# Banks, Credit Market Frictions, and Business Cycles[*]

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## Abstract

This paper proposes a fully micro-founded framework that incorporates an active banking sector into a DSGE model with a financial accelerator. Then, it evaluates the role and importance of banks' behavior and financial shocks in U.S. business cycles. The banking sector consists of two types of profit-maximizing banks that offer different banking services and transact in an interbank market. Loans are produced using interbank borrowing and bank capital subject to a bank capital requirement condition. Banks have monopoly power, set nominal deposit and prime lending rates, choose their leverage ratio and their portfolio composition, and can endogenously default on a fraction of their interbank borrowing. Also, the model includes two unconventional monetary policies. Overall, because it is costly to raise fresh bank capital to satisfy the requirement condition, the active banking sector, as modelled in this paper, dampens the real impacts of aggregate shocks. Specifically, it attenuates the real effects of financial shocks, reduces macroeconomic volatilities, and stabilizes the economy. Moreover, expansionary unconventional monetary policies reduce negative impacts of financial crises.

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# 1. Introduction

In light of the recent financial crisis, real-financial linkages have become the focus of attention of an increasing number of papers that aim to develop DSGE models with financial frictions in both the demand- and supply-sides of credit markets. Such models would allow understanding the role of the banking sector in macroeconomic fluctuations, providing a structural framework to examine banks' behavior in the transmission and propagation of aggregate shocks, and an assessment of the importance of financial shocks, originating in the banking sector, as a source of the business cycles. Before the financial crisis, the banking sector, however, has been ignored in most DSGE models developed in the literature, except some recent papers.[1] Moreover, in the literature, financial frictions are usually modelled only on the demand side of credit markets using usually either the Bernanke, Gertler and Gilchrist (1999) financial accelerator mechanism (BGG, hereafter) or the Iacovello (2005) framework.[2] This is influenced by the Modigliani–Miller theorem in which the capital structure is irrelevant for investment decisions.

This paper proposes a microfounded framework that incorporates an active banking sector, which includes an interbank market and is subject to the bank capital requirement condition, into a DSGE model with a financial accelerator à la BGG.[3] Unlike previous studies that incorporate bank capital to solve the moral hazard problem between households and banks, this paper introduces bank capital to satisfy the capital requirement condition exogenously imposed by regulators.[4] It is a pre-condition for banks to operate and provide loans to entrepreneurs. Therefore, this requirement condition allows bank capital to act as an attenuation mechanism of the real impacts of aggregate shocks, rather then an amplification mechanism as in these previous studies. For instance, in the event of a positive shock, an increase in borrowing demand by entrepreneurs forces banks to increase their leverage ratio and/or bank capital holdings to be able to extend their loan supply. Higher leverage ratio and/or higher bank capital imply higher marginal costs of raising bank capital and, thus, higher marginal costs of producing

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[1]For example, Goodfriend and McCallum (2007), Markovic (2006), and van Den Heuvel (2006).

[2]For example, Carlstrom and Fuerst (1997), Cespedes, Chang and Velasco (2004), Faia and Monacelli (2007), Christensen and Dib (2008), De Graeve (2008), and Queijo von Heideken (2009).

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

[4]Examples of these studies are Holmstrom and Tirole (1997), Gertler and Kiyotaki (2010), Goodfriend and McCallum (2007), Markovic (2006), Meh and Moran (2010), and others.

loans. Banks transfer this additional costs to entrepreneurs by charging a higher prime lending rate. This increases external financing costs and erodes a part of initial entrepreneurs' demand for loans to finance new investment. Consequently, increase in investment and output will be smaller in the presence of the capital requirement condition.

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, Pierrard and Rouabah (2009), Gerali, Neri, Sessa and Signoretti (2010), Gertler and Karadi (2010), and Gertler and Kiyotaki (2010). Our model is a DSGE model for a closed economy based on BGG. The key addition is formally modelling an active banking sector that includes an interbank market and subject to the bank capital requirement condition. 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 transact in the interbank market.[5] Saving banks refer to all financial intermediaries that are net lender (creditor) in the interbank market, while lending banks are net borrower (debtor). Banks have the monopoly power when setting nominal deposit and prime lending rates, but subject to quadratic adjustment costs.

Savings banks collect deposits from workers, set nominal deposit rates, and optimally choose the composition of their portfolio (composed of government bonds and risky interbank lending). Lending banks borrow from savings banks in the interbank market and raise bank capital (equity) from household (shareholders) in the financial market to satisfy the bank capital requirement condition.

In addition, lending 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.[6] 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 have substantial effects on business cycles fluctuations, as pointed out by Fostel and Geanakopolos (2008) and Geanakopolos (2009). Following Goodhart *et al.* (2006), we assume endogenous strategic defaults on bank in-

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[5]The two different banks are necessary to generate heterogeneity, which in turn leads to an interbank market where different banks can interact.

[6]The cost of bank capital depends on the bank's capital position. If banks hold bank capital in excess, the marginal cost of raising equity in the financial market will be lower, since banks are well capitalized.

terbank borrowing. Also, as in Gertler and Kiyotaki (2010), lending banks' mangers can divert a fraction of bank capital received from shareholders for their own benefit. Nevertheless, when defaulting on interbank borrowing or diverting a fraction of bank capital, lending banks must pay convex penalties in the next period. Finally, to introduce unconventional (quantitative and qualitative) monetary policies in the model, we assume that the lending banks can receive, if needed, money injection from the central bank and/or swap a fraction of their loans (risky assets) for government bonds.[7]

In this framework, variations in a bank's balance sheet can affect credit supply conditions and, thus, the real economy through the following channels: (1) variations in marginal costs of raising bank capital; (2) the optimal choice of the banks' leverage ratio subject to the capital requirement condition; (3) monopoly power in setting nominal deposit and lending interest rates with nominal rigidities implying time-varying interest rate spreads over business cycles;[8] (4) the optimal allocation of the banks' portfolio between interbank lending (risky-assets) and risk-free asset holdings; and (5) the default risk channels that arise from the endogenous default on interbank borrowing and diversion of a fraction of bank capital.

The economy is subject to two supply and demand shocks, financial shocks (riskiness and financial intermediation process), and unconventional monetary policy shocks. Supply and demand shocks are commonly used in the literature; however, financial shocks require some explanation. Riskiness shocks are modelled 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 in Christiano *et al.* (2009), shocks to agency costs paid by lending banks to monitor entrepreneurs' output, and/or shocks to entrepreneurs' default threshold.[9] These shocks may be interpreted as exogenous changes in the confidence of banks with credit risks in their borrowers and/or the overall health of the economy. Shocks to financial intermediation process are exogenous events that affect the credit supply of lending banks. They may represent technological advances or disruptions in

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[7]Quantitative monetary easing, which is associated with newly created money, expands banks' balance sheets; while Qualitative monetary easing (swapping banks' assets for government bonds) changes only banks' assets compositions.

[8]See Cúrdia and Woodford (2009a) for the importance of time-varying spreads on monetary policy.

[9]As shown in Bernanke *et al.* (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.

the intermediation process, or approximate perceived changes in creditworthiness.[10] Finally, unconventional monetary policy shocks include quantitative and qualitative monetary easing shocks used by the central banks to provide money to the banking system and to enhance banks' conditions during the times of financial crises.

The model is calibrated to the U.S. economy and used to evaluate the role of the banking sector in the transmission and propagation of real effects of aggregate shocks, to assess the importance of financial shocks in the U.S. business cycle fluctuations, and to examine the potential role of unconventional monetary policies in offsetting the real impacts of financial crises.

The model is successful in reproducing most of the salient features of the U.S. economy: key macroeconomic volatilities, autocorrelations, and correlations with output. Importantly, the impulse responses of key macro variables to different shocks show that, under the capital requirement condition, the active banking sector attenuates the real effects of aggregate shocks, particularly financial shocks, and thus it stabilizes the economy. Moreover, the dynamic effects of financial shocks originating in the banking sector have substantial impacts on the U.S. business cycles, and could be a substantial source of macroeconomic fluctuations. We also find that bank leverage is procyclical, indicating that banks are willing to extend more loans during booms and tend to restrict their supply of credit during recessions.

This paper is organized as follows. In section 2, we present the model. In section 3, we discuss the parameter calibration. In section 4, we report and discuss the empirical results. Section 5 provides the conclusion.

## 2.   The Model

The economy is inhabited by two types of households (workers and bankers) that differ in their degrees of risk aversion and in the access to financial markets. The banking sector consists of two types of heterogenous monopolistically competitive banks. We call them "savings" and "lending" banks to indicate that they offer different banking services, but interact in an interbank market. As in BGG, the production sector consists of entrepreneurs, capital

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

producers, and retailers. Finally, there is a central bank and a government.

## 2.1 Households

### 2.1.1 Workers

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

$$V_0^w = E_0 \sum_{t=0}^{\infty} \beta_w^t u \left( C_t^w, H_t \right). \tag{1}$$

The single-period utility is

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

where $\varphi \in (0, 1)$ is a habit formation parameter; $\gamma_w$ is a positive parameter denoting the workers' risk aversion; and $\varsigma$ is the inverse of the Frisch wage elasticity of labour supply. The parameter $\eta$ measures the weight on leisure in the utility function. $e_t$ is a preference shock that is common to workers and bankers, and follows an AR(1) process.

The representative worker enters period $t$ with $D_{t-1}$ units of real deposits in savings banks. Deposits pay the gross nominal interest rate $R_t^D$ set by savings banks between. During period $t$, workers supply labour to the entrepreneurs, for which they receive real labor payment $W_t H_t$, ($W_t$ is the economy-wide real wage). Furthermore, they receive dividend payments, $\Pi_t^R$, from retail firms, as well as a lump-sum transfer from the monetary authority, $T_t$, and pay lump-sum taxes to government, $\widetilde{T}_t^w$. Workers allocate their funds to private consumption and real deposits, $D_t$. Their budget constraint in real terms is

$$C_t^w + D_t \leq W_t H_t + \frac{R_{t-1}^D D_{t-1}}{\pi_t} + \Pi_t^R + T_t - \widetilde{T}_t^w, \tag{3}$$

where $\pi_{t+1} = P_{t+1}/P_t$ is the gross inflation rate. A representative worker chooses $C_t^w$, $H_t$, and $D_t$ to maximize the expected lifetime utility, Eq. (1), subject to the single-period utility function, Eq. (2), and the budget constraint, Eq. (3). The first-order conditions of this optimization problem are reported in Appendix A.

### 2.1.2 Bankers

Bankers are the owners of the two types of banks, from which they receive profits. They consume, save in government bond, and accumulate bank capital supplied to lending banks. Their preferences depend only on consumption and given by

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

The single-period utility function is

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

where $\gamma_b$ is a positive structural parameter denoting bankers' risk aversion.

Bankers enter period $t$ with $(1 - \delta_{t-1}^Z)Z_{t-1}$ units of the stock of bank capital, whose price is $Q_t^Z$ in period $t$, where $\delta_{t-1}^Z$ is the fraction of bank capital diverted by lending bank managers in $t-1$, and $Z_t$ is the volume of bank equity (shares) held by bankers. Bank capital pays a contingent nominal return rate (dividend), $R_t^Z$. Bankers also enter period $t$ with $B_{t-1}$ units of government bonds that pay the risk-free nominal interest rate $R_t$. During period $t$, bankers receive profit payments, $\Pi_t^{sb}$ and $\Pi_t^{lb}$, from savings and lending banks, and pay lump-sum taxes to government, $\widetilde{T}_t^b$. They allocate these funds to consumption, $C_t^b$, government bonds, $B_t$, and bank capital, $Z_t$. We assume that bankers pay costs when adjusting their stock of bank capital across periods.[11] Formally, the adjustment costs are given by

$$Adj_t^Z = \frac{\chi_Z}{2}\left(\frac{Z_t}{Z_{t-1}} - 1\right)^2 Q_t^Z Z_t, \tag{6}$$

where $\chi_Z$ is a positive parameter determining the bank capital adjustment costs. Bankers' budget constraint, in real terms, is

$$C_t^b + Q_t^Z Z_t + B_t = \frac{R_{t-1}B_{t-1}}{\pi_t} + \frac{R_t^Z(1 - \delta_{t-1}^Z)Q_t^Z Z_{t-1}}{\pi_t} - Adj_t^Z + \Pi_t^{sb} + \Pi_t^{lb} - \widetilde{T}_t^b. \tag{7}$$

A representative banker chooses $C_t^b$, $B_t$, and $Z_t$ in order to maximize the expected lifetime utility Eq.(4), subject to Eqs.(5)–(7). The first-order conditions for this optimization problem

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

are:

$$e_t \left( \frac{C_t^b}{(C_{t-1}^b)^\varphi} \right)^{1-\gamma_b} - \beta_b \varphi E_t \left[ e_{t+1} \left( \frac{C_{t+1}^b}{(C_t^b)^\varphi} \right)^{1-\gamma_b} \right] = C_t^b \lambda_t^b; \tag{8}$$

$$\frac{\lambda_t^b}{R_t} = \beta_b E_t \left[ \frac{\lambda_{t+1}^b}{\pi_{t+1}} \right]; \tag{9}$$

$$\beta_b E_t \left\{ \frac{\lambda_{t+1}^w Q_{t+1}^Z}{\pi_{t+1}} \left[ (1-\delta_t^Z) R_{t+1}^Z + \chi_Z \left( \frac{Z_{t+1}}{Z_t} - 1 \right) \left( \frac{Z_{t+1}}{Z_t} \right)^2 \pi_{t+1} \right] \right\}$$
$$= \lambda_t^w Q_t^Z \left[ 1 + \chi_Z \left( \frac{Z_t}{Z_{t-1}} - 1 \right) \frac{Z_t}{Z_{t-1}} \right]; \tag{10}$$

where $\lambda_t^b$ is the Lagrangian multiplier associated with the bankers' budget constraint.

Eq.(8) determines the marginal utility of banker's consumption. Eq.(9) relates the marginal rate of substitution to the real risk-free rate. Finally, Eq.(10) corresponds to the optimal dynamic evolution of the stock of bank capital. Combining conditions (9) and (10) yields the following condition relating the expected return on bank capital, $E_t R_{t+1}^Z$, to the risk-free rate, $R_t$, diversion on bank capital, $\delta_t^Z$, and current costs/future gains of adjusting the stock of bank capital:

$$E_t \left\{ \frac{Q_{t+1}^Z}{Q_t^Z} \left[ (1-\delta_t^Z) R_{t+1}^Z + \chi_Z \left( \frac{Z_{t+1}}{Z_t} - 1 \right) \left( \frac{Z_{t+1}}{Z_t} \right)^2 \pi_{t+1} \right] \right\}$$
$$= R_t \left[ 1 + \chi_Z \left( \frac{Z_t}{Z_{t-1}} - 1 \right) \frac{Z_t}{Z_{t-1}} \right]. \tag{11}$$

This condition leads to three channels, through which changes in bank capital affect the real economy: (1) the price expectation channel, which arises from expectations of capital gains or losses from holding bank capital shares, due to expected changes in the price of bank capital $E_t \left[ Q_{t+1}^Z / Q_t^Z \right]$. (2) the adjustment cost channel, which is a result of asymmetric information between bankers and banks. The presence of adjustment costs is necessary to reduce asymmetric information and the adjustment costs are interpreted as costs to enter into the bank capital market. Finally, the diversion risk channel that arises from the existence of the possibility that banks' mangers divert a fraction $\delta_t^Z$ of bank capital repayment to their own benefits. 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

Savings banks refer to all financial intermediaries that are net creditor (lender) in the interbank market. There is a continuum of monopolistically competitive, profit-maximizing savings banks indexed by $j \in (0,1)$. Each $j$ bank collects fully insured deposits from workers and pays a deposit interest rate $R_{j,t}^D$, which is optimally set as a mark-down over the marginal return of its assets. In addition, it optimally allocates a fraction $s_{j,t}$ of deposits to lending in the interbank market and uses the remaining fraction $1 - s_{j,t}$ to purchase government bonds. Thus, the $j^{th}$ savings bank's portfolio is composed of interbank lending $D_{j,t}^{IB} = s_{j,t}D_{j,t}$ and government bonds $B_t^{sb} = (1 - s_{j,t})D_{j,t}$. Interbank lending pays a gross nominal interbank rate $R_t^{IB}$ and are subject to a probability $\delta_t^D$ that lending banks default on their interbank borrowing. The interbank rate, $R_t^{IB}$, is endogenously determined to clear the interbank market. Table 1 displays the balance sheet of the $j'th$ savings bank.

**Table 1: Savings bank's balance sheet**

| Assets | Liabilities |
|---|---|
| Interbank lending: $D_{j,t}^{IB}$ | Deposits: $D_{j,t}$ |
| Government bonds: $B_{j,t}^{sb}$ | |

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. As in Gerali *et al.* (2010), the individual deposit supply is

$$D_{j,t} = \left( \frac{R_{j,t}^D}{R_t^D} \right)^{\vartheta_D} D_t, \tag{12}$$

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.[12]

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[12]This 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:

Savings banks face quadratic adjustment costs à la Rotemberg (1982) when adjusting the deposit interest rate:

$$Ad_{j,t}^{R^D} = \frac{\phi_{R^D}}{2} \left( \frac{R_{j,t}^D}{R_{j,t-1}^D} - 1 \right)^2 D_t, \tag{13}$$

where $\phi_{R^D} > 0$ is an adjustment cost parameter. These adjustment costs implies an interest rate spread, between deposit and policy rates, that varies over the business cycle. In addition, we assume that savings banks must pay monitoring costs when lending in the interbank market. They incur higher monitoring costs if the share $s_{j,t}$ of deposits lent in the interbank market deviates from a target level $\bar{s}$. The individual cost of monitoring interbank lending is

$$\Delta_{j,t}^s = \frac{\chi_s}{2} \left( (s_{j,t} - \bar{s}) D_{j,t} \right)^2, \tag{14}$$

where $\chi_s$ is a positive parameter determining the steady-state value of the monitoring costs.

Formally, the $j^{th}$ savings bank's optimization problem is:

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

subject to Eqs. (12)–(14). Since bankers are the owners of banks, the discount factor is the stochastic process $\beta_b^t \lambda_t^b$, where $\lambda_t^b$ denotes the marginal utility of bankers' consumption.[13] The term $s_{j,t} R_t^{IB} (1 - \delta_t^D) + (1 - s_{j,t}) R_t$ is the gross nominal return of savings bank's assets.

In symmetric equilibrium where $s_{j,t} = s_t$ and $R_{j,t}^D = R_t^D$ for all $t > 0$, the first-order conditions of this optimization problem with respect to $s_t$ and $R_t^D$ are:

$$s_t = \bar{s} + \frac{R_t^{IB}(1 - \delta_t^D) - R_t}{\chi_s D_t}; \tag{15}$$

$$\frac{1 + \vartheta_D}{\vartheta_D}(R_t^D - 1) = s_t(R_t^{IB} - 1)(1 - \delta_t^D) + (1 - s_t)(R_t - 1) - \chi_s(s_t - \bar{s})^2 D_t$$

$$- \frac{\phi_{R^D}}{\vartheta_D} \left( \frac{R_t^D}{R_{t-1}^D} - 1 \right) \frac{R_t^D}{R_{t-1}^D} + \frac{\beta_b \phi_{R^D}}{\vartheta_D} \left( \frac{R_{t+1}^D}{R_t^D} - 1 \right) \frac{R_{t+1}^D}{R_t^D}, \tag{16}$$

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$D_t = \left( \int_0^1 D_{j,t}^{\frac{1 + \vartheta_D}{\vartheta_D}} dj \right)^{\frac{\vartheta_D}{\vartheta_D + 1}}$ and $R_t^D = \left( \int_0^1 R_{j,t}^{D \, 1 + \vartheta_D} dj \right)^{\frac{1}{1 + \vartheta_D}}$, where $D_{j,t}$ and $R_{j,t}^D$ are the supply and deposit interest rate faced by each savings bank $j \in (0, 1)$.

[13]Savings banks take $R_t^{IB}$, $R_t$, and $\delta_t^D$ as given when maximizing their profits.

where the interbank rate is given by $R_t^{IB} = R_t(1 + \delta_t^D) + \chi_s(s_t - \bar{s})D_t$. This rate includes the risk-free rate, which is the opportunity cost of savings banks for not investing total deposits in government bonds. It also compensates savings banks for default risk they are facing in the interbank market, and covers the average marginal cost of monitoring interbank lending. Consequently, the spread between interbank and policy rates, $R_t^{IB} - R_t$, is increasing in the probability of default in the interbank market and in the marginal cost of monitoring interbank lending. In normal time, this spread is constant.[14]

Condition (15) describes the share of deposits allocated to interbank lending as decreasing in the probability of default on interbank lending, in the risk-free interest rate, and in the total deposits, while it is increasing in the interbank rate. Note that an increase in $s_t$ indirectly leads to an expansion in credit supply available in the interbank market. Therefore, rising riskiness of interbank lending (a higher $\delta_t^D$) encourages savings banks to increase their risk-free holdings and to reduce their interbank lending. Condition (16) defines the deposit interest rate as a mark-down of the net average return of savings banks' assets.[15]

Therefore, this framework adds two channels through which savings banks' behavior affects credit supply conditions. First, optimal allocation of deposits between interbank lending and risk-free asset holding affects directly the availability of loanable funds supplied to firms as credit to finance new investment. Second, nominal stickiness in the deposit rates influence the intertemporal substitution of consumption across periods and thus facilitate consumption smoothing.[16]

### 2.2.2 Lending banks

Lending banks refer to all net debtors (borrowers) banks in the interbank market. There is a continuum of monopolistically competitive lending banks indexed by $j \in (0, 1)$. Lending banks borrow from saving banks in the interbank market and raise bank capital from bankers to satisfy the capital requirement condition. We assume that the stock of bank capital $Z_t$ is valued at capital price $Q_t^Z$ and held by banks as government bonds that pay the risk-free return rate $R_t$. In addition, lending banks can receive money injections from the central bank,

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[14]Since in normal time, no financial crises, variations in $\delta_t^D$ and $\chi_s D_t$ are very small.

[15]This condition allows us to derive an equation relating $R_{j,t}^D$ to $R_{j,t-1}^D$, $R_{j,t+1}^D$, and $R_t^{IB}$.

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

which interpreted as a quantitative monetary easing. Also, if needed, lending banks may swap a fraction of their risky assets (loans to firms) for government bonds from the central bank (qualitative monetary easing). Through these two channels, the central bank can serve as lender of last resort to lending banks in times of crisis.

### *Production of loans*

To produce loans, $L_{j,t}$, provided to entrepreneurs, each lending bank $j$ combines funds received from saving banks in the interbank market, $D_{j,t}^{IB}$, plus any money injection, $m_{j,t}$, with the value of bank capital raised from bankers, $Q_t^Z Z_{j,t}$, plus any new assets swapped with the central bank, $x_{j,t}$. We assume that banks use the following Leontief technology to produce loans:

$$L_{j,t} = \min \left\{ D_{j,t}^{IB} + m_{j,t}; \kappa_{j,t} \left( Q_t^Z Z_{j,t} + x_{j,t} \right) \right\} \Gamma_t, \tag{17}$$

where $\kappa_{j,t} \leq \bar{\kappa}$ is the bank $j$'s optimally chosen leverage ratio and $\bar{\kappa}$ is the maximum leverage ratio imposed by regulators.[17] When $\kappa_{j,t} < \bar{\kappa}$, the bank $j$ holds excess of bank capital, beyond the required level. $\Gamma_t$ is a shock to the financial intermediation process affecting credit supply. It represents exogenous factors affecting loan production and the banks' balance sheet, such as perceived changes in creditworthiness, technological changes in the intermediation process due to advances in computational finance, and sophisticated methods of sharing risk.[18] It is assumed that $m_t$, $x_t$, and $\Gamma_t$ evolve exogenously according to AR(1) processes.[19]

Leontief technology implies perfect complementarity between interbank borrowing and bank capital, and imposes the bank capital requirement condition. This allows bank capital to attenuate the real impacts of different shocks. For example, following a positive technology shock, the demand for investment and loans increases. Loan expansion requires a higher bank leverage ratio or raising fresh bank capital in the financial market. These two actions are, however, costly for the lending banks. Consequently, the marginal cost of of producing loans increases and banks transfer these additional costs to the entrepreneurs. This, in turn, increases the external financing costs and partly offsets initial increases in investment. Furthermore, with a Leontief technology, the marginal cost of producing loans is simply the weighted sum of the

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[17]$\kappa_{j,t}$ is the ratio of bank's loans to bank capital, which is the inverse of the bank capital ratio.

[18]Banks may underevaluate (overevaluate) risk during booms (recessions), which affects the loan supply.

[19]The steady state values of $m_t$ and $x_t$ are zero, while that of $\Gamma_t$ is equal to unity.

cost of borrowing in the interbank market and the marginal cost of raising bank capital. 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: $D_{j,t}^{IB}$ |
| Government bonds: $B_{j,t}^{lb}$ | Bank capital: $Q_t^Z Z_{j,t}$ |
| | Central bank's money injection: $m_{j,t}$ |
| | Other terms: $(\Gamma_t - 1)(D_{j,t}^{IB} + m_{j,t})$ |

Note that swapping a fraction of loans for government bonds, $x_{j,t}$, simply changes the composition of banks' assets, while shocks to money injections and financial intermediation, $m_{j,t}$ and $\Gamma_t$, imply expansion or contraction of banks's balance sheet.

### The optimization problem

The lending bank $j$ optimally sets the prime lending rate, $R_{j,t}^L$, as a mark-up over the marginal cost of producing loans, and faces quadratic costs when adjusting the prime lending rate. These adjustment costs are modelled à la Rotemberg (1982):

$$Ad_{j,t}^{R^L} = \frac{\phi_{R^L}}{2}\left(\frac{R_{j,t}^L}{R_{j,t-1}^L} - 1\right)^2 L_t, \tag{18}$$

where $\phi_{R^L} > 0$ is an adjustment cost parameter. When lending to entrepreneurs, the $j^{th}$ lending bank faces the following demand function for loans:

$$L_{j,t} = \left(\frac{R_{j,t}^L}{R_t^L}\right)^{-\vartheta_L} L_t, \tag{19}$$

where $\vartheta_L > 1$ is the elasticity of substitution between different types of provided loans.[20]

---

[20]This 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 demand for loans and the lending rate faced by each lending bank $j \in (0,1)$.

The $j^{th}$ lending bank optimally chooses its leverage ratio $\kappa_{j,t}$, taking subject to the maximum leverage ratio imposed by the regulators, $\bar{\kappa}$. We assume that having a lower leverage ratio than the required level entails convex gains for the bank. Changes in the optimally chosen leverage ratio directly affect the marginal cost of raising bank capital and, thus, the marginal costs of producing loans. The quadratic gains for the bank $j$ are modelled using:

$$\Delta_{j,t}^{\kappa} = \frac{\chi_{\kappa}}{2} \left( \frac{\bar{\kappa} - \kappa_{j,t}}{\bar{\kappa}} Q_t^Z Z_{j,t} \right)^2, \tag{20}$$

where $\chi_{\kappa}$ is a positive parameter. Note that when $\kappa_{j,t} = \bar{\kappa}$, the bank's leverage ratio meets the required level exactly and $\Delta_{j,t}^{\kappa} = 0$. In contrast, when $\kappa_{j,t} < \bar{\kappa}$, banks maintain excess bank capital and are well-capitalized, which reduces the costs of raising bank capital.[21]

Furthermore, following Goodhart *et al.* (2006), we allow lending banks to optimally default on a fraction of their interbank borrowing, $\delta_{j,t}^D > 0$. In addition, lending banks' manager can divert a fraction, $\delta_{j,t}^Z$, of bank capital to their own benefit. The default and diversion can be either strategic or mandatory (when a bank cannot afford to repay their debt). Nevertheless, it is costly for banks to default on the interbank borrowing or divert a fraction of bank capital. In this case, banks must pay convex penalties in the next period. The $j'th$ bank's penalties are given by,

$$\Delta_{j,t}^D = \frac{\chi_{\delta^D}}{2} \left( \frac{\delta_{j,t-1}^D D_{j,t-1}^{IB}}{\pi_t} \right)^2 R_{t-1}^{IB} \tag{21}$$

and

$$\Delta_{j,t}^Z = \frac{\chi_{\delta^z}}{2} \left( \frac{\delta_{j,t-1}^Z Q_{t-1}^Z Z_{j,t-1}}{\pi_t} \right)^2 R_t^Z, \tag{22}$$

where $\chi_{\delta^D}$ and $\chi_{\delta^z}$ are positive parameters determining the steady-state values of $\Delta_t^D$ and $\Delta_t^Z$, respectively.

Specifically, the $j^{th}$ lending bank's optimization problem is to choose $R_{j,t}^L$, $\kappa_{j,t}$, $\delta_{j,t}^D$, and $\delta_{j,t}^Z$ to maximize its profit, and is given by

$$\max_{\{R_{j,t}^L, \kappa_{j,t}, \delta_{j,t}^D, \delta_{j,t}^Z\}} E_0 \sum_{t=0}^{\infty} \beta_b^t \lambda_t^b \left\{ R_{j,t}^L L_{j,t} - (1 - \delta_{j,t}^D) R_t^{IB} D_{j,t}^{IB} - \left[ (1 - \delta_{j,t}^Z) R_{t+1}^Z - R_t \right] Q_t^Z Z_{j,t} \right.$$
$$\left. - A d_{j,t}^{R^L} - \Delta_{j,t}^D - \Delta_{j,t}^Z - R_t m_{j,t} - (R_{j,t}^L - R_t) x_{j,t}, \right\},$$

---

[21]Equation (27) hereafter displays the relation between the marginal cost of loans and the cost of raising bank capital.

13

subject to Eqs (17)–(22). The discount factor is given by the stochastic process $\beta_b^t \lambda_t^b$, where $\lambda_t^b$ denotes the marginal utility of consumption of bankers—the owners of the lending banks. Note that the term $\left[(1 - \delta_{j,t}^Z)R_{t+1}^Z - R_t\right] Q_t^Z Z_{j,t}$ represents the marginal costs of holding one unit of bank capital to satisfy the capital requirement condition, which depends on payment of non-diverted fraction of bank capital net of the return from holding bank capital as government bonds. The terms $R_t m_{j,t}$ and $(R_{j,t}^L - R_t)x_{j,t}$ are the total costs of money injections, received from the central bank, and the costs of swapping a fraction of loans for government bonds.

In symmetric equilibrium where $R_{j,t}^L = R_t^L$, $\kappa_{j,t} = \kappa_t$, $\delta_{j,t}^D = \delta_t^D$, and $\delta_{j,t}^Z = \delta_t^Z$, for all $t > 0$, the first-order conditions of this optimization problem are:

$$
\begin{aligned}
R_t^L &= 1 + \frac{\vartheta_L}{\vartheta_L - 1}(\zeta_t - 1) - \frac{\phi_{R^L}}{\vartheta_L - 1}\left(\frac{R_t^L}{R_{t-1}^L} - 1\right)\frac{R_t^L}{R_{t-1}^L} \\
&\quad + \frac{\beta_b \phi_{R^L}}{\vartheta_L - 1}E_t\left[\left(\frac{R_{t+1}^L}{R_t^L} - 1\right)\frac{R_{t+1}^L}{R_t^L}\right]; \qquad\qquad (23)
\end{aligned}
$$

$$
\kappa_t = \bar{\kappa}\left(1 - \frac{\bar{\kappa}\Gamma_t(R_t^L - 1)}{\chi_\kappa Q_t^Z Z_t}\right); \qquad\qquad (24)
$$

$$
\delta_t^D = E_t\left[\frac{R_t \pi_{t+1}}{\chi_{\delta^D} D_t^{IB}}\right]; \qquad\qquad (25)
$$

$$
\delta_t^Z = E_t\left[\frac{R_t \pi_{t+1}}{\chi_{\delta^Z} Q_t^Z Z_t}\right], \qquad\qquad (26)
$$

where $\zeta_t > 1$ is the marginal cost of producing loans and given by

$$
\zeta_t = \Gamma_t^{-1}\left[R_t^{IB} + \left(E_t R_{t+1}^Z - R_t - (R_t^L - 1)\frac{\bar{\kappa} - \kappa_t}{\bar{\kappa}}\right)\frac{Q_t^Z}{\kappa_t}\right]. \qquad\qquad (27)
$$

In addition, the Leontief technology implies the following implicit demand functions of inter-bank borrowing and bank capital:

$$
L_t = \Gamma_t(D_t^{IB} + m_t); \qquad\qquad (28)
$$

$$
L_t = \Gamma_t \kappa_t \left(Q_t^Z Z_t + x_t\right). \qquad\qquad (29)
$$

The pricing equation (23) relates the net lending rate to the net marginal cost of producing loans, and to current costs and future gains of adjusting the lending rate. Under the flexible interest rate, with $\phi_{R^L} = 0$, lending rate is set simply as a markup over the marginal costs,

14

$\zeta_t$.[22] Eq. (24) shows that the banks' optimal leverage ratio increases in the maximum imposed leverage ratio, $\bar{\kappa}$, and in the value of bank capital, $Q_t^Z Z_t$. Moreover, it decreases in the interest rate on loans, because a higher lending rate reduces the entrepreneurs' demand for loans, which implies bank deleveraging. Eq.(25) indicates that the default on interbank borrowing increases in expected inflation and the policy rate, while it decreases in total interbank borrowing. Eq.(26) states that diversion of bank capital increases in expected inflation and the policy rate, while it decreases in the value of bank capital. In Eqs(25) and (26), $\delta_t^D$ and $\delta_t^Z$ increases in expected inflation and the policy rate because, if defaults in $t$, higher expected inflation reduces expected real costs of penalties paid next period; while a higher policy rate implies a higher discounted value of the present benefits of defaulting or diverting in the current period.

Eq.(27) indicates that the marginal cost of producing loans, $\zeta_t$, is the sum of the interbank market, $R_t^{IB}$, and that cost of bank capital $\left(E_t R_{t+1}^Z - R_t - (R_t^L - 1)\frac{\bar{\kappa} - \kappa_t}{\bar{\kappa}}\right) \frac{Q_t^Z}{\kappa_t}$. Note that the chosen bank leverage ratio $\kappa_t$ positively affects $\zeta_t$. The term $(R_t^L - 1)(\bar{\kappa} - \kappa_t)Q_t^Z/\bar{\kappa} > 0$ is the marginal gain of holding bank capital in excess of the required level.[23] In Eq.(27), the marginal cost of bank capital is increasing in the expected risky return rate and in the leverage ratio, while it is decreasing in the maximum imposed leverage, in the risk-free rate, and in the prime lending rate.[24] This is because a higher leverage ratio reduces the excess in bank capital, reduces marginal gains, and thus increases the marginal cost of producing loans; however, a higher $\bar{\kappa}$ indicates relaxing the capital requirement condition, which allows banks to costlessly extend their lending to firms, while maintaining relatively lower bank capital.

## 2.3 Production sector

### 2.3.1 Entrepreneurs

As in BGG, entrepreneurs, who manage wholesale-goods-producing firms, are risk neutral and have a finite expected horizon. The probability that an entrepreneur survives until the next period is $\nu$. This assumption ensures that entrepreneurs' net worth is never sufficient to self-

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[22]In this case, $R_t^L - 1 = \frac{\vartheta_L}{\vartheta_L - 1}(\zeta_t - 1)$.

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

[24]Eq. (27) can be written as $\zeta_t = \Gamma_t^{-1}\left[R_t^{IB} + \frac{E_t R_{t+1}^Z - R_t}{\kappa_t}Q_t^Z - (R_t^L - 1)\left(\frac{1}{\kappa_t} - \frac{1}{\bar{\kappa}}\right)Q_t^Z\right]$. Therefore,

$\frac{\partial \zeta_t}{\partial \kappa_t} = -\frac{R_{t+1}^Z - R_t}{\kappa_t^2}Q_t^Z + \frac{R_t^L - 1}{\kappa_t^2}Q_t^Z > 0$, since $R_{t+1}^Z - R_t < R_t^L - 1$. Also, $\frac{\partial \zeta_t}{\partial \bar{\kappa}} = -\frac{R_t^L - 1}{\bar{\kappa}^2}Q_t^Z < 0$.

finance new capital acquisitions, so they must issue debt contracts to finance their desired investment.

At the end of each period, entrepreneurs purchase capital, $K_{t+1}$, 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 its expected marginal return and the expected marginal external financing cost $E_t F_{t+1}$, which equals the real interest rate on external (borrowed) funds. Optimization guarantees that

$$E_t F_{t+1} = E_t \left[ \frac{r_{t+1}^K + (1-\delta)Q_{t+1}^K}{Q_t^K} \right], \tag{30}$$

where $\delta$ is the capital depreciation rate. The expected marginal return of capital is given by the right-side terms of (30), 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—debt 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 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:

$$E_t F_{t+1} = E_t \left[ \frac{R_t^L}{\pi_{t+1}} \Psi(\cdot) \right], \tag{31}$$

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 producing loans) and the external finance premium is given by

$$rp_t \equiv \Psi(\cdot) = \Psi \left( \frac{Q_t^K K_{t+1}}{N_t}; \psi_t \right), \tag{32}$$

with $\Psi'(\cdot) < 0$ and $\Psi(1) = 1$, and $\psi_t$ represents an aggregate riskiness shock, similar to that in Christiano *et al.* (2009).

16

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.[25] Formally, the external finance premium is assumed to have the following functional form

$$rp_t \equiv \Psi(\cdot) = \left( \frac{Q_t^K K_{t+1}}{N_t} \right)^{\psi_t}, \qquad (33)$$

where $\psi_t$ 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 $\psi_t$ is an aggregate riskiness shock that follows an AR(1) process. BGG show that this elasticity, $\psi > 0$, depends positively on the standard deviation of the distribution of entrepreneurs' idiosyncratic shocks, agency cost and entrepreneurs' default threshold.[26]

Aggregate entrepreneurial net worth evolves according to

$$N_t = \nu V_t + (1 - \nu) g_t, \qquad (34)$$

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.[27] $V_t$ is given by

$$V_t = \left[ F_t Q_{t-1}^K K_t - E_{t-1} F_t (Q_{t-1}^K K_t - N_{t-1}) \right], \qquad (35)$$

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

$$E_{t-1} F_t = E_{t-1} \left[ \frac{R_{t-1}^L}{\pi_t} \Psi \left( \frac{Q_{t-1}^K K_t}{N_{t-1}}; \psi_{t-1} \right) \right] \qquad (36)$$

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

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[25]When 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.

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

[27]The parameter $\nu$ will affect the persistence of changes in net worth.

sign a debt contract that specifies a nominal interest rate.[28] 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:

$$Y_t \leq A_t K_t^\alpha H_t^{1-\alpha}, \quad \alpha \in (0,1), \tag{37}$$

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 (37). 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 $\Upsilon_t$, 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 $\Upsilon_t$ is a shock to the marginal efficiency of investment. Since $I_t$ is expressed in consumption units, $\Upsilon_t$ 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 $\frac{\chi_I}{2}\left(\frac{I_t}{I_{t-1}}-1\right)^2 I_t$, with $\chi_I > 0$ is an adjustment cost parameter.

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

$$\max_{I_t} E_t \sum_{t=0}^{\infty} \beta_w^t \lambda_t^w \left\{ Q_t^K \left[ \Upsilon_t I_t - \frac{\chi_I}{2}\left(\frac{I_t}{I_{t-1}}-1\right)^2 I_t \right] - I_t \right\}. \tag{38}$$

Thus, the optimal condition is

$$\frac{1}{Q_t^K} = \Upsilon_t - \chi_I \left(\frac{I_t}{I_{t-1}}-1\right)\frac{I_t}{I_{t-1}} + \beta_w \chi_I E_t \left[ \left(\frac{I_{t+1}}{I_t}-1\right)\left(\frac{I_{t+1}}{I_t}\right)^2 \frac{Q_{t+1}^K}{Q_t^K}\frac{\lambda_{t+1}^w}{\lambda_t^w} \right], \tag{39}$$

---

[28]In BGG, the contract is specified in terms of the real interest rate.

18

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, the 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 (31) and (A.4), whereas the supply of capital is given by equation (39). 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

$$K_{t+1} = (1 - \delta)K_t + \Upsilon_t I_t - \frac{\chi_I}{2} \left( \frac{I_t}{I_{t-1}} - 1 \right)^2 I_t, \tag{40}$$

where $\delta$ is the capital depreciation rate, and the shock $\Upsilon_t$ follows an AR(1) process.

### 2.3.3 Retail firms

The retail sector is used to introduce nominal rigidity into the 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 $\phi_p$, the retailer $j$ must charge the same price at the preceding period, indexed to the steady-state gross rate of inflation, $\pi$. At time $t$, if the retailer $j$ receives the signal to reoptimize, it chooses a price $\widetilde{P}_t(j)$ 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 policy rate, $R_t$, in response to deviations of inflation, $\pi_t$, and output, $Y_t$, from their steady-state values. Thus monetary policy evolves

19

according to the following Taylor-type policy rule:

$$\frac{R_t}{R} = \left(\frac{\pi_t}{\pi}\right)^{\varrho_\pi} \left(\frac{Y_t}{Y}\right)^{\varrho_Y} \exp(\varepsilon_{Rt}) \tag{41}$$

where $R$, $\pi$, and $Y$ are the steady-state values of $R_t$, $\pi_t$, and $Y_t$, respectively; and $\varepsilon_{Rt}$ is a monetary policy shock normally distributed with zero mean and standard deviation $\sigma_R$.

During the financial crisis time, the central bank can use unconventional monetary policies: quantitative and/or qualitative monetary easing shocks, $m_t$ and $x_t$. Therefore, it can inject money into the banking system and/or swap a fraction of banks loans for government bonds used to enhance the lending 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, $\widetilde{T}_t^w + \widetilde{T}_t^b$. Therefore, government's budget is

$$G_t + \left[B_{t-1} + B_{t-1}^{sb} + B_{t-1}^{lb}\right] R_{t-1}/\pi_t = B_t + B_t^{sb} + B_t^{lb} + \widetilde{T}_t^w + \widetilde{T}_t^b \tag{42}$$

where $B_t^{sb} = (1 - s_t)D_t$ and $B_t^{lb} = Q_t^Z Z_t + \widetilde{m}_t$ 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 resource constraint implies that $Y_t = C_t^w + C_t^b + I_t + G_t + \omega_t$, where $\omega_t$ 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

Apart from the monetary policy shock, $\varepsilon_{Rt}$, which is a zero-mean i.i.d. shock with a standard deviation $\sigma_R$, the other structural shocks follow AR(1) processes:

$$\log(X_t) = (1 - \rho_X)\log(X) + \rho_X \log(X_{t-1}) + \varepsilon_{Xt}, \tag{43}$$

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 $\varepsilon_{Xt}$ is normally distributed with zero mean and standard deviation $\sigma_X$.

# 3. Calibration

We calibrate the model's parameters to capture the key features of the U.S. economy for the period 1980Q1–2008Q4 using quarterly data. Table 3 reports the calibration values. The steady-state gross domestic inflation rate, $\pi$, is set equal to 1.0075, which is the historical average in the sample. The discount factors, $\beta_w$ and $\beta_b$, 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, $\gamma_w$ and $\gamma_b$, 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 $\eta$, the parameter determining the weight of leisure in utility, and $\varsigma$, the inverse of the elasticity of intertemporal substitution of labour, to 1.013 and 1, respectively. The habit formation parameter, $\varphi$, is set to 0.65, as estimated in Christiano *et al.* (2009).

The capital share in the production, $\alpha$, and the capital depreciation rate, $\delta$, are set to 0.33 and 0.025, respectively. The parameter measuring the degree of monopoly power in the retail goods market $\theta$ is set to 6, which implies a 20 percent markup in the steady-state equilibrium. The parameters $\vartheta_D$ and $\vartheta_L$, which measure the degrees of monopoly power of saving and lending banks, are set equal to 1.53 and 4.21, 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, $\phi_p$, in the Calvo-Yun contract setting is set to 0.75, implying that the average price remains unchanged for four quarters. This value is that 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, $\phi_{R^D}$ and $\phi_{R^L}$, 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 $\varrho_\pi$ and $\varrho_Y$ are set values of 1.2 and 0.05, respectively, and these values satisfy the Taylor principle. The standard deviation of monetary policy shock, $\sigma_R$, is given the usually estimated value of 0.006.

The investment and bank capital adjustment cost parameters, $\chi_I$ and $\chi_Z$, 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 $\chi_s$, which determines the ratio of bank lending to total assets held by the savings banks $s_t$, is set to 0.001, so that the steady-state value of $s_t$ is equal to 0.82, which corresponds to the historical ratio observed in the data.[29] The parameter $\chi_\kappa$ is set to 14.45, so that the steady-state value of the bank's leverage ratio, $\kappa$, is equal to 11.5, 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.[30] Similarly, we calibrate $\chi_{\delta D}$ and $\chi_{\delta Z}$, the parameters determining total costs of banks' defaults on interbank borrowing and bank capital, are set at 0.0025 and 0.004, so that the probability of default in the interbank market and the bank capital diversion are equal to 1% and 1.6% in annual terms. (See Table 3).

Following BGG, 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, $\nu$, is set at 0.9833; while $\psi$, the steady-state elasticity of the external finance premium, is set at 0.05, the value used by BGG and close to that estimated by Christensen and Dib (2008).[31]

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 $\rho_G$, the autocorrelation coefficients, is 0.81; while the estimated standard errors, $\sigma_G$, is 0.0166.

To calibrate the parameters of the riskiness shock process $\psi_t$, we set the autocorrelation coefficient $\rho_\psi$ at 0.83, the estimated value in Christiano *et al.* (2009), while the standard error $\sigma_\psi$ is set to 0.05 to match the volatility of the external risk premium to that observed in the data, measured as 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 intermediation process $\rho_\Gamma$ and $\sigma_\Gamma$ to 0.8 and 0.003, respectively. These values are motivated

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

[30]This 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.

[31]Christensen and Dib (2008) estimate $\psi$ at 0.046 for the U.S. economy.

by the potential persistence and low volatility of this financial shock.[32]  Finally, we set the autocorrelation coefficients of quantitative and qualitative monetary easing shocks, $\rho_m$ and $\rho_x$, equal to 0.5, and their standard deviations, $\sigma_m$ and $\sigma_x$, to 0.

# 4.   Empirical results

To assess the role and the importance of banking sector frictions in the U.S. business cycle fluctuations, we simulate two alternative models: (1) the above-described model (baseline model, hereafter) that incorporates both financial frictions in the banking sector and the financial accelerator mechanism; and (2) a model that includes only the financial accelerator mechanism à la BGG (FA model).[33]  In addition, as a sensitive analysis exercise, we report the impulse responses of a constraint version of the baseline model without the interest rate rigidity (NOIR model).

## 4.1   Impulse responses

First, we evaluate the role and implications of banking sector frictions in the transmission and propagation of real effects of standard supply and demand shocks.  Then, we analyze the dynamic responses of key macroeconomic variables to financial shocks originating in the banking sector. Figures 1–2 display the impulse responses to technology and monetary policy shocks, respectively. Figures 3–4 plot the responses to financial shocks—riskiness and financial intermediation. Finally, Figures 5–6, plot those to quantitative and qualitative monetary easing shocks. Each response is expressed as the percentage deviation of a variable from its steady-state level.

### 4.1.1 *Responses to technology and monetary policy shocks*

Figure 1 plots the responses to a 1% positive technology shock. Following this shock, output, investment, and consumption increase; however, the increase is smaller in the baseline model

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[32]Future 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 Bayesien approach used in Christiano *et al.* (2009), Dib *et al.* (2008), Elkdag *et al.* (2006), Queijo von Heideken (2009), and others.

[33]Note that, besides the external risk premium, the external financing cost depends on the prime lending rate in the baseline model, while it depends on the risk-free rate in the FA model.

than in the FA model. In addition, inflation and the policy rate decline, but the decline is less substantial in the baseline model. In the presence of the banking sector, expansion of loans to entrepreneurs is subject to the capital requirement condition. Thus, to extend the loan supply, banks must raise fresh capital in the financial markets, which pushes up the marginal cost of bank capital. Therefore, though the decline in the policy rate reduces the interbank rate, the prime lending rate increases on impact, before gradually falling under its steady-state level. This leads to an increasing spread between the prime lending and policy rates.[34] A higher spread entails higher entrepreneurs' debt repayment that erodes the initial increase in their net worth. Thereby, firms' net worth decreases very slightly in the baseline model, while it increases substantially in the FA model. Consequently, the external finance premium persistently increases in the baseline model, while it falls in the FA model. Because firms' net worth decreases in the baseline model, firms depend further on the external funds (borrowing) to finance their new capital acquisitions. Therefore, the demand for loans persistently increases in the baseline model, while it increases only temporally in the FA model.

Figure 1 also shows that following a positive technology shock, the bank leverage ratio decreases on impact, before moving persistently above its steady-state level. Also, bank capital holding increases persistently, and for a longer horizons. We note that, following a positive technology shock, deposit rate slightly declines, while the prime lending rates jump on impact before declining after a quarter. The fall in deposit and lending rates are smaller than that in the policy rate. This is partially caused by the presence of costs of adjusting both interest rates, which implies partial pass-through of policy rate variations to deposit and prime lending rates. The default on interbank borrowing and diversion on bank capital decrease on impact, and they are very persistent. Similar results are found in response of macroeconomic variables to a positive investment-efficiency shock. See Figure 7 in Appendix D for these impulse responses.

Figure 2 displays the responses to an expansionary monetary policy shock, i.e. an exogenous decrease in the policy rate by 100 basic points. In response to this shock, the nominal interest rate drops sharply, while output and investment persistently increase, even for a longer term. The responses of these variables are substantially larger and persistent in the FA model. Also, in the NOIR model, where interest rates are flexible, the increase in output and investment is

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[34]For example, Figure 1 shows that, on impact, the policy rate falls in the two models, while the lending rate slightly increases.

smaller than that in the baseline model.

In Figure 2, in the two models with the banking sector, the lending rate increases sharply on impact by 20 basic points, while the policy rate falls by about 100 basic points. This reflects the need of banks to raise their bank capital to satisfy the requirement condition. Therefore, higher demand of bank capital, which is costly, increases the marginal cost of producing loans and thus reduces the increase in net worth in the presence of the banking sector. Therefore, net worth rises in the baseline and NOIR model, but by less than in the FA model. This explains the smaller decline in the firms' risk premium in the models incorporating the banking sector. In the FA model, the lower funding cost, caused by the decline in policy rate, stimulates the demand for investment and creates the financial acceleration effects discussed in BGG. The presence of the bank capital requirement condition allows bank capital to attenuate the real effects of monetary policy shocks. Since firms' net worth slightly increases in the models with the banking sector, entrepreneurs still need external funds to finance their investment, so the demand for loans remains almost unchanged, while it substantially decreases in the FA model. Therefore, the drop of the lending rate is significantly smaller than that of the policy rate. This increases the spread between lending and policy rates.

Thus, the presence of the banking sector implies a significant dampening of the impacts of monetary policy shocks on output, investment, net worth, 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 an easing monetary policy 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 quarter later. The probability of defaulting on interbank borrowing increases after a positive monetary policy shock, while the supply of interbank lending sharply falls on impact, before persistently drops below its steady-state level. Also, the impulse responses to a 1% preference and government spending shocks are reported in Figure 8 and 9 in Appendix D.

**4.1.2** *Responses to financial shocks*

Figure 3 displays the impulse responses to a 10% increase in the riskiness shock, which is similar to that examined in Christiano *et al.* (2009). This financial shock is interpreted as an exogenous increase in the degree of riskiness in the entrepreneurial sector. It may result from an increase in the standard deviation of the entrepreneurial distribution, and implies that lending banks are unable to distinguish between higher and lower riskier entrepreneurs. Consequently, they raise the external financing premium to all firms whatever their leverage positions.

In response to this shock, output, investment, and net worth fall persistently below their steady-state levels in all models. Consumption, however, responds positively, as the result of the wealth effect induced by higher demand for labour to substitute declining capital in the wholesale goods production. In addition, inflation and the policy rate increase in the baseline and NOIR models, while they fall slightly in the FA model.

Note also that the external finance premium rises in response to the riskiness shock, while loans temporarily decline, before jumping above their steady-state levels. Figure 3 shows that the lending banks react to this negative financial shock by increasing their leverage ratio slightly on impact, before persistently reducing it, which implies further accumulation of bank capital in excess of the required level. Because loans decrease, lending banks reduce their capital holding in the short term. This reduces the marginal cost of producing loans in the short terms and allows firms to reduce gradually investment. Therefore, in the short term, the lending banks are able to reduce the lending rate, despite the increase in the policy rate. This leads to smaller drops in net worth in the two models with the banking sector compared to that in the FA model. In addition, after this riskiness shock, the default on the interbank borrowing and the diversion of bank capital increase.

The impact of the riskiness shocks 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. The absence of the interest rates rigidity amplifies the dampening effects, as interest rates quickly adjust to reduce the marginal cost of producing loans.

Figure 4 shows the impulse responses to a 1% positive financial intermediation shock. This is a positive shock to "loan production", leading to rising credit supply without varying the inputs used in the loan production function. Following this shock, loans rise on impact, but

fall persistently a few quarters later. At the same time, output, investment, and net worth, 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 diversion on bank capital.

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

### 4.1.3 *Responses to quantitative and qualitative monetary easing shocks*

Figure 5 displays the impulse responses to a 1% quantitative monetary easing shock, $m_t$, a positive money injection into lending banks. This shock gradually increases output, investment, and net worth, while inflation, the policy rate, and the external finance premium decline. Following this shock, the lending banks reduce their prime lending rate to accommodate the impact of this expansionary monetary shock. The shock also causes substantial decline in bank capital, because banks prefer relying on cheap funds from the central bank. This in turn reduces the marginal cost of producing loans.

We note that loans increase slightly on impact, but fall persistently two quarters after the shock. This is explained by the substantial increase in net worth. Firms with sound net worth borrow less to finance their capital acquisitions. Consequently, they reduce their demand for loans. Also, banks respond to this shock by increasing their leverage ratio and loanable funds, as the fraction of deposits lent out on the interbank market persistently increases.

Interestingly, the default on interbank borrowing and diversion of bank capital 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 affects output and investment only marginally. It leads, however, to higher inflation and policy rates. This shock also reduces the bank leverage ratio and increases both defaults in the economy. Note also that interbank

lending slightly increases. Also, the marginal cost of producing loans falls because of the decline in the cost of raising bank capital following this shock.

Overall, the active banking sector that is subject to the capital requirement condition, as proposed in this framework, attenuates the real impacts of different shocks. Also, the nominal rigidity of the detail interest rates marginally affects the dynamics of key macroeconomic variables.

## 4.2   Volatility and autocorrelations

In this subsection, we assess the ability of the baseline model that incorporates the banking frictions in reproducing the salient features of the U.S. business cycles. 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.[35]   The standard deviations are expressed in percentage terms. All the model-implied moments are calculated using all the shocks.

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 1.31, investment is 6.26, while consumption is 1.03. Loans have a standard deviation of 4.60. The external finance premium, however, is considerably less volatile; its standard deviation is only 0.38. Also, Panel B shows that investment and loans are 4.77 and 3.51 times as volatile as output, while consumption and the external finance premium are less volatile than output, with relative volatilities of 0.78 and 0.29, respectively. In Panel C, the data show that output, investment, loans, and the external finance premium are highly persistent, with autocorrelation coefficients larger than 0.8; while consumption is less so, with a coefficient of 0.73.

The simulation results show that in the model with an active banking sector, all volatilities are close to those in the data. The FA model, in which the banking sector is absent, overpredicts all the volatilities. 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,

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

28

the FA model slightly underpredicts the relative volatilities of consumption and the external finance premium.

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. This helps in reducing the external finance costs of entrepreneurs and push further investment and output.

## 5.   Conclusion

Following the recent financial crisis, there has been an increasing number of papers that aim to incorporate an active banking sector into macro economic DSGE models. Such models would help in understanding the role of the financial intermediation in transmission and propagation of the real impacts of aggregate shocks and evaluate the importance of financial shocks originating in the banking sector as source of business cycle fluctuations. This paper contributes to this growing literature by proposing a microfounded framework to incorporate an active banking into DSGE models. Besides the financial accelerator mechanism à la BGG, it introduces financial frictions in the supply-side of credit market using the banks' balance sheet channel. We assume a banking sector that consists of two types of monopolistically competitive banks that offer different banking services and transact in the interbank market. Banks raise deposits and bank capital (equity) from households. Bank capital is introduced to satisfy the capital requirement condition imposed by regulators: Banks must hold a minimum of bank capital to provide loans to entrepreneurs.

The paper provides rich and rigorous framework to address monetary and financial stability issues. It allows for policy simulation analysis of factors such as: (1) bank capital regulations; (2) optimal choice of banks' leverage ratios; (3) interest rate spreads resulting from the

monopoly power of banks when setting deposit and prime lending rates; (4) endogenous bank defaults on interbank borrowing; and (5) optimal choice of banks' portfolio compositions.

The key result is that, under the capital requirement condition, the banking sector dampens the real impacts of different shocks. This, however, contradicts finding in previous studies using models with bank capital introduced to solve asymmetric information between households and banks.[36] The model also reproduces salient features of the U.S. economy: volatilities of key macroeconomic variables and their correlations with output.

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

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[36]For example, Gertler and Kiyotaki (2010), and Gertler and Karadi (2010), and Meh and Moran (2010) among others.

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**Table 3:** Parameter Calibration: Baseline Model

| Preferences | | | |
|---|---|---|---|
| $\beta_w = 0.9979,$ | $\beta_b = 0.9943,$ | $\gamma_w = 3,$ | $\gamma_b = 2,$ |
| $\eta = 1.013,$ | $\varsigma = 1,$ | $\varphi = 0.65,$ | |
| **Monetary policy** | | | |
| $\varrho_\pi = 1.2,$ | $\varrho_Y = 0.05,$ | $\sigma_R = 0.006,$ | |
| **Technologies** | | | |
| $\alpha = 0.33,$ | $\delta = 0.025,$ | | |
| $\theta = 6,$ | $\vartheta_D = 1.53,$ | $\vartheta_L = 4.21,$ | |
| **Adjustment and default costs** | | | |
| $\chi_I = 8,$ | $\chi_Z = 70,$ | | |
| $\chi_s = 0.001,$ | $\chi_\kappa = 14.45,$ | $\chi_{\delta D} = 163.1,$ | $\chi_{\delta Z} = 1078,$ |
| **Nominal rigidities** | | | |
| $\phi_p = 0.75,$ | $\phi_{R^D} = 40,$ | $\phi_{R^L} = 55,$ | |
| **Financial sector** | | | |
| $\nu = 0.9833,$ | $\psi = 0.05,$ | $K/N = 2,$ | $\bar{\kappa} = 11.5,$ |
| **Exogenous processes** | | | |
| $A = 1,$ | $\rho_A = 0.8,$ | $\sigma_A = 0.009,$ | |
| $\Upsilon = 1,$ | $\rho_\Upsilon = 0.7,$ | $\sigma_\Upsilon = 0.033,$ | |
| $e = 1,$ | $\rho_e = 0.8,$ | $\sigma_e = 0.0073,$ | |
| $G/Y = 0.17,$ | $\rho_G = 0.60,$ | $\sigma_G = 0.0166,$ | |
| $\psi = 0.05,$ | $\rho_\psi = 0.83,$ | $\sigma_\psi = 0.050,$ | |
| $\Gamma = 1,$ | $\rho_\Gamma = 0.8,$ | $\sigma_\Gamma = 0.003,$ | |
| $m = 0,$ | $\rho_m = 0.5,$ | $\sigma_m = 0.00,$ | |
| $x = 0,$ | $\rho_x = 0.5,$ | $\sigma_x = 0.00,$ | |

**Table 4:** Steady-State Values and Ratios: Baseline Model

| Variables | Definitions | Values |
|:---:|:---|:---:|
| | *A. Steady-state values* | |
| $\pi$ | inflation | 1.0075 |
| $R$ | policy rate | 1.0141 |
| $R^D$ | deposit rate | 1.0097 |
| $R^L$ | prime lending | 1.0220 |
| $rp$ | external finance premium | 1.0027 |
| $S$ | fraction of interbank lending | 0.82 |
| $\kappa$ | bank leverage ratio | 11.5 |
| $\delta^D$ | default on interbank borrowing | 0.0025 |
| $\delta^Z$ | diversion on bank capital | 0.004 |
| | *B. Steady-state ratios* | |
| $C/Y$ | consumption to output | 0.661 |
| $C^w/Y$ | workers' consumption to output | 0.624 |
| $C^b/Y$ | bankers' consumption to output | 0.037 |
| $I/Y$ | investment to output | 0.16 |
| $G/Y$ | government spending to output | 0.17 |
| $K/Y$ | capital stock to output | 6.753 |
| $Z/Y$ | Bank capital to output | 0.294 |
| $\Pi^S/Y$ | savings bank profit to output | 0.015 |
| $\Pi^L/Y$ | lending bank profit to output | 0.02 |
| $K/N$ | capital to entrepreneurs'net worth | 2 |

**Table 5:** Standard Deviations and Relative Volatilities:
(Data 1980:1–2008:4)

| Variables | Definitions | Data | Baseline | FA |
|---|---|---|---|---|
| *A. Standard deviations (in %)* | | | | |
| $Y_t$ | output | 1.31 | 1.48 | 2.60 |
| $I_t$ | investment | 6.26 | 7.27 | 12.28 |
| $C_t$ | consumption | 1.03 | 1.27 | 1.87 |
| $L_t$ | loans | 4.60 | 4.73 | 9.00 |
| $rp_t$ | external finance premium | 0.38 | 0.43 | 0.54 |
| *B. Relative volatilities* | | | | |
| $Y_t$ | output | 1 | 1 | 1 |
| $I_t$ | investment | 4.77 | 4.91 | 4.72 |
| $C_t$ | consumption | 0.78 | 0.86 | 0.72 |
| $L_t$ | loans | 3.51 | 3.20 | 3.46 |
| $rp_t$ | external finance premium | 0.29. | 0.29 | 0.21 |
| *C. Autocorrelations* | | | | |
| $Y_t$ | 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 | 0.99 |
| $rp_t$ | external finance premium | 0.81 | 0.88 | 0.90 |

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

| Variables | Definitions | Data | Baseline | FA |
|---|---|---|---|---|
| $Y_t$ | output | 1 | 1 | 1 |
| $I_t$ | investment | 0.90 | 0.78 | 0.87 |
| $C_t$ | consumption | 0.85 | 0.51 | 0.63 |
| $L_t$ | loans | 0.30 | 0.34 | 0.39 |
| $rp_t$ | external finance premium | -0.30 | -0.25 | -0.35 |
| $\kappa_t$ | bank leverage ratio | + | 0.48 | . |
| $\delta_t^D$ | default on Interbank borrowing | + | -0.36 | . |
| $\delta_t^Z$ | default on bank capital | + | -0.21 | . |

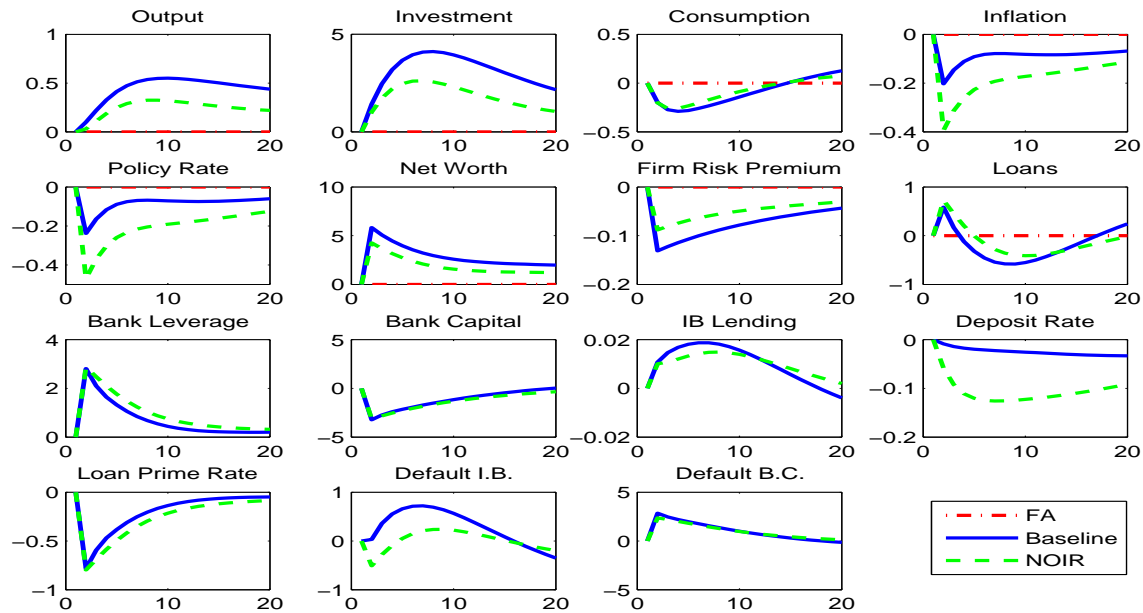**Figure 1:** Responses to Positive Technology Shocks
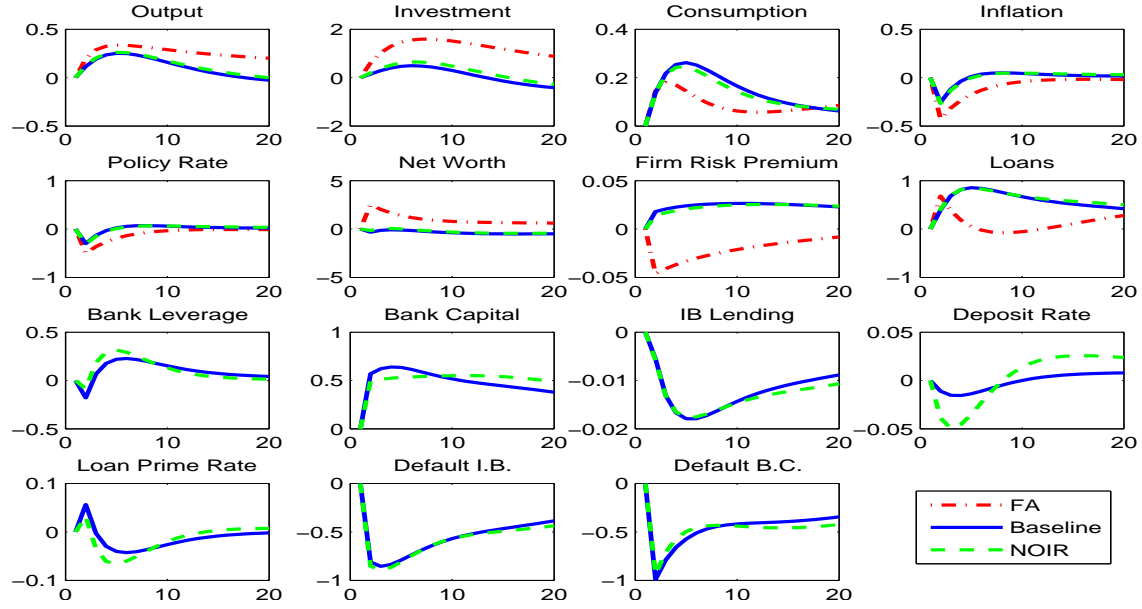


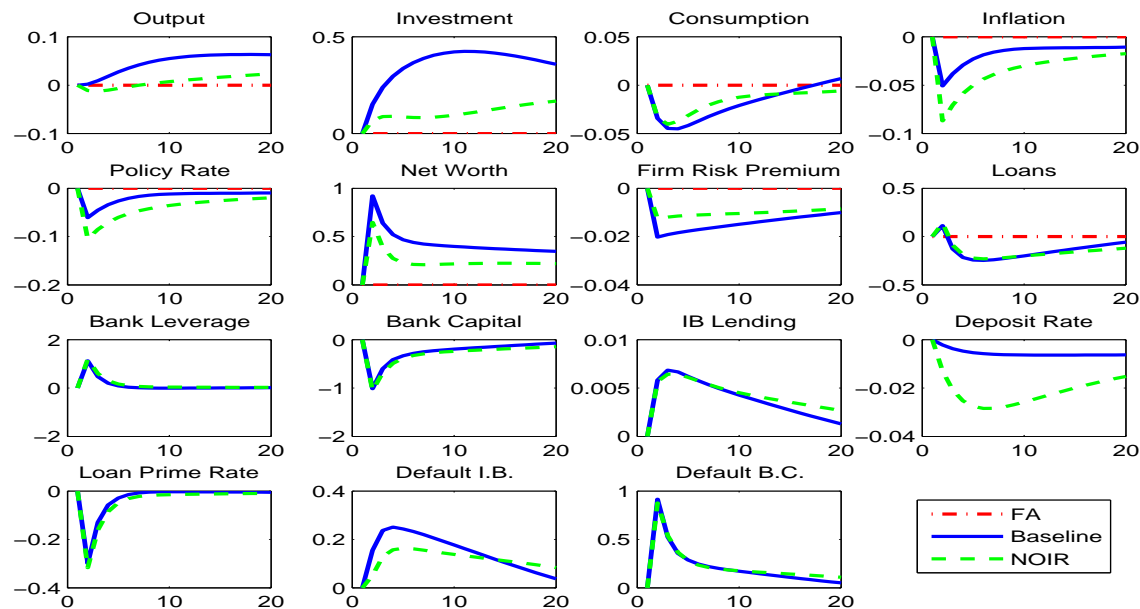**Figure 2:** Responses to Monetary Policy Shocks
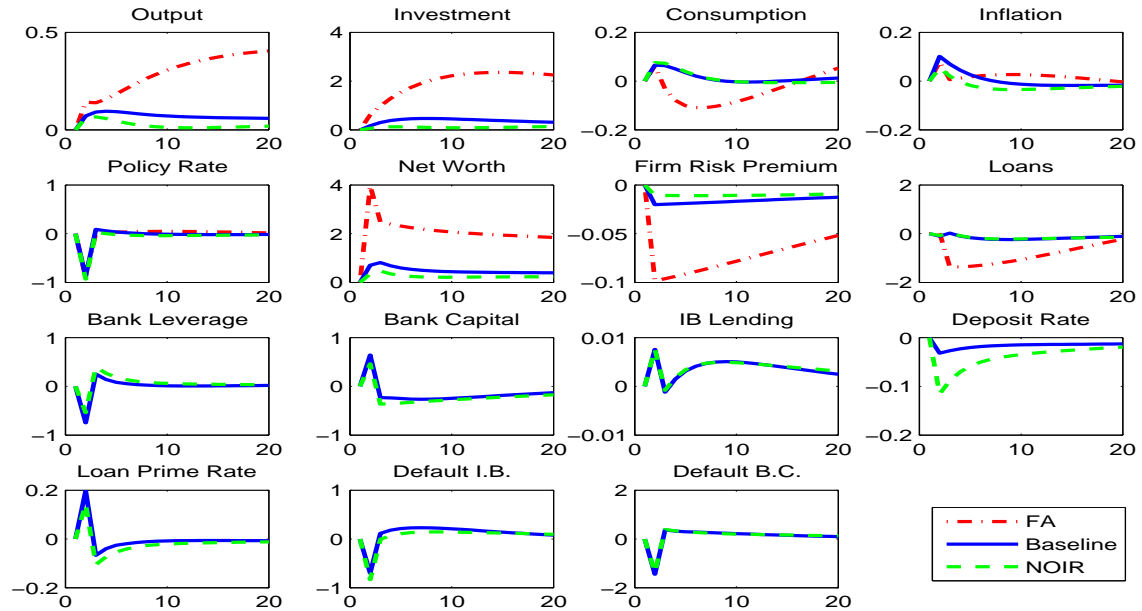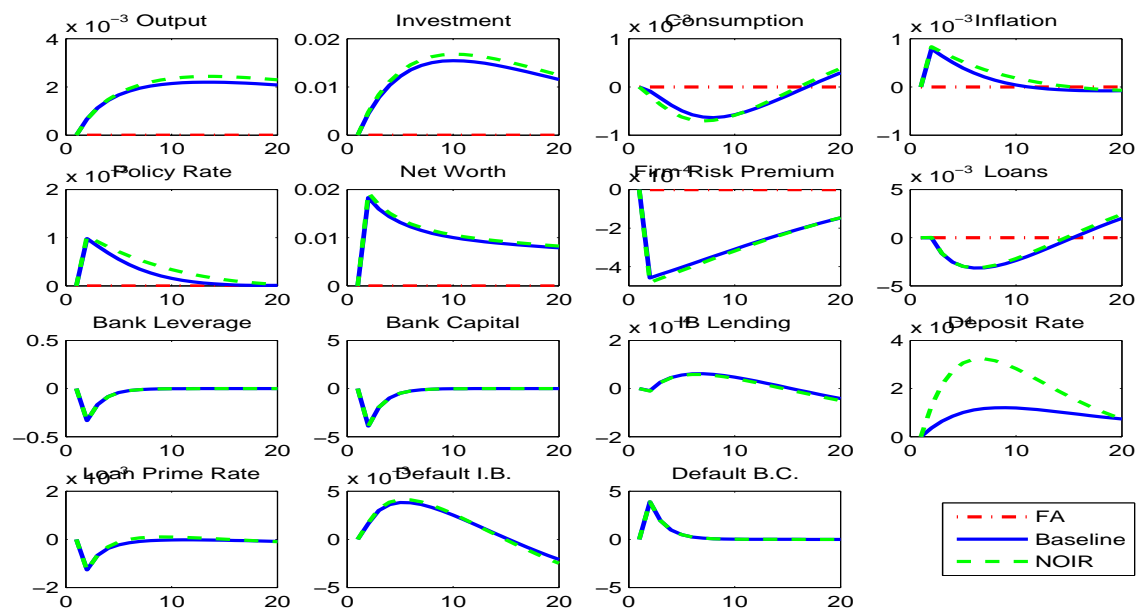
**Figure 3:** Responses to Riskiness Shocks
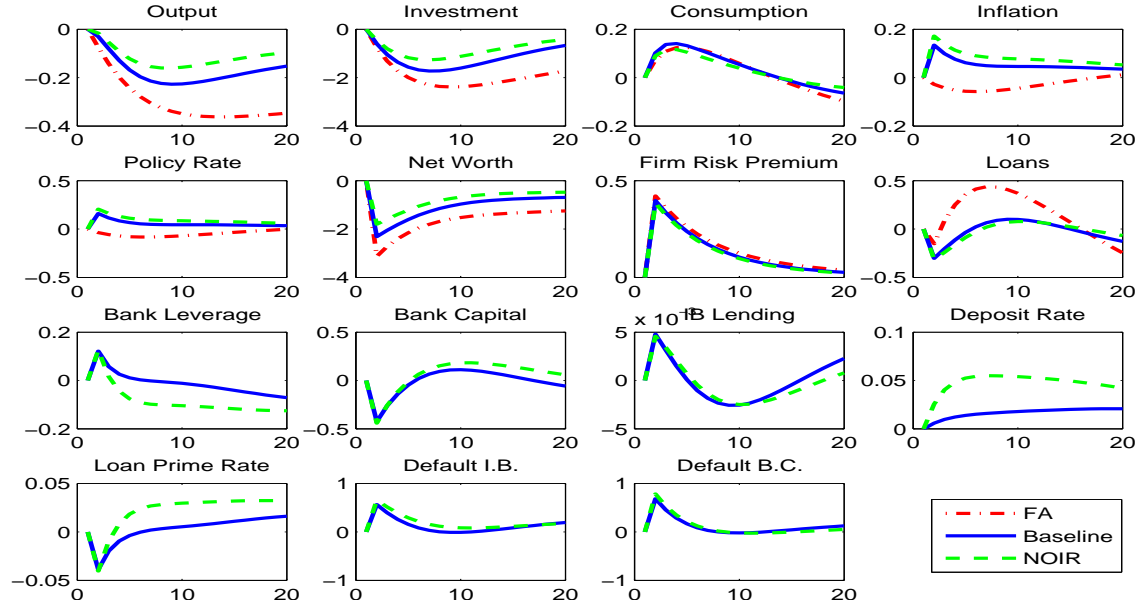


**Figure 4:** Responses to Financial Intermediation Shocks



38

**Figure 5:** Responses to Quantitative Monetary Easing Shocks



**Figure 6:** Responses to Qualitative Monetary Easing Shocks

## Appendix A: First-Order Conditions

### A.1. Workers' first-order conditions

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

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

$$\frac{\eta}{(1-H_t)^\varsigma} = \lambda_t^w W_t; \tag{A.2}$$

$$\frac{\lambda_t^w}{R_t^D} = \beta_w E_t \left( \frac{\lambda_{t+1}^w}{\pi_{t+1}} \right), \tag{A.3}$$

where $\lambda_t^w$ 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:

$$r_t^K = \alpha \xi_t \frac{Y_t}{K_t}; \tag{A.4}$$

$$W_t = (1-\alpha) \xi_t \frac{Y_t}{H_t}; \tag{A.5}$$

$$Y_t = A_t K_t^\alpha H_t^{1-\alpha}, \tag{A.6}$$

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

### A.3. The retailer's optimization problem

The retailer's optimization problem is

$$\max_{\{\widetilde{P}_t(j)\}} E_0 \left[ \sum_{l=0}^\infty (\beta_w \phi_p)^l \lambda_{t+l}^w \Pi_{t+l}^R(j) \right], \tag{A.7}$$

subject to the demand function[37]

$$Y_{t+l}(j) = \left( \frac{\widetilde{P}_t(j)}{P_{t+l}} \right)^{-\theta} Y_{t+l}, \tag{A.8}$$

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[37]This 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 $j \in (0,1)$.

where the retailer's nominal profit function is

$$\Pi^R_{t+l}(j) = \left(\pi^l \widetilde{P}_t(j) - P_{t+l}\xi_{t+l}\right) Y_{t+l}(j)/P_{t+l}. \tag{A.9}$$

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

$$\widetilde{P}_t(j) = \frac{\theta}{\theta - 1} \frac{E_t \sum_{l=0}^{\infty}(\beta_w \phi_p)^l \lambda^w_{t+l} Y_{t+l}(j)\xi_{t+l}}{E_t \sum_{l=0}^{\infty}(\beta_w \phi_p)^l \lambda^w_{t+l} Y_{t+l}(j)\pi^l/P_{t+l}}. \tag{A.10}$$

The aggregate price is

$$P_t^{1-\theta} = \phi_p(\pi P_{t-1})^{1-\theta} + (1-\phi_p)\widetilde{P}_t^{1-\theta}. \tag{A.11}$$

These lead to the following equation:

$$\hat{\pi}_t = \beta_w E_t \hat{\pi}_{t+1} + \frac{(1 - \beta_w \phi_p)(1 - \phi_p)}{\phi_p}\hat{\xi}_t, \tag{A.12}$$

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

## 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 money stock is measured by real M2 money stock per capita;

8. Output is measured by real GDP per capita;

9. Total Consumption is measured by Personal Consumption Expenditures (PCEC);

10. Investment is measured by Gross Private Domestic Investment (GPDI);

11. Government spending is measured by output minus consumption and investment (GDP - PCEC- GPDI).

**Figure 7:** Responses to Investment-Efficiency Shocks
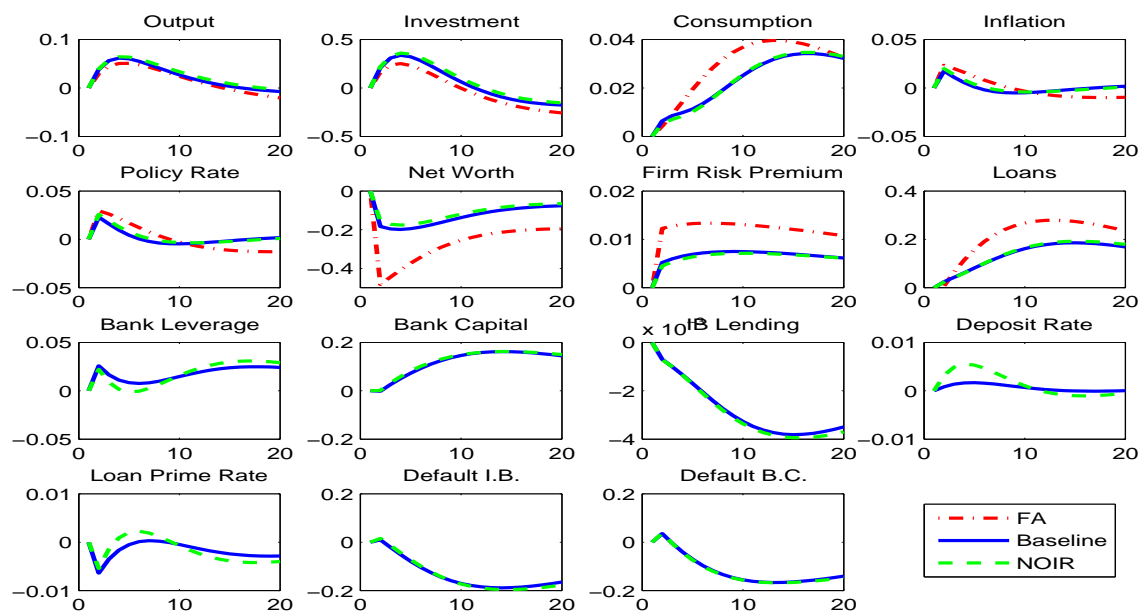


**Figure 8:** Responses to Preference Shocks
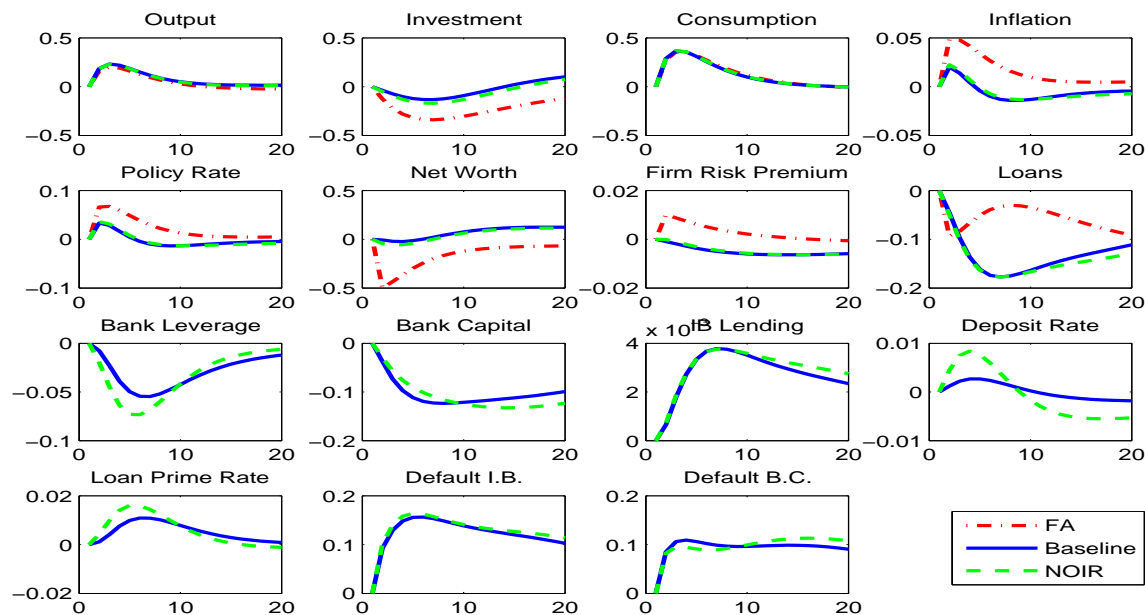
**Figure 9:** Responses to Government Spending Shocks