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by Ali Dib

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Abstract

The author develops a dynamic stochastic general-equilibrium model with an active banking sector, a financial accelerator, and financial frictions in the interbank and bank capital markets. He investigates the importance of banking sector frictions on business cycle fluctuations and assesses the role of a regulatory capital requirement in propagating the effects of shocks in the real economy. Bank capital is introduced to satisfy the regulatory capital requirement, and serves as collateral for borrowing in the interbank market. Financial frictions are introduced by assuming asymmetric information between lenders and borrowers that creates moral hazard and adverse selection problems in the interbank and bank capital markets, respectively. Highly leveraged banks are vulnerable and therefore pay higher costs when raising funds. The author finds that financial frictions in the interbank and bank capital markets amplify and propagate the effects of shocks; however, the capital requirement attenuates the real impacts of aggregate shocks (including financial shocks), reduces macroeconomic volatilities, and stabilizes the economy.

JEL classification: E32, E44, G1
Bank classification: Economic models; Business fluctuations and cycles; Financial markets; Financial stability

Résumé

L'auteur élabore un modèle d'équilibre général dynamique et stochastique qui comporte un secteur bancaire actif, un accélérateur financier et des frictions financières sur le marché interbancaire et le marché des fonds propres bancaires. Il cherche à déterminer l'importance des frictions du secteur bancaire dans les fluctuations économiques et évalue le rôle des exigences réglementaires en matière de fonds propres dans la propagation des effets des chocs au sein de l'économie réelle. Les fonds propres bancaires sont introduits pour satisfaire aux exigences réglementaires, et ils servent de garantie d'emprunt sur le marché interbancaire. Les frictions financières sont introduites sous l'hypothèse d'une asymétrie d'information entre prêteurs et emprunteurs qui crée des problèmes d'aléa moral et d'antisélection sur le marché interbancaire et le marché des fonds propres bancaires, respectivement. Les banques à fort levier financier sont vulnérables et, par conséquent, se financent à coût plus élevé. L'auteur constate que les frictions financières sur les deux marchés amplifient et propagent les effets des chocs; par contre, les exigences en matière de fonds propres atténuent l'incidence réelle des chocs globaux (dont les chocs financiers), réduisent les volatilités macroéconomiques et stabilisent l'économie.

Classification JEL : E32, E44, G1
Classification de la Banque : Modèles économiques; Cycles et fluctuations économiques; Marchés financiers; Stabilité financière

1. Introduction

The large and persistent impact of the 2007–09 financial crisis on global real activity has underscored the need to develop dynamic stochastic general-equilibrium (DSGE) models with real-financial linkages and an active banking sector. The models used by policy-makers, which typically abstract from financial frictions, have not been useful for understanding the implications of the financial crisis. Therefore, there is growing consensus among macroeconomists about the need to incorporate both banking intermediation and financial market frictions into the macroeconomic DSGE models.[1] Such models would allow an empirical evaluation of banks' behaviour in the transmission and propagation of supply and demand shocks, and an assessment of the importance of financial shocks, originating in the banking sector, as a source of business cycle fluctuations. The banking sector has been ignored in most DSGE models developed in the literature, except for some very recent papers.[2] Moreover, in the literature, financial frictions are usually modelled only on the demand side of the credit market, using either the Bernanke, Gertler, and Gilchrist (1999, BGG hereafter) financial accelerator mechanism or the Iacoviello (2005) framework.[3]

The principal motivation of this paper is to introduce micro-founded financial frictions in the interbank and bank capital markets into a New Keynesian DSGE model with a financial accelerator à la BGG.[4] The financial frictions are modelled by assuming imperfect information (asymmetric information) between lenders and borrowers in both markets. In contrast to Markovic (2006), Meh and Moran (2010), Hirakata, Sudo, and Ueda (2009), and Zhang (2009), this paper introduces bank capital to satisfy the capital requirement exogenously imposed by regulators, as in the Basel II Accord.[5] In this accord, banks must hold a minimum of bank capital to be able to provide risky loans to entrepreneurs. This requirement causes bank capital

[1]In light of the recent financial crisis, real-financial linkages have become the focus of an increasing number of papers. See Arend (2010) for more details about the recent papers.

[2]For example, Cúrdia and Woodford (2010); de Walque, Pierrard, and Rouabah (2010); Gertler and Karadi (2010); Gertler and Kiyotaki (2010); Zhang (2009).

[3]For example, Carlstrom and Fuerst (1997); Cespedes, Chang, and Velasco (2004); Christensen and Dib (2008); Van den Heuvel (2008).

[4]This paper extends Dib's (2010) model by proposing a fully micro-founded framework, in that all banks maximize profits and take optimal decisions under different constraints.

[5]de Walque, Pierrard, and Rouabah (2010), Gerali et al. (2010), and Van den Heuvel (2008) also introduce bank capital under an exogenous requirement.

to attenuate the real effects of different shocks. For instance, an increase in borrowing demand by entrepreneurs, induced by a drop in the monetary policy rate, forces banks to increase their leverage ratio and/or bank capital holdings. A higher leverage ratio and/or higher bank capital imply higher marginal costs of raising bank capital, and thus higher marginal costs of producing loans. Consequently, banks charge a higher lending prime rate, which increases the external financing costs of entrepreneurs and erodes the initial increase in demand for loans to finance new investment.

To model the interbank market, we assume the presence of two types of banks, "savings" and "lending" banks, that supply different banking services and transact in the interbank market.[6] Savings banks are owned by risk-averse agents, and operate in a monopolistically competitive market for collecting fully insured deposits from households. They set deposit rates and supply the received deposits to lending banks in the interbank market. Lending banks are risk neutral and perfectly competitive in the credit market. They borrow from the interbank market and raise bank capital (equity) in the bank capital market in order to provide loans to entrepreneurs. Bank capital is required to satisfy the capital requirement. Unlike the existing literature, bank capital in this model is a necessary input and a perfect complement to deposits in the production of loans. Lending banks optimally choose their leverage ratio and optimally allocate interbank borrowing between loans to entrepreneurs and investing in risk-free assets (government bonds). To borrow from the interbank market, lending banks use their assets (including loans to firms and government bonds) as collateral. We assume that loans are risky assets, but accepted as collateral with a haircut.

We assume that lending banks are subject to idiosyncratic shocks. The realized return on loans is observed costlessly only by lending banks, while savings banks must pay an agency cost to observe it. The asymmetric information across savings and lending banks creates a moral hazard problem in the interbank market. Therefore, the optimal debt contract in the interbank market is risky. That is, when the idiosyncratic shock to the lending bank exceeds a certain default threshold, the lending bank pays a fixed amount to the savings banks; but it defaults if the idiosyncratic shock is below this threshold. In this case, savings banks pay the agency costs and keep what remains of the defaulting lending bank's assets. Since lending

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

banks are risk neutral, they absorb all of the risk by offering an interbank risk premium. This risk premium depends on the ratio of total interbank borrowing to the risk-weighted lending bank's assets.

In addition, we introduce imperfect information into the bank capital market by assuming that there is an adverse selection problem between lending banks and investors in bank equity. Investors cannot perfectly observe the bank capital position and the degree of riskiness of lending banks. Therefore, lending banks use their excess bank capital (their bank capital buffer, which is bank capital held beyond the required level) to signal their positions. Well-capitalized banks are those with a lower leverage ratio.[7] These banks are relatively less risky, so they pay lower costs when raising capital in the bank capital market. These costs are increasing in the optimally chosen bank leverage ratio, which in equilibrium is lower than the maximum imposed level. Consequently, banks with smaller leverage ratios are well capitalized and pay lower costs when raising equity in the capital market. Through this channel, movements in banks' leverage ratio affect business cycle fluctuations (Fostel and Geanakoplos 2009; Geanakoplos 2009).[8]

In the model, the economy is disturbed by the usual aggregate demand and supply shocks. In addition, there are four shocks originating in the financial sector: riskiness, financial intermediation, haircut, and money injection (unconventional monetary policy). Riskiness shocks are modelled as shocks to the elasticity of the risk premium that affects the entrepreneurial external financing premium in the financial accelerator mechanism à la BGG. They are meant to represent shocks to the standard deviation of the entrepreneurial distribution, as in Christiano, Motto, and Rostagno (2010).[9] Financial intermediation shocks are exogenous events that affect credit supply, such as technological advances in the intermediation process, or perceived changes in creditworthiness.[10] Shocks to the haircut rate are interpreted as shocks to the interbank market affecting the interbank risk premium. They reflect the degree of confidence in the

[7]Repullo and Suarez (2009) develop a framework in which banks are unable to access equity markets in every period. Therefore, by holding capital buffers today, banks reduce the possibility of decreasing their lending in the future due to negative shocks to their earnings.

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

[9]These shocks may be interpreted as exogenous changes in the confidence of banks with credit risks in borrowers or in the overall health of the economy.

[10]Examples of shocks to the financial intermediation process are advances in financial engineering, credit rationing, and highly sophisticated methods for sharing risk.

value of risky assets used as collateral for borrowing in the interbank market. Therefore, an exogenous increase in the haircut reduces the value of risk-weighted assets used as collateral, thereby increasing the costs of borrowing in the interbank market. Finally, as in de Walque, Pierrard, and Rouabah (2010), we assume that the central bank injects liquidity (money) in the interbank market. The injections of money are exogenously used by the central bank to ease credit supply conditions in the banking system.

This model differs from Dib (2010) in terms of modelling the banking sector. First, we formally introduce asymmetric information in the banking sector that creates a moral hazard in the interbank market and an adverse selection problem in the bank capital market. The model incorporates, therefore, a double moral hazard framework leading to two financial accelerator mechanisms. Second, we assume that lending banks are perfectly competitive and subject to idiosyncratic shocks affecting their return on loans to firms. Finally, we allow the lending banks to optimally allocate interbank borrowing between providing loans and purchasing government bonds.

The model is calibrated to the U.S. economy and used to investigate the role of banking intermediation and bank capital channels in the transmission of real effects of aggregate shocks. Also, the model is simulated to evaluate the importance of financial shocks, originating in the banking sector, in explaining macroeconomic fluctuations. The model is successful in reproducing the dynamic effects of most key macroeconomic variables. We also find that bank leverage is procyclical following demand and supply shocks, indicating that banks are willing to expand more loans during booms and tend to restrict their supply of credit during recessions. Interestingly, financial frictions in the interbank and bank capital amplify and propagate the effects of shocks on output and investment. In contrast, the presence of bank capital, to satisfy the capital requirement, acts as an important "attenuation mechanism" that dampens the real effects of different aggregate shocks.

For example, following an expansionary monetary policy shock, the cost of borrowing for entrepreneurs falls, leading to an increase in entrepreneurs' net worth, which pushes down the external risk premium, raises entrepreneurs' demand for loans, and increases investment. Nevertheless, to expand their loans, lending banks have to increase their capital holdings to satisfy the capital requirement, or increase their leverage ratio. Both actions are costly for lending banks and push up the marginal cost of raising bank capital in the financial market. This raises the marginal cost of producing loans, and partially offsets the initial drop in the marginal cost triggered by the fall in the monetary policy rate. Consequently, the lending rate declines by less, and firms' demand for loans and investment increases by less. Thus, under capital requirements the decline in the external finance cost caused by an expansionary monetary policy is partly offset by the increase in the cost of raising bank capital. Therefore, bank capital regulations reduce the amplification effects that arise from financial frictions in the interbank and bank capital markets. This mechanism stabilizes the economy and reduces the uncertainty related to different structural shocks (particularly financial shocks). The simulation results indicate that financial shocks cause business cycles and are a substantial source of macroeconomic fluctuations.

This paper is organized as follows. Section 2 describes the model. Section 3 discusses the parameter calibration. Section 4 reports the impulse responses. Section 5 offers some conclusions.

2. The Model

The economy is inhabited by three types of households (workers, bankers, and entrepreneurs) that differ in their degree of risk aversion and their access to the financial markets, capital producers, retailers, a central bank, and a government. The banking sector consists of two types of heterogeneous banks: "savings" and "lending" banks. They offer different banking services and transact in the interbank market. Savings banks are owned by risk-averse bankers and are monopolistically competitive when collecting deposits from workers. In contrast, lending banks are risk neutral and perfectly competitive in the credit market when providing loans to entrepreneurs.[11]

[11] In Dib (2010), both savings and lending banks are monopolistically competitive and are subject to quadratic costs when adjusting their retail interest rates. In addition, savings banks optimally allocate deposits between interbank lending and government bonds.

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, $\gamma_w > 0$ is a parameter denoting the workers' risk aversion and the inverse of the elasticity of intertemporal substitution of consumption, and $\varsigma > 0$ is the inverse of the Frisch wage elasticity of labour supply. The parameter $\eta > 0$ measures the weight on leisure in the utility function. e_t is a preference (taste) shock that follows an AR(1) process.

We assume that workers save only in deposits in savings banks. A representative worker enters period t with D_{t-1} units of real deposits that pay the gross non-contingent nominal interest rate, R_t^D, between t and $t+1$.[12] During period t, workers supply labour to the entrepreneurs, for which they receive real labour payment $W_t H_t$, (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 the government, $\widetilde{T}_t^w$. Workers allocate their funds to private consumption and real deposits. 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 $\pi_t = P_t / P_{t-1}$ is the gross CPI inflation rate. A representative worker household chooses C_t^w, H_t, and D_t to maximize its expected lifetime utility, equation (1), subject to the single-period utility function, equation (2), and the budget constraint, equation (3). The first-order conditions of this optimization problem are provided in Appendix A.

[12] In this economy, R_t^D is different from the gross nominal rate of return on government bonds.

2.1.2 Bankers

Bankers (bank shareholders) own savings banks, from which they receive profits, and supply bank capital (bank equity) to lending banks, which is used to satisfy a capital requirement imposed by regulators. Bankers consume, save in non-contingent government bonds, and accumulate bank capital. It is assumed that bankers' preferences depend only on consumption and are given by

$$V_0^b = E_0 \sum_{t=0}^{\infty} \beta_b^t \frac{e_t}{1-\gamma_b} \left(\frac{C_t^b}{(C_{t-1}^b)^{\varphi}} \right)^{1-\gamma_b}, \tag{4}$$

where $\gamma_b > 0$ is a structural parameter denoting bankers' risk aversion and the inverse of the elasticity of intertemporal substitution. e_t is an AR(1) preference shock; this is the same shock for workers and bankers.

Banker households enter period t with $(1-\delta_{t-1}^Z)Z_{t-1}$ units of bank capital (equity) stock, whose price is Q_t^Z in period t, where $\delta_{t-1}^Z \in (0,1)$ is the fraction of bank capital diverted to lending banks' managers for their own benefit at the end of period $t-1$, and Z_t is the total claims (bank equity or shares) held by bankers.[13] Bank capital pays a contingent (risky) gross 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-1} between $t-1$ and t. During period t, bankers receive profit payments, Π_t^{sb}, from savings banks, and pay lump-sum taxes to the government, $\widetilde{T}_t^b$. They allocate their after-tax income to consumption C_t^b, real government bonds B_t, and bank capital acquisition $Q_t^Z Z_t$. We assume that bankers are subject to quadratic adjustment costs to alter the stock bank capital.[14] These costs are specified as:

$$Adj_t^Z = \frac{\chi_Z}{2} \left(\frac{Z_t}{Z_{t-1}} - 1 \right)^2 Q_t^Z Z_t, \tag{5}$$

where $\chi_Z > 0$ is the adjustment cost parameter. The bankers' budget constraint in real terms is

$$C_t^b + Q_t^Z Z_t + B_t = \frac{R_{t-1}B_{t-1}}{\pi_t} + \frac{(1-\delta_{t-1}^Z)R_t^Z Q_t^Z Z_{t-1}}{\pi_t} - Adj_t^Z + \Pi_t^{sb} - \widetilde{T}_t^b. \tag{6}$$

[13] In this economy, we assume that bankers invest in lending banks' capital, while bank managers run the banks. The diversion of a fraction of bank capital can be interpreted as bonuses paid to bank managers that reduce dividend payments to shareholders.

[14] These adjustment costs can be interpreted as entry costs to the financial market; for example, fees paid to brokers.

A representative banker chooses C_t^b, B_t, and Z_t to maximize its expected lifetime utility, equation (4), subject to equations (5) and (6). The first-order conditions derived from this optimization problem are:

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

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

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

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

Equation (7) determines the marginal utility of the banker's consumption, equation (8) relates the marginal rate of substitution to the real risk-free interest rate, and equation (9) corresponds to the optimal dynamic evolution of the stock of bank capital.

Combining conditions (8) and (9) yields the following condition relating the risky return on bank capital, R_t^Z, to the risk-free interest rate, diversion rate on bank capital, changes in expected prices of bank capital, and current costs/future gains of adjusting the stock of bank capital:

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

This condition shows that the expected risky return, R_{t+1}^Z, is increasing in the diversion rate on bank capital, δ_t^Z, in the risk-free rate, R_t, and in the marginal cost of adjusting bank capital between t and $t-1$. In addition, R_{t+1}^Z is decreasing in the expected changes in bank equity prices, $E_t \left[Q_t^Z / Q_{t+1}^Z \right]$, and in the expected gain from adjusting bank capital in t rather than in $t+1$.

Condition (10) leads to the following channels through which movements in bank capital affect the costs of credit supply and thus the real economy. The first is the price expectation channel, which arises from expectations of capital gains or losses from holding bank equity, due to expected changes in the price of bank capital. The second is the adjustment cost channel, which implies that it is costly for bankers to change their bank capital holdings. The adjustment costs smooth the response of bank capital to aggregate shocks.[15] Bankers will include these costs into their expectations of the risky return on bank capital that they receive from lending banks. The third channel is the diversion risk channel that arises from the existence of the possibility that lending banks' managers divert a fraction of bank capital payment for their personal benefit. Therefore, movements in bank capital, caused by macroeconomic fluctuations, have direct impacts on the expected costs of bank capital (paid to bankers) and, consequently, on credit supply conditions (the costs and quantities of loanable funds). Higher costs of raising bank capital imply higher lending prime rates charged to entrepreneurs when they borrow from lending banks.

2.2 Banking sector

2.2.1 Savings banks

Savings banks refer to all financial intermediaries that are net lenders (creditors) in the interbank market and are owned by risk-averse (households) bankers. We assume the existence of a continuum of monopolistically competitive savings banks indexed by $j \in (0, 1)$. Each bank j collects fully insured deposits $D_{j,t}$ from (households) workers and optimally sets the nominal deposit interest rate $R^D_{j,t}$ as a markdown below the risk-free return rate, R_t. Savings banks lend deposits in the interbank market to "lending banks" at the market-clearing interbank rate R^I_t, but pay an agency cost to monitor lending banks.

We introduce financial frictions into the interbank market by assuming that the return on lending banks' loans to entrepreneurs is subject to both idiosyncratic and aggregate shocks. Savings banks cannot observe the realized idiosyncratic shocks that affect lending banks unless they pay an agency (monitoring) cost, which can be interpreted as the cost of bankruptcy (including auditing, legal costs, and losses associated with asset liquidation) paid by the savings bank. This asymmetric information between the two types of banks creates a moral hazard problem in the interbank market, in that lending banks have the incentive to misreport the

[15] That is, in response to shocks, bank capital will adjust more slowly the higher the cost.

realized return on loans provided to entrepreneurs.[16] This implies that the optimal debt contract in the interbank market is risky. Nevertheless, since lending banks are risk neutral, they absorb all of the idiosyncratic risk and, in the end, savings banks get a risk-free return rate, R_t, on their interbank lending.[17] Nevertheless, savings banks are not protected against aggregate shocks.

As in Gerali et al. (2010), 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 individual relative deposit rate, $R^D_{j,t}/R^D_t$, and in the total supply of deposits by workers D_t:

$$D_{j,t} = \left(\frac{R^D_{j,t}}{R^D_t} \right)^{\vartheta_D} D_t, \tag{11}$$

where $\vartheta_D > 1$ is the elasticity of substitution between different types of deposits.[18] Also, when setting the deposit interest rate, $R^D_{j,t}$, savings banks are subject to quadratic adjustment costs. These costs allow an interest rate spread (between deposit and policy rates) that evolves over the cycle. We assume adjustment costs à la Rotemberg (1982), given by

$$Adj_t = \frac{\phi_R}{2} \left(\frac{R^D_{j,t}}{R^D_{j,t-1}} - 1 \right)^2 D_t, \tag{12}$$

where $\phi_R > 0$ is an adjustment cost parameter. The optimization problem of the j^{th} savings bank is to choose $R^D_{j,t}$ that maximizes:

$$\max_{\{R^D_{j,t}\}} E_0 \sum_{t=0}^{\infty} \beta_b^t \lambda_t^b \left\{ \left[R_t - R^D_{j,t} \right] D_{j,t} - \frac{\phi_R}{2} \left(\frac{R^D_{j,t}}{R^D_{j,t-1}} - 1 \right)^2 D_t \right\},$$

[16]Following Townsend (1979), we assume that there exists a costly state verification problem for savings banks when lending in the interbank market.

[17]The risk-free rate is equal to the interbank rate R^I_t minus the agency costs paid to monitor lending banks.

[18]This supply function from a representative savings bank is derived from the definition of the aggregate supply of deposits, D_t, and the corresponding deposit interest rate, R^D_t, in the monopolistic competition framework, as follows:
$D_t = \left(\int_0^1 D_{j,t}^{\frac{1+\vartheta_D}{\vartheta_D}} dj \right)^{\frac{\vartheta_D}{\vartheta_D+1}}$ and $R^D_t = \left(\int_0^1 {R^D_{j,t}}^{1+\vartheta_D} dj \right)^{\frac{1}{1+\vartheta_D}}$, where $D_{j,t}$ and $R^D_{j,t}$ are, respectively, the supply and deposit interest rates faced by each savings bank $j \in (0,1)$.

subject to (11); where R_t is the gross nominal risk-free rate received by savings banks from providing interbank loans. 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. The j^{th} savings bank optimally sets the deposit rate, $R_{j,t}^D$, to maximize the flow of its profits.

In symmetric equilibrium, where $R_{j,t}^D = R_t^D$ for all $j \in (0,1)$, the first-order condition, with respect to $R_{j,t}^D$, is:

$$\frac{1+\vartheta_D}{\vartheta_D}(R_t^D - 1) = R_t - 1$$
$$-\frac{\phi_R}{\vartheta_D}\left(\frac{R_t^D}{R_{t-1}^D} - 1\right)\frac{R_t^D}{R_{t-1}^D} + \frac{\beta_b \phi_R}{\vartheta_D}\left(\frac{R_{t+1}^D}{R_t^D} - 1\right)\frac{R_{t+1}^D}{R_t^D}, \tag{13}$$

where $\phi_R \left(\frac{R_t^D}{R_{t-1}^D} - 1\right)\frac{R_t^D}{R_{t-1}^D}$ is the marginal cost of adjusting the deposit interest rate between t and $t-1$.

This optimal condition defines the deposit interest rate as a markdown below the risk-free rate. Therefore, the spread between policy and deposit rates, $R_t - R_t^D$, is time varying and increasing in the net marginal cost of adjusting the deposit rate across periods. Consequently, this framework adds a new channel through which savings banks' behaviour affects credit supply conditions and the real economy. In the presence of the nominal rigidity of deposit rates, savings banks influence the intertemporal substitution of consumption across periods and thus facilitate consumption smoothing.

2.2.2 Lending banks

There is a continuum of risk-neutral lending banks that are perfectly competitive in the credit market. These banks borrow from savings banks and raise funds from bankers (shareholders) in the form of equity (bank capital). To provide loans to entrepreneurs, lending banks must maintain sufficient capital to satisfy the minimum regulatory capital requirement. Bank capital is also used as part of the collateral when borrowing in the interbank market. The return on bank loans is subject to both idiosyncratic and aggregate shocks. We assume that the realized return on loans is observed costlessly only by lending banks: the idiosyncratic shocks are independent across time and lending banks, and distributed with log-normal distribution with a mean of one.

Let $D_t = \int_0^1 D_{j,t} dj$ denote total interbank borrowing from savings banks. Lending banks optimally allocate a fraction s_t of total interbank borrowing to lend to entrepreneurs and use $(1 - s_t)$ to purchase government bonds. We assume that the stock of bank capital, Z_t, priced at Q_t^Z, is held by lending banks as government bonds. Therefore, the total risk-free asset held by lending banks in period t is $B_t^L = (1 - s_t)D_t + Q_t^Z Z_t$ and it pays the risk-free interest rate R_t.

As in Gertler and Karadi (2010), we assume that, during times of financial crisis, the central bank may conduct unconventional monetary policy (quantitative monetary easing) by directly injecting money, m_t, into the lending banks. This allows the central bank to act as a lender of last resort. Table 1 reports the lending bank's balance sheet in period t.

Table 1: Lending bank's balance sheet

Assets	**Liabilities**
Government bonds: B_t^L	Bank capital: $Q_t^Z Z_t$
Loans: L_t	Interbank borrowing: D_t
	Money injection: m_t
	Other terms: $(\Gamma_t - 1)(s_t D_t + m_t)$

The table shows that money injection, m_t, and shocks to financial intermediation, Γ_t, affect the total value of lending banks' balance sheets, implying balance sheet expansion or contraction.

A. Asymmetric information in the interbank market

Because of the asymmetric information problem between savings and lending banks, the optimal debt contract in the interbank market is risky. Therefore, when a lending bank's idiosyncratic return shock exceeds a certain default threshold, the lending bank pays the interbank rate, R_t^I, to a savings bank; however, it will default if the idiosyncratic return shock falls below this threshold. In this case, a savings bank pays an agency cost and gets to keep what remains of the lending bank's assets. The defaulting bank's shareholders receive nothing. Thus, this type of debt contract prevents any lending bank from misreporting its true realized return.

To borrow from the interbank market, a lending bank uses its assets as collateral. Assets include government bonds, B_t^L, and loans to entrepreneurs, L_t, which are risky assets. If a lending bank defaults on its interbank borrowing, savings banks pay agency costs and seize its assets. We assume that savings banks accept loans—which are provided by lending banks to entrepreneurs—as collateral, but subject to a haircut discount. This is to protect themselves against unexpected fluctuations in the market values of these risky loans. Therefore, the risk-weighted value of a lending bank's assets used as collateral is $(1-\mu_t)L_t + B_t^L$, where $\mu_t \in (0,1)$ is a time-varying haircut rate imposed by savings banks on risky assets.[19]

Given the agency cost, the default threshold, and the standard deviation of the distribution of bank idiosyncratic shocks, the debt contract in the interbank market implies an endogenous finance premium, Υ_t (which we call an interbank premium hereafter). Similar to the financial accelerator framework, this premium depends on the ratio of a borrower's interbank debt to its risk-weighted asset value. Specifically, the interbank finance premium is assumed to have the following reduced form:

$$rp_t^B \equiv \Upsilon_t = \left(\frac{D_t}{(1-\mu_t)L_t + B_t^L} \right)^{\upsilon}, \tag{14}$$

where $\Upsilon(1) = 1$, $\Upsilon'(\cdot) > 0$, and $\Upsilon''(\cdot) < 0$; $\upsilon > 0$ is a parameter measuring the elasticity of the interbank risk premium with respect to the ratio of interbank borrowing to lending banks' risk-weighted assets. The interbank external finance premium increases in total interbank borrowing, D_t, as well as in the haircut rate, μ_t; however, it decreases in loans and risk-free assets (i.e., L_t and B_t^L, respectively). This interbank premium may also arise from a lack of liquidity, which could occur when lending banks are unable to pay back their debt because they hold only illiquid assets (loans to entrepreneurs). We assume that μ_t evolves according to the following autoregressive process:

$$\log(\mu_t) = (1-\rho_\mu)\log(\mu) + \rho_\mu \log(\mu_{t-1}) + \epsilon_{\mu t}, \tag{15}$$

where $\mu \in (0,1)$ is the steady-state value of μ_t, $\rho_\mu \in (0,1)$ is the autoregressive coefficient, and $\epsilon_{\mu t}$ is normally distributed with mean zero and standard deviation σ_μ.

The cost of borrowing in the interbank market, the gross nominal interbank rate R_t^I, depends on the policy interest rate, R_t, the opportunity costs of savings banks, and the interbank premium, Υ_t. The interbank rate is

$$R_t^I = R_t \Upsilon_t. \tag{16}$$

[19] The haircut rate reduces the value of loans used as collateral when borrowing on the interbank market. It depends on the degree of riskiness of assets used as collateral. Because bank capital (held as government bonds) and securities are risk-free assets, the haircut rate applied to both is zero.

Therefore, financial frictions in the interbank market imply a time-varying spread between the interbank rate and the policy rate (an interbank spread). This spread is given by the net interbank premium, $\log(\Upsilon_t) = \log(R_t^I) - \log(R_t)$, and fluctuates over the cycle. It increases in agency costs, banks' default threshold, and the degree of riskiness in the banking system. In normal times, fluctuations in the interbank spread are very small, but can be substantial during times of financial stress.[20]

B. Asymmetric information in the bank capital market

We introduce an adverse selection problem into the bank capital financial market by assuming that there is imperfect information between bankers and lending banks.[21] When investing in bank equity capital, bankers do not have complete information about lending banks' capital positions and the degree of risk they are bearing.[22] Lending banks could either be well capitalized and hold substantial excess bank capital beyond the minimum required level, or be in a more vulnerable position where they are heavily leveraged, or holding excessive risky assets.

This imperfect information provides the incentive to lending banks to signal their capital position to the financial market. This can be achieved by indicating their capital buffer holding (bank capital held beyond the minimum required level). This helps investors to distinguish between well- and poorly capitalized banks. The cost of raising bank capital decreases when banks hold excess bank capital. To prevent banks from taking excessive risk (including high leverage and investing in very risky loans), bankers require a risk premium, in addition to the expected return (R_t^Z), that depends on the lending banks' leverage ratio relative to the maximum imposed by regulators. Therefore, well-capitalized banks (i.e., those that hold substantial excess bank capital) face lower costs when raising bank capital.

Lending banks face a capital requirement imposed by regulators, and so they must hold a minimum amount of bank equity as a fraction of risky assets (loans). Taking into account the maximum leverage ratio imposed by regulators, $\bar{\kappa}$, lending banks optimally choose their

[20] Cúrdia and Woodford (2010) examine the implications of time-varying spreads on the conduct of monetary policy.

[21] See Morrison and White (2005), who discuss the role of capital requirements and adverse selection in the banking sector. A recent study by Eisfeldt, Green, and Uhlig (2010) examines the role of adverse selection in banking.

[22] Bankers cannot observe the realization of lending banks' idiosyncratic shocks. If a lending bank defaults, savings banks will seize its bank capital, and bankers (shareholders) will lose their investment.

leverage ratio, κ_t, that is defined as the ratio of loans to bank capital.[23] We assume that a lower-than-imposed leverage ratio entails the holding of excess bank capital, which reduces the cost of raising bank capital.

The bank capital premium that banks pay depends negatively on the amount of excess bank capital (the capital buffer), and is given by the following reduced form:

$$rp_t^{\kappa} \equiv \Xi_t = \left(\frac{\bar{\kappa} - \kappa_t}{\bar{\kappa}} Q_t^Z Z_t \right)^{-\xi} > 1, \tag{17}$$

where $\xi > 0$ denotes the elasticity of the bank capital premium with respect to excess bank capital holdings. This premium decreases with the level of the capital buffer. The bank capital premium is increasing in the optimally chosen leverage ratio, κ_t, while it is decreasing in both the maximum imposed ratio, $\bar{\kappa}$, and in the market value of bank capital, $Q_t^Z Z_t$.[24] A higher-leverage ratio (a lower bank capital buffer) implies greater bank risk and vulnerability. Therefore, shareholders require a higher bank capital premium, to be compensated for this risk.

When $\kappa_t < \bar{\kappa}$, the bank's chosen leverage ratio is below the required level, its holding of excess capital reduces the financing premium. Thus, the optimal choice of the bank's leverage ratio affects the costs of lending directly through its impact on bank capital funding costs. Nevertheless, as $\kappa_t \to \bar{\kappa}$, the bank's leverage ratio converges to the required level, the premium that a bank has to pay substantially increases. In the event of a negative shock, banks will deleverage by either reducing their loans to entrepreneurs or raising new bank equity.[25]

C. Production of loans

To produce loans for entrepreneurs, the representative lending bank uses a fraction of interbank borrowing, $s_t D_t$, plus any injection of money from the central bank (quantitative monetary easing), m_t, and the total market value of its bank capital, $Q_t^Z Z_t$. In contrast to recent studies that introduce bank capital into DSGE models, we assume that bank capital is a perfect

[23]Note that κ_t is defined as the ratio of risky assets held by banks (loans to entrepreneurs) to bank capital holdings. Therefore, it is the inverse of the bank capital ratio.

[24]Note that $\frac{\partial \Xi_t}{\partial \kappa_t} > 0$, $\frac{\partial \Xi_t}{\partial \bar{\kappa}_t} < 0$, and $\frac{\partial \Xi_t}{\partial Z_t} < 0$.

[25]Banks can achieve deleveraging objectives by either reducing their loans to entrepreneurs or raising extra bank capital; however, in this framework, the costs of raising new capital are very high, forcing banks to reduce their loans.

complement to interbank borrowing because it is used to satisfy the capital requirement.[26] This complementarity implies that bank capital acts as an attenuation mechanism, rather than an amplification mechanism. Therefore, as in Dib (2010), we assume that lending banks use a Leontief technology to produce loans supplied to entrepreneurs:[27]

$$L_t = \min\left\{s_t D_t + m_t; \kappa_t Q_t^Z Z_t\right\} \Gamma_t, \tag{18}$$

where $\kappa_t < \bar{\kappa}$ is the bank's optimally chosen leverage ratio. Γ_t represents a financial intermediation shock affecting the supply of loans, and is thus a shock to the balance sheet of lending banks. It represents exogenous factors such as perceived risk, or technological advances in financial intermediation. For example, banks may underevaluate (overevaluate) risk during booms (recessions), which exogenously increases (decreases) the loan supply.[28] It is assumed that m_t and Γ_t evolve according to AR(1) processes, where the steady-state value of m_t is zero, while that of Γ_t is equal to unity.[29]

The marginal cost of producing loans is the weighted sum of the marginal cost of interbank borrowing and the marginal cost of raising bank capital. Loan expansion requires either adopting a higher-leverage ratio or an increase in bank capital holdings. Therefore, a higher demand for bank capital or a higher-leverage ratio implies higher costs of raising bank capital, thereby increasing the marginal cost of producing loans and borrowing costs for entrepreneurs. These extra costs partly dampen the initial demand for loans and investment.

As in Dib (2010), we assume that lending bank managers divert a fraction, δ_t^Z, of bank capital to their own benefit, which reduces dividend payments to banks' shareholders. The diversion of a fraction of bank capital entails convex penalties (costs) paid in the next period. This penalty is given by

$$\Delta_t^Z = \frac{\chi_{\delta^Z}}{2}\left(\frac{\delta_{t-1}^Z Q_{t-1}^Z Z_{t-1}}{\pi_t}\right)^2 R_t^Z, \tag{19}$$

[26]Examples of recent studies are Meh and Moran (2010), Hirakata, Sudo, and Ueda (2009), and Zhang (2009). In these studies, bank capital is introduced to solve asymmetric information between lenders and borrowers, and is assumed to be a perfect substitute to deposits in loan production (loans are the sum of bank capital and deposits).

[27]Leontief technology implies perfect complementarity between deposits and bank capital when producing loans, and satisfies the capital requirement.

[28]The process of loan evaluation certainly has evolved over time, through technological advances in information services. Advances in computational finance and sophisticated methods of sharing risk are examples of this shock.

[29]See Dib (2010) for more details.

where $\chi_{\delta^Z} > 0$ is a parameter determining the steady-state value of δ_t^Z.

The lending bank's optimization problem is to choose s_t, κ_t, and δ_t^Z to maximize its profits, subject to its production of loans. The representative lending bank's profit maximization problem is

$$\max_{s_t,\kappa_t,\delta_t^Z} E_t \left\{ R_t^L L_t + R_t(1-s_t)D_t - R_t \Upsilon_t D_t - \left[R_{t+1}^Z \Xi_t - R_t \right] Q_t^Z Z_t + \delta_t^Z R_{t+1}^Z - R_t m_t - \Delta_t^Z \right\},$$

subject to $B_t^L = (1-s_t)D_t + Q_t^Z Z_t$, equation (14) and equations (17)–(19). R_t^L is the gross nominal lending rate that represents the return on loans between t and $t+1$, and so the total return on loans is $R_t^L L_t$. The term $R_t(1-s_t)D_t$ represents the total return on the fraction of interbank borrowing invested as government bonds, while $\left[R_{t+1}^Z \Xi_t - R_t \right] Q_t^Z Z_t$ is the cost of bank capital, which depends on the cost of raising bank equity less the return on holding bank capital as government bonds. The term $R_t m_t$ denotes the cost of money injections received from the central bank.

The first-order conditions of this optimization problem with respect to s_t, κ_t, and δ_t^Z are:

$$R_t^L = R_t + R_t \upsilon \left(\frac{D_t}{(1-\mu_t)L_t + B_t^L} \right)^{1+\upsilon} \tag{20}$$

$$R_t^L - R_t \Upsilon_t = \xi \left(\frac{\bar{\kappa} - \kappa_t}{\bar{\kappa}} Q_t^Z Z_t \right)^{-\xi} \frac{E_t R_{t+1}^Z}{\bar{\kappa} - \kappa_t}; \tag{21}$$

$$\delta_t^Z = E_t \left[\frac{\pi_{t+1}}{\chi_{\delta^Z} Q_t^Z Z_t} \right], \tag{22}$$

where $\Upsilon_t > 1$ is the interbank risk premium. In addition, the Leontief technology implies the following implicit demand functions for interbank borrowing and bank capital:

$$L_t = (s_t D_t + m_t)\Gamma_t; \tag{23}$$

$$L_t = \kappa_t Q_t^Z Z_t \Gamma_t. \tag{24}$$

Equation (20) is the optimal condition for allocating a fraction of interbank borrowing to government bonds. It states that lending banks optimally choose s_t, so that the marginal cost is equal to the marginal cost of investing in government bonds. In this framework, the marginal cost is given by R_t^L, the opportunity cost of not extending loans. The marginal gain is given by the right-hand terms in equation (20); it is the sum of the return on investing in government bonds and the decrease in the interbank risk premium caused by the additional holding of risk-free assets used as collateral when borrowing in the interbank market. The fraction of interbank borrowing invested in government bonds increases in interbank borrowing, the interbank rate, and the policy interest rate, but it decreases in the lending rate, loans, and bank capital. Therefore, to reduce the cost of borrowing, banks can substitute bank capital by holding more risk-free assets. This explains why banks hold government bonds, despite the fact that they are dominated by other types of assets.

Equation (22) is the optimal condition determining the evolution of the bank leverage ratio, κ_t; it depends on the maximum imposed leverage ratio $\bar{\kappa}$, the policy rate, the interbank premium, the lending rate, the risky return on bank capital, and the market value of bank capital. The leverage ratio is optimally chosen so that the marginal cost of holding bank capital in excess (the bank capital buffer) equals the marginal gain. The marginal cost is given by the terms $R_t^L - R_t\Upsilon_t$, which is the opportunity cost of not increasing loans. The right-hand terms in equation (22) indicate that the marginal gain is equal to the decrease in the bank capital premium associated with holding an extra dollar as a bank capital buffer. Thus, the marginal gain is simply the decrease in the cost of raising bank equity in the financial market due to holding an excess bank capital (the decline in the financial market risk premium).

The marginal cost of producing loans, ζ_t, is the weighted sum of the marginal cost of borrowing in the interbank market plus the marginal cost of raising bank capital, so that

$$\zeta_t = \Gamma_t^{-1}\left[R_t\Upsilon_t + \kappa_t^{-1}\left(R_{t+1}^Z\Xi_t - R_t\right)Q_t^Z\right]. \tag{25}$$

Since lending banks operate in a perfectly competitive market, the gross nominal lending rate they charge to entrepreneurs is equal to the marginal cost of producing loans. Therefore, $R_t^L = \zeta_t$. The marginal cost increases in both risk premia affecting the interbank and bank capital financial markets; i.e., Υ_t and Ξ_t. Consequently, credit frictions in these markets have direct implications for the costs of providing loans to firms.

2.3 Production sector

2.3.1 Entrepreneurs

The entrepreneurs' behaviour follows that in BGG. 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 an entrepreneur's net worth (the firm equity) alone is never sufficient to finance new capital acquisitions, and so the entrepreneur must borrow to finance investment.

At the end of each period, the entrepreneur purchases capital, K_{t+1}, to be used in the next period, at the real price Q_t^K. Capital acquisition is financed partly by net worth, N_t, and the remainder 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

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

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 the parameter values associated with the cost of monitoring the borrower, the characteristics of the distribution of entrepreneurial returns, and the expected life span of firms—the optimal debt contracts between banks and entrepreneurs imply an external finance premium, $\Psi(\cdot)$, which 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 the gross real prime lending rate plus an external finance premium. Thus, the demand for capital should satisfy the following optimality condition:

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

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. The external finance premium is given by

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

where $\Psi'(\cdot) < 0$ and $\Psi(1) = 1$, and ψ_t represents an aggregate riskiness shock, as in Christiano, Motto, and Rostagno (2010).

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.[30] Specifically, the external finance premium is assumed to have the following functional form:

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

where ψ_t is the time-varying elasticity of the external finance premium with respect to the entrepreneurs' leverage ratio. Following Christiano, Motto, and Rostagno (2010), we assume that ψ_t, the aggregate riskiness shock, follows an AR(1) process. BGG show that this elasticity depends on the standard deviation of the distribution of the entrepreneurs' idiosyncratic shocks, the agency costs, and the entrepreneurs' default threshold. Therefore, a positive shock to ψ_t may result from exogenous increases in the distribution of entrepreneurs' idiosyncratic shocks, the agency costs, and/or the entrepreneurs' default threshold. The result is a rise in ψ_t and thus the external finance premium.[31]

Aggregate entrepreneurial net worth evolves according to

$$N_t = \nu V_t + (1 - \nu) g_t, \tag{30}$$

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.[32] V_t is given by

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

[30]When the riskiness of loans increases, the agency costs rise and the lender's expected losses increase. A higher external finance premium paid by successful entrepreneurs offsets these higher expected losses.

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

[32]The parameter ν will affect the persistence of changes in net worth.

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

$$E_{t-1}F_t = E_{t-1}\left[\frac{R^L_{t-1}}{\pi_t}\Psi\left(\frac{Q^K_{t-1}K_t}{N_{t-1}};\psi_{t-1}\right)\right] \tag{32}$$

is the cost of borrowing (the interest rate in the loan contract signed at time $t-1$). Earnings from operations in this period become the next period's net worth. In our formulation, borrowers sign a debt contract that specifies a nominal interest rate.[33] Loan repayment (in real terms) will then depend on the realized inflation rate. An unanticipated increase (decrease) in inflation will reduce (increase) the real cost of debt repayment and, therefore, increase (decrease) entrepreneurial net worth.

To produce output Y_t, the entrepreneur uses K_t units of capital and H_t units of labour following a constant-returns-to-scale technology:

$$Y_t \leq A_t K_t^{\alpha} H_t^{1-\alpha}, \quad \alpha \in (0,1)\,, \tag{33}$$

where A_t is a technology shock common to all entrepreneurs and is assumed to follow a stationary AR(1) process. Each entrepreneur sells his or her output in a perfectly competitive wholesale-good market for a price that equals the entrepreneur's nominal marginal cost. The entrepreneur maximizes profits by choosing K_t and H_t subject to the production function (33). See Appendix A for the entrepreneur's first-order conditions.

2.3.2 Capital producers

Capital producers use a linear technology, subject to an investment-specific shock x_t, to produce physical capital, K_{t+1}. They use a fraction of the final goods purchased from retailers as investment goods, I_t, and the existing capital stock to produce new capital. The new capital replaces depreciated capital and adds to the capital stock. At the end of period t, the entire stock of capital is sold to the entrepreneurs to be used in the production of wholesale goods in the next period, $t+1$.

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

$$\max_{I_t} E_t \sum_{t=0}^{\infty} \beta_w^t \lambda_t^w \left\{ Q_t^K \left[x_t I_t - \frac{\chi_I}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 I_t \right] - I_t \right\}. \tag{34}$$

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

The disturbance x_t is a shock to the marginal efficiency of investment and is assumed to follow an AR(1) process. Since I_t is expressed in consumption units, x_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 $\frac{\chi_I}{2}\left(\frac{I_t}{I_{t-1}}-1\right)^2 I_t$, where $\chi_I > 0$ is the investment adjustment cost parameter.

Thus, the optimal condition is

$$\frac{1}{Q_t^K} = x_t - \chi_I\left(\frac{I_t}{I_{t-1}}-1\right)\frac{I_t}{I_{t-1}} + \beta_w \chi_I E_t\left[\left(\frac{I_{t+1}}{I_t}-1\right)\left(\frac{I_{t+1}}{I_t}\right)^2 \frac{Q_{t+1}^K}{Q_t^K}\frac{\lambda_{t+1}^w}{\lambda_t^w}\right], \tag{35}$$

which is the standard Tobin's Q equation that relates the price of capital to the marginal adjustment cost.[34]

The quantity and price of capital are determined in the capital market. The entrepreneurial demand curve for capital is obtained from equation (27) and, in Appendix A, equation (A.4), whereas the supply of capital is given by equation (35). The intersection of these curves gives the market-clearing quantity and price of capital. Capital adjustment costs slow down the response of investment to shocks, which directly affects the price of capital. In addition, the aggregate capital stock evolves according to

$$K_{t+1} = (1-\delta)K_t + x_t I_t - \frac{\chi_I}{2}\left(\frac{I_t}{I_{t-1}}-1\right)^2 I_t. \tag{36}$$

2.3.3 Retail firms

The retail sector is used to introduce nominal price rigidity into the economy. Retail firms purchase wholesale goods at a price equal to their nominal marginal cost, and differentiate 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 does not 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, retailer j must charge the same price as in the preceding period, indexed to the steady-state gross rate of inflation, π. At time

[34] Note that, in the absence of investment adjustment costs, the capital price Q_t^K is constant and equals 1. Investment adjustment costs generate capital price variability, which contributes to the volatility of entrepreneurial net worth.

t, if 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 and output from their steady-state values. Thus, monetary policy evolves according to the following Taylor-type policy rule:

$$\log\left(R_t/R\right) = \varrho_\pi \log\left(\pi_t/\pi\right) + \varrho_Y \log\left(Y_t/Y\right) + \varepsilon_{Rt}, \tag{37}$$

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 a period of financial stress, the central bank can use unconventional monetary policy by injecting money into the banking system, m_t.

2.4.2 Government

In each period, the government buys a fraction of the final retail good, G_t, pays the principal debt from the previous period, and makes interest payments. We assume that the government runs a balanced budget financed with newly contracted debt and lump-sum taxes, $\widetilde{T}_t^w + \widetilde{T}_t^b$. Therefore, the government's budget constraint, in real terms, is

$$G_t + \left[B_{t-1} + B_{t-1}^L\right] R_{t-1}/\pi_t = B_t + B_t^L + \widetilde{T}_t^w + \widetilde{T}_t^b, \tag{38}$$

where B_t and B_t^L are government bonds held by households (bankers) 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, and so $B_t = 0$ in equilibrium. The newly created money is transferred to workers, so that $T_t = D_t - D_{t-1}/\pi_t$. The resource constraint implies that $Y_t = C_t^w + C_t^b + I_t + G_t$. Finally, 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, 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:

$$\log(X_t) = (1 - \rho_X)\log(X) + \rho_X \log(X_{t-1}) + \varepsilon_{Xt}, \tag{39}$$

where $X_t = \{A_t, x_t, e_t, G_t, \psi_t, \Gamma_t, \mu_t, m_t\}$, $X > 0$ 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

Following Dib (2010), we calibrate the model's parameters to capture the key features of the U.S. economy, using quarterly data, for the period 1980Q1–2008Q4. Table 2 reports the calibration values. The steady-state gross 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 0.9989 and 0.9949 to match the historical averages of nominal deposit and risk-free interest rates, R_t^D and R_t (see Table 3 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, since 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 habit formation parameter, φ, is set to 0.65, as estimated in Christiano, Motto, and Rostagno (2010).

The capital share in aggregate output 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 goods market θ is set to 6, which implies a 20 per cent markup in the steady-state equilibrium. The parameter ϑ_D, which measures the degree of monopoly power of the savings banks, is set equal to 2.2. This value is set to match the historical average of the deposit rate, R_t^D.

The nominal price rigidity parameter, ϕ_p, in the Calvo-Yun price contract is set to 0.75, implying that the average price remains unchanged for four quarters. This value is that estimated by Christensen and Dib (2008) for the U.S. economy and is commonly used in the literature. The parameter of the adjustment costs of the deposit interest rate, ϕ_R, is set to 2.4 to match the standard deviation of the deposit rate to that observed in the data.

Monetary policy parameters ϱ_π and ϱ_Y are 1.5 and 0.05, respectively; these values satisfy the Taylor principle. The standard deviation of monetary policy shock, σ_R, is given the usually estimated value of 0.006.

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 the next quarter, 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 that estimated by Christensen and Dib (2008).[35] Similarly, we calibrate υ, the elasticity of the interbank premium with respect to the ratio of total interbank borrowing to risk-weighted assets, at 0.05, assuming that it is similar to the one used in the entrepreneurs' external finance premium.

We set ξ, the elasticity of the bank capital premium, at 2.2, so that the steady-state value of the bank capital premium, Ξ, is 1.0025 (1 per cent in annual terms). In contrast, we set the steady-state bank's leverage ratio, κ, at 11.5 to match that observed in the U.S. data. Based on the Basel II minimum required bank capital ratio of 8 per cent, we assume that the maximum imposed bank leverage, $\bar{\kappa}$, is 12.5.[36]

We calibrate the shocks' process parameters using either 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 the 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 coefficient, is 0.81, while the estimated standard error, σ_G, is 0.0166.

To calibrate the parameters of the riskiness shock process ψ_t, we set the autocorrelation coefficient ρ_ψ to 0.83, the estimated value in Christiano, Motto, and Rostagno (2010), while the standard deviation σ_ψ 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 and AAA corporate bond yields, as in Christiano, Motto, and Rostagno (2010). We set the autocorrelation

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

[36] The maximum bank leverage ratio is simply the inverse of the minimum required bank capital ratio, which is 8 per cent in the Basel II Accord.

coefficient and the standard deviation of the financial 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 type of financial shock.[37] Finally, we set the autocorrelation coefficients of the injection of money and haircut rate shocks, ρ_m and ρ_μ, equal to 0.5, and their standard deviations, σ_m and σ_μ, to 0.

4. Impulse Responses

To assess the contribution of frictions in the interbank and bank capital markets, we plot and compare the impulse responses of key macroeconomic variables to demand, supply, and financial shocks in four models: (1) the model with no financial frictions (the NoFF model); (2) the model with only a financial accelerator in the production sector, as in BGG (the FA model); (3) the model with a financial accelerator in the production sector and bank capital (the FABC model);[38] and (4) the full baseline model, described above, that includes both the bank capital and interbank markets (the BS model).

Figures 1 and 2 depict the impulse responses to technology and monetary policy shocks, respectively. Figures 3–5 report the impulse responses to riskiness, financial intermediation, and haircut shocks. Each variable's response is expressed as the percentage deviation from its steady-state level.

4.1 Responses to technology and monetary policy shocks

As in previous studies, incorporating the financial accelerator mechanism à la BGG in the demand side of the credit market amplifies and propagates the dynamic effects of standard supply and demand shocks, as illustrated in Figures 1 and 2 (the FA versus the NoFF model). Nevertheless, Figure 1 shows that the financial accelerator only moderately amplifies and propagates the impact of technology shocks on output and consumption. This results from debt deflation

[37] In future work, we will estimate the model's structural parameters using either a maximum-likelihood procedure, as used in Christensen and Dib (2008), or a Bayesien approach, as used in Christiano, Motto, and Rostagno (2010), Queijo von Heideken (2009), and others.

[38] In this model, in addition to the financial accelerator à la BGG, we incorporate frictions in the bank capital market by assuming an adverse selection problem that arises from imperfect information between bank investors and lending banks. In the FABC model, we turn off the interbank market acceleration mechanism by setting the interbank premium equal to its steady-state value.

effects.[39] Following a positive technology shock, output increases, while prices decrease, pushing down the inflation rate. The decline in inflation increases the real costs of repaying existing debt, which erodes a part of the increase in entrepreneurs' net worth and results in a smaller decline in the external finance premium. Therefore, the response of investment is slightly larger in the FA model compared to that in the NoFF model, since the costs of borrowing are smaller.

In contrast, following a monetary policy shock, the implication of the financial acceleration mechanism is obvious, because output and prices move in the same direction. Figure 2 shows that, following a tightening shock of monetary policy, output and inflation fall in both NoFF and FA models, but by much more in the latter case, particularly in the longer term. Lower output and lower inflation exacerbate negative effects on entrepreneurs' net worth, which leads to a significant increase in the external finance premium. This triggers a substantial and persistent drop in investment, consumption, and output. Consequently, aggregate responses to the monetary policy shock are substantially amplified and propagated in the FA model.

We next examine the implications of frictions in the bank capital market, under the capital requirement and a constant interbank premium. We compare the dynamic effects of technology and monetary policy shocks generated in the FABC model to those in the FA model. Figures 1 and 2 show that adding frictions in bank capital, which is used to satisfy capital adequacy and to solve the adverse selection problem in the bank capital market (the FABC model), dampens the real impacts of technology and monetary policy shocks on output and investment. This is due to the fact that bank capital is a perfect complement to deposits. Therefore, following a positive technology shock, entrepreneurs' net worth increases and the external finance premium decreases. Demand for investment increases and entrepreneurs increase their borrowing to finance investment expansions, and so loans increase. Nevertheless, to extend loans to meet the demand of firms, lending banks have to increase their bank capital holdings to satisfy the capital requirement, or increase their leverage ratio and reduce their capital buffer.

Both actions are costly for lending banks. The increase in the demand for new bank capital increases the cost of raising bank equity (particularly, the prices of bank capital) in the financial market. Similarly, an increase in the banks' leverage ratio reduces the capital buffer and increases the probability of default. Consequently, the bank capital premium paid

[39] This result is similar to the results in Christensen and Dib (2008); Christiano, Motto, and Rostagno (2010); and Queijo von Heideken (2009).

by lending banks rises, as well as the marginal costs of producing loans and lending rates. The higher lending costs erode the increase in the firms' net worth, thereby reducing firms' demand for investment and partially offsetting an increase in investment.

Therefore, in this framework, bank capital acts as an "attenuation mechanism," because bank capital is held to satisfy the capital requirement. In addition, the need to hold excess bank capital, due to imperfect information in the bank capital market, reduces the supply of loanable funds from lending banks.

We analyze the role of the frictions in the interbank market as a transmission and propagation mechanism of aggregate shocks. These effects arise from the endogenous interbank premium that depends on the banks' balance sheet position, which directly affects the interbank borrowing costs. Figures 1 and 2 show that, when considering frictions in the interbank market, the attenuation effect implied by the capital requirement is mostly offset in the baseline model, since the responses of output and investment in the baseline model are much larger than in the FABC model. Consequently, the interbank market frictions amplify and propagate the real impacts of the shocks and generate an acceleration effect similar to that in the BGG framework. This result is similar to the previous studies that incorporate bank capital to solve the asymmetric information between households and banks.[40]

The interbank market frictions mechanism works as follows. A positive technology shock increases entrepreneurs' demand for loans, implying a need to increase bank capital to satisfy the regulatory requirement. As in the FABC model, the increase in the demand for bank capital raises the marginal cost of producing loans. Nonetheless, higher bank capital holdings raise banks' collateral, which, in turn, reduces the cost of borrowing in the interbank market. As shown in Figure 1, the decline in interbank borrowing costs reduces the cost of raising bank capital, and allows banks to supply cheaper loans to entrepreneurs. Therefore, firms' net worth increases and the external premium falls by more in the baseline model, compared to the FABC model. This leads to larger effects of shocks on output and investment in the baseline model.

Figure 1 shows that, following a positive technology shock, the increase in bank capital is much smaller in the baseline model than in the FABC model, implying a lower cost of raising bank capital. Moreover, the interbank premium declines sharply in the baseline model, while

[40]For example, Gertler and Kiyotaki (2010); Hirakata, Sudo, and Ueda (2009); Meh and Moran (2010); Zhang (2009).

the bank capital premium increases. Therefore, in the presence of frictions in the interbank market, an increase in lending banks' asset holdings reduces the costs of borrowing in the interbank markets and mitigates the dampening impact of the capital requirement.

In addition, following a positive technology shock, lending banks respond by sharply increasing their leverage ratio in the baseline model, whereas they slightly decrease it in the FABC model. The sharp increase in the leverage ratio in the baseline model is explained by the drop in the marginal cost of providing loans caused by the decline in the interbank risk premium. Therefore, lending banks take advantage by extending their loan supply. We also note that bank capital increases in both models; however, the increase is gradual and persistent in the baseline model, while it is substantial and short-lived in the FABC model. In the baseline model, the interbank premium drops sharply on impact, as a result of an improvement in lending banks' balance sheets (an increase in bank capital and loans). The bank capital premium increases sharply on impact, because of the reduced bank capital buffer resulting from the jump in the bank leverage ratio.

The responses of the lending and deposit rates are very similar in both the FABC and baseline models. Following a positive technology shock, the prime lending rate decreases to accommodate the shock, because of the drop in the marginal costs of producing loans. Also, the deposit rate decreases, but by less than the policy rate. This is due to the adjustment costs of changing the deposit rate, which implies a partial pass-through of policy rate variations to deposit rates.

Figure 2 plots the responses to a shock resulting from a tightening of monetary policy by 1 per cent. In response to this shock, the nominal interest rate increases sharply, and output and investment fall persistently. In the FABC model, following a tightening of monetary policy, net worth drops by less than in the baseline model, because capital prices rise by less. Therefore, the external finance premium increases by less, reflecting the increase in firms' leverage, and leading to a lower cost of lending. The relatively lower funding cost of purchasing new capital limits the drop in demand for investment. On the other hand, when allowing for frictions in the interbank market, the attenuation effects implied by the capital requirement are offset, and the impact of a tightening of monetary policy is significantly amplified and propagated to macro variables. Therefore, incorporating frictions in the interbank market offsets the dampening effects of the capital requirement, and implies significant amplifications and propagations of the impacts of monetary policy shocks on output, investment, net worth, and loans; the responses of these variables in the baseline model are almost twice as large as in the FABC model, and they are more persistent.

Figure 2 also shows that a shock resulting from a tightening of monetary policy moves the deposit and prime lending rates in the same direction. They both increase on impact. The bank leverage ratio falls on impact, and lending banks hold more capital. This effect results in a decrease in the default on bank capital.

4.2 Responses to financial shocks

Figure 3 depicts the impulse responses to a 10 per cent riskiness shock in the FA, FABC, and baseline models. This shock may be interpreted as an exogenous increase in the degree of riskiness in the entrepreneurial sector. It is generated by either an increase in the standard deviation of the entrepreneurial distribution or by an increase in agency costs paid by lending banks to monitor entrepreneurs in efforts to reduce asymmetric information. In response to this shock, output, investment, net worth, and prices of capital fall persistently below their steady-state levels in both models. Consumption, however, responds positively to the riskiness shock in the short run, before decreasing at longer horizons. We note that the responses of output and investment are substantially dampened in the FABC model, while they are amplified in the model incorporating frictions in the interbank market (the baseline model).

The impacts of riskiness shocks in the baseline and FA models are much larger than in the FABC model, implying that frictions in bank capital play a substantial role in dampening the impacts of these shocks and contribute to macroeconomic stability. Note also that the external finance premium rises in response to riskiness shocks, while loans temporarily decline, before jumping above their steady-state level, and then decrease in the long run.[41] To accommodate the shift in the demand for loans, lending banks decrease their leverage ratio on impact, and then slightly increase it over the medium term, before persistently reducing it in the longer term.

Figure 4 shows the impulse responses to a 1 per cent positive financial intermediation shock

[41] Loans increase in the medium term and then decrease in the long term to smooth changes in investment and reduce the costs of adjusting investment across periods.

in the FABC and baseline models. This raises the credit supply without varying the inputs used in the loan production function. In response to this shock, loans gradually but persistently increase, reflecting the persistent decline in the costs of borrowing. These costs decline because of the decrease in the marginal cost of providing loans and the fall in the monetary policy rate induced by the monetary authority's response to the decline in inflation. At the same time, output, investment, and net worth positively respond to this shock. We also note that the bank leverage ratio is counter-cyclical, and the external finance premium, deposit, and prime lending rates respond negatively to the shock. The instantaneous decline in the prime lending rate accommodates the excess loan supply generated by the positive financial intermediary shock.

Figure 5 shows the impulse responses to a 100 per cent exogenous increase in the haircut rate, μ_t, in the baseline model. This reflects the changes in the confidence level of savings banks in the riskiness and the health of the lending banks. The shock substantially increases the interbank premium, by four times on impact. This raises the costs of interbank borrowing, since lending banks have to pay a higher risk premium to borrow from savings banks. This leads to a significant increase in the lending rate, which pushes up the external cost of borrowing for entrepreneurs and lowers net worth. Entrepreneurs react to this shock by cutting investment. This gradually decreases output. Inflation, the policy rate, and the external finance premium rise in the baseline model. We note that loans increase in the short term, but fall in the long term. Thus, firms with deteriorated net worth increase their borrowing to finance their capital acquisition in the short run, even at a higher cost for external financing. Banks respond to this shock by reducing their leverage ratio, holding a higher bank capital buffer, and increasing their bank capital holdings.

Finally, Figure 6 depicts the impulse responses to a 10 per cent quantitative monetary easing shock, m_t, a positive injection of money into lending banks. The shock causes a substantial decline in the demand for interbank borrowing and bank capital, because banks prefer to rely on cheaper funds from the central bank. The lending banks reduce their prime lending rate to accommodate the impact of this expansionary monetary shock. Therefore, output, investment, and net worth gradually increase in both the FABC and baseline models, while inflation, the policy rate, and loans decline in the FABC model and slightly increase in the baseline model.

In the baseline model, the decline in the demand for interbank borrowing and bank capital reduces the interbank risk premium and increases the bank leverage ratio. The decrease in the interbank risk premium reduces the costs of raising funds in the interbank market, which reduces the marginal costs of producing loans. Nevertheless, a higher leverage ratio implies a lower bank capital buffer and, therefore, a larger bank equity premium. This increases the marginal costs of raising bank capital, and thus increases the costs of producing loans. Figure 6 shows that the increase in the costs of raising bank capital outweighs those of interbank borrowing, and so the drop of the lending rate is smaller in the baseline model, relative to the FABC model. Consequently, the response of real variables to this quantitative monetary easing shock is dampened in the baseline model.

5. Conclusion

The recent financial crisis has shown the need to develop DSGE models that incorporate financial frictions in both the demand and the supply sides of credit markets. Incorporating such frictions and an active banking sector allows policy-makers to understand the role of real-financial linkages in the transmission and propagation of real shocks. It also enables empirical assessment of the contribution of financial shocks originating in the banking sector to aggregate fluctuations.

This paper proposes a micro-founded framework to incorporate financial frictions into the interbank and bank capital markets using a DSGE framework. It introduces bank capital to satisfy the capital requirement imposed by regulators. Financial frictions are modelled by assuming imperfect information (asymmetric information) between lenders and borrowers, which creates a moral hazard and adverse selection problems in the interbank and bank capital markets.

To assess the role and importance of financial frictions and the capital requirement, we simulate four models. The main findings are that financial frictions in the interbank and bank capital markets amplify and propagate the real effects of different shocks, while the capital requirement allows bank capital to act as an attenuation mechanism that dampens substantially the real effects of shocks and helps to stabilize the economy.

This model provides a rich and rigorous framework to address monetary and financial stability issues, since it includes both the demand and the supply sides of the credit market. This allows for policy simulation analysis of factors such as bank capital regulations, interest rate spreads, and the optimal choice for banks' leverage ratios. The model can be used to address policy and financial stability issues, such as bank capital adequacy regulations and the efficiency versus stability of the banking sector. Future work will consist of estimating the model's structural parameters, incorporating credit to households, and extending the framework to an open-economy setting.

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Table 2: Parameter Calibration: Baseline model

Preferences			
$\beta_w = 0.9989$,	$\beta_b = 0.9949$,	$\gamma_w = 3$,	$\gamma_b = 2$,
$\varphi = 0.65$,	$\eta = 0.996$,	$\varsigma = 1$,	
Monetary policy			
$\varrho_\pi = 1.5$,	$\varrho_Y = 0.05$,	$\sigma_R = 0.006$,	
Technologies			
$\alpha = 0.33$,	$\delta = 0.025$,	$\theta = 6$,	$\vartheta_D = 2.2$,
Adjustment and default costs			
$\chi_I = 12$,	$\chi_Z = 4$,	$\chi_{\delta^Z} = 1648$,	
Nominal rigidities			
$\phi_p = 0.75$,	$\phi_R = 2.4$,		
Financial sector			
$\nu = 0.9833$,	$\psi = 0.05$,	$K/N = 2$,	$\bar{\kappa} = 12.5$,
$\upsilon = 0.05$,	$\xi = 2.2$,		
Exogenous processes			
$A = 1$,	$\rho_A = 0.8$,	$\sigma_A = 0.009$,	
$\Upsilon = 1$,	$\rho_\Upsilon = 0.7$,	$\sigma_\Upsilon = 0.033$,	
$e = 1$,	$\rho_e = 0.8$,	$\sigma_e = 0.0073$,	
$G/Y = 0.17$,	$\rho_G = 0.81$,	$\sigma_G = 0.0166$,	
$\psi = 0.05$,	$\rho_\psi = 0.83$,	$\sigma_\psi = 0.050$,	
$\Gamma = 1$,	$\rho_\Gamma = 0.8$,	$\sigma_\Gamma = 0.003$,	
$\mu = 0.90$,	$\rho_\mu = 0.5$,	$\sigma_\mu = 0.00$,	
$m = 0$,	$\rho_m = 0.5$,	$\sigma_m = 0.00$	

Table 3: Steady-state values and ratios: Baseline model

Variables	Definitions	Values
	A. Steady-state values	
π	inflation	1.0075
R	policy rate	1.0141
R^D	deposit rate	1.0097
R^L	prime lending	1.0220
κ	bank leverage ratio	11.5
δ^Z	default on bank capital	0.0025
rp^E	firm's external finance premium	1.0027
rp^B	interbank finance premium	1.0023
rp^κ	bank capital finance premium	1.0025
	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
K/N	capital to entrepreneurs' net worth	2
s	interbank borrowing to deposits	0.87

Figure 1: Responses to a 1 Per Cent Positive Technology Shock

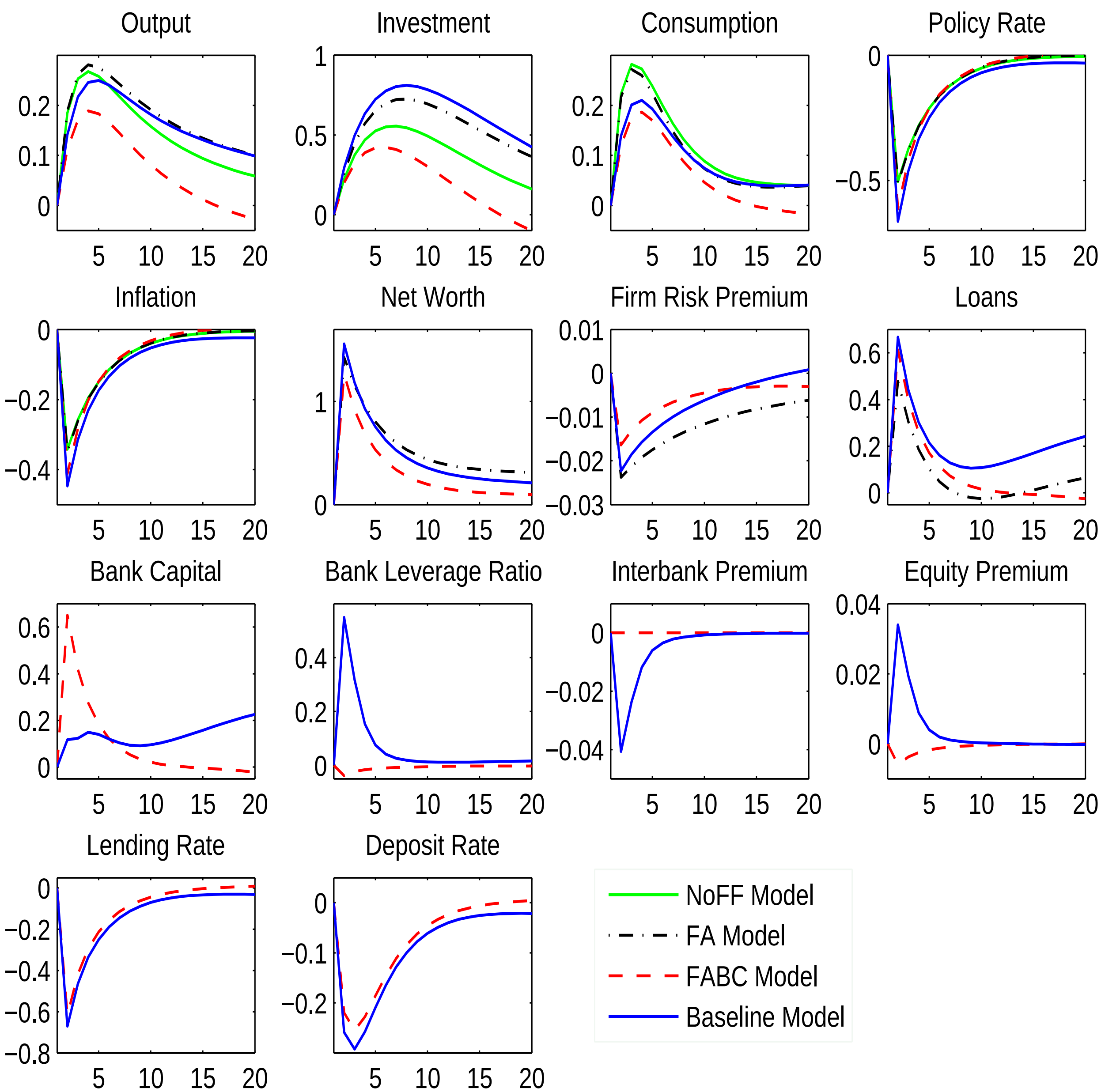


Figure 2: Responses to a 1 Per Cent Tightening Monetary Policy Shock

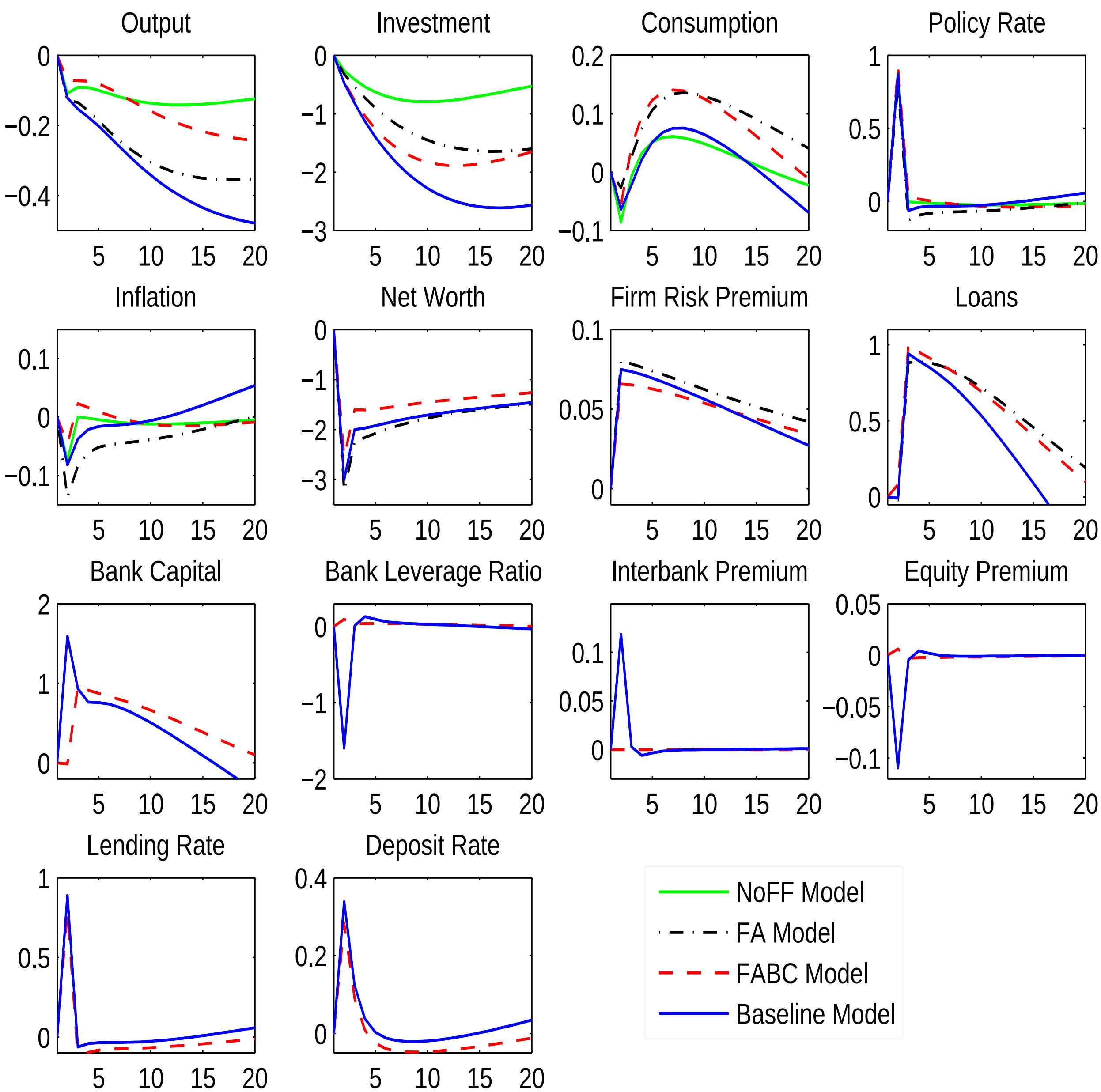


Figure 3: Responses to a 10 Per Cent Increase in the Riskiness Shock

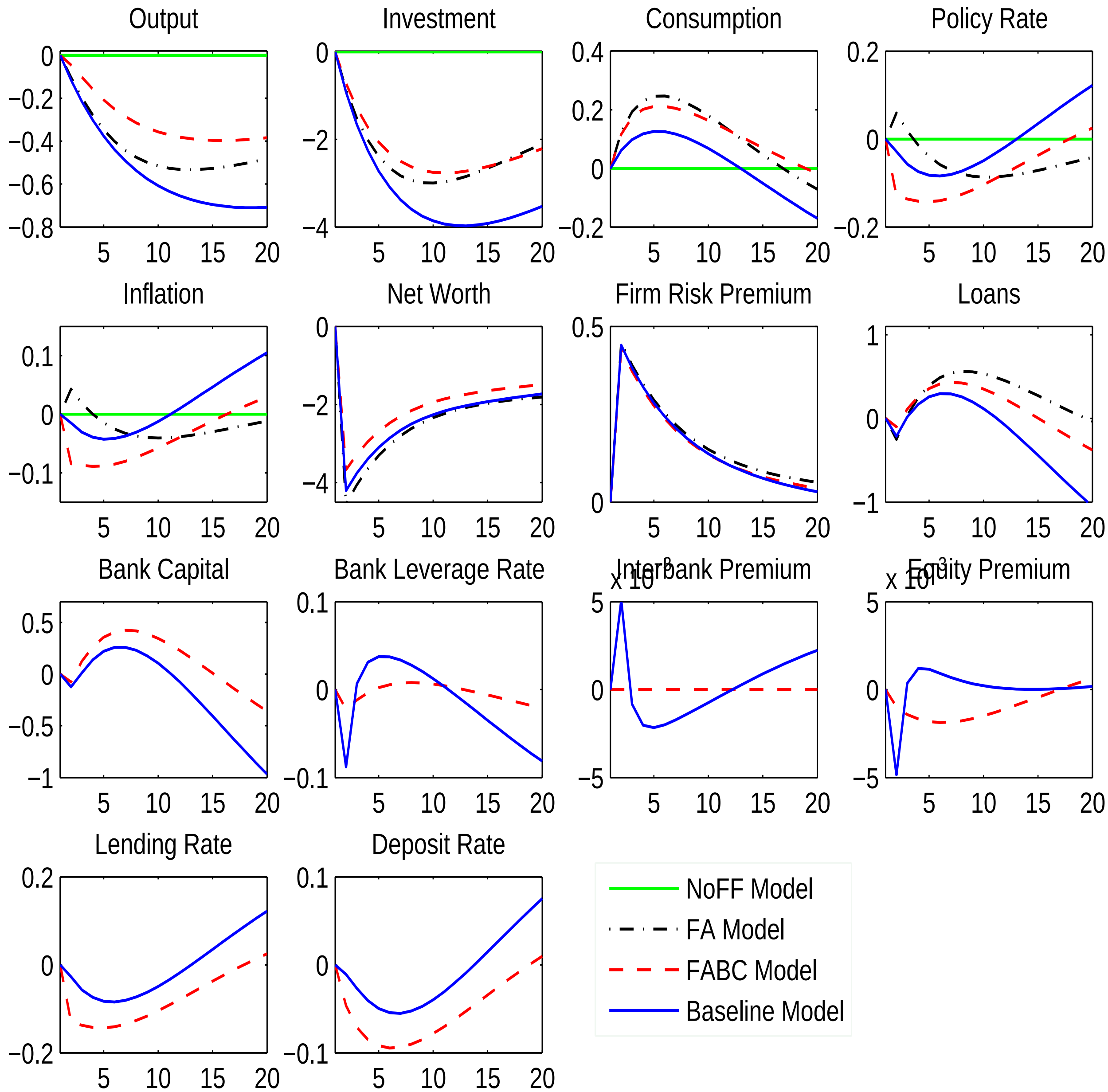


Figure 4: Responses to a 1 Per Cent Positive Financial Intermediation Shock

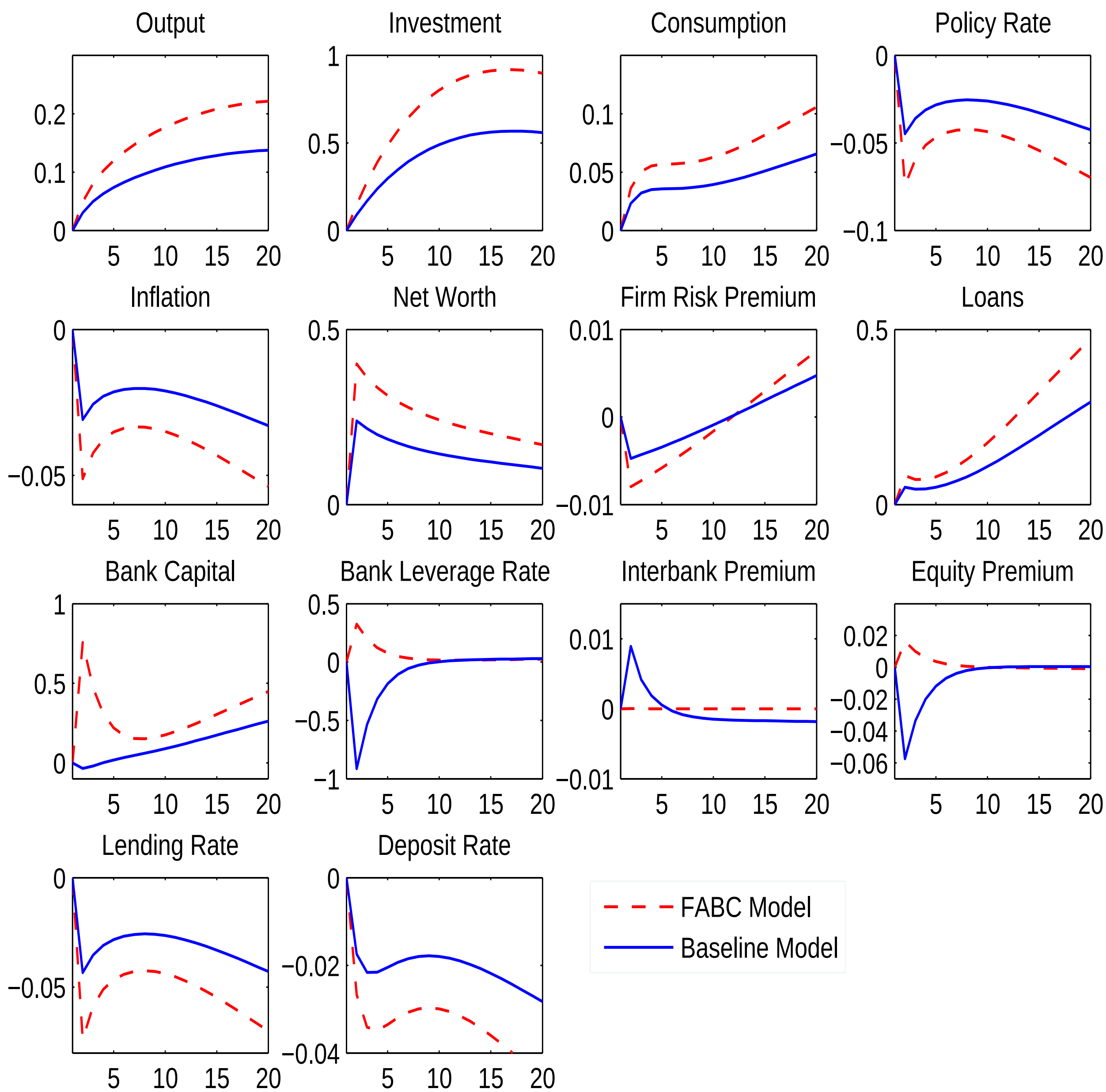


Figure 5: Responses to a 100 Per Cent Increase in the Haircut Shock

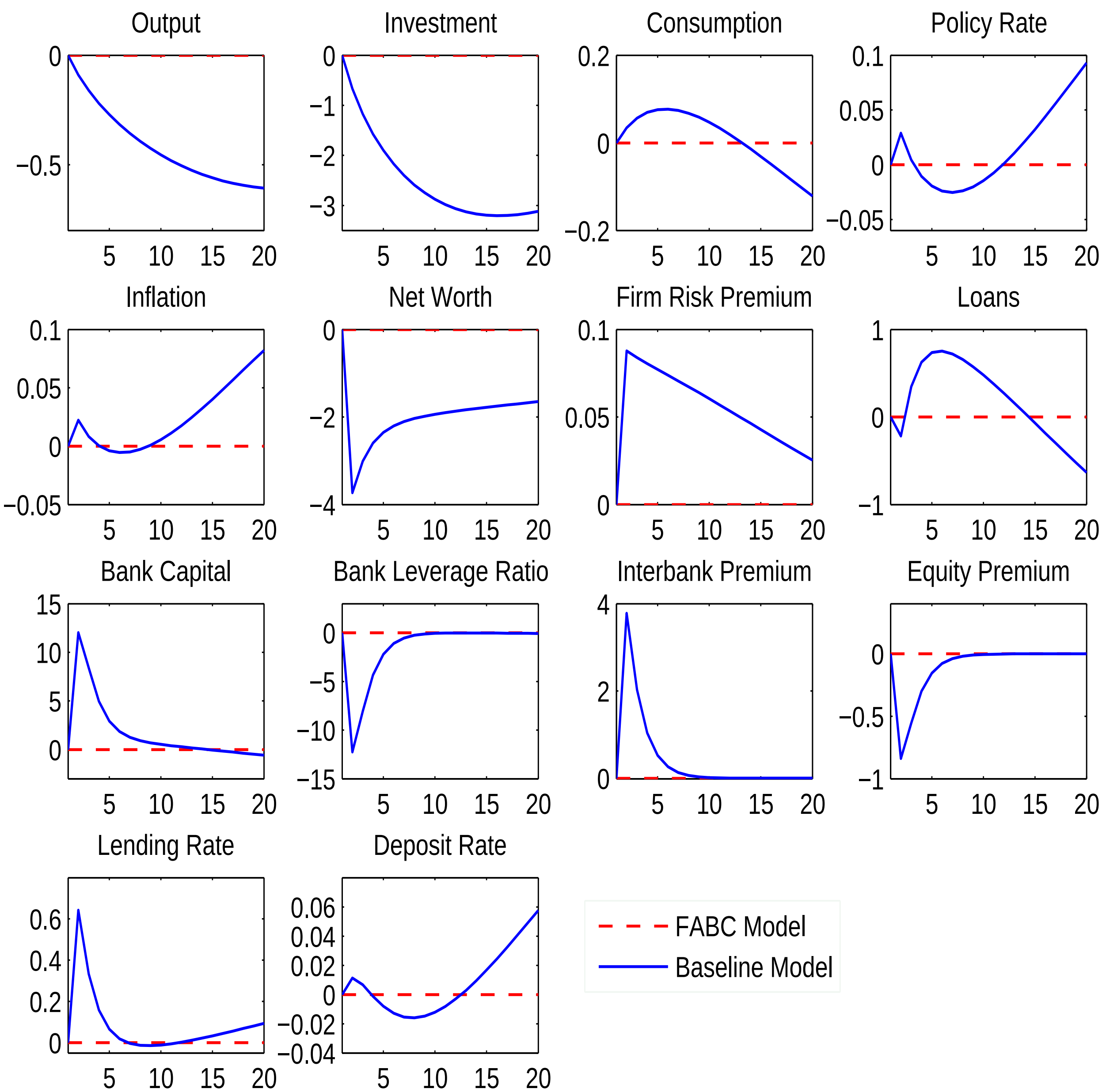
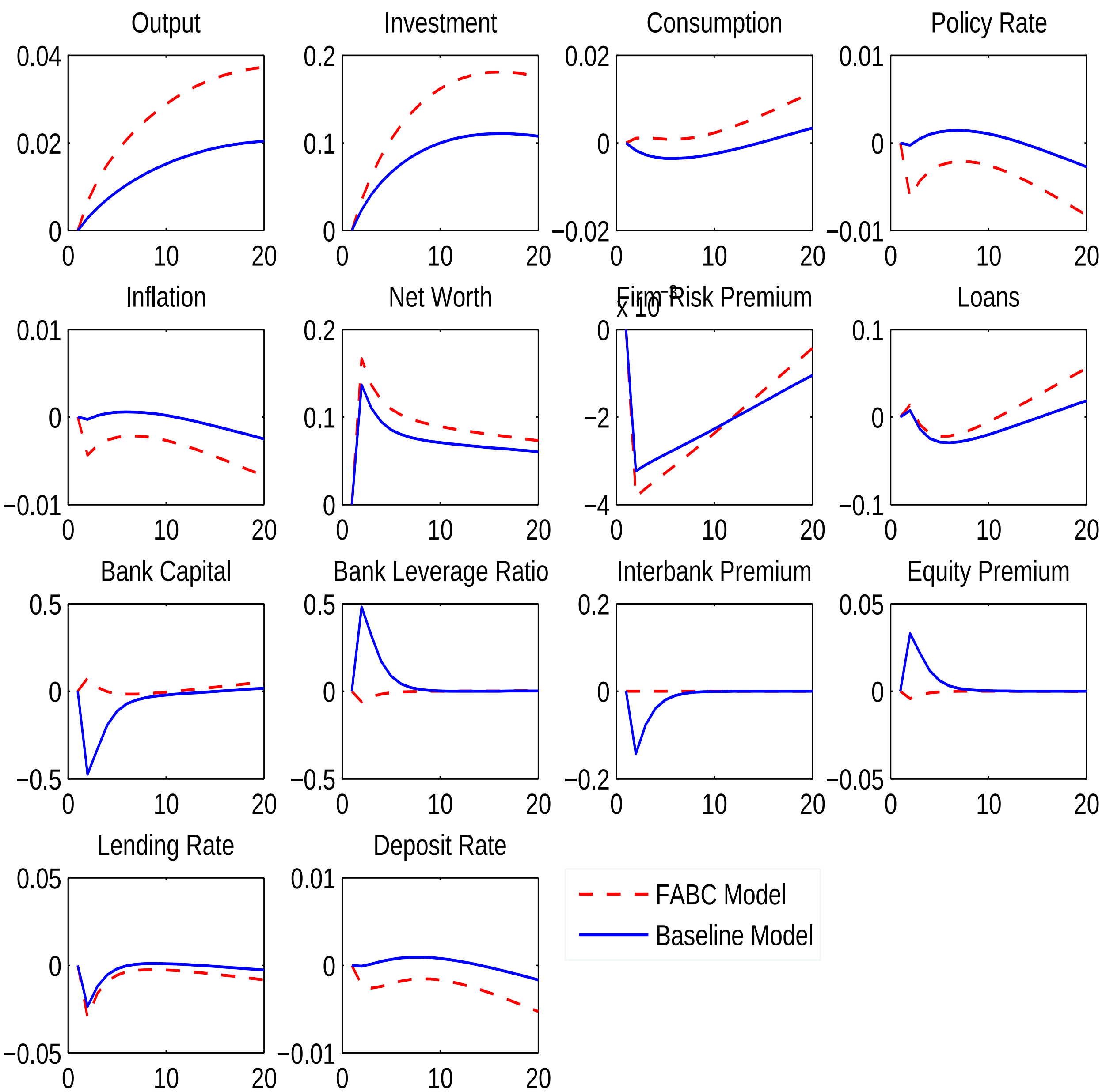


Figure 6: Responses to a 10 Per Cent Positive Quantitative Monetary Easing Shock



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 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:

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

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

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

where $mc_t > 0$ 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[42]

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

[42] 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

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

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

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

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:

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

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

Appendix B: Data

1. Loans are measured by Commercial and Industrial Loans of all Commercial Banks (BUSLOANS), quarterly and seasonally adjusted;
2. The external finance premium is measured by the difference between the Moody's BAA and AAA corporate bond yields;
3. Inflation is measured by quarterly changes in the GDP deflator ($\Delta \log(GDPD)$);
4. The prime lending rate is measured by the Bank Prime Loan Rate (MPRIME);
5. The monetary policy rate is measured by the 3-Month Treasury Bill (TB3MS);
6. The deposit rate is measured by the weighted average of the rates received on the interest-bearing assets included in M2 (M2OWN);
7. The real money stock is measured by the 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).