

Banks, Credit Market Frictions, and Business Cycles*

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Abstract

The current financial crisis highlights the need to develop DSGE models with real-financial linkages and an active banking sector. This paper proposes a fully micro-founded framework that incorporates optimizing banks, the interbank market, and the credit market into a DSGE model, and evaluates the role of banks and financial shocks in the U.S. business cycles. We assume two types of heterogeneous banks that offer different banking services and interact in an interbank market. Loans are produced using interbank borrowing and bank capital subject to the bank capital requirement condition. Banks have monopoly power, set nominal deposit and prime lending rates, choose their portfolio compositions and their leverage ratio, and may endogenously default on fractions of their interbank borrowing and bank capital returns. The model also includes financial and unconventional monetary policy shocks. The main findings are that: (1) The model captures the key features of the U.S. economy; (2) bank behavior substantially affects credit supply conditions and the transmission of different shocks; (3) the banks' leverage ratio is procyclical; and (4) financial shocks have significant effects on the U.S. business cycle fluctuations, while unconventional monetary easing policies may reduce the negative impacts of the financial crisis.

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1. Introduction

The ongoing global financial crisis underscores the need to develop DSGE models with real-financial linkages and an active banking sector. Such a model would allow an empirical evaluation of banks' role and behavior in the transmission and propagation of supply and demand shocks, and an assessment of the importance of financial shocks as a source of business cycles. The banking sector, however, has been ignored in most DSGE models used for policy purposes. Moreover, in the literature, financial frictions are usually modeled only on the demand side of the credit market using either the Bernanke, Gertler and Gilchrist (1999) financial accelerator mechanism (BGG, hereafter) or the Iacovello (2005) framework.¹ In light of the ongoing financial crisis, real-financial linkages have become the focus of attention.

This paper proposes a microfounded framework that incorporates an active banking sector, interbank market, bank capital, and a credit market into a DSGE model with a financial accelerator à la BGG (1999).² The model is calibrated to the U.S. economy and used to evaluate the role of profit-maximizing banks in business cycles and in the transmission and propagation of shocks to the real economy, to assess the importance of financial shocks in explaining macroeconomic fluctuations, and to examine the potential role of unconventional monetary policies (quantitative and qualitative monetary easing) in offsetting the real impacts of the financial crisis.

The paper is related to the following studies: Goodhart, Sunirand and Tsomocos (2006), Christiano, Motto and Rostagno (2009), Cúrdia and Woodford (2009a,b), de Walque, Pierard and Rouabah (2009), and Gerali, Neri, Sessa and Signoretti (2009). In contrast to the previous studies that examine the role of bank capital in the business cycle fluctuations, this paper introduces bank capital to satisfy the bank's capital requirement condition as in Basel II Accords, which is a pre-condition to operate and make loans to entrepreneurs.³

Our basic model is a DSGE model for a closed economy similar to Christensen and Dib (2008), which is based on BGG (1999). The key additions to this model are the supply-side of

¹For example, Carlstrom and Fuerst (1997), Cespedes, Chang and Velasco (2004), Elekdag, Justiniano and Tchakarov (2006), and Christensen and Dib (2008).

²This framework is fully microfounded in the sense that all banks maximize profits and take optimal decisions under different constraints.

³For example, Holmstrom and Tirole (1997), Meh and Moran (2004), Markovic (2006), Goodfriend and McCallum (2007), and others.

the credit market and an active banking sector. The model incorporates an optimizing banking sector with two types of monopolistically competitive banks: “savings banks” and “lending banks”. Banks supply different banking services and the two types of banks interact in the interbank market.⁴ They have the monopoly power when setting nominal deposit and prime lending rates (subject to quadrating adjustment costs). Savings banks collect deposits from workers, set nominal deposit rates, and choose the composition of their portfolio (composed of risk-free assets and risky interbank lending) to maximize profits. Lending banks borrow from savings banks on the interbank market and receive bank capital from bankers to satisfy the bank capital requirement condition that imposes a minimum level of bank capital lending banks must hold in order to provide loans to entrepreneurs. Lending banks can receive, if needed, liquidity injections from the central bank and/or swap a fraction of their loans (risky assets) for government bonds (risk-free assets).

Following Goodhart *et al.* (2006), we assume endogenous strategic or necessary defaults on bank capital and interbank borrowing, optimally chosen by lending banks; however, when defaulting, banks pay expected convex penalties in the next period. In addition, banks optimally choose their leverage ratio, that is, the ratio of loans to bank capital, subject to the maximum leverage ratio imposed by regulators. We assume the presence of convex gains of holding bank capital in excess of the required level. This implies that variations in the banks’ leverage ratio directly affect the marginal cost of raising bank capital. Therefore, movements in the banks leverage ratio may amplify the effects the business cycles, as pointed out by Fostel and Geanakoplos (2008) and Geanakoplos (2009).⁵

In addition, the economy is inhabited by two types of heterogeneous households (workers and bankers); three goods producers, entrepreneurs, capital producers, and retailers; a central bank; and the government. Households differ in their preferences, degree of risk aversion, and access to financial markets. Workers supply labor services to entrepreneurs, hold cash money, and save only via deposits at savings banks. Bankers own the banks, accumulate bank capital, and save by holding government bonds.

During the normal time, the central bank conducts its monetary policy following a standard

⁴To introduce heterogeneity in the banking sector, we distinguish between two types of banks: “savings banks” and “lending banks.” This is to incorporate an interbank market where different banks can interact.

⁵The cost of bank capital depends on the bank’s capital position. If banks hold excess bank capital, the marginal cost of raising bank capital on the market is lower, since banks are well capitalized.

Taylor rule: The central bank adjusts short-term nominal interest rates in response to inflation and output changes. However, during crisis periods, the central bank can use unconventional (quantitative and qualitative) monetary policies by injecting newly created money to the banking system and/or swapping a fraction of banks loans for government bonds.⁶ Through these channels, the central bank can serve as the lender of last resort to lending banks in times of crisis.

In the proposed framework, the banking sector affects credit market conditions and, thus, the real economy through the following channels: (1) variations in bank capital and bank capital price expectations; (2) monopoly power in setting nominal deposit and lending interest rates with nominal rigidities that imply moving interest rate spreads over business cycles;⁷ (3) the optimal allocation of the banks' portfolio between interbank lending and risk-free asset holdings; (4) the optimal choice of the banks' leverage ratio that is subject to the bank capital requirement condition; (5) the default risk channels that arise from endogenous strategic or necessary defaults on interbank borrowing and bank capital returns; and (6) marginal costs of raising bank capital.

The economy is subject to two supply shocks—technology and investment-efficiency shocks; three demand shocks—monetary policy, government spending, and preferences shocks—, four financial shocks—risk, financial intermediation process, and quantitative and qualitative monetary easing shocks. Supply and demand shocks are commonly used in the literature; however, financial shocks require some explanation. Riskiness shocks are modeled as shocks to the elasticity of the risk premium that affect the external finance costs of entrepreneurs. They are meant to represent shocks to the standard deviation of the entrepreneurial distribution, as Christiano *et al.* (2009) argue, shocks to agency costs paid by lending banks to monitor entrepreneurs' output, and/or shocks to entrepreneurs' default threshold.⁸ These shocks may be interpreted as exogenous changes in the confidence level of banks with credit risks of their borrowers and the health of the economy, thus affecting external costs of entrepreneurial borrowing. Shocks

⁶Quantitative easing, which is associated with newly created money, expands banks' balance sheets; while swapping banks' assets for government bonds changes only banks' assets compositions.

⁷See Cúrdia and Woodford (2009) for the importance of moving spreads on monetary policy.

⁸As shown in BGG (1999), the elasticity of the external finance premium to the entrepreneurs' leverage ratio depends on the standard deviation of the entrepreneurial distribution, the agency cost parameter, and entrepreneurs' default threshold.

to financial intermediation process are exogenous events that affect loan production technology (credit supply) of lending banks. They may represent technological advances in the intermediation process and approximate perceived changes in creditworthiness.⁹ Finally, quantitative and qualitative monetary easing shocks are used by the central bank to provide liquidity to the banking system and to enhance banks' conditions.

The model is successful in reproducing most of the salient features of the U.S. economy: key macroeconomic volatilities, autocorrelations, and correlations with output. Moreover, the presence of an active banking sector with sticky deposit rates is welfare improving. The welfare cost of uncertainty is lower in the model with the banking sector than without it. This results from the role of banks in sharing risks with entrepreneurs by offering non-contingent debt contracts. Also, bankers act in this case as insurers of workers' consumption. Thus, the main role of banks in this economy is to reduce the negative impact of uncertainty in the presence of different structural shocks, particularly financial shocks.

The presence of the banking sector also affects the transmission and propagation of different types of shocks. In addition, financial shocks largely contribute to business cycle fluctuations. Thus, disturbances in the banking sector may be a substantial source of macroeconomic fluctuations and economic turmoil. We also find that the banks' leverage ratio is procyclical, indicating that banks are willing to extend loans during booms and tend to restrict their supply of credit during recessions. As well, the external finance premium and defaults on interbank borrowing and bank capital are negatively correlated with output.

The paper proceeds as follows. Section 2 presents the model. Section 3 discusses the parameter calibration. Section 4 discusses the empirical results. Section 5 concludes.

2. The Model

The economy is inhabited by two types of households (workers and bankers). The banking sector consists of two types of heterogeneous monopolistically competitive banks (savings and lending banks) that offer different banking services and interact in an interbank market. As in BGG (1999), the production sector consists of entrepreneurs, capital producers, and retailers.

⁹Advances in financial engineering, credit rationing, and highly sophisticated methods for sharing risk are examples of intermediation process shocks.

Finally, there is a central bank and a government.

2.1 Households

2.1.1 Workers

Workers derive utility from total consumption, C_t^w ; real money balances, M_t^c ; and leisure, $1 - H_t$, where H_t denotes hours worked. The workers' preferences are described by the following expected utility function:

$$V_0^w = E_0 \sum_{t=0}^{\infty} \beta_w^t u(C_t^w, M_t^c, H_t). \quad (1)$$

The single-period utility is

$$u(\cdot) = \frac{e_t}{1 - \gamma_w} \left(\frac{C_t^w}{(C_{t-1}^w)^\varphi} \right)^{1 - \gamma_w} + \frac{\varpi (M_t^c)^{1 - v}}{1 - v} + \frac{\eta (1 - H_t)^{1 - \varsigma}}{1 - \varsigma}, \quad (2)$$

where $\varphi \in (0, 1)$ is a habit formation parameter; γ_w is a positive parameter denoting the workers' risk aversion and the inverse of the elasticity of intertemporal substitution of consumption; v denotes the money-interest elasticity; and ς is the inverse of the elasticity of intertemporal substitution of leisure. The parameters ϖ and η measure the weight on real cash balances and leisure in the utility function, respectively. e_t is a taste shock that follows an AR(1) process.

The representative worker enters period t with D_{t-1} units of real deposits in savings banks and M_{t-1}^c units of real money balances held outside of banks that do not earn interest. Deposits pay the gross nominal interest rate R_t^D set by savings banks between t and $t + 1$.¹⁰ During period t , workers supply labour to the entrepreneurs, for which they receive real labor payment $W_t H_t$, where W_t is the economy-wide real wage. Furthermore, they receive dividend payments, Π_t^R , from retail firms, as well as a lump-sum transfer from the monetary authority, T_t , and pay lump-sum taxes to government, \tilde{T}_t^w . Workers allocate their funds to private consumption C_t^w , real money holdings M_t^c , and real deposits, D_t . Their budget constraint in real terms is

$$C_t^w + M_t^c + D_t \leq W_t H_t + \frac{R_{t-1}^D D_{t-1}}{\pi_t} + \frac{M_{t-1}^c}{\pi_t} + \Pi_t^R + T_t - \tilde{T}_t^w, \quad (3)$$

where $\pi_{t+1} = P_{t+1}/P_t$ is the gross inflation rate. A representative worker household chooses C_t^w , M_t^c , H_t , and D_t to maximize its expected lifetime utility, Eq. (1), subject to the single-

¹⁰In this economy, R_t^D is different from the rate of return on government bonds.

period utility function, Eq. (2), and the budget constraint, Eq. (3). The first-order of this optimization problem are in Appendix A.

2.1.2 Bankers

Bankers (bank owners) own the two types of banks from which they receive profits. They consume, have access to the non-contingent government bond market, and accumulate bank capital supplied to lending banks to satisfy the bank capital requirement for a contingent bank capital return. It is assumed that bankers' preferences depend only on consumption and are given by

$$V_0^b = E_0 \sum_{t=0}^{\infty} \beta_b^t u(C_t^b). \quad (4)$$

The single-period utility function is

$$u(\cdot) = \frac{e_t}{1 - \gamma_b} \left(\frac{C_t^b}{(C_{t-1}^b)^\varphi} \right)^{1 - \gamma_b}, \quad (5)$$

where γ_b is a positive structural parameter denoting bankers' risk aversion and the inverse of the elasticity of intertemporal substitution. e_t denotes the preference shock that follows an AR(1) process.

Bankers enter period t with $(1 - \delta_{t-1}^Z)Z_{t-1}$ units of bank capital stock, whose price is Q_t^Z in period t , where δ_{t-1}^Z is a probability of banks' default on bank capital occurring at the end of the period $t - 1$. Bank capital pays a contingent nominal return rate R_t^Z between $t - 1$ and t . Bankers also enter period t with B_{t-1} units of real government bonds that pay the gross risk-free nominal interest rate R_t between t and $t + 1$. During period t , bankers receive profit payments, Π_t^{sb} and Π_t^{lb} from saving and lending banks, and pay lump-sum taxes to government, \tilde{T}_t^b . They allocate these funds to consumption C_t^b , real government bonds B_t , and real bank capital acquisition $Q_t^Z Z_t$. We assume quadratic adjustment costs to alter the bank's capital

stock.¹¹ Bankers' budget constraint in real terms is

$$C_t^b + Q_t^Z Z_t + B_t = \frac{R_{t-1} B_{t-1}}{\pi_t} + (1 - \delta_{t-1}^Z) \frac{R_t^Z Q_t^Z Z_{t-1}}{\pi_t} - \frac{\chi_Z}{2} \left(\frac{\pi_t Z_t}{Z_{t-1}} - \pi \right)^2 Q_t^Z Z_t + \Pi_t^{sb} + \Pi_t^{lb} - \tilde{T}_t^b. \quad (6)$$

A representative banker chooses C_t^b , B_t , and Z_t in order to maximize its expected lifetime utility Eq.(4), subject to Eq.(5) and the budget constraint, Eq.(6). The first-order conditions for this optimization problem are:

$$e_t \left(\frac{C_t^b}{(C_{t-1}^b)^\varphi} \right)^{1-\gamma_b} - \beta_b \varphi E_t \left[e_{t+1} \left(\frac{C_{t+1}^b}{(C_t^b)^\varphi} \right)^{1-\gamma_b} \right] = C_t^b \lambda_t^b; \quad (7)$$

$$\frac{\lambda_t^b}{R_t} = \beta_b E_t \left[\frac{\lambda_{t+1}^b}{\pi_{t+1}} \right]; \quad (8)$$

$$\begin{aligned} \beta_b E_t \left\{ \frac{\lambda_{t+1}^w Q_{t+1}^Z}{\pi_{t+1}} \left[(1 - \delta_t^Z) R_{t+1}^Z + \chi_Z \left(\frac{\pi_{t+1} Z_{t+1}}{Z_t} - \pi \right) \left(\frac{\pi_{t+1} Z_{t+1}}{Z_t} \right)^2 \right] \right\} \\ = \lambda_t^w Q_t^Z \left[1 + \chi_Z \left(\frac{\pi_t Z_t}{Z_{t-1}} - \pi \right) \frac{\pi_t Z_t}{Z_{t-1}} \right]; \end{aligned} \quad (9)$$

where λ_t^b is the Lagrangian multiplier associated with the bankers' budget constraint.

Eq. (7) determines the marginal utility of banker's consumption. Eq. (8) relates the marginal rate of substitution to the real interest rate on bonds. Finally, Eq. (9) corresponds to the optimal dynamic evolution of the bank capital stock.

Combining conditions (8) and (9) yields the following condition relating return on bank capital R_t^Z to the risk-free interest rate on government bonds R_t :

$$\begin{aligned} E_t \left\{ \frac{Q_{t+1}^Z}{Q_t^Z} \left[(1 - \delta_t^Z) R_{t+1}^Z + \chi_Z \left(\frac{\pi_{t+1} Z_{t+1}}{Z_t} - \pi \right) \left(\frac{\pi_{t+1} Z_{t+1}}{Z_t} \right)^2 \right] \right\} \\ = R_t \left[1 + \chi_Z \left(\frac{\pi_t Z_t}{Z_{t-1}} - \pi \right) \frac{\pi_t Z_t}{Z_{t-1}} \right]. \end{aligned} \quad (10)$$

This condition implies three channels through which bank capital movements affect the real economy. First, the price expectation channel that arises from expectations of capital gains or

¹¹We interpret these adjustment costs as costs paid to brokers or the costs of collecting information about the banks' balance sheet.

losses from holding bank capital shares, due to expected changes in the price of bank capital $E_t [Q_{t+1}^Z/Q_t^Z]$. This channel implies that the efficient market hypothesis does not hold in the short run. Second, the adjustment cost channel, a result of the information asymmetry between bankers and banks, implies changes in current and expected stocks of bank capital given by the terms $\chi_Z(\cdot)$. The presence of adjustment costs is necessary to reduce the information asymmetry and the adjustment costs are interpreted as costs to enter into the bank capital market. Finally, the default risk channel arises from the existence of the probability of default on bank capital repayment, $\delta_t^Z > 0$, decided by the lending banks. This default probability is counter-cyclical. Therefore, movements in bank capital, caused by macroeconomic fluctuations, have direct impacts on bank capital accumulation and consequently on credit supply conditions.

2.2 Banking sector

The banking sector consists of two types of heterogenous profit-maximizing banks: Savings and lending banks.

2.2.1 Savings banks

There is a continuum of savings banks, operating in a monopolistically competitive environment and collecting deposits D_t from workers. We assume that all deposits are fully insured. Each bank $j \in (0, 1)$ sets the deposit interest rate $R_{j,t}^D$ paid on deposits and chooses the optimal allocation of its portfolio between lending a fraction $s_{j,t}$ of deposits on the interbank market, $\tilde{D}_{j,t} = s_{j,t}D_{j,t}$, (interbank lending) to lending banks, and investing the fraction $(1 - s_{j,t})$ in risk-free assets, B_t^{sb} , (government bonds). Each period, there is a probability δ_t^D that lending banks default on their interbank borrowing. When investing in non-risky assets, savings banks must pay an insurance premium (cost of holding risk-free assets). The interbank rate R_t is set by the central bank. Table 1 displays the balance sheet of the j 'th savings bank.¹²

Table 1: Savings bank's balance sheet

Assets	Liabilities
Interbank lending: $\tilde{D}_{j,t}$	Deposits: $D_{j,t}$
Government bonds: $B_{j,t}^{sb}$	

¹²Note that $\tilde{D}_{j,t} = s_{j,t}D_{j,t}$ and $B_{j,t}^{sb} = (1 - s_{j,t})D_{j,t}$ where $s_{j,t} \in (0, 1)$.

Given monopolistic competition and the imperfect substitution between deposits, the j^{th} savings bank faces the following deposit supply function, that is increasing in the relative deposit interest rate across period. As in Gerali *et al.* (2009), the individual deposit supply is

$$D_{j,t} = \left(\frac{R_{j,t}^D}{R_t^D} \right)^{\vartheta_D} D_t, \quad (11)$$

where $D_{j,t}$ is deposits supplied to bank j , while D_t denotes total deposits in the economy; and $\vartheta_D > 1$ is the elasticity of substitution between different types of deposits.¹³ Also, there is a quadratic adjustment cost of intertemporally varying the deposit interest rate. This rigidity allows an interest rate spread that evolves over the cycle. We assume adjustment costs à la Rotemberg (1982), given by

$$Ad_{j,t}^{R^D} = \frac{\phi_{R^D}}{2} \left(\frac{R_{j,t}^D}{R_{j,t-1}^D} - 1 \right)^2 D_t, \quad (12)$$

where $\phi_{R^D} > 0$ is an adjustment cost parameter. The optimization problem of the j^{th} savings bank is

$$\max_{\{s_{j,t}, R_{j,t}^D\}} E_0 \sum_{t=0}^{\infty} \beta_b^t \lambda_t^b \left\{ [(1 - s_{j,t}) \delta_t^D R_t - R_{j,t}^D] D_{j,t} - \frac{\chi_s}{2} ((1 - s_{j,t}) D_{j,t})^2 - Ad_{j,t}^{R^D} \right\},$$

subject to (11) and (12). Because bankers are the sole owners of banks, the discount factor is the stochastic process $\beta_b^t \lambda_t^b$, where λ_t^b denotes the marginal utility of bankers' consumption.¹⁴

The terms $0.5\chi_s ((1 - s_{j,t}) D_{j,t})^2$ represents the costs of holding risk-free assets and the payment of an insurance premium, where $\chi_s > 0$ is a parameter determining the steady-state level of these costs.

¹³This supply function is derived from the definition of aggregate supply of deposits, D_t , and the corresponding deposit interest rate, R_t^D , in the monopolistic competition framework, as follows:

$$D_t = \left(\int_0^1 D_{j,t}^{\frac{1+\vartheta_D}{\vartheta_D}} dj \right)^{\frac{\vartheta_D}{\vartheta_D+1}} \quad \text{and} \quad R_t^D = \left(\int_0^1 R_{j,t}^{D \cdot 1+\vartheta_D} dj \right)^{\frac{1}{1+\vartheta_D}},$$

where $D_{j,t}$ and $R_{j,t}^D$ are the supply and deposit interest rate faced by each savings bank $j \in (0, 1)$.

¹⁴Savings banks take R_t and δ_t^D as given when maximizing their profits.

In the symmetric equilibrium, the first-order conditions of this optimization problem, with respect to s_t and R_t^D , are:

$$s_t = 1 - \frac{\delta_t^D R_t}{\chi_s D_t}; \quad (13)$$

$$\begin{aligned} \frac{1 + \vartheta_D}{\vartheta_D} (R_t^D - 1) &= (1 - s_t \delta_t^D) (R_t - 1) - \chi_s (1 - s_t)^2 D_t \\ &- \frac{\phi_{RD}}{\vartheta_D} \left(\frac{R_t^D}{R_{t-1}^D} - 1 \right) \frac{R_t^D}{R_{t-1}^D} + \frac{\beta_b \phi_{RD}}{\vartheta_D} \left(\frac{R_{t+1}^D}{R_t^D} - 1 \right) \frac{R_{t+1}^D}{R_t^D}. \end{aligned} \quad (14)$$

Condition (13) describes the interbank lending supplied by the savings banks; it states that the fraction s_t of deposits allocated to interbank lending is decreasing in the probability of default on interbank lending and in the interbank rate, while it is increasing in total deposits. An increase in s_t leads to an expansion in credit supply. Condition (14) defines the deposit interest rate, R_t^D , as a mark-down of the interbank rate.¹⁵

Thus, increases in the riskiness of interbank lending, a higher δ_t^D , encourage savings banks to increase their risk-free holdings and to reduce their interbank lending. Also, an increase in the interbank rate, the return rate on risk-free assets, reduces interbank lending supply. Nevertheless, an increase in total deposits expands interbank lending, leading to an expansion in credit supply conditions.

This framework, therefore, adds two channels through which savings banks' behavior affects credit supply conditions and the real economy. First, by setting deposit return rates in a monopolistically competitive market, combined with the nominal rigidity of deposit rates, savings banks influence the intertemporal substitution of consumption across periods and thus facilitate consumption smoothing.¹⁶ Second, by optimally dividing deposits between interbank lending and risk-free asset holding, savings banks affect credit supply conditions by expanding or tightening credit market conditions.

2.2.2 Lending banks

There is a continuum of lending banks, indexed by $j \in (0, 1)$, that operate in a monopolistically competitive market to provide loans to entrepreneurs. The j 'th lending bank borrows $\tilde{D}_{j,t}$ from

¹⁵This equation allows us to derive a New-Philips curve relating R_t^D to R_{t-1}^D , R_{t+1}^D , and R_t .

¹⁶Since the marginal rate of substitution equals the deposit rate, the sluggishness in this rate affects the intertemporal substitution between current and future consumption.

savings banks on the interbank market and demand bank capital $Z_{j,t}$ from bankers, paying the bank capital price Q_t^Z and a non-contingent return rate R_{t+1}^Z .¹⁷ We assume that bank capital is held by lending banks as government bonds that pay the risk-free rate R_t . Each lending bank j can receive liquidity injections from the central bank, $m_{j,t}$, (quantitative monetary easing). Also, if needed, bank j may swap a fraction of its loans for government bonds, $x_{j,t}$, from the central bank in crisis periods (qualitative monetary easing). Through these channels, the central bank can serve as lender of last resort to lending banks in times of crisis.

Each lending bank has monopoly power when setting its prime lending rate $R_{j,t}^L$ subject to quadratic adjustment costs. The bank j may also decide to default on some of its interbank borrowing and bank capital payments. Defaults can be either strategic or mandatory (when a bank cannot afford to repay their debt). In addition, lending bank optimally chooses its leverage ratio (ratio of loans to bank capital), taking into account the maximum ratio imposed by the regulators. We assume that having a bank leverage ratio below the maximum required level (holding bank capital in excess) entails quadratic gains for the bank. This gains directly affect the marginal cost of raising bank capital in the financial market.

To produce loans $L_{j,t}$ for entrepreneurs, the lending bank j uses interbank borrowing, $\tilde{D}_{j,t}$, plus liquidity injection received from the central bank (quantitative monetary easing), $m_{j,t}$, and the total market value of its bank capital $Q_t^Z Z_{j,t}$, plus liquidity received from the central bank, $x_{j,t}$. We assume that banks use the following Leontief technology to produce loans:¹⁸

$$L_{j,t} = \min \left\{ \tilde{D}_{j,t} + m_{j,t}; \kappa_{j,t} (Q_t^Z Z_{j,t} + x_{j,t}) \right\} \Gamma_t, \quad (15)$$

where $\kappa_{j,t} \leq \bar{\kappa}$ is the bank's j leverage ratio that is optimally chosen and $\bar{\kappa}$ is the maximum leverage ratio imposed by regulators.¹⁹ When $\kappa_{j,t} < \bar{\kappa}$, the bank j accumulates bank capital beyond the required level. The variable Γ_t represents a shock to the intermediation process affecting credit supply (loan production).²⁰ It represents exogenous factors and approximates perceived changes in creditworthiness. Technological advances in the intermediation process can

¹⁷In this economy, interbank borrowing is always equal to interbank lending, so that $\tilde{D}_t = s_t D_t$.

¹⁸Leontief technology implies perfect complementarity between deposits and bank capital when producing loans and satisfies the bank capital requirement condition.

¹⁹Note that $\kappa_{j,t}$ is the ratio of bank's loans to its bank capital. Therefore, it is the inverse of the bank capital ratio.

²⁰ Γ_t is a shock to the balance sheet of lending banks.

be considered another source of variation in Γ_t . The process of loan evaluation certainly has evolved over time, through stochastic technological advances in information services. These variations may represent changes in total factor productivity in the intermediation process. Advances in computational finance and sophisticated methods of sharing risk are examples of this shock.²¹ It is assumed that m_t , x_t , and Γ_t evolve according to AR(1) processes.²²

Using Leontief technology to produce loans implies perfect complementarity between interbank borrowing and bank capital. Furthermore, the marginal cost of producing loans is simply the sum of the marginal cost of interbank borrowing and that of raising bank capital. The latter is adjusted by the Bank's leverage ratio. Table 2 shows the j 'th lending bank's balance sheet in period t .

Table 2: Lending bank's balance sheet

Assets	Liabilities
Loans: $L_{j,t} - x_{j,t}$	Interbank borrowing: $\tilde{D}_{j,t}$
Government bonds: $B_{j,t}^{lb} = Q_t^Z Z_{j,t} + x_{j,t}$	Bank capital: $Q_t^Z Z_{j,t}$
	Central bank's money injection: $m_{j,t}$
	Other terms: $(\Gamma_t - 1)(\tilde{D}_{j,t} + m_{j,t})$

We note that swapping a fraction of loans for government bonds, $x_{j,t}$, modifies only the composition of the bank lending assets. Nevertheless, shocks of liquidity injections, $m_{j,t}$, and financial intermediation, Γ_t , affect the total values of lending banks balance sheet, implying balance sheet expansion.

At each period, the lending bank j sets the prime lending rate, $R_{j,t}^L$, as a mark-up of the marginal cost of producing loans and the marginal costs of adjusting this nominal rate across periods. Bank j also optimally chooses $\kappa_{j,t}$ subject to the bank capital requirement condition, $\bar{\kappa}$, and the defaults on bank capital and interbank borrowing, $\delta_{j,t}^Z$ and $\delta_{j,t}^D$, respectively. As in Gerali *et al.* (2009), the adjustment costs associated with changes in prime lending rates are

²¹This shock may reflect lending banks' perception of the risk in the economy. Banks may underevaluate (overevaluate) risk during booms (recessions). This exogenously increase (decrease) loan supply. During booms, $\Gamma_t > 1$, so it is a credit easing shock, while during recession $\Gamma_t < 1$ means a credit rationing shock.

²²The steady state values of m_t and x_t are zero, while that of Γ_t is equal to unity.

modelled à la Rotemberg (1982) and given by

$$Ad_{j,t}^{RL} = \frac{\phi_{RL}}{2} \left(\frac{R_{j,t}^L}{R_{j,t-1}^L} - 1 \right)^2 L_t, \quad (16)$$

where $\phi_{RL} > 0$ is an adjustment cost parameter. In addition, when choosing $\kappa_{j,t} < \bar{\kappa}$, there are quadratic gains since banks are well-capitalized. These gains are modelled using the following function: $0.5\chi_\kappa ((\bar{\kappa} - \kappa_{j,t})Q_t^Z Z_{j,t}/\bar{\kappa})^2$, where $\chi_\kappa > 0$ is a parameter determining the steady-state value of κ_t . When $\kappa_{j,t} = \bar{\kappa}$, the bank's leverage ratio meets the required level exactly, and there are no gains associated with it. However, when $\kappa_{j,t} < \bar{\kappa}$, the bank leverage ratio is below the requirement and banks are well-capitalized. Well-capitalized banks have lower costs of raising capital. Thus, the optimal choice of the banks' leverage ratio affects the costs of lending directly through its impact on bank capital raising costs.²³

The lending bank optimization problem is to choose $\kappa_{j,t}$, $\delta_{j,t}^D$, $\delta_{j,t}^Z$, and $R_{j,t}^L$. The lending banks' profit maximization problem is

$$\begin{aligned} \max_{\{R_{j,t}^L, \kappa_{j,t}, \delta_{j,t}^D, \delta_{j,t}^Z\}} E_0 \sum_{t=0}^{\infty} \beta_b^t \lambda_t^b \left\{ R_{j,t}^L L_{j,t} - (1 - \delta_{j,t}^D) R_t \tilde{D}_{j,t} - R_t m_{j,t} - [(1 - \delta_{j,t}^Z) R_{t+1}^Z - R_t] Q_t^Z Z_{j,t} \right. \\ \left. - \frac{\chi_{\delta^D}}{2} \left(\frac{\delta_{j,t-1}^D \tilde{D}_{j,t-1}}{\pi_t} \right)^2 - \frac{\chi_{\delta^Z}}{2} \left(\frac{\delta_{j,t-1}^Z Q_{t-1}^Z Z_{j,t-1}}{\pi_t} \right)^2 \right. \\ \left. + \frac{\chi_\kappa}{2} \left(\frac{\bar{\kappa} - \kappa_{j,t}}{\bar{\kappa}} Q_t^Z Z_{j,t} \right)^2 - (R_{j,t}^L - R_t) x_{j,t} - Ad_{j,t}^{RL} \right\}, \end{aligned}$$

subject to (15), (16), and the following demand function for loans:

$$L_{j,t} = \left(\frac{R_{j,t}^L}{R_t^L} \right)^{-\vartheta_L} L_t, \quad (17)$$

where $\vartheta_L > 1$ is the elasticity of substitution between different types of loans that provided by different lending banks.²⁴ The discount factor is given by the stochastic process $\beta_b^t \lambda_t^b$, where

²³Equation (23) hereafter displays the relation between the marginal cost of loans and the cost of raising bank capital.

²⁴This demand function is derived from the definition of aggregate demand of loans, L_t , and the corresponding prime lending rate, R_t^L , in the monopolistic competition framework, as follows:

$L_t = \left(\int_0^1 L_{j,t}^{\frac{1-\vartheta_L}{\vartheta_L}} dj \right)^{\frac{\vartheta_L}{1-\vartheta_L}}$ and $R_t^L = \left(\int_0^1 R_{j,t}^{L^{1-\vartheta_L}} dj \right)^{\frac{1}{1-\vartheta_L}}$, where $L_{j,t}$ and $R_{j,t}^L$ are the loan demand and lending rate faced by each lending bank $j \in (0, 1)$.

λ_t^b denotes the marginal utility of consumption of bankers—the owners of the lending banks.

The terms $R_t m_{j,t}$ represents the cost of liquidity injections received from the central bank, while $\left[(1 - \delta_{j,t}^Z) R_{t+1}^Z - R_t \right] Q_t^Z Z_{j,t}$ denotes the net cost of bank capital, which depends on payment of non-defaulted fraction net of the return from holding bank capital as government bonds, B_t^{lb} . The terms $0.5\chi_{\delta^D} \left(\delta_{j,t-1}^D \tilde{D}_{j,t-1} / \pi_t \right)^2$ and $0.5\chi_{\delta^Z} \left(\delta_{j,t-1}^Z Q_{t-1}^Z Z_{j,t-1} / \pi_t \right)^2$ are increasing in the defaults on interbank borrowing and bank capital that occurred during the previous period. The terms $(R_{j,t}^L - R_t) x_{j,t}$ denote the effects of qualitative monetary easing shocks on bank's profits, where $R_{j,t}^L - R_t$ is the cost of swapping a fraction of loans for government bonds.

In a symmetric equilibrium, where all banks take the same decisions, the first-order conditions of this optimization problem, with respect to κ_t , δ_t^D , δ_t^Z , and R_t^L are:

$$\kappa_t = \bar{\kappa} \left(1 - \frac{\Gamma_t (R_t^L - 1)}{\chi_{\kappa} Q_t^Z Z_t} \right); \quad (18)$$

$$\delta_t^D = E_t \left[\frac{R_t \pi_{t+1}}{\chi_{\delta^D} \tilde{D}_t} \right]; \quad (19)$$

$$\delta_t^Z = E_t \left[\frac{R_t \pi_{t+1}}{\chi_{\delta^Z} Q_t^Z Z_t} \right]; \quad (20)$$

$$R_t^L = 1 + \frac{\vartheta_L}{\vartheta_L - 1} (\zeta_t - 1) - \frac{\phi_{RL}}{\vartheta_L - 1} \left(\frac{R_t^L}{R_{t-1}^L} - 1 \right) \frac{R_t^L}{R_{t-1}^L} \quad (21)$$

$$+ \frac{\beta_b \phi_{RL}}{\vartheta_L - 1} E_t \left[\left(\frac{R_{t+1}^L}{R_t^L} - 1 \right) \frac{R_{t+1}^L}{R_t^L} \right], \quad (22)$$

where

$$\zeta_t = \Gamma_t^{-1} \left[R_t + \left(R_{t+1}^Z - R_t - (R_t^L - 1) \frac{\bar{\kappa} - \kappa_t}{\bar{\kappa}} \right) \frac{Q_t^Z}{\kappa_t} \right], \quad (23)$$

is the marginal cost of producing loans. In addition, the Leontief technology implies the following implicit demand functions of interbank borrowing and bank capital:

$$L_t = \Gamma_t (\tilde{D}_t + m_t); \quad (24)$$

$$L_t = \Gamma_t \kappa_t (Q_t^Z Z_t + x_t). \quad (25)$$

Eq.(18) describes the banks leverage ratio as a function of different macroeconomic variables. It shows that κ_t is decreasing in the return rate of loans, R_t^L , and financial intermediation shocks, Γ_t ; whereas it is increasing in bank capital and bank capital prices. Eq.(19) indicates

that the default on interbank borrowing increases in expected inflation and the policy rate, while it decreases in total interbank lending. An increase in expected inflation reduces future default penalty payments. In Eq.(20), the default on bank capital increases in expected inflation, the policy rate, while it decreases in total value of bank capital. Eq.(22) relates the prime lending rate, R_t^L , to the marginal cost of producing loans, ζ_t , and to current costs and future gains of adjusting the prime lending rate.

Eq.(23) indicates that the marginal cost of producing loans depends on the cost of interbank borrowing, R_t , and the shadow price of using capital to satisfy the capital requirement condition. In this case, the marginal cost of bank capital is equal to the difference between R_{t+1}^Z and R_t , the risky return paid on bank capital and the risk-free return on holding bank capital as government bonds, and the marginal benefit of holding bank capital in excess of the required level.²⁵

2.3 Production sector

2.3.1 *Entrepreneurs*

The entrepreneurs' behavior follows BGG (1999). Entrepreneurs, who manage firms that produce wholesale goods, are risk neutral and have a finite expected horizon for planning purposes. The probability that an entrepreneur will survive until the next period is ν . This assumption ensures that entrepreneurs' net worth (the firm equity) is never sufficient to self-finance new capital acquisitions, so they issue debt contracts to finance their desired investment expenditures in excess of net worth.

At the end of each period, entrepreneurs purchase capital, K_{t+1} , that will be used in the next period at the real price Q_t^K . Capital acquisition is financed partly by their net worth, N_t , and by borrowing $L_t = Q_t^K K_{t+1} - N_t$ from lending banks.

The entrepreneurs' demand for capital depends on the expected marginal return and the expected marginal external financing cost at $t + 1$, $E_t F_{t+1}$, which equals the real interest rate on external (borrowed) funds. Optimization guarantees that

$$E_t F_{t+1} = E_t \left[\frac{r_{t+1}^K + (1 - \delta) Q_{t+1}^K}{Q_t^K} \right], \quad (26)$$

²⁵If $\kappa_t = \bar{\kappa}$, then $\zeta_t = \Gamma_t^{-1} [R_t + \bar{\kappa}^{-1} Q_t^Z (R_{t+1}^Z - R_t)]$.

where δ is the capital depreciation rate. The expected marginal return of capital is given by the right-side terms of (26), where r_{t+1}^K is the marginal productivity of capital at $t + 1$ and $(1 - \delta)Q_{t+1}^K$ is the value of one unit of capital used in $t + 1$.

BGG solve a financial contract that maximizes the payoff to the entrepreneur, subject to the lender earning the required rate of return. BGG show that—given parameter values associated with the cost of monitoring the borrower, characteristics of the distribution of entrepreneurial returns, and the expected life span of firms—their contract implies an external finance premium, $\Psi(\cdot)$, that depends on the entrepreneur’s leverage ratio. The underlying parameter values determine the elasticity of the external finance premium with respect to the firm leverage.

In our framework, the marginal external financing cost is equal to a external finance premium plus the gross real prime lending rate. Thus, the demand for capital should satisfy the following optimality condition:

$$E_t F_{t+1} = E_t \left[\frac{R_t^L}{\pi_{t+1}} \Psi(\cdot) \right], \quad (27)$$

where $E_t \left(\frac{R_t^L}{\pi_{t+1}} \right)$ is an expected real prime lending rate (with R_t^L set by the lending bank and depends on the marginal cost of making loans) and the external finance premium is given by

$$rp_t \equiv \Psi(\cdot) = \Psi \left(\frac{Q_t^K K_{t+1}}{N_t}; \psi_t \right), \quad (28)$$

with $\Psi'(\cdot) < 0$ and $\Psi(1) = 1$, and ψ_t represents an aggregate riskiness shock.

The external finance premium, $\Psi(\cdot)$, depends on the borrower’s equity stake in a project (or, alternatively, the borrower’s leverage ratio). As $Q_t^K K_{t+1}/N_t$ increases, the borrower increasingly relies on uncollateralized borrowing (higher leverage) to fund the project. Since this raises the incentive to misreport the outcome of the project, the loan becomes riskier, and the cost of borrowing rises.²⁶ In particular, the external finance premium is assumed to have the following functional form

$$rp_t \equiv \Psi(\cdot) = \left(\frac{Q_t^K K_{t+1}}{N_t} \right)^{\psi_t}, \quad (29)$$

where ψ_t is a time-varying elasticity of the external finance premium with respect to the entrepreneurs’ leverage ratio. Following Christiano *et al.* (2009), we assume that ψ_t is an

²⁶When loans riskiness increases, the agency costs rise and the lender’s expected losses increase. A higher external finance premium paid by successful entrepreneurs offsets these higher losses.

aggregate riskiness shock that follows an AR(1) process. BGG (1999) show that this elasticity, $\psi > 0$, depends on the standard deviation of the distribution of the entrepreneurs idiosyncratic shocks, the agency cost and the entrepreneurs' default threshold. Therefore, a positive shock to ψ_t may result from exogenous increases in the distribution of the entrepreneurs' idiosyncratic shocks, the agency costs, and/or the entrepreneurs' default threshold. The result is a rise in ψ_t and thus in the external finance premium.²⁷

Aggregate entrepreneurial net worth evolves according to

$$N_t = \nu V_t + (1 - \nu)g_t, \quad (30)$$

where V_t denotes the net worth of surviving entrepreneurs net of borrowing costs carried over from the previous period, $1 - \nu$ is the share of new entrepreneurs entering the economy, and g_t is the transfer or "seed money" that new entrepreneurs receive from entrepreneurs who exit.²⁸ V_t is given by

$$V_t = [F_t Q_{t-1}^K K_t - E_{t-1} F_t (Q_{t-1}^K K_t - N_{t-1})], \quad (31)$$

where F_t is the ex post real return on capital held in t , and

$$E_{t-1} F_t = E_{t-1} \left[\frac{R_{t-1}^L}{\pi_t} \Psi \left(\frac{Q_{t-1}^K K_t}{N_{t-1}}; \psi_{t-1} \right) \right]$$

is the cost of borrowing (the interest rate in the loan contract signed in time $t - 1$). Earnings from operations in this period become next period's net worth. In our formulation, borrowers sign a debt contract that specifies a nominal interest rate.²⁹ The loan repayment (in real terms) will then depend on the ex post real interest rate. An unanticipated increase (decrease) in inflation will reduce (increase) the real cost of debt repayment and, therefore, will increase (decrease) entrepreneurial net worth.

To produce output Y_t , the entrepreneurs use K_t units of capital and H_t units of labor following a constant-returns-to-scale technology:

$$Y_t \leq A_t K_t^\alpha H_t^{1-\alpha}, \quad \alpha \in (0, 1), \quad (32)$$

²⁷A positive shock to the standard deviation widens the entrepreneurs' distribution, so lending banks are unable to distinguish the quality of the entrepreneurs.

²⁸The parameter ν will affect the persistence of changes in net worth.

²⁹In BGG, the contract is specified in terms of the real interest rate.

where A_t is a technology shock common to all entrepreneurs and it assumed to follow a stationary an AR(1) process. Each entrepreneur sells his output in a perfectly competitive market for a price that equals his nominal marginal cost. The entrepreneur maximizes profits by choosing K_t and H_t subject to the production function (32). See Appendix A for entrepreneurs' first-order conditions.

2.3.2 Capital producers

Capital producers use a linear technology, subject to an investment-specific shock Υ_t , to produce capital goods K_{t+1} , sold at the end of period t . They use a fraction of final goods purchased from retailers as investment goods, I_t , and the existing capital stock to produce new capital goods. The new capital goods replace depreciated capital and add to the capital stock. The disturbance Υ_t is a shock to the marginal efficiency of investment. Since I_t is expressed in consumption units, Υ_t influences the amount of capital in efficiency units that can be purchased for one unit of consumption. Capital producers are also subject to quadratic investment adjustment costs specified as $\frac{\chi_I}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 I_t$.

The capital producers' optimization problem, in real terms, consists of choosing the quantity of investment I_t to maximize their profits, so that:

$$\max_{I_t} E_t \sum_{t=0}^{\infty} \beta_w^t \lambda_t^w \left\{ Q_t^K \left[\Upsilon_t I_t - \frac{\chi_I}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 I_t \right] - I_t \right\}. \quad (33)$$

Thus, the optimal condition is

$$\frac{1}{Q_t^K} = \Upsilon_t - \chi_I \left(\frac{I_t}{I_{t-1}} - 1 \right) \frac{I_t}{I_{t-1}} + \beta_w \chi_I E_t \left[\left(\frac{I_{t+1}}{I_t} - 1 \right) \left(\frac{I_{t+1}}{I_t} \right)^2 \frac{Q_{t+1}^K}{Q_t^K} \frac{\lambda_{t+1}^w}{\lambda_t^w} \right], \quad (34)$$

which is the standard Tobin's Q equation that relates the price of capital to marginal adjustment costs. Note that in the absence of investment adjustment costs, capital price Q_t^K is constant and equals 1. We introduce investment adjustment costs in the model to allow for capital price variability, which contributes to the volatility of entrepreneurial net worth.

The quantity and price of capital are determined in the capital market. The entrepreneurial demand curve for capital is determined by equations (27) and (A.5), whereas the supply of capital is given by equation (34). The intersection of these curves gives the market-clearing

quantity and price of capital. Capital adjustment costs slow down the response of investment to different shocks, which directly affects the price of capital.

Furthermore, the aggregate capital stock evolves according to

$$K_{t+1} = (1 - \delta)K_t + \Upsilon_t I_t - \frac{\chi I}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 I_t, \quad (35)$$

where δ is the capital depreciation rate, and the shock Υ_t follows an AR(1) process.

2.3.3 Retail firms

The retail sector is used to introduce nominal rigidity into this economy. Retail firms purchase the wholesale goods at a price equal to their nominal marginal cost and diversify them at no cost. They then sell these differentiated retail goods in a monopolistically competitive market. Following Calvo (1983) and Yun (1996), we assume that each retailer cannot reoptimize its selling price unless it receives a random signal. The constant probability of receiving such a signal is $(1 - \phi_p)$; and, with probability ϕ_p , the retailer j must charge the same price at the preceding period, indexed to the steady-state gross rate of inflation, π . At time t , if the retailer j receives the signal to reoptimize, it chooses a price $\tilde{P}_t(j)$ that maximizes the discounted, expected real total profits for l periods.

2.4 Central bank and government

2.4.1 Central bank

We assume that the central bank adjusts the interbank rate, R_t , which is also the nominal risk-free interest rate, in response to deviations of inflation, π_t , and output, Y_t , from their steady-state values. Thus monetary policy evolves according to the following Taylor-type policy rule:

$$\frac{R_t}{R} = \left(\frac{\pi_t}{\pi} \right)^{\rho_\pi} \left(\frac{Y_t}{Y} \right)^{\rho_Y} \exp(\varepsilon_{Rt}) \quad (36)$$

where R , π , and Y are the steady-state values of R_t , π_t , and Y_t , respectively; and ε_{Rt} is a monetary policy shock normally distributed with zero mean and standard deviation σ_R .

During financial crisis periods, the central bank can use unconventional monetary policies: quantitative and/or qualitative monetary easing shocks, m_t and x_t . Therefore, it can inject

liquidity into the banking system and/or swap a fraction of banks loans for risk-free assets (government bonds) used to enhance banks' capital position.

2.4.2 Government

Each period, the government buys a fraction of the final good G_t , reimburses its last period contracted debt, and makes interest payments. We assume that the government runs a balanced budget financed with lump-sum taxes, $\tilde{T}_t^w + \tilde{T}_t^b$. Therefore, government's budget in real terms is

$$G_t + \left[B_{t-1} + B_{t-1}^{sb} + B_{t-1}^{lb} \right] R_{t-1}/\pi_t = B_t + B_t^{sb} + B_t^{lb} + \tilde{T}_t^w + \tilde{T}_t^b \quad (37)$$

where $B_t^{sb} = (1 - s_t)D_t$ and $B_t^{lb} = Q_t^Z Z_t + \tilde{m}_t$ are government bonds held by saving and lending banks, respectively. We assume that government spending G_t follows an AR(1) process.

2.5 Markets clearing

Under Ricardian equivalence, government bonds held by bankers are equal to zero, so $B_t = 0$ in equilibrium. The real aggregate money stock, M_t , is composed of workers' money demand: deposit and cash balances and money injections from quantitative monetary easing shocks, such that $M_t = D_t + M_t^c + m_t$. The newly created money is transferred to workers, so that $T_t = M_t - M_{t-1}/\pi_t$.

Lastly, the resource constraint implies that $Y_t = C_t^w + C_t^b + I_t + G_t + \omega_t$, where ω_t represents the default penalties minus the gains of excess bank capital holdings. Total consumption, C_t , is simply the sum of workers and bankers consumption. Thus, $C_t = C_t^w + C_t^b$.

2.6 Shock processes

A part from monetary policy shock, ε_{Rt} , which is a zero-mean i.i.d. shock with a standard deviation σ_R , the other structural shocks follow AR(1) processes:

$$\log(X_t) = (1 - \rho_X) \log(X) + \rho_X \log(X_{t-1}) + \varepsilon_{Xt}, \quad (38)$$

where $X_t = \{A_t, \Upsilon_t, e_t, G_t, \psi_t, \Gamma_t, x_t, m_t\}$, $X > 0$ is the steady-state value of X_t , $\rho_X \in (-1, 1)$, and ε_{Xt} is normally distributed with zero mean and standard deviation σ_X .

3. Calibration

We calibrate the model's parameters to capture the key features of the U.S. economy for the period 1980Q1–2008Q4. Table 3 reports the calibration values. The steady-state gross domestic inflation rate, π , is set equal to 1.0075, which is the historical average in the sample. The discount factors, β_w and β_b , are set to 0.9979 and 0.9943 to match the historical averages of nominal deposit and risk-free interest rates, R_t^D and R_t^L . (See Table 4 for the steady-state values of some key variables). The risk aversion parameters in workers' and bankers' utility functions, γ_w and γ_b , are set to 3 and 2, respectively, as we assume that workers are more risk averse than bankers. Assuming that workers allocate one third of their time to market activities, we set η , the parameter determining the weight of leisure in utility, and ς , the inverse of the elasticity of intertemporal substitution of labour, to 0.996 and 1, respectively. The weight of real cash balances in the workers utility function, ϖ , is set to 0.0003, so that, in the steady-state equilibrium, real cash balances is about one tenth of the money stock, matching the ratio of M1 to M2 that observed in the data. The parameter ν is set to 4, implying a money-interest elasticity of 0.25. The habit formation parameter, φ , is set to 0.65, a commonly used value.

The capital share in the production α and the capital depreciation rate, δ , are set to 0.33 and 0.025, respectively; values commonly used in the literature. The parameter measuring the degree of monopoly power in the retail market θ is set to 6, which implies a 20 percent markup in the steady-state equilibrium. The parameters ϑ_D and ϑ_L that measure the degree of monopoly power of saving and lending banks are set equal to 2.9 and 2.91, respectively. These values are set to match the historical averages of deposit and prime lending rates, R^D and R^L , (see Table 4.)

The nominal price rigidity parameter ϕ_p in the Calvo-Yun contract setting, is set to 0.75, implying that the average price remains unchanged for four quarters. This value is estimated in Christensen and Dib (2008) for the U.S. economy and commonly used in the literature. The parameters of the adjustment costs of deposit and prime lending interest rates, ϕ_{RD} and ϕ_{RL} , are respectively set to 40 and 55 to match the standard deviations (volatilities) of deposit and prime lending rates to those observed in the data.

Monetary policy parameters ϱ_π and ϱ_Y are set values of 1.2 and 0.05, respectively. These values satisfy the Taylor rule principle. The standard deviation of monetary policy shock, σ_R ,

is given the usually estimated value of 0.006.

The investment and bank capital adjustment cost parameters χ_I and χ_Z are set to 8 and 70, respectively. This is to match the relative volatilities of investment and loans (with respect to output) to those observed in the data. Similarly, the parameter χ_s , which determines the ratio of bank lending to total assets held by the savings banks s_t , is set to 0.0075, so that the steady-state value of s_t is equal to 0.82, which corresponds to the historical ratio observed in the data.³⁰ The parameter χ_κ is set to 2.41, so that the steady-state value of the bank's leverage ratio, κ , is equal to 12, which matches the historical average observed in the U.S. data.

Based on the Basel II minimum required bank capital ratio of 8%, we assume that the maximum imposed bank leverage, $\bar{\kappa}$, is 12.5.³¹ Similarly, we calibrate $\chi_{\delta D}$ and $\chi_{\delta Z}$, the parameters determining total costs of banks' defaults on interbank borrowing and bank capital, so that these probabilities of defaults are equal to 1.6% in annual terms. (See Table 3).

Following BGG (1999), the steady-state leverage ratio of entrepreneurs, $1 - N/K$, is set to 0.5, matching the historical average. The probability of entrepreneurial survival to next period, ν , is set at 0.9833; while ψ , the steady-state elasticity of the external finance premium, is set at 0.05, the value used by BGG and close to the one estimated by Christensen and Dib (2008).³²

We calibrate the shocks' process parameters either using values in previous studies or estimated values. The parameters of technology, preference, and investment-specific shocks are calibrated using the estimated values in Christensen and Dib (2008). To calibrate the parameters of government spending process, we use an OLS estimation of government spending in real per capita terms. (See Appendix B.) The estimated values of ρ_G , the autocorrelation coefficients, is 0.81; while the estimated standard errors, σ_G , is 0.0166. These values are very similar to those commonly used in the literature.

To calibrate the parameters of the riskiness shock process ψ_t , we set the autocorrelation coefficient ρ_ψ at 0.83, the estimated value in Christiano *et al.* (2009), while the standard error σ_ψ is set to 0.05 to match the volatility of the external risk premium to that observed in the data, measured the difference between Moody's BAA yield corporate bond yields and the 3Month T-bill rate. We set the autocorrelation coefficient and the standard error of financial

³⁰In the data, the ratio of total government securities held by banks to their assets, $1 - s$, is 0.18.

³¹This is because the maximum bank leverage ratio is simply the inverse of the minimum required bank capital ratio, which is 8% in Basel II Accords.

³²Christensen and Dib (2008) estimate ψ at 0.046 for the U.S. economy.

intermediation process ρ_Γ and σ_Γ to 0.8 and 0.003, respectively. These values are motivated by the potential persistence and low volatility of this financial shock.³³

Finally, we set the autocorrelation coefficients of quantitative and qualitative monetary easing shocks, ρ_m and ρ_x , equal to 0.5, and their standard deviations, σ_m and σ_x , to 0.

4. Empirical results

4.1 Impulse responses

To assess the contribution of the banking sector in our baseline model, we plot the impulse responses of key macroeconomic variables to the structural shocks in three models: (1) the full model with banking sector (baseline, hereafter) and (2) a model with only a financial accelerator mechanism (FA model, hereafter). Figures 1 to 6 display the impulse responses shocks to technology, monetary policy, riskiness, financial intermediation, and quantitative and qualitative monetary easing). Each variable's response is expressed as the percentage deviation from its steady-state level.

Figure 1 shows that, the effects of a 1% positive technology shock on output and investment are amplified when the banking sector is present. There is a significant amplification of investment and larger effects on the external finance premium and loans. Nevertheless, following the technology shock nominal interest rates and inflation fall. The decline in inflation increases the real cost of repaying existing debt, creating a debt-deflation effect which pushes down net worth. Lower net worth increases the external finance premium and demand for loans. As a result, the response of loans to the technology shock are larger in the model with the banking sector, indicating that firms need further external funds to finance their capital acquisitions.

Figure 1 also shows that following a positive technology shock, the bank leverage ratio decreases on the impact, before moving persistently above its steady-state level. Therefore, bank leverage is procyclical. The bank capital price increases persistently after the shock, while bank capital falls moderately, but for a longer time. We note also, after a positive technology shock, both deposit and prime lending rates decrease, but less than the policy rate.

³³Future work consists of estimating the model's structural parameters using either a maximum likelihood procedure, used in Christensen and Dib (2008), Ireland (2003) and Dib(2003), or a Bayesian approach used in Christiano *et al.* (2009), Dib *et al.* (2008), Elkdag *et al.* (2006), Queijo von Heideken (2009), and others.

This is due to the presence of the adjustment costs of changing both rates, which implies partial pass-through of policy rate variations to deposit and prime lending rates.

Both defaults on interbank borrowing and bank capital decrease on impact, but the former is very persistent. We also note that, following a technology shock, the fraction of deposits allocated by savings banks to the interbank market increases persistently, easing credit supply. This fact is explained by the lower policy rate (which is the return on risk-free assets) and lower defaults on interbank borrowing. See also Figure 7 in Appendix D for the impulse responses to a 1% investment-efficiency shock.

Figure 2 plots the responses to a negative 1% monetary policy shock. In response to this shock, the nominal interest rate falls sharply and output and investment rise for few quarters. There is a dampening effect of the banking sector. After a monetary policy easing, net worth rises less in the model with the banking sector, because of the smaller increase in capital prices. Therefore, the external finance premium falls further, reflecting the decrease in firm leverage and leading to a higher cost of lending. The higher funding cost of purchasing new capital depresses the demand for investment and the expected price of capital increases slightly above its steady-state value. The presence of the banking sector implies a significant dampening of the impacts of monetary policy shocks on output, investment, net worth, capital prices, and loans, as the responses of these variables in the FA model are almost twice as large as in the baseline model, and persist for longer.

Figure 2 also shows that a monetary policy easing shock moves deposit and prime lending rates in opposite directions: the deposit rate decreases slightly but persistently, while the prime lending rate rises on impact, before falling below its steady-state value. The bank leverage ratio falls on impact before increasing one period later. The default on interbank borrowing increases after a positive monetary policy shock, while the supply of interbank lending increases on impact before persistently dropping below its steady-state level. See also Figure 8 in Appendix D for the impulse responses to a 1% government spending shock.

Figure 3 displays the impulse responses to a 10% riskiness shock. This shock may be interpreted as an exogenous increase in the degree of riskiness in the entrepreneurial sector generated by an increase in the standard deviation of the entrepreneur distribution or by an increase in agency costs paid by banks to monitor entrepreneurs and thus to reduce information asymme-

try. In response to this shock, output, investment, net worth, and prices of capital persistently fall below their steady-state levels in both models. Consumption, however, responds positively to the riskiness shock in the short term before decreasing at longer horizons. On the other hand, inflation and the policy rate move in opposite directions following the shock, increasing in the baseline model, while falling in the FA model.

The impact in the FA model is much larger, implying that the banking sector plays a substantial role in dampening the negative effects of riskiness shocks on the economy. We also note that the external finance premium rises, while loans temporarily decline before jumping above their steady-state levels. Banks react to this shock by increasing their leverage ratio slightly on impact, before persistently reducing it, implying the accumulation of excess bank capital. In addition, after this riskiness shock, both bank defaults increase, while the share of interbank lending in total deposits decreases, reflecting precautionary actions taken by banks.

Figure 4 shows the impulse responses to a 1% positive financial intermediation shock. This is a positive shock to the loan production that leads to rising credit supply without varying the inputs used in the loan production function. Following this shock, loans rise on impact only to fall persistently few quarters later. At the same time, output, investment, net worth, and prices of capital positively respond to this shock. Nevertheless, inflation and policy rate decrease sharply. We note also that the bank leverage ratio is procyclical, and the exogenous expansion raises defaults on interbank borrowing and bank capital, reducing the interbank lending supply.

Note that the external finance premium and deposit and prime lending rates negatively respond to the shock. The instantaneous decline in the prime lending rate is larger than that of the policy rate. This is to accommodate the excess loan supply generated by the positive financial intermediary shock.

Figure 5 displays the impulse responses to a 1% quantitative monetary easing shock, m_t , a positive money injection in the interbank market. This shock gradually increases output, investment, and net worth, while inflation, the policy rate, and the external finance premium decline. We note that loans increase in the short term, but fall in the long run. Thus, firms with sound net worth will borrow less to finance their capital acquisition. As a consequence, they reduce their demand for credit in the medium term. Also, banks respond to this shock

by increasing their leverage ratio and reducing their loanable funds as the fraction of deposits lent out on the interbank market persistently declines.

Banks also reduce their prime lending rates to accommodate the impact of this expansionary monetary shock. Interestingly, defaults rise after this expansionary shock. This reflects the changes in the confidence level of the economic agents with respect to the future riskiness and the health of the economy that results from the easing of monetary conditions.

Finally, Figure 6 displays the impulse responses to a 1% positive qualitative monetary easing shock, x_t , in which the central bank swaps a fraction of banks loans for government bonds used to enhance the bank capital holdings. This shock marginally affects output and investment. It leads, however, to higher inflation and policy rates. This shock also reduces the bank leverage ratio and increases both defaults in the economy. We also note that interbank lending decreases following the increase in the risk-free asset return rate, the policy rate. Also, the marginal cost of producing loans increases because of the increases in the cost of the two factors.

Overall, the presence of an active banking sector, as proposed in this model, amplifies and propagates the impact of the supply-side shocks—technology and investment-efficiency shocks—on output and investment and the price of capital. However, the banking sector has dampening effects in the transmission and propagation of demand-side shocks—monetary policy, preference, and government spending shocks—on real variables. Moreover, the presence of the banking sector strongly dampens the effects of financial shocks on real variables, in particular those of the riskiness shock.

4.2 Volatility and autocorrelations

We consider the model-implied volatilities (standard deviations), relative volatilities, and correlations with output of the main variables of interest. Table 5 reports the standard deviations and relative volatilities of output, investment, consumption, loans, and the external finance premium from the data, and for the two simulated models.³⁴ The standard deviations are expressed in percentage terms. All the model-implied moments are calculated using all the shocks.

³⁴In the data, all series are HP-filtered before calculating their standard deviations as well as their unconditional correlations with output.

Column 3 in Table 5 displays standard deviations, relative volatilities, and unconditional autocorrelations of the actual data. Columns 4–5 reports simulations with the baseline and FA models, respectively. In the data, Panel A shows that the standard deviation of output is 1.27, investment is 6.15, while consumption is 1.06. Loans have a standard deviation of 4.21. The external finance premium, however, is very less volatile; its standard deviation is only 0.38. Also, Panel B shows that investment and loans are 4.84 and 3.31 times as volatile as output, while consumption and the external finance premium are less volatile than output, with relative volatilities of 0.83 and 0.30, respectively. The data also show, in Panel C, that output, investment, loans, and the external finance premium are highly persistent, with autocorrelation coefficients larger than 0.8; while consumption is moderately autocorrelated, with an autocorrelation coefficient of 0.73.

The simulation results show that in the model with an active banking sector, all volatilities, except that of the loans, are close to those in the data. The FA model, in which the banking sector is absent, overpredicts all the volatilities, except that of loans. This feature is common in standard sticky-price models. The baseline model is also very successful at matching the relative volatility of most of the variables. In contrast, the FA model underpredicts the relative volatilities of consumption and loans, but overpredicts that of the external finance premium.

Panel C in Table 5 displays the unconditional autocorrelations of the data and of the key variables generated by the two simulated models. In general, both models show larger autocorrelations in output, investment, consumption and loans than those observed in the data. Both models match the autocorrelation in the external finance premium very well. Interestingly, the baseline model is successful in reproducing negative correlations of the external risk premium, and banks' defaults on interbank borrowing and bank capital with output. Moreover, the model shows that banks' leverage ratio and the share of interbank lending in total deposits are procyclical (positively correlated with output). Thus, during boom periods savings banks and lending banks expand their interbank lending and credit supply to . This helps in reducing the external finance costs of entrepreneurs and push further investment and output.

4.3 Welfare analysis

This section assesses welfare implications of including a banking sector in our baseline model by comparing it to the FA model. Using utility-based unconditional welfare calculations, we assess the welfare costs using different combinations of the model's structural shocks: all shocks, supply, demand, and financial shocks. We compute a weighted average of households' (workers and bankers) steady-state consumption that they are willing to pay to avoid the loss associated with the presence of uncertainty, driven by the shocks in the economy (see Appendix C for further details of the welfare calculation).

Table 7 reports the main findings. Welfare cost is measured in percentage of steady-state total consumption. In all cases, the implied welfare costs of business cycles fluctuations in terms of deterministic steady state are lower in the model with the banking sector. For example, using all shocks, the implied welfare cost is 0.14% of consumption in the deterministic steady state, compared to 0.69% in the FA model. Interestingly, the welfare cost caused by financial shocks is 0.103% of the steady-state of total consumption in the model with the banking sector, while it jumps to 0.47% in the model with only financial accelerator. In addition, the presence of the banking sector almost offsets the negative impacts of supply and demand shocks, as the welfare costs are only 0.001% and 0.051%; whereas, they are 0.08 and 0.135 in the FA model, respectively. Welfare costs associated with financial shocks are about 73% of the total welfare costs in the baseline model, and drop to 0.68% in the model without the banking sector. The effect of the banking sector on welfare, therefore, depends on the nature of the shocks.

Thus, the presence of an active banking sector reduces the impact of the financial shocks, lowers macroeconomic volatilities, and improves social welfare. These results can be explained by the fact that optimizing banks help consumption smoothing by optimally allocating resources between consumption and investment, in effect, offering insurance against business cycles fluctuations.

5. Conclusion

The ongoing global financial crisis highlights the need for DSGE models with real-financial linkages. This has become a key issue in the leading-edge research agenda in central banks and academia. This paper proposes a microfounded framework that incorporates a banking

sector, credit market, and interbank market into a DSGE model to evaluate the role of an active banking sector in business cycles and the contribution of financial shocks to the U.S. economy fluctuations.

Financial frictions are modeled using both the demand and supply sides of credit market. We use the financial accelerator à la BGG (1999) to model the demand-side of credit market. The supply-side of credit market consists of two types of heterogeneous banks that offer different banking services and interact in an interbank market. This model provides rich and rigorous framework to address monetary and financial stability issues. The model includes demand- and supply-sides of credit market and thus allows for policy simulation analysis of factor such as: (1) bank capital regulations; (2) expectations of bank capital prices; (3) endogenous bank defaults on interbank borrowing and bank capital; (4) interest rate spreads resulting from the monopoly power of banks when setting deposit and prime lending rates; (5) optimal choice of banks' portfolio compositions; and (6) optimal choice of banks' leverage ratios.

The model reproduces salient features of the U.S. economy, reproducing volatilities of key macroeconomic variables and their correlations with output, and the pro-cyclical banks' leverage ratio. Banks can affect credit supply conditions and the transmission of real effects of shocks to the economy. Also, financial shocks explain a large fraction of business cycles. We also show that an active banking sector with sticky deposit interest rate is welfare improving. This result is robust to simulations with different shocks. Thus, the main role banks play in this economy is to reduce the effects of uncertainty.

Future work will consist of estimating the model's structural parameters, incorporating credit to households, and extending the framework to an open economy model. The model can be used to address policy and financial stability questions, such as a zero-bound on interest rate, bank capital requirement regulations, and efficiency versus stability of the banking system.

References

- Bernanke, B. and M. Gertler. 1989. "Agency Costs, Net Worth and Business Fluctuations." *American Economic Review* 79: 14–31.
- Bernanke, B., M. Gertler, and S. Gilchrist. 1999. "The Financial Accelerator in a Quantitative Business Cycle Framework." *Handbook of Macroeconomics*. Amsterdam: North Holland.
- Blanchard, O.J. and C.M. Kahn. 1980. "The Solution of Linear Difference Models under Rational Expectations." *Econometrica* 48: 1305–11.
- Calvo, G.A. 1983. "Staggered Prices in a Utility-Maximizing Framework." *Journal of Monetary Economics* 12: 383–98.
- Carlstrom, G. and T.S. Fuerst. 1997. "Agency Costs, Net Worth, and Business Fluctuations: A Computable General Equilibrium Analysis." *American Economic Review* 87: 893–910.
- Céspedes, L.F., R. Chang, and A. Velasco. 2004. "Balance Sheets and Exchange Rate Policy." *American Economic Review* 94(4): 1183–93.
- Chari V.V., L.J. Christiano, and P.J. Kehoe. 2008. "Facts and Myths about the Financial Crisis of 2008." Federal Reserve Bank of Minneapolis Working Paper No. 666.
- Christensen I. and A. Dib. 2008. "The Financial Accelerator in an Estimated New-Keynesian Model." *Review of Economic Dynamics* 11: 155–78.
- Christiano, L., M. Eichenbaum, and C. Evans. 2005. "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy." *Journal of Political Economy* 113: 1–45.
- Christiano, L.J., R. Motto, and M. Rostagno. 2008. "Financial Factors in Economic Fluctuations." Northwestern University Draft.
- Cúrdia, V., and M. Woodford. 2009. "Credit Frictions and Optimal Monetary Policy." Bank for International Settlements Working Paper No. 278.
- De Graeve, F. 2008. "The External Finance Premium and the Macroeconomy: US Post-WWII Evidence." *Journal of Economic Dynamics and Control* 32: 3415–40.
- de Walque G., O. Pierrard, and A. Rouabah. 2009. "Financial (In)stability, Supervision and Liquidity Injections: A Dynamic General Equilibrium Approach." C.E.P.R. Discussion Papers No. 7202.
- Dib, A., C. Mendicino, and Y. Zhang. 2008. "Price Level Targeting in a Small Open Economy with Financial Frictions: Welfare Analysis." Bank of Canada Working Paper No. 2008-40.

- Dib, A. 2003. "An Estimated Canadian DSGE Model with Nominal and Real Rigidities." *Canadian Journal of Economics* 36: 949–72.
- Elekdag, S., A. Justiniano, and I. Tchakarov. 2006. "An Estimated Small Open Economy Model of the Financial Accelerator." *IMF Staff Papers* 53: 219–41.
- Faia, E., and T. Monacelli. 2007. "Optimal Interest Rate Rules, Asset Prices, and Credit Frictions." *Journal of Economic Dynamics and Control* 31: 3228–325.
- Fisher I. 1933. "The Debt Deflation Theory of the Great Depression." *Econometrica* 1: 377–90.
- Fostel, A., and J. Geankoplos. 2008. "Leverage Cycles and the Anxious Economy." *American Economic Review* 98: 1211–44.
- Geankoplos. J. 2008. "The Leverage Cycle." Cowles Foundations Discussion Paper No. 1715.
- Gerali, A., S. Neri, L. Sessa, and F. Signoretti. 2009. "Credit and Banking in a DSGE Model of the Euro Area." Draft, Bank of Italy.
- Gertler, M., S. Gilchrist, and F. Natalucci. 2007. "External Constraints on Monetary Policy and the Financial Accelerator." *Journal of Money, Credit, and Banking*, 39: 295–330.
- Goodfriend, M., and B. T. McCallum. 2007. "Banking and Interest Rates in Monetary Policy Analysis: A Quantitative Exploration." *Journal of Monetary Economics* 54: 1480–507.
- Goodhart, A.E., P. Sunirand, and D.P. Tsomocos. 2006. "A Model to Analyse Financial Fragility." *Economic Theory* 27: 107–42.
- Holmstrom, and J. Tirole. 1997. "Financial Intermediation, Loanable Funds, and the Real Sector." *The Quarterly Journal of Economics* 112: 663–91.
- Iacoviello M. 2005. "House Prices, Borrowing Constraints, and Monetary Policy in the Business Cycles." *American Economic Review* 95: 739–64.
- Ireland P. 2003. "Endogenous Money or Sticky Prices?" *Journal of Monetary Economics* 50: 1623–48.
- Kashyap, A. R.G. Rajan, and J.C. Stein. 2002. "Banks as Liquidity Providers: An Explanation for the Co-Existence of Lending and Deposit-Taking." *Journal of Finance* 57: 33–73.
- Kiyotaki, N. and J. Moore. 1997. "Credit Cycles." *The Journal of Political Economy* 105: 211–48.
- Markovic, B. 2006. "Bank Capital Channels in the Monetary Transmission Mechanism." Bank of England Working Paper No. 313.

- Meh, C. and K. Moran. 2004. "Bank Capital, Agency Costs, and Monetary Policy." Bank of Canada Working Paper No. 2004-6.
- Queijo von Heideken, V. 2009. "How Important are Financial Frictions in the U.S. and the Euro Area?" *Scandinavian Journal of Economics*, forthcoming.
- Rotemberg, J. 1982. "Monopolistic Price Adjustment and Aggregate Output." *Review of Economic Studies* 49: 517–31.
- Taylor, J.B. 1993. "Discretion versus Policy Rules in Practice." *Carnegie-Rochester Conference Series on Public Policy* 39: 195–214.
- Yun, T. 1996. "Nominal Price Rigidity, Money Supply Endogeneity, and Business Cycles." *Journal of Monetary Economics* 37: 345–70.

Table 3: Parameter Calibration: Baseline model

Preferences			
$\beta_w = 0.9979,$	$\beta_b = 0.9943,$	$\gamma_w = 3,$	$\gamma_b = 2,$
$\varpi = 0.0003,$	$v = 4,$	$\eta = 0.994,$	$\varsigma = 1,$
$\varphi = 0.65,$			
Monetary policy			
$\varrho_\pi = 1.2,$	$\varrho_Y = 0.05,$	$\sigma_R = 0.006,$	
Technologies			
$\alpha = 0.33,$	$\delta = 0.025,$		
$\theta = 6,$	$\vartheta_D = 2.9,$	$\vartheta_L = 6.3,$	
Adjustment and default costs			
$\chi_I = 8,$	$\chi_Z = 70,$		
$\chi_s = 0.0003,$	$\chi_\kappa = 2.41,$	$\chi_{\delta^D} = 228.12,$	$\chi_{\delta^Z} = 4478,$
Nominal rigidities			
$\phi_p = 0.75,$	$\phi_{R^D} = 40,$	$\phi_{R^L} = 55,$	
Financial sector			
$\nu = 0.9833,$	$\psi = 0.05,$	$K/N = 2,$	$\bar{\kappa} = 12.5,$
Exogenous processes			
$A = 1,$	$\rho_A = 0.8,$	$\sigma_A = 0.009,$	
$\Upsilon = 1,$	$\rho_\Upsilon = 0.7,$	$\sigma_\Upsilon = 0.033,$	
$e = 1,$	$\rho_e = 0.8,$	$\sigma_e = 0.0073,$	
$G/Y = 0.17,$	$\rho_G = 0.81,$	$\sigma_G = 0.0166,$	
$\psi = 0.05,$	$\rho_\psi = 0.83,$	$\sigma_\psi = 0.050,$	
$\Gamma = 1,$	$\rho_\Gamma = 0.8,$	$\sigma_\Gamma = 0.003,$	
$m = 0,$	$\rho_m = 0.5,$	$\sigma_m = 0.00,$	
$x = 0,$	$\rho_x = 0.5,$	$\sigma_x = 0.00,$	

Table 4: Steady-state values and ratios: Baseline model

Variables	Definitions	Values
<i>A. Steady-state values</i>		
π	inflation	1.0075
R	policy rate	1.0141
R^D	deposit rate	1.0058
R^L	prime lending	1.0219
rp	external finance premium	1.0027
S	fraction of interbank lending	0.82
κ	bank leverage ratio	12
δ^D	default on interbank borrowing	0.004
δ^Z	default on bank capital	0.004
<i>B. Steady-state ratios</i>		
C/Y	consumption to output	0.67
C^w/Y	workers' consumption to output	0.63
C^b/Y	bankers' consumption to output	0.04
I/Y	investment to output	0.16
G/Y	government spending to output	0.17
K/Y	capital stock to output	6.55
Z/Y	Bank capital to output	0.27
Π^S/Y	savings bank profit to output	0.002
Π^L/Y	lending bank profit to output	0.033
M^c/M	real cash balance to money stock	0.11
K/N	capital to entrepreneurs'net worth	2

Table 5: Standard deviations and relative volatilities:
(Data 1980:1–2008:4)

Variables	Definitions	Data	Baseline	FA
<i>A. Standard deviations (in %)</i>				
Y_t	output	1.27	1.48	2.21
I_t	investment	6.15	7.20	9.64
C_t	consumption	1.06	1.26	1.61
L_t	loans	4.21	4.80	4.24
rp_t	external finance premium	0.38	0.44	0.51
<i>B. Relative volatilities</i>				
Y_t	output	1	1	1
I_t	investment	4.84	4.86	4.36
C_t	consumption	0.83	0.85	0.73
L_t	loans	3.31	3.25	1.91
rp_t	external finance premium	0.30	0.30	0.23
<i>C. Autocorrelations</i>				
Y_t	output	0.81	0.96	0.98
I_t	investment	0.80	0.98	0.99
C_t	consumption	0.73	0.97	0.98
L_t	loans	0.93	0.99	0.97
rp_t	external finance premium	0.81	0.87	0.89

Table 6: Correlations with output (Data 1980:1–2008:4)

Variables	Definitions	Data	Benchmark	FA
Y_t	output	1	1	1
I_t	investment	0.87	0.79	0.87
C_t	consumption	0.84	0.53	0.43
L_t	loans	0.20	0.30	0.17
rp_t	external finance premium	-0.30	-0.28	-0.55
s_t	Share of interbank lending	+	0.34	.
κ_t	bank leverage ratio	+	0.51	.
δ_t^D	default on interbank borrowing	-	-0.35	.
δ_t^Z	default on bank capital	-	-0.27	.

Table 7: Welfare analysis

	All of the shocks	Supply shocks	Demand shocks	Financial shocks:	
				Risk, ψ_t	All
<i>A. Baseline model</i>					
Welfare cost (in % of the steady state of consumption)	0.1406	0.0097	0.0511	0.0622	0.1030
<i>B. FA model</i>					
Welfare cost (in % of the steady state of consumption)	0.6953	0.0785	0.1346	0.4710	

Welfare costs in terms of steady state of total consumption as percentage.

Figure 1: Responses to a 1% Positive Technology Shock

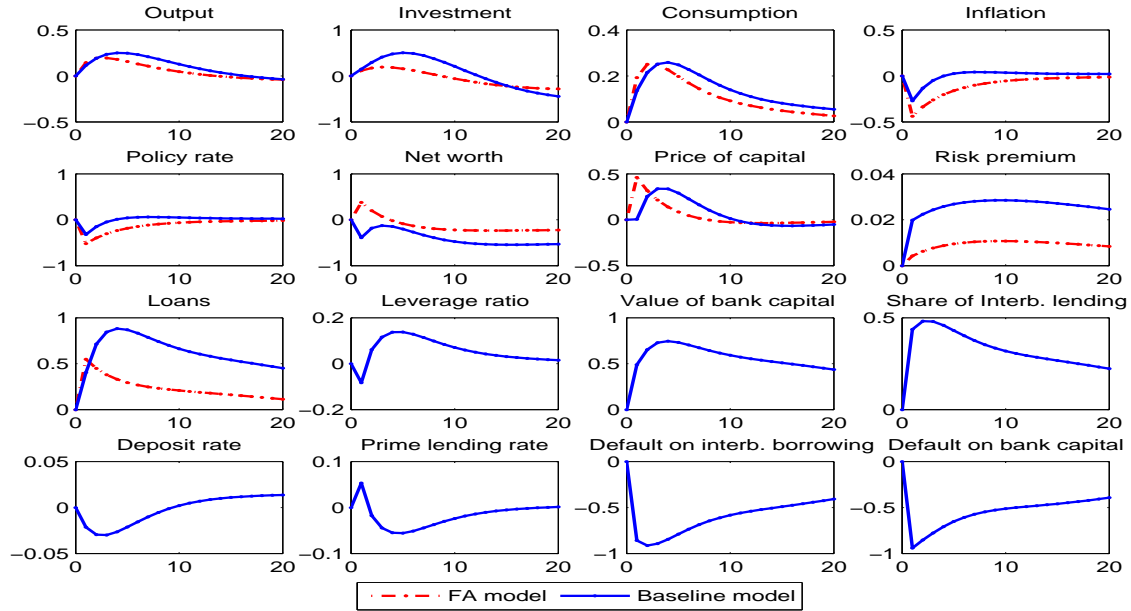


Figure 2: Responses to an Expansionary Monetary Policy Shock

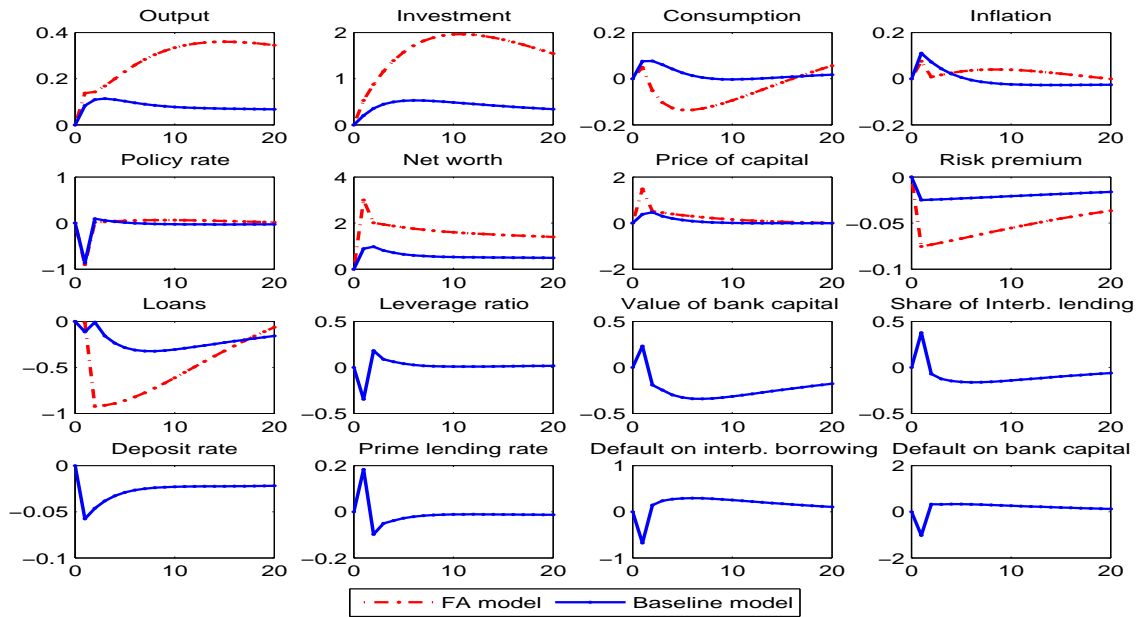


Figure 3: Responses to a 10% Increase in the Riskiness Shock

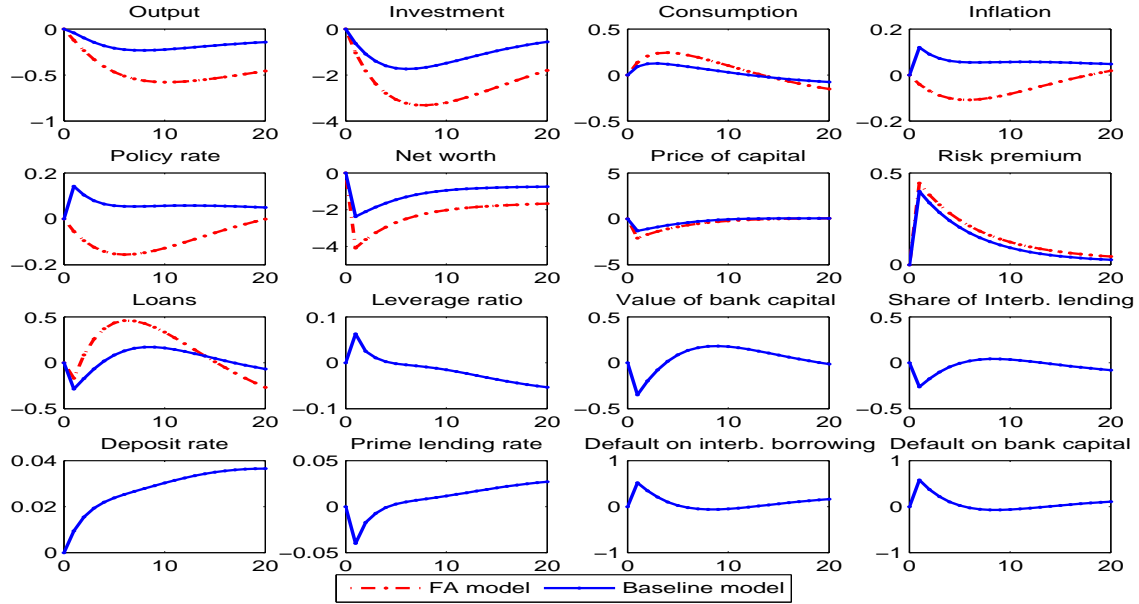


Figure 4: Responses to a 1% Positive Financial Intermediation Shock

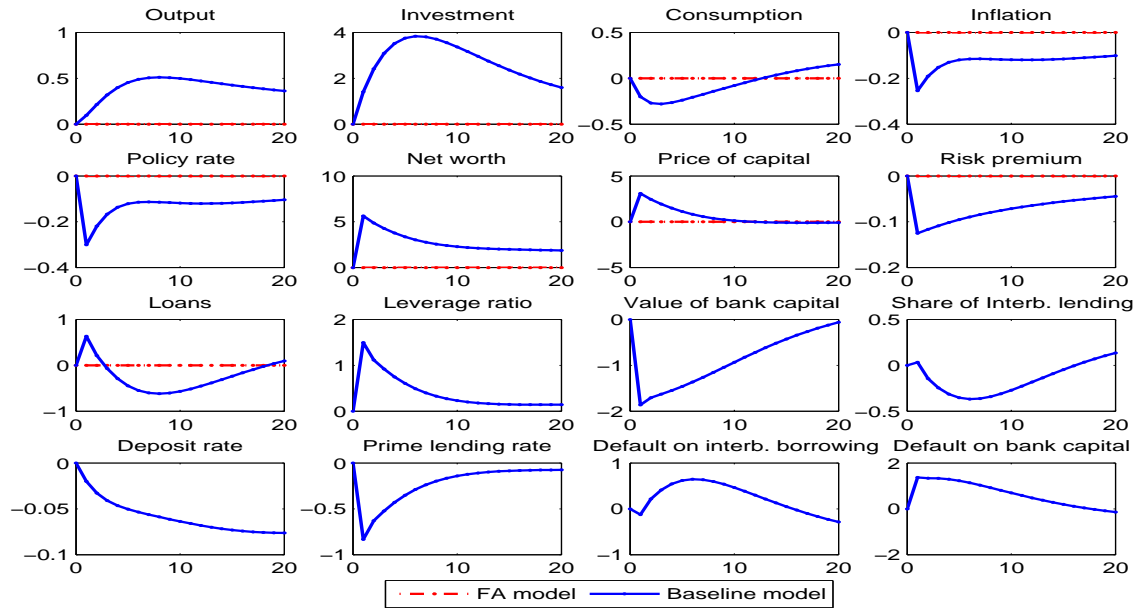


Figure 5: Responses to a 1% Positive Quantitative Monetary Easing Shock, m_t

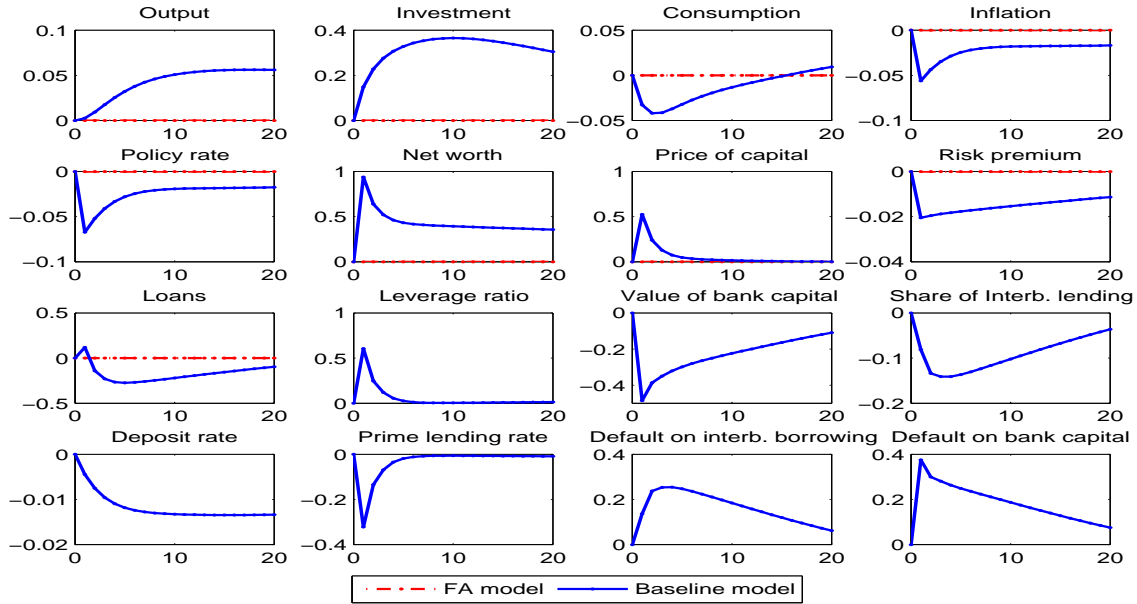
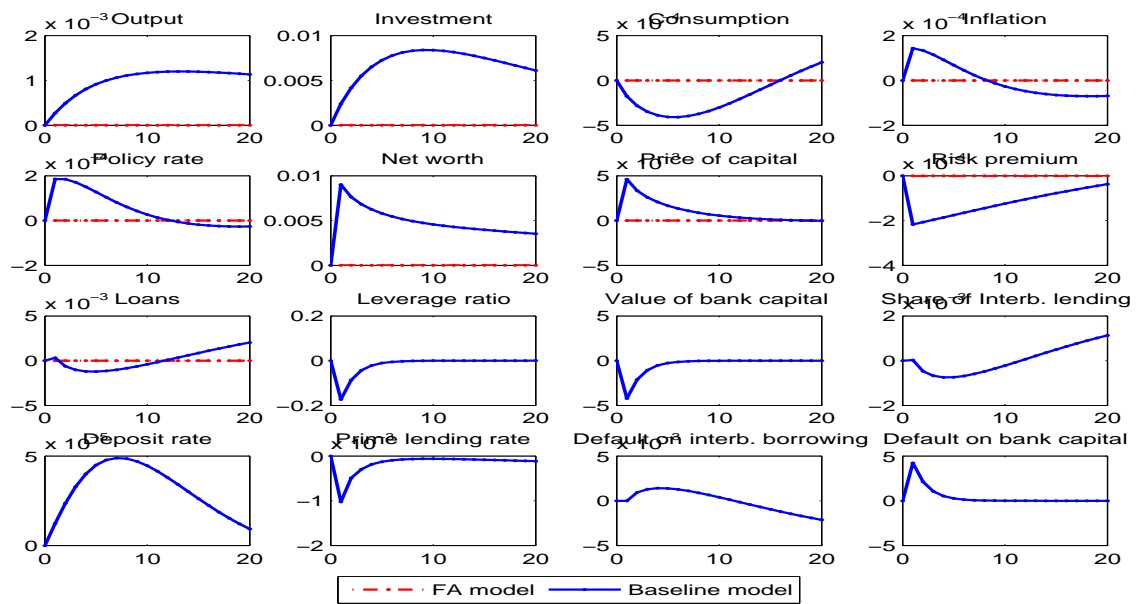


Figure 6: Responses to a 1% Positive Qualitative Monetary Easing Shock, x_t



Appendix A: First-Order Conditions

A.1. Workers' first-order conditions

The first-order conditions of the workers optimization problem are:

$$e_t \left(\frac{C_t^w}{(C_{t-1}^w)^\varphi} \right)^{1-\gamma_w} - \beta_w \varphi E_t \left[e_{t+1} \left(\frac{C_{t+1}^w}{(C_t^w)^\varphi} \right)^{1-\gamma_w} \right] = C_t^w \lambda_t^w; \quad (\text{A.1})$$

$$\frac{\varpi}{(M^e)_t^v} = \lambda_t^w \left(1 - \frac{1}{R_t^D} \right); \quad (\text{A.2})$$

$$\frac{\eta}{(1-H_t)^\varsigma} = \lambda_t^w W_t; \quad (\text{A.3})$$

$$\frac{\lambda_t^w}{R_t^D} = \beta_w E_t \left(\frac{\lambda_{t+1}^w}{\pi_{t+1}} \right), \quad (\text{A.4})$$

where λ_t^w is the Lagrangian multiplier associated with the budget constraint.

A.2. Entrepreneurs' first-order conditions

The first-order conditions of the entrepreneurs' optimization problem are:

$$r_t^K = \alpha \xi_t \frac{Y_t}{K_t}; \quad (\text{A.5})$$

$$W_t = (1-\alpha) \xi_t \frac{Y_t}{H_t}; \quad (\text{A.6})$$

$$Y_t = A_t K_t^\alpha H_t^{1-\alpha}, \quad (\text{A.7})$$

where $\xi_t > 0$ is the real marginal cost.

A.3. The retailer's optimization problem

The retailer's optimization problem is

$$\max_{\{\tilde{P}_t(j)\}} E_0 \left[\sum_{l=0}^{\infty} (\beta_w \phi_p)^l \lambda_{t+l}^w \Pi_{t+l}^R(j) \right], \quad (\text{A.8})$$

subject to the demand function³⁵

$$Y_{t+l}(j) = \left(\frac{\tilde{P}_t(j)}{P_{t+l}} \right)^{-\theta} Y_{t+l}, \quad (\text{A.9})$$

where the retailer's nominal profit function is

$$\Pi_{t+l}^R(j) = \left(\pi^l \tilde{P}_t(j) - P_{t+l} \xi_{t+l} \right) Y_{t+l}(j) / P_{t+l}. \quad (\text{A.10})$$

The first-order condition for $\tilde{P}_t(j)$ is

$$\tilde{P}_t(j) = \frac{\theta}{\theta - 1} \frac{E_t \sum_{l=0}^{\infty} (\beta_w \phi_p)^l \lambda_{t+l}^w Y_{t+l}(j) \xi_{t+l}}{E_t \sum_{l=0}^{\infty} (\beta_w \phi_p)^l \lambda_{t+l}^w Y_{t+l}(j) \pi^l / P_{t+l}}. \quad (\text{A.11})$$

The aggregate price is

$$P_t^{1-\theta} = \phi_p (\pi P_{t-1})^{1-\theta} + (1 - \phi_p) \tilde{P}_t^{1-\theta}. \quad (\text{A.12})$$

These lead to the following equation:

$$\hat{\pi}_t = \beta_w E_t \hat{\pi}_{t+1} + \frac{(1 - \beta_w \phi_p)(1 - \phi_p)}{\phi_p} \hat{\xi}_t, \quad (\text{A.13})$$

where ξ_t is the real marginal cost, and variables with hats are log deviations from the steady-state values (such as $\hat{\pi}_t = \log(\pi_t/\pi)$).

³⁵This demand function is derived from the definition of aggregate demand as the composite of individual final output (retail) goods and the corresponding price index in the monopolistic competition framework, as follows: $Y_{t+l} = \left(\int_0^1 Y_{t+l}(j)^{\frac{\theta-1}{\theta}} dj \right)^{\frac{\theta}{\theta-1}}$ and $P_{t+l} = \left(\int_0^1 P_{t+l}(j)^{1-\theta} dj \right)^{\frac{1}{1-\theta}}$, where $Y_{t+l}(j)$ and $P_{t+l}(j)$ are the demand and price faced by each individual retailer $j \in (0, 1)$.

Appendix B: Data

1. Loans are measured by Commercial and Industrial Loans of all Commercial Banks (BUS-LOANS), quarterly and seasonally adjusted;
2. The external finance premium is measured by the difference between Moody's BAA corporate bond yields and 3-Month Treasury Bill (TB3MS);
3. Inflation is measured by quarterly changes in GDP deflator ($\Delta \log(GDPD)$).
4. Prime lending rate is measured by Bank Prime Loan Rate (MPRIME);
5. Monetary policy rate is measured by the 3-Month Treasury Bill (TB3MS);
6. Deposit rate is measured by weighted average of the rates received on the interest-bearing assets included in M2 (M2OWN);
7. Real cash balances is measured by real M1 money stock per capita;
8. Real money stock is measured by real M2 money stock per capita;
9. Output is measured by real GDP per capita;
10. Total Consumption is measured by Personal Consumption Expenditures (PCEC);
11. Investment is measured by Gross Private Domestic Investment (GPDI);
12. Government spending is measured by output minus consumption and investment ($GDP - PCEC - GPDI$).

Appendix C: Welfare calculation

We use the second approximation procedure to calculate welfare. We define the present discounted value of the workers and bankers utility as:

$$V_t^w = \sum_{t=0}^{\infty} u(C_t^w, M_t^c, H_t),$$

and

$$V_t^b = \sum_{t=0}^{\infty} u(C_t^b),$$

where $u(\cdot)$ denotes the single-period utility of workers and bankers.

Let λ_{ss}^w and λ_{ss}^b be the marginal utility of workers and bankers' at the deterministic steady state. Therefore, the weighted average welfare cost is

$$\frac{\Delta C}{C_{ss}} = \frac{C_{stoch} - C_{ss}}{C_{ss}} = a \frac{V_{stoch}^w - V_{ss}^w}{\lambda_{ss}^w C_{ss}^w} + (1 - a) \frac{V_{stoch}^b - V_{ss}^b}{\lambda_{ss}^b C_{ss}^b},$$

where *stoch* and *ss* denote stochastic and deterministic steady-state means of total consumption, workers and bankers' consumption, discounted values of utility, and the marginal utilities; the parameter a is the share of workers' consumption in the total consumption, so that

$$a = \frac{C_{ss}^w}{C_{ss}^w + C_{ss}^b}.$$

Appendix D: Impulse Responses

Figure 7: Responses to a 1% Positive Investment-Efficiency Shock

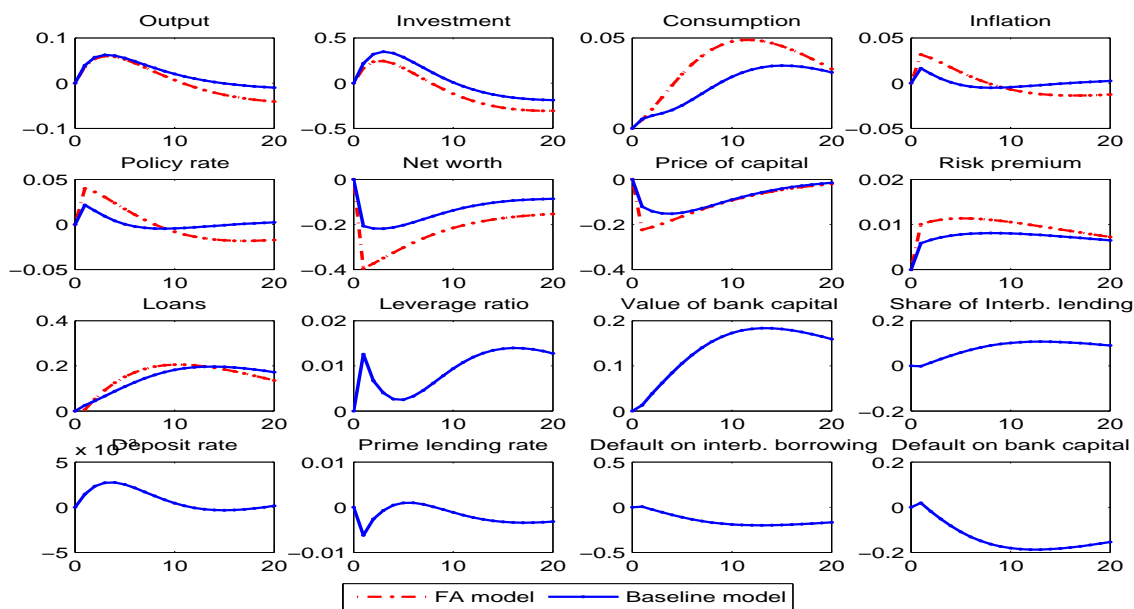


Figure 8: Responses to a 1% Positive Government Spending Shock

