + \frac{I_{t-1}^d D_{t-1}^s}{P_t} + \frac{Q_t^{\psi}\Psi_{t-1}^s}{P_t} + \frac{\Pi_{\psi,t}^s}{P_t} \tag{2}$$

The household allocates periodic income from wages (W_t), gross returns on deposits ($I_{t-1}^d D_{t-1}^s$), capital

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

gains/losses ($Q_t^{\psi}\Psi_{t-1}^s$) and dividends ($\Pi_{\psi,t}^s$) to current consumption and new financial wealth holdings. The dividend policy is characterized by periodic rebated profits from entrepreneurs and banks to shareholders of equity (both borrower and saver households), where $\Psi_t = \Psi_t^s + \Psi_t^b$ is the total aggregate equity stock.[6] Dividends are exogenously determined and aggregated across both types of households, and defined as a proportion of each household's equity holdings $\zeta_{\psi} Q_t^{\psi} \Psi_{t-1}^{\Gamma}$.

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

$$a\xi_{d,t}\left(\frac{D_t^s}{P_t}\right)^{-1} = (C_t^s - \phi C_{t-1}^s)^{-\gamma^s} - \beta_s E_t\left[(C_{t+1}^s - \phi C_t^s)^{-\gamma^s} R_t^d\right] \quad (3)$$

$$\frac{W_t}{P_t} = (C_t^s - \phi C_{t-1}^s)^{\gamma^s}(H_t^s)^{\eta} \quad (4)$$

$$(1-a)\xi_{\psi,t}\left(\frac{P_t}{Q_t^{\psi}\Psi_t^s}\right) = (\tilde{C}_t^s)^{-\gamma^s} - \beta_s E_t\left[(\tilde{C}_{t+1}^s)^{-\gamma^s}\frac{Q_{t+1}^{\psi}(1+\zeta_{\psi})}{Q_t^{\psi}\Pi_{t+1}}\right] \quad (5)$$

Eq. 3 indicates that the demand for deposits depends on households' consumption and the real return on deposits. Eq. 4 gives the standard real wage equation: that is, the real wage equals the marginal rate of substitution between consumption and labor. Eq. 5 gives the demand for equity shares. Assuming no direct utility from equity holdings ($a = 1$), the first order condition for equity holdings collapses to the standard consumption-based asset pricing equation,

$$1 = \beta_s E_t\left[\left(\frac{\tilde{C}_{t+1}^s}{\tilde{C}_t^s}\right)^{-\gamma^s}\frac{Q_{t+1}^{\psi}(1+\zeta_{\psi})}{Q_t^{\psi}\Pi_{t+1}}\right] \quad (6)$$

3.3 Borrowers

Borrower households are subject to the following budget constraint,

$$C_t^b + \frac{D_t^b}{P_t} + \frac{Q_t^{\psi}\Psi_t^b}{P_t} + \frac{I_{t-1}^h L_{t-1}^h}{P_t} = \frac{W_t}{P_t}H_t^b + \frac{I_{t-1}^d D_{t-1}^b}{P_t} + \frac{L_t^h}{P_t} + \frac{Q_t^{\psi}\Psi_{t-1}^b}{P_t} + \frac{\Pi_{\psi,t}^b}{P_t} \quad (7)$$

The household allocates periodic income from wages, deposits, 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 a borrowing constraint,

$$I_t^h L_t^h \leq \nu_{h,t}\left[\phi_w W_t H_t^b + (1-\phi_w)Q_t^{\psi}\Psi_t^b\right] \quad (8)$$

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

[6] The total aggregate equity stock is equal to the total supply of equity from banks Ψ_t^B and entrepreneurs Ψ_t^e, which is constant, i.e. no new equity shares are issued. Therefore, in equilibrium $\Psi_t^B + \Psi_t^e = \Psi_t = \Psi_t^s + \Psi_t^b \equiv \Psi$.

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

$$a\xi_{d,t}\left(\frac{D_t^b}{P_t}\right)^{-1} = (C_t^b - \phi C_{t-1}^b)^{-\gamma^b} - \beta_b E_t\left[(C_{t+1}^b - \phi C_t^b)^{-\gamma^b} R_t^d\right] \tag{9}$$

$$\frac{W_t}{P_t} = \frac{(C_t^b - \phi C_{t-1}^b)^{\gamma^b}(H_t^b)^{\eta}}{1 + (C_t^b - \phi C_{t-1}^b)^{\gamma^b}\lambda_t^h \nu_{h,t}\phi_w} \tag{10}$$

$$1 = \beta_b E_t\left[\frac{(C_t^b - \phi C_{t-1}^b)^{\gamma^b}}{(C_{t+1}^b - \phi C_t^b)^{\gamma^b}}\frac{I_t^h}{\Pi_{t+1}}\right] + \lambda_t^h I_t^h (C_t^b - \phi C_{t-1}^b)^{\gamma^b} \tag{11}$$

$$(1-a)\xi_{\psi,t}\left(\frac{P_t}{Q_t^{\psi}\Psi_t^b}\right) = (\tilde{C}_t^b)^{-\gamma^b} - \beta_b E_t\left[(\tilde{C}_{t+1}^b)^{-\gamma^b}\frac{Q_{t+1}^{\psi}(1+\zeta_{\psi})}{Q_t^{\psi}\Pi_{t+1}}\right] - \lambda_t^h \nu_{h,t}(1-\phi_w) \tag{12}$$

where λ_t^h is the Lagrangian multiplier of the borrowing constraint. Eq. 9 gives the demand for deposits and Eq. 10 is the first-order condition for borrowers' labor supply. Eq. 10 and Eq. 4 give the aggregate labor supply schedule. Eq. 12 gives borrowers' demand for equity holdings. By introducing heterogeneity in households and equity holdings in the households' utility function, we are 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, $|\triangle\ \Psi_t^b| = |\triangle\ \Psi_t^s|$.

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 (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 with a markup 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 given by:

$$\max E_t \sum_{z=0}^{\infty} \theta_R^z \Lambda_{t,z}\left[P_{k,t}^* Y_{k,t+z} - P_{j,t+z}^W X Y_{k,t+z}\right] \tag{13}$$

subject to the demand for goods $Y_{k,t+z}$,

$$Y_{k,t+z} = \left(\frac{P_{k,t}^*}{P_{t+z}}\right)^{-\varepsilon_t^p} Y_{t+z} \tag{14}$$

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

The aggregate price level is given by:

$$P_t^{1-\varepsilon_t^p} = \theta_R \left((\frac{P_{t-1}}{P_{t-2}})^{\gamma_p} P_{t-1} \right)^{1-\varepsilon_t^p} + (1-\theta_R)(P_t^*)^{1-\varepsilon_t^p} \tag{15}$$

where γ_p determines the degree of price indexation. Combining and linearizing Eq. 13 and Eq. 15 gives the forward-looking Phillips Curve, where current inflation is positively related to expected inflation and negatively related to the markup.

3.5 Entrepreneurs

Entrepreneurs produce the intermediate good using a standard Cobb-Douglas production function,

$$Y_t = \xi_{z,t} K_{t-1}^{\alpha} H_t^{1-\alpha} \tag{16}$$

where K_{t-1} is physical capital, H_t is the labor supply, and $\xi_{z,t}$ is the technology.

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

$$\max_{\{K_t; H_t; L_t^e\}} E_0 \sum_{t=0}^{\infty} \beta_e^t \left[\frac{(C_t^e)^{1-\gamma^e}}{1-\gamma^e} \right] \tag{17}$$

subject to the production technology (Eq. 16) and the following flow of funds constraint,

$$\frac{Y_t}{X_t} + \frac{L_t^e}{P_t} = C_t^e + \frac{I_{t-1}^e L_{t-1}^e}{P_t} + \frac{W_t}{P_t} H_t + K_t - (1-\delta_e) K_{t-1} + Adj_t^e + \Pi_{\psi,t}^e \tag{18}$$

where Adj_t^e captures the capital adjustment costs:

$$Adj_t^e = \kappa_v (\frac{V_t}{K_{t-1}} - \delta_e)^2 \frac{K_{t-1}}{(2\delta_e)} \tag{19}$$

and where V_t is the investment used to accumulate capital and κ_v is the capital adjustment cost parameter. $\Pi_{\psi,t}^e = (\zeta_\psi Q_t^\psi \Psi^e)/P_t$ is the real dividend paid out. We assume entrepreneurs are more impatient than saver households ($\beta_e^t < \beta_s^t$), as in Iacoviello (2005).[7] However, what is different from Iacoviello (2005) here is that we introduce the coefficient of relative risk aversion for entrepreneurs (γ^e) to capture the sensitivity of entrepreneur consumption in the model economy. This allows us to compare the relative risk aversion of households and entrepreneurs. More importantly, by estimating these relative risk aversion coefficients, we are able to show to what extent the equity price channel affects agents' economic activities in the model economy.

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

$$I_t^e L_t^e \leq \nu_{e,t} [\phi_k Q_t^k K_t + (1-\phi_k) Q_t^\psi \Psi^e] \tag{20}$$

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

where Q_t^k is the nominal price of physical capital, $\nu_{e,t}$ is the exogenous stochastic loan-to-value ratio, and I_t^e is the gross nominal interest rate on entrepreneur bank loans (L_t^e). The value of physical capital ($Q_t^k K_t$) and the market value of the initial stock of entrepreneur equity ($Q_t^{\psi}\Psi^e$) act as a kind of collateral when borrowing. $\phi_k \in (0,1)$ is the weight on physical capital stock.[8] The equity price channel is introduced into the production sector in such a way that it has an impact on entrepreneurs' creditworthiness and, in turn, affects the productivity of the economy.

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

$$\frac{W_t}{P_t} = \frac{(1-\alpha)Y_t}{H_t X_t} \tag{21}$$

$$(C_t^e)^{-\gamma^e} = \beta_e E_t\left[(C_{t+1}^e)^{-\gamma}\frac{I_t^e}{\Pi_{t+1}}\right] + \lambda_t^e I_t^e \tag{22}$$

$$\begin{aligned} Q_t^k = {} & \beta_e E_t\left[\frac{1}{(C_{t+1}^e)^{\gamma^e}}\left(\frac{\kappa_v}{\delta_e}\left(\frac{V_{t+1}}{K_t}-\delta_e\right)\frac{V_{t+1}}{K_t} - \frac{\kappa_v}{2\delta_e}\left(\frac{V_{t+1}}{K_t}-\delta_e\right)^2\right)\right. \\ & \left. + Q_{t+1}^k(1-\delta_e) + \frac{\alpha Y_{t+1}}{(C_t^e)^{\gamma^e} X_{t+1} K_t}\right] + \lambda_t^e \nu_{e,t}\phi_k Q_t^k \end{aligned} \tag{23}$$

where λ_t^e is the Lagrangian multiplier of the borrowing constraint. Eq. 21 is the standard labor demand schedule. Eq. 22 gives the entrepreneur consumption Euler equation and Eq. 23 gives the shadow price for physical capital.

3.6 Loan and deposit demand

Following Gerali et al. (2010), we 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 ($L_{j,t}^h$) and entrepreneurs ($L_{j,t}^e$). The deposit and loan demand schedules are:

$$D_{j,t} = \left(\frac{i_{j,t}^d}{i_t^d}\right)^{-\varepsilon_t^d} D_t \tag{24}$$

$$L_{j,t}^h = \left(\frac{i_{j,t}^h}{i_t^h}\right)^{-\varepsilon_t^h} L_t^h \qquad L_{j,t}^e = \left(\frac{i_{j,t}^e}{i_t^e}\right)^{-\varepsilon_t^e} L_t^e \tag{25}$$

where $D_t = D_t^s + D_t^b \;\forall\; j \in [0,1]$. 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.

[8] Although a borrowing constraint with the expected physical capital price is identified as being robust (e.g. Brzoza-Brzezina et al., 2011; Iacoviello, 2005), we find no significant quantitative difference between the results from the above specification and the one with the expected physical capital price.

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.

We 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. 28). The equity price channel, therefore, plays a key role in determining credit supply. A negative shock to equity price adversely affects the total bank capital, and simultaneously worsens the capital-to-asset ratio. A declined capital-to-asset ratio forces banks to reduce credit extension and this, in turn, negatively hits the real economy. This is, indeed, how variations in the market value of bank equity affect the real economy through the bank funding channel.

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 decisions and banks' ability to extend credit.

Wholesale branch

The wholesale branch chooses wholesale loans (L_t) and deposits (D_t) to maximize the periodic discounted cash flows:

$$\max_{\{L_t, D_t\}} E_0 \sum_{t=0}^{\infty} \beta_B^t \left[i_t^l L_t - i_t^d D_t - \frac{\kappa_k}{2} \left(\frac{K_t^B}{L_t} - \tau \right)^2 K_t^B \right] \tag{26}$$

subject to the binding balance sheet identity,

$$L_t = K_t^B + D_t \tag{27}$$

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,

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

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 able to supply. δ_B is the bank capital depreciation rate, capturing management costs for banks. Retained earnings ($\omega_{B,t-1}$)

are bank profits net of dividend payments.[9]

The banking sector is closed by assuming that banks have access to unlimited funds from the central bank at the policy rate i_t. Household deposits are collected by the retail deposit branch of bank j and deposited at its wholesale branch. The wholesale branch remunerates the retail deposit branch at the policy rate because arbitrage in the interbank market drives the wholesale deposit rate towards i_t. The retail loan branch receives wholesale loans and remunerates the wholesale branch at i_t^l. The first-order conditions for loans and deposits give the spread between the competitive wholesale loan rate and the deposit rate,

$$i_t^l = i_t^d - \kappa_k \left(\frac{K_t^B}{L_t} - \tau \right) \left(\frac{K_t^B}{L_t} \right)^2 \tag{29}$$

Retail branches

Wholesale loans $L_{j,t}$ collected by the retail loan branch of bank j are differentiated at zero cost and resold 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:

$$\max_{\{i_{j,t}^h, i_{j,t}^e\}} E_0 \sum_{t=0}^{\infty} \beta_B^t \left[i_{j,t}^h L_{j,t}^h + i_{j,t}^e L_{j,t}^e - i_t^l L_{j,t} - \frac{\kappa_h}{2} \left(\frac{i_{j,t}^h}{i_{j,t-1}^h} - 1 \right)^2 i_t^h L_t^h - \frac{\kappa_e}{2} \left(\frac{i_{j,t}^e}{i_{j,t-1}^e} - 1 \right)^2 i_t^e L_t^e \right] \tag{30}$$

subject to demand schedules (25), with $L_{j,t}^h + L_{j,t}^e = L_{j,t}$.

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. With flexible interest rates, the loan rate is a markup over the marginal cost,

$$i_t^z = \frac{\varepsilon_t^z}{\varepsilon_t^z - 1} i_t^l \tag{31}$$

The log-linearized equation for the loan rate is:

$$\begin{aligned} \hat{i}_t^z \quad = \quad & \frac{\kappa_z}{\varepsilon^z - 1 + (1 + \beta_B)\kappa_z} \hat{i}_{t-1}^z + \frac{\beta_B \kappa_z}{\varepsilon^z - 1 + (1 + \beta_B)\kappa_z} E_t \hat{i}_{t+1}^z \\ & + \frac{\varepsilon^z - 1}{\varepsilon^z - 1 + (1 + \beta_B)\kappa_z} \hat{i}_t^l - \frac{\varepsilon_t^z}{\varepsilon^z - 1 + (1 + \beta_B)\kappa_z} \end{aligned} \tag{32}$$

Eq. 32 shows that the 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 $\hat{i}_t^l$), which depends on the policy rate and the balance sheet position of the bank.

The log-linearized equation for the deposit rate is:

$$\hat{i}_t^d = \frac{\kappa_d}{1 - \varepsilon^d + (1 + \beta_B)\kappa_d} \hat{i}_{t-1}^d + \frac{\beta_B \kappa_d}{1 - \varepsilon^d + (1 + \beta_B)\kappa_d} E_t \hat{i}_{t+1}^d + \frac{1 - \varepsilon^d}{1 - \varepsilon^d + (1 + \beta_B)\kappa_d} \hat{i}_t \tag{33}$$

With flexible interest rates, Eq. 33 implies $i_t^d = i_t$. Gerali et al. (2010) show that the deposit rate is a

[9] $\omega_{B,t} = \Pi_{B,t} - \zeta_\psi Q_t^\psi \Psi^B$, where $\Pi_{B,t}$ is the overall profit of the bank.

markdown of the policy rate. However, based on the inspection of U.S. deposit rate data over the sample period $1982Q01 - 2012Q01$, we find an aggregate steady-state markup of 0.16 percentage points over the federal fund rate. This implies that the retail deposit branch is indeed making a negligible loss based on the model's setup.

3.8 Labor supply decisions and the wage-setting equation

The wage-setting equilibrium stems from the work of Gali et al. (2007).[10] Monopolistically competitive unions set the optimal wage at the prevailing labor demand equilibrium. There is a continuum of unions, and each union represents workers of a certain type ι, which is uniformly distributed across both types of households.

Following Calvo (1983), in each time period only a random fraction $1-\theta_w$ of unions have the opportunity to reset their wages, whereas those unions that cannot reset their 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:

$$W_t^{1-\varepsilon^w} = \theta_w(\left(\frac{P_{t-1}}{P_{t-2}}\right)^{\gamma_w} W_{t-1})^{1-\varepsilon^w} + (1-\theta_w)(W_t^*)^{1-\varepsilon^w} \tag{34}$$

where γ_w is the degree of wage indexation. The unions' problem is to choose $\{W_t^\iota\}_{t=0}^\infty$ to maximize the consumption-weighted wage income:

$$\max_{W_t^*} E_t \sum_{i=0}^{\infty}(\theta_w\beta)^i\left[\phi_s\left(\frac{W_t^* H_{t+i}^\iota}{P_{t+i}\tilde{C}_{t+i}^s} - \frac{(H_{t+i}^\iota)^{1+\eta}}{1+\eta}\right) + (1-\phi_s)\left(\frac{W_t^* H_{t+i}^\iota}{P_{t+i}\tilde{C}_{t+i}^b} - \frac{(H_{t+i}^\iota)^{1+\eta}}{1+\eta}\right)\right] \tag{35}$$

subject to the labor demand schedule,

$$H_{t+i}^\iota = \left(\frac{W_t^*}{W_{t+i}}\right)^{-\varepsilon_t^w} H_{t+i} \tag{36}$$

Assuming a constant wage elasticity of substitution, the first-order condition for W_t^* is:

$$E_t \sum_{i=0}^{\infty}(\theta_w\beta)^i\left[\frac{W_t^*}{P_{t+i}}\left(\frac{\phi_s}{MRS_{t+i}^s} + \frac{(1-\phi_s)}{MRS_{t+i}^b}\right)\right] = E_t \sum_{i=0}^{\infty}(\theta_w\beta)^i\left[\mu^w\left(\frac{W_t^*}{W_{t+i}}\right)^{-\varepsilon^w\eta}\right] \tag{37}$$

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

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

$$w_t^* = \frac{(1-\theta_w\beta)}{(\varepsilon^w\eta+1)} E_t \sum_{i=0}^{\infty}(\theta_w\beta)^i\left(\chi_s mrs_{t+i}^s + \chi_b mrs_{t+i}^b + \varepsilon^w\eta w_{t+i} + p_{t+i}\right) \tag{38}$$

where $\chi_s \equiv \frac{\phi_s W}{MRS^s\mu^w}$, $\chi_b \equiv \frac{(1-\phi_s)W}{MRS^b\mu^w}$ and $\tilde{c} = \chi_s\tilde{c}_t^s + \chi_b\tilde{c}_t^b$. [11]

Combining (38) with the log-linearized wage index equation (34) gives the aggregate sticky wage equation:

[10] See technical appendix for the full derivation of the wage-setting equation.

[11] $MRS^\Gamma = C^\Gamma H^\eta$ and $\tilde{c}_t^\Gamma = c_t^\Gamma - \phi c_{t-1}^\Gamma$ for $\Gamma = s, b$.

$$\begin{aligned}\hat{w}_t &= \Phi\hat{w}_{t-1} + \Phi\beta E_t\hat{w}_{t+1} + \Phi^*(\varepsilon^w\eta\hat{w}_t + \chi_s mrs_t^s + \chi_b mrs_t^b) \\ &\quad +\Phi\beta E_t\hat{\pi}_{t+1} - \Phi\hat{\pi}_t - \Phi\theta_w\beta\gamma_w\hat{\pi}_t + \Phi\gamma_w\hat{\pi}_{t-1} \end{aligned} \tag{39}$$

where $\Phi^* = \frac{(1-\theta_w)(1-\theta_w\beta)}{(1+\theta_w^2\beta)(1+\varepsilon^w\eta)}$ and $\Phi = \frac{\theta_w}{(1+\theta_w^2\beta)}$.

3.9 Monetary policy and market clearing conditions

The monetary authority follows a Taylor-type interest rate rule,

$$I_t = (I_{t-1})^{\kappa_i}\left(\frac{\Pi_t}{\Pi^{target}}\right)^{\kappa_\pi(1-\kappa_i)}\left(\frac{Y_t}{Y_{t-1}}\right)^{\kappa_y(1-\kappa_i)}\xi_{i,t} \tag{40}$$

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,

$$Y_t = C_t + V_t + \delta_B\frac{K_{t-1}^B}{P_{t-1}} \tag{41}$$

where $\delta_B K_{t-1}^B$ represents the banks' management cost in terms of bank capital, and $C_t \equiv C_t^s + C_t^b + C_t^e$ is aggregate consumption.

4 Estimation

We estimate the model with Bayesian techniques using U.S. data over the sample period $1982Q01 - 2012Q01$.[12] Since the model has a total of nine shocks, our data set contains nine observable variables: output, inflation (GDP deflator), equity price, household loans, entrepreneur loans, deposits, 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. We take the log-difference of real variables prior to estimation.

4.1 Calibrated parameters

Table 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, we fix the discount factors for borrower households (β_b) and entrepreneurs (β_e) to 0.95. As in Gerali et al. (2010), we assume $\beta_B = \beta_s$ for the banks. The inverse of the Frisch elasticity (η) is set to 1. The capital-output share α is set to 0.36, 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 of $\varepsilon^p = 11$. The price elasticity of demand for different types of labor ε^w is fixed at 5, implying a steady-state

[12] The model is estimated using Dynare, developed by Michel Juillard and his collaborators at CEPREMAP.

Table 1: Calibrated parameters

Parameter	Description	Value
β_s	Discount factor for saver households	0.99
β_b	Discount factor for borrower households	0.95
β_e	Discount factor for entrepreneurs	0.95
η	Inverse of the Frisch elasticity	1
α	Capital share in the production function	0.36
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^e	Elasticity of substitution for entrepreneur loans	1.352
ε^h	Elasticity of substitution for household loans	1.436
δ_B	Bank capital depreciation rate	0.1044
ϕ_ψ	Ratio of market capitalization of bank equity to bank capital	0.2
ϕ_B	Banks' share of total equity stock	0.3
$\frac{L^h}{L_t}$	Households' share of total loans	0.45
$\frac{L^e}{L_t}$	Entrepreneurs' share of total loans	0.55
$\frac{K^B}{Y}$	Total bank capital-output ratio	0.165
$\frac{C}{Y}$	Consumption-output ratio	0.6785
ϕ_s	Share of saver households in U.S. economy	0.53
ϕ_w	Weight on wages in borr. constraint	0.6
ϕ_k	Weight on physical capital in borr. constraint	0.6

wage markup (μ^w) of 0.25. Lastly, parameters in the wage-setting equation are based on the estimates from Christiano et al. (2005) and Smets and Wouters (2007).

The second block 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. The bank capital depreciation rate (δ_B) equals 0.1044.[13] Parameter ϕ_ψ[14] is the ratio of the market capitalization of bank equity to bank capital, which captures the pass-through effect of equity price changes on bank capital accumulation. We set it to 0.2, based on our preliminary estimations. We fix the ratio of the bank equity share to total equity stock in the U.S. to 0.3. Shares of household and entrepreneur loans to total bank loans, the consumption-output ratio, and the total bank capital to output ratio are calculated using 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 the capital requirements. Based on the $2007 - 2009$ Panel Survey of Consumer Finances, between 46.6 and 47.8% of households hold mortgage debt in the U.S. We therefore approximate the borrower households share (1 - ϕ_s) to 0.47, implying the saver households share ϕ_s to be 0.53. Finally, the weights on wages (ϕ_w) and physical capital (ϕ_k) in the borrowing constraints are set to 0.6. This implies that the amount households can borrow depends slightly more heavily on their wage income than on the market value of their

[13] We assume that there are no undivided profits in the steady-state equilibrium, and therefore derive the value from net income data (FDIC, 2012).

[14] $\phi_\psi = \frac{Q^\Psi \Psi^B}{K^B}$ appears in the log-linearized bank capital accumulation equation.

equity holdings. Similarly, a slightly higher weight on physical capital assets is imposed in the entrepreneurs' borrowing constraint. By fixing these two parameters, we can compare the effect of an equity price shock on both households' and entrepreneurs' borrowing capability with a higher or lower weight on equity leverage. Moreover, we can use these two parameters to test the mark-to-market inefficiencies in the credit market.

4.2 Prior distributions and posterior estimates

The prior distributions of the structural parameters are reported in columns 3-5 in Tables 2 and 3. We assume that the coefficients of relative risk aversion $\{\gamma^s, \gamma^b, \gamma^e\}$ follow a gamma distribution with a mean of 2 and a standard deviation of 0.5. The prior on habit formation parameter ϕ is set at 0.5 with a standard deviation of 0.15. Prior means and standard deviations of the parameters in the Phillips Curve and the monetary policy rule are based on the estimates from Christiano et al. (2005) and Smets and Wouters (2007). Iacoviello and Neri (2010) report an average LTV ratio of 0.76, and more recent data from the Federal Housing Finance Board gives an average LTV of 70%. Therefore, we 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). Following Gerali et al. (2010), we set the prior means for the interest rate adjustment cost parameters κ_h and κ_e to 5 and 3, and the leverage deviation cost parameter κ_k to 10. We set the prior mean of the physical capital adjustment cost parameter κ_v to 2 (e.g. Iacoviello, 2005). The prior mean of the capital-output ratio is set to 10, 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.

The estimated posterior means and standard deviations for the structural parameters are reported in columns 6-9 in Tables 2 and 3. The estimated relative risk aversion coefficient for borrower households is higher than that for saver households. This implies that borrower households are less sensitive to the financial market status and have a stronger preference for smoothing their lifetime consumption. The estimated relative risk aversion coefficient for entrepreneurs is 3.3, which is higher than that of saver households and lower than that of borrower households. The estimated consumption habit formation parameter is relatively small compared with those in the literature. However, as described in Boldrin et al. (2001) and Uhlig (2007), higher wage rigidities correspond with a lower estimate of habit formation. The estimated parameters for price-setting and the monetary policy rule all conform well to the literature.

The LTV ratios for households (0.7) and entrepreneurs (0.73) are found to be consistent with the data. The estimated parameter capturing entrepreneur loan rate adjustment cost (2.69) is smaller than that of the household loan rate adjustment cost (6.37). The estimated parameter measuring the cost of deviating from targeted leverage is 8.55. Interestingly, the estimated parameters measuring the interest rate adjustment costs in our paper (for the U.S. data) are all lower than those in Gerali et al. (2010) for the Euro area. Indeed, both our paper and theirs allude to the limited relevance of the sticky interest rate structure in banking.[15]

[15] See further discussion on this in the following section.

Table 2: Structural parameters

		Prior distribution			Posterior distribution			
	Parameter	Type	Mean	Std.dev	Mean	2.5%	Median	97.5%
Preferences								
γ^s	Relative risk aversion for savers	Inv.Gamma	2	0.5	1.511	1.16	1.497	1.84
γ^b	Relative risk aversion for borrowers	Inv.Gamma	2	0.5	4.068	3.32	4.023	4.80
γ^e	Relative risk aversion for Entrep.	Inv.Gamma	2	0.5	3.317	2.04	3.169	4.48
ϕ	Habit formation	Beta	0.5	0.15	0.165	0.07	0.159	0.26
Price-setting								
θ_R	Price stickiness	Beta	0.8	0.03	0.845	0.83	0.845	0.86
γ_p	Degree of price indexation	Beta	0.6	0.03	0.619	0.58	0.619	0.66
Monetary policy rule								
κ_i	Coefficient on lagged policy rate	Beta	0.8	0.04	0.755	0.70	0.755	0.80
κ_π	Coefficient on inflation	Gamma	1.45	0.05	1.532	1.45	1.531	1.61
κ_y	Coefficient on output change	Beta	0.25	0.02	0.256	0.22	0.255	0.29
Credit and banking								
ν_h	Households' LTV ratio	Beta	0.75	0.04	0.700	0.63	0.700	0.77
ν_e	Entrepreneurs' LTV ratio	Beta	0.55	0.04	0.726	0.69	0.727	0.76
κ_h	HH loan rate adjust. cost	Gamma	5	1	6.372	4.89	6.349	7.83
κ_e	Entrep. loan rate adjust. cost	Gamma	3	1	2.691	1.97	2.661	3.45
κ_k	Leverage deviation cost	Gamma	10	2	8.545	6.90	8.514	10.31
Equity and capital								
κ_v	Physical capital adjust. cost	Gamma	2	0.1	2.112	1.96	2.109	2.27
$\frac{K^e}{Y}$	Capital-output ratio	Gamma	10	0.4	9.629	9.24	9.621	10.05

Table 3: Exogenous processes

		Prior distribution			Posterior distribution			
	Parameter	Type	Mean	Std.dev	Mean	2.5%	Median	97.5%
AR(1) coefficients								
ρ_z	Technology	beta	0.95	0.005	0.951	0.95	0.951	0.96
ρ_i	Monetary policy	beta	0.5	0.05	0.522	0.45	0.522	0.59
ρ_d	Deposit	beta	0.8	0.05	0.937	0.91	0.937	0.96
ρ_e	Entrepreneur loan markup	beta	0.5	0.05	0.694	0.63	0.697	0.76
ρ_h	Household loan markup	beta	0.5	0.05	0.513	0.44	0.513	0.58
ρ_{ν_h}	Households' LTV	beta	0.75	0.05	0.924	0.90	0.925	0.94
ρ_{ν_e}	Entrepreneurs' LTV	beta	0.75	0.05	0.816	0.78	0.816	0.86
ρ_ψ	Equity	beta	0.5	0.05	0.744	0.71	0.744	0.78
ρ_p	Price markup	beta	0.3	0.05	0.454	0.38	0.454	0.53
Standard deviations								
ϵ_z	Technology	Inv.Gamma	0.01	inf	0.007	0.006	0.007	0.007
ϵ_i	Monetary policy	Inv.Gamma	0.01	inf	0.006	0.005	0.006	0.007
ϵ_d	Deposit	Inv.Gamma	0.01	inf	0.010	0.009	0.010	0.011
ϵ_e	Entrepreneur loan markup	Inv.Gamma	0.01	inf	0.008	0.006	0.008	0.010
ϵ_h	Household loan markup	Inv.Gamma	0.01	inf	0.021	0.016	0.021	0.026
ϵ_{ν_h}	Household LTV	Inv.Gamma	0.01	inf	0.009	0.008	0.009	0.010
ϵ_{ν_e}	Entrepreneur LTV	Inv.Gamma	0.02	inf	0.024	0.021	0.024	0.028
ϵ_ψ	Equity	Inv.Gamma	0.01	inf	0.026	0.022	0.026	0.031
ϵ_p	Price markup	Inv.Gamma	0.005	inf	0.001	0.001	0.001	0.001

5 Results and robustness analysis

In this section, we assess the benchmark New-Keynesian DSGE model with the equity price channel (BEP hereafter) by examining the dynamics of the model in response to technology and monetary shocks. In order to draw more valuable insights from the model and perform the robustness analysis, we 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 the redeemable collateral for borrower households and entrepreneurs. Bank capital is accumulated through retained earnings only. For the FI model, there are no quadratic interest rate adjustment costs, i.e. $\kappa_h = \kappa_e = 0$. The main focus here is on how the equity price channel affects the dynamics of the model through the financial accelerator and bank funding channels.

Fig. 3 shows the impulse responses of the observed variables to a positive technology shock.[16] For the BEP model, the responses of inflation, output, policy rate, and equity price conform to the findings in Castelnuovo and Nistico (2010) and the empirical VAR evidence in Iacoviello (2005).[17] In contrast to Gerali et al. (2010), we do not observe a decline in inflation and policy rate in reaction to the shock. But importantly, we do observe a pro-cyclical capital-asset ratio. Moreover, the capital-asset ratio is extremely stable, which supports the increasing emphasis on common equity capital in Basel III. Comparing the FI model to the BEP model, flexible interest rates only slightly reduce the responses of inflation and interest rates, indicating that sticky interest rates have a negligible pass-through effect on loan rates.

Overall, the equity price channel exacerbates the impact of a positive technology shock: all the observed variables except for entrepreneur loans respond much more strongly to the shock under the BEP model than under the NEP model. The equity market reacts bullishly to the positive macroeconomic outlook, resulting a favorable creditworthiness for borrowers. The positive financial wealth effect of equity is strongly evident in both household loans and entrepreneur loans. This suggests that it is through the financial accelerator channel that the equity price channel exacerbates the impact of the shock. Both borrower households and entrepreneurs are able to borrow more and stimulate aggregate demand through financial wealth gains. On the other hand, for the BEP model, both the increase in equity prices (and hence, bank equity capital) and the growth in bank deposits strengthen bank funding, which enables banks to increase their credit supply. However, for the NEP model, we observe a persistent decline in bank deposits. Without bank equity as a part of funding, banks have to use retained earnings to offset the reduced deposits to finance the increasing demand for entrepreneur loans. Therefore, we conclude that the equity price channel exacerbates business cycle fluctuations through both the financial accelerator and bank funding channels.

Fig. 4 shows the impulse responses of the observed variables to a contractionary monetary policy shock. The equity price channel exacerbates the impact of the shock through both the financial accelerator and bank funding channels: the responses of all the observed variables, output in particular, are much stronger with the BEP model than with the NEP model. On the one hand, the equity price channel propagates the

[16] We include the impulse response of the bank capital-asset ratio in support of our analysis.
[17] Iacoviello (2005) focuses on housing prices instead of equity prices.

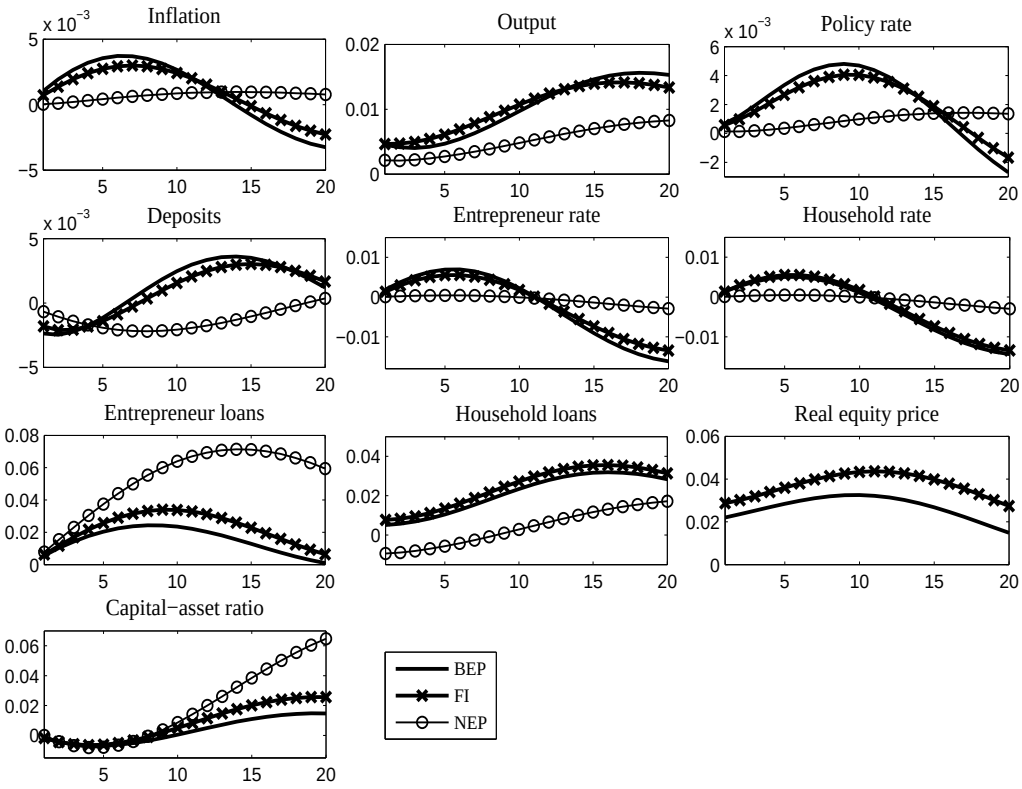

Figure 3: IRFs to a positive technology shock

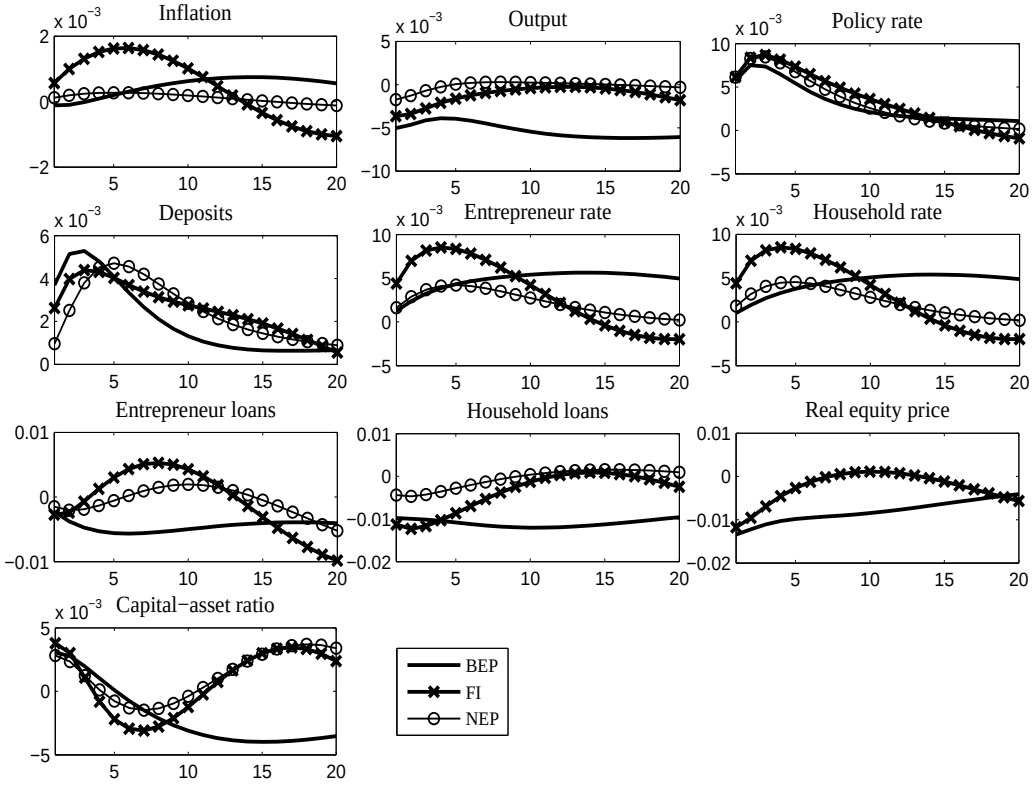

Figure 4: IRFs to a contractionary monetary policy shock

financial accelerator effect by directly worsening borrowers' creditworthiness. A contractionary monetary policy induces a decline in equity prices and, hence, borrowers' creditworthiness (market value of equity assets). Moreover, the decrease in both household and entrepreneur loans is much greater and more persistent with the BEP model than with the NEP model. On the other hand, an increase in the policy rate results in a decline in equity prices and an increase in the return on deposits. Therefore, in the BEP model, households shift their investment from equity assets to deposits. Even though the increase in deposits with the NEP model is less than with the BEP model, with the absence of an impact of equity prices in the bank funding channel, the supply of bank loans declines less with the NEP model than with the BEP model. This implies that the equity price channel exacerbates business cycle fluctuations through the bank funding channel too. In addition, the bank capital-asset ratio initially increases in response to the shock and then decreases substantially. The substantial downward adjustment in the bank capital-asset ratio increases credit costs, and hence, decreases the credit supply. This suggests that bank capital requirements tend to amplify business cycle fluctuations (see Meh and Moran, 2010).

For the BEP model, quadratic interest rate adjustment costs induce persistent responses in loan rates. Initially, increases in loan rates for the FI model are greater than those for the BEP model, due to the inverse relationship between loan rates and the interest rate adjustment cost coefficients. However, approximately nine quarters after the shock, increases in loan rates for the FI model are lower than those for the BEP model. This is due not only to the adjustment costs, but also to the negative relationship between loan rates and the capital-asset ratio. Initially, the capital-asset ratio responds to the shock positively and then starts decreasing immediately, resulting in a downward pressure on loan rates. However, only for the FI model does the capital-asset ratio start increasing approximately nine quarters after the shock, whereas it continues to decline for the BEP model. In short, we observe some significance of the sticky interest rate in the model in response to a contractionary monetary policy shock.

To perform the robustness analysis, we compare the posterior estimates of the parameters of each alternative model. Overall, as reported in Table 4, most of the parameter estimates are consistent across models. Some interesting points are worth noting here. The estimated relative risk aversion coefficients for households are greater for the NEP model than for the BEP model. This reflects the fact that households are more averse to risk in a model setup without the equity market. In contrast, for the BEP model, in which households can invest in the equity market, households become less averse to risk. Parameters measuring loan rate adjustment costs (κ_e and κ_h) are approximately the same (4.16 and 4.29) for the NEP model, whereas estimates of the two for the BEP model are 2.7 and 6.37 respectively, reflecting the information loss from excluding the equity price channel in the model. The estimated capital adjustment cost parameter κ_k for the BEP model is 8.55, whereas it is 0.53 for the NEP model. The reduction of κ_k from 8.55 to 0.53 reflects the significance of the equity price channel on bank capital. 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.

Table 4: Alternative model estimated parameter comparisons

	Posterior distribution means				Posterior distribution means		
	Benchmark BEP	Flexible rates FI	No equity NEP		Benchmark BEP	Flexible rates FI	No equity NEP
Parameters				AR(1) processes			
γ^s	1.511	1.870	6.366	ρ_z	0.951	0.952	0.949
γ^b	4.068	4.493	7.280	ρ_i	0.522	0.548	0.553
γ^e	3.317	4.322	4.074	ρ_d	0.937	0.938	0.927
ϕ	0.165	0.149	0.132	ρ_e	0.694	0.864	0.476
θ_R	0.845	0.872	0.936	ρ_h	0.513	0.807	0.456
γ_p	0.619	0.673	0.564	ρ_{ν_h}	0.924	0.917	0.834
ν_h	0.700	0.705	0.751	ρ_{ν_e}	0.816	0.812	0.861
ν_e	0.726	0.889	0.666	ρ_ψ	0.744	0.704	–
κ_v	2.112	2.070	2.160	ρ_p	0.454	0.324	0.212
$\frac{K^e}{Y}$	9.629	7.925	7.394	ϵ_z	0.007	0.007	0.008
κ_k	8.545	3.445	0.528	ϵ_i	0.006	0.006	0.006
κ_e	2.691	–	4.163	ϵ_d	0.010	0.010	0.011
κ_h	6.372	–	4.286	ϵ_e	0.008	0.003	0.014
κ_i	0.755	0.751	0.779	ϵ_h	0.021	0.003	0.016
κ_π	1.532	1.558	1.518	ϵ_{ν_h}	0.009	0.008	0.014
κ_y	0.256	0.256	0.253	ϵ_{ν_e}	0.024	0.033	0.079
				ϵ_ψ	0.026	0.029	–
				ϵ_p	0.001	0.001	0.001

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

6 The equity price channel

The discussion thus far reveals the relevance and the significance of the equity price channel in the model. In this section we show that an exogenous negative equity price shock can be viewed as a systemic risk across all sectors of the economy. In addition, we show that the macroeconomic implications of the equity price channel in a general equilibrium model are as follows: contagion from unrelated self-fulfilling pessimism in the stock market; the stock market wealth effect on bank capital, liquidity and the borrower's balance sheet; and mark-to-market inefficiencies when equity capital is not accurately represented.[18]

Fig. 5 displays the estimated impulse responses to a negative equity price shock from a vector autoregression (VAR). The VAR consists of the same variables being used in the BEP DSGE model estimation.[19] Due to a sudden decline in equity prices, households shift equity assets to deposit holdings. This strengthens the argument for including both deposits and equity investments as financial wealth in households' utility function. The strong positive correlation between output and equity prices further justifies the adoption of the consumption-based asset pricing approach in the DSGE model setup (see also, Cochrane, 2008). Both loans to households and entrepreneurs decrease in response to a negative equity price shock, reflecting the strong wealth effect of the equity market. With these results in mind, we move on to the comparison analysis with the results from the estimated BEP DSGE model.

[18] From the perspective of borrowers, a mark-to-market shock is similar to a loan-to-value shock, but only on the equity portion of borrowers' total financial wealth, and therefore, is not associated with micro-prudential policies or specific risk to debtors. For banks, we view mark-to-market inefficiencies as disruptions to bank capital embedded in credit and capital requirement dynamics.

[19] The VAR contains two lags of each variable. The same data transformations and sample period are used as in the BEP DSGE model estimation.

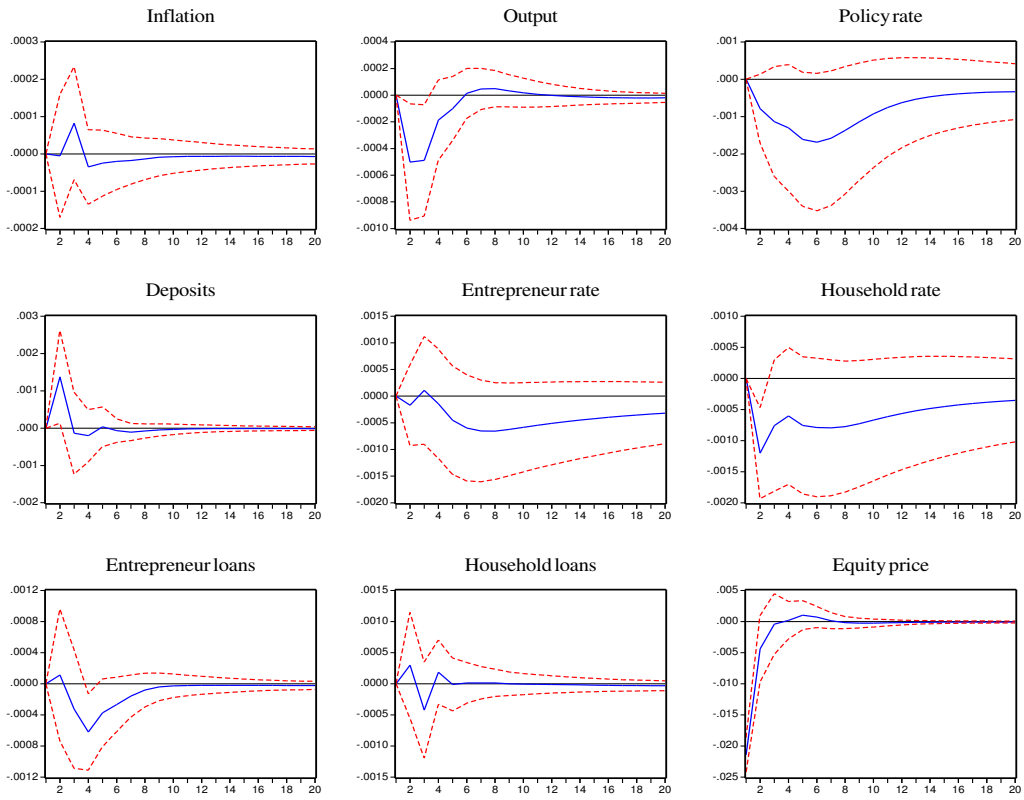

Figure 5: VAR IRFs to a negative equity price shock

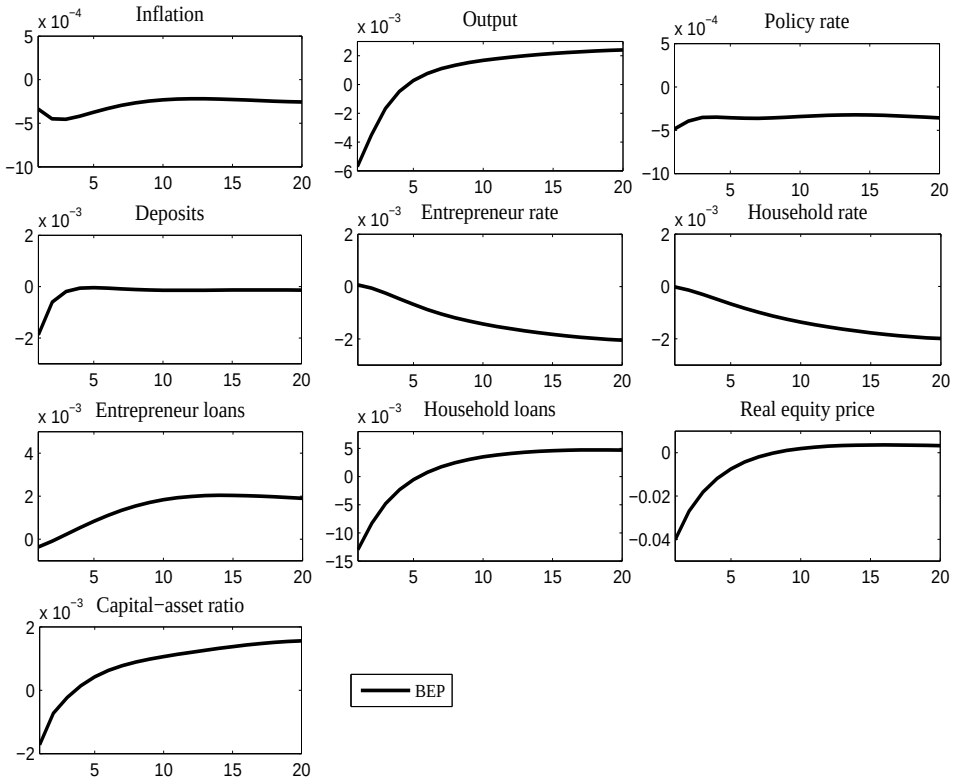

Figure 6: IRFs to a negative equity price shock

Fig. 6 displays the estimated impulse responses to a negative equity price shock from the estimated BEP model. The responses of output, interest rates, and loans to households are qualitatively the same as those from the estimated VAR. Both results suggest that the equity price channel propagates the financial accelerator channel through the direct wealth effect on households, borrower household balance sheets on the demand-side of credit, and bank capital requirements on the supply-side of credit. In comparison with Castelnuovo and Nistico (2010), we find the same, that for the recovery of output, the direct wealth effect on household consumption and balance sheets (bank and borrower) initially dominates the indirect substitution effect of interest rates. In addition, the estimated impulse responses to a negative equity price shock are qualitatively similar to a negative technology shock. However, in contrast to Castelnuovo and Nistico (2010) and the empirical evidence, we do not observe a shift from equity investments to deposits in response to a negative equity price shock from the BEP DSGE model.

As discussed in Section 4.1, potential mark-to-market inefficiencies may arise if banks allow a larger weight on equity as borrowers' (both households and entrepreneurs) collateral. We therefore compare the model dynamics in response to a negative equity price shock with weights of 40% and 20% on equity in the borrowing constraints.[20] From Fig. 7 we can immediately see that the responses of variables are greater with a relatively higher weight on equity assets in the borrowing constraints. Greater leverage on equity assets

[20] We assume that, in principle, banks do not accept a weight of more than 50% on equity assets in borrowers' collateral, as equity prices can be extremely volatile.

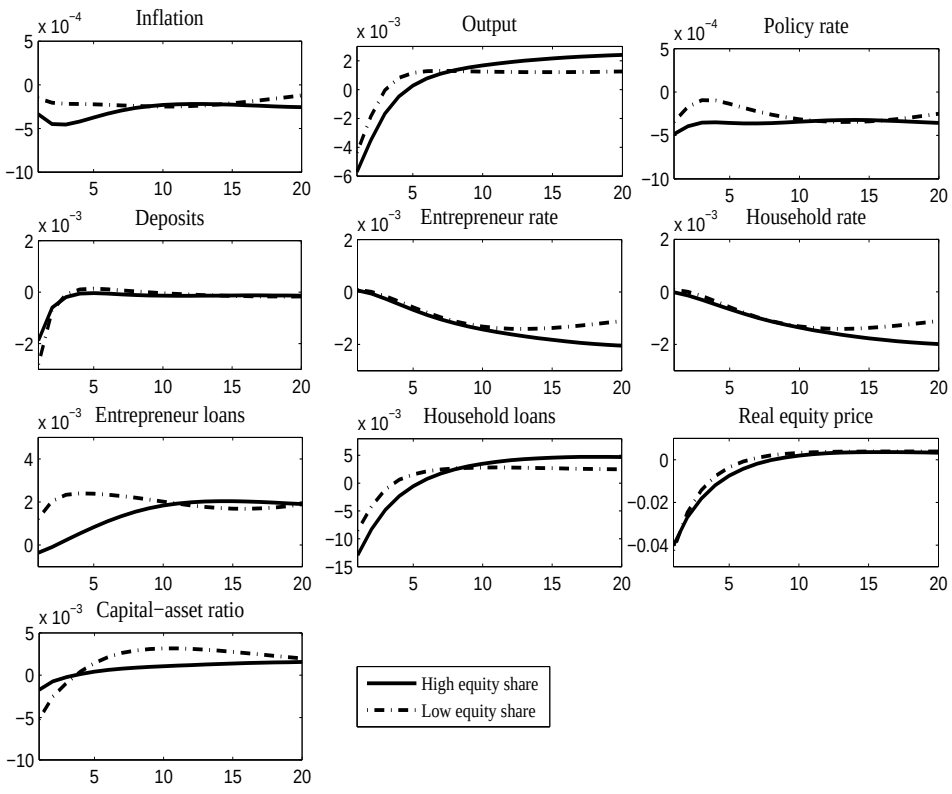

Figure 7: IRFs to a negative equity price shock: high vs. low equity share

therefore tends to propagate the financial accelerator channel and the bank funding channel. Two important findings are worth noting here. On the one hand, a higher equity leverage shifts risk off banks' balance sheets, and reduces bank capital-asset adjustment costs. This finding supports the emphasis of the Basel III capital requirements on higher leverage ratios on common equity and the recent structural changes in banks' balance sheets. Yet, on the other hand, the evidence suggests that higher shares of leverage on equity can adversely affect the broader economy. Indeed, an adverse equity price shock transmits simultaneously through multiple channels, revealing the potential inherent financial instability risk in financial markets and the real economy. It also highlights the argument for monetary policymakers to focus on the presence of financial instability within the context of contemporaneous equity price collapses after the 2007/2008 financial crisis.

7 Concluding remarks

This paper highlights the equity price channel as a different aspect to general equilibrium models with financial frictions. We acknowledge that the model developed here, as with other general equilibrium models in the literature, lacks a comprehensive description of complex stock price dynamics. Our focus here is on the implication of introducing the equity price channel into a general equilibrium model: how the equity price channel affects the dynamics of the model through the financial accelerator and bank funding channels. We show that a New-Keynesian DSGE model with an equity price channel reproduces the U.S. business cycle well. Moreover, the equity price channel significantly exacerbates the pro-cyclical features of the model through both the financial accelerator and bank funding channels: the financial wealth effect on borrowers, bank balance sheets, and bank capital regulation. Although equity price volatility induces benign macroeconomic effects, an equity market collapse (as in 1987 and 2008) may transmit simultaneously through multiple transmission channels and hit the real economy severely, highlighting the consequences of the (in)stability of financial markets on the real economy.

References

BCBS, 2011. The transmission channels between the financial and real sectors: a critical survey of the literature. Basel Committee on Banking Supervision, Working Paper No. 18. Bank for International Settlements. Basel.

Bernanke, B., Gertler, M., 1989. Agency costs, net worth, and business fluctuations. American Economic Review 79 (1), 14–31.

Bernanke, B., Gertler, M., Gilchrist, S., 1999. The financial accelerator in a quantitative business cycle framework. In: Taylor, J. B., Woodford, M. (Eds.), Handbook of Macroeconomics. Vol. 1c. North-Holland, Amsterdam, pp. 1341–1393.

BIS, 2012. Bank for international settlements. Available at: http://www.bis.org/bcbs/basel3/b3summarytable.pdf.

Boldrin, M., L, C., Fischer, J., 2001. Habit persistence, asset returns and the business cycle. American Economic Review 77, 647–666.

Brzoza-Brzezina, M., Kolasa, M., Makarski, K., 2011. The anatomy of standard dsge models with financial frictions. Bank of Poland, Working Paper no. 80. Available at SSRN: http://dx.doi.org/10.2139/ssrn.1816134.

Calvo, G., 1983. Staggered prices in a utility-maximizing framework. Journal of Monetary Economy 12 (3), 383–398.

Castelnuovo, E., Nistico, S., 2010. Stock market conditions and monetary policy in a dsge model for the us. Journal of Economic Dynamics and Control 34 (9), 1700–1731.

Christiano, L., Ilut, C., Motto, R., Rostagno, M., 2008. Monetary policy and stock market boom-bust cycles. Working Paper Series No. 995. European Central Bank.

Christiano, L., Motto, R., Rostango, M., 2010. Financial factors in business cycles. Working Paper Series No. 1192. European Central Bank.

Christiano, L. J., Eichenbaum, M., Evans, C. L., 2005. Nominal rigidities and the dynamic effects of a shock to monetary policy. Journal of Political Economy 113 (1), 1–45.

Cochrane, J. H., 2008. Financial markets and the real economy. In: Mehra, R. (Ed.), Handbook of the Equity Risk Premium. Elsevier BV, Ch. 7, pp. 237–325.

de Walque, G., Pierrard, O., Rouabah, A., 2010. Financial (in)stability, supervision and liquidity injections: a dynamic general equilibrium approach. The Economic Journal 120, 1234–1261.

Farmer, R. E. A., 2012. Confidence, crashes and animal spirits. The Economic Journal 122 (559), 155–172.

FDIC, 2012. Federal deposit insurance corporation bank data and statistics. Available at: http://www.fdic.gov/bank/statistical/.

Gali, J., Lopez-Salido, J. D., Valles, J., 2007. Understanding the effects of government spending on consumption. Journal of the European Economic Association 5, 227–270.

Gerali, A., Neri, S., Sessa, L., Signoretti, F. M., 2010. Credit and banking in a dsge model of the euro area. Journal of Money, Credit, and Banking 42 (6), 107–141.

Iacoviello, M., 2005. House prices, borrowing constraints and monetary policy in the business cycle. American Economic Review 95 (3), 739–764.

Iacoviello, M., Neri, S., 2010. Housing market spillovers: evidence from an estimated dsge model. American Economic Journal: Macroeconomics 2 (2), 125–164.

Kiyotaki, N., Moore, J., 1997. Credit cycles. Journal of Political Economy 105 (2), 211–248.

Markovic, B., 2006. Bank capital channels in the monetary transmission mechanism. Working Paper, No. 313. Bank of England.

Meh, C. A., Moran, K., 2010. The role of bank capital in the propagation of shocks. Journal of Economic Dynamics and Control 34, 555–576.

Mishkin, F., 2011. Monetary policy strategy: lessons from the crisis. NBER Working Paper Series no. 16755.

Pesaran, M. H., Xu, T., 2011. Business cycle effects of credit and technology shocks in a dsge model with firm defaults. CESifo working paper no. 3609.

Smets, F., Wouters, R., 2007. Shocks and frictions in us business cycles: a bayesian approach. American Economic Review 97 (3), 586–606.

Taylor, J. B., 2009. Getting off track: How government actions and interventions caused, prolonged, and worsened the financial crisis. Hoover Institution Press, ISBN 0-8179-4971-2.

Uhlig, H., 2007. Explaining asset prices with external habits and wage rigidities in a dsge model. American Economic Review, American Economic Association 97 (2), 239–243.

Van den Heuvel, S. J., 2008. The welfare cost of banking capital requirements. Journal of Monetary Economics 55 (2), 298–320.

Wei, C., 2010. Inflation and stock prices: No illusion. Journal of Money, Credit, and Banking 42, 325–345.

Woodford, M., 2012. Methods of policy accommodation at the interest-rate lower bound. Jackson Hole Symposium, The Changing Policy Landscape, August 31-September 1, 2012.

8 Appendix: 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. Inflation: Gross Domestic Product: Implicit Price Deflator (GDPDEF), Index 2005=100, Quarterly, Seasonally Adjusted.

3. Nominal interest rate: Effective Federal Funds Rate (FEDFUNDS), Percent, Quarterly, Not Seasonally Adjusted.

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

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 (closely related to M2SL).

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

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