Credit and Banking in a DSGE Model of the Euro Area

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Abstract

This paper studies the role of credit-supply factors in business cycle fluctuations. To this end, an imperfectly competitive banking sector is introduced into a DGSE model with financial frictions. Banks issue loans to both households and firms, obtain funding via deposits and accumulate capital out of retained earnings. Margins charged on loans depend on bank capital-to-asset ratio and on the degree of interest rate stickiness. Bank balance-sheet constraints establish a link between the business cycle, which affects bank profits and thus capital, and the supply and the cost of loans. The model is estimated with Bayesian techniques using data for the euro area. We show that shocks originating in the banking sector explain the largest fraction of the fall of output in 2008 in the euro area, while macroeconomic shocks played a smaller role. We also find that an unexpected reduction in bank capital can have a substantial impact on the real economy and particularly on investment.

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1 Introduction

Policymakers have often highlighted the importance of financial factors in shaping the business cycle: the possible interactions between credit markets and the real economy are a customary part of the overall assessment on the policy stance. Since the onset of the financial turmoil in August 2007, banks have come again under the spotlight, as losses from subprime credit exposure and from significant write-offs on asset-backed securities raised concerns that a wave of widespread credit restrictions might trigger a severe economic downturn. Credit standard for firms and households were tightened considerably both in the US and the euro area (Figure 1) as suggested by the Senior Loan Officer Survey of the Federal Reserve and the Bank Lending Survey of the Eurosystem. Past episodes like the U.S. Great Depression, the Savings and Loans crises again in the U.S. in the 1980s or the prolonged recession in Finland and Japan in the 1990s stand as compelling empirical evidence that the banking sector can considerably affect the developments of the real economy.[1]

Despite this relevance for policy-making, most workhorse general equilibrium models routinely employed in academia and policy institutions to study the dynamics of the main macroeconomic variables generally lack any interaction between financial and credit markets, on the one hand, and the rest of the economy, on the other. The introduction of financial frictions in a dynamic general equilibrium (DSGE) framework by Bernanke, Gertler and Gilchrist (1999) and Iacoviello (2005) has started to fill this gap by introducing credit and collateral requirements and by studying how macroeconomic shocks are transmitted or amplified in the presence of these financial elements. These models assume that credit transactions take place through the market and do not assign any role to financial intermediaries such as banks.

But in reality banks play a very influential role in modern financial systems, and especially in the euro area. In 2006, bank deposits in the euro area accounted for more than three-quarters of household short-term financial wealth, while loans equaled around 90 per cent of total households liabilities (ECB, 2008); similarly, for firms, bank lending accounted for almost 90 per cent of total corporate debt liabilities in 2005 (ECB, 2007). Thus, the effective cost/return that private agents in the euro area face when taking their borrowing/saving decisions are well approximated by the level of banks' interest rates on loans and deposits.

[1] Awareness seemed to be widespread among economists and policy-makers well before the financial turmoil burst out. For example, in a speech at the "The Credit Channel of Monetary Policy in the Twenty-first Century"Conference held on 15 June 2007 at the Federal Reserve Bank of Atlanta, chairman Bernanke stated that "*...Just as a healthy financial system promotes growth, adverse financial conditions may prevent an economy from reaching its potential. A weak banking system grappling with nonperforming loans and insufficient capital, or firms whose creditworthiness has eroded because of high leverage or declining asset values, are examples of financial conditions that could undermine growth*".

In this paper we introduce a banking sector in a DSGE model in order to understand the role of banking intermediation in the transmission of monetary impulses and to analyze how shocks that originate in credit markets are transmitted to the real economy. We are not the first to do this. Recently there has been increasing interest in introducing a banking sector in dynamic models and to analyze economies where a plurality of financial assets, differing in their returns, are available to agents (Christiano *et al.*, 2007, and Goodfriend and McCallum, 2007). But in these cases banks operate under perfect competition and do not set interest rates. We think that a crucial element in modeling banks sector consists in recognizing them a degree of monopolistic power (in both the deposits and the loans markets). This allows us to model their interest rate setting behavior and hence also the different speeds at which banks interest rates adjust to changing conditions in money market interest rates. Empirical evidence shows that bank rates are indeed heterogeneous in this respect, with deposit rates adjusting somewhat slower than rates on households loans, and those in turn slower than rates on firms loans (Kok Sorensen and Werner, 2006 and de Bondt, 2005). On the other hand, compliance to Basel Accords imposes capital requirements to exert banking activity. We therefore enrich a standard model, featuring credit frictions and borrowing constraints as in Iacoviello (2005), and a set of real and nominal frictions as in Christiano *et al.* (2005) and Smets and Wouters (2003) with an imperfectly competitive banking sector that collects deposits and then, subject to the requirement of using banking capital as an input, supplies loans to the private sector. These banks set different rates for households and firms, applying a time-varying and slowly adjusting mark-up over the marginal cost of loan production, which includes the interbank rate and the cost of equity. Loan demand is constrained by the value of housing collateral for households and capital for entrepreneurs. Banks obtain funding either by tapping the interbank market at a rate set by the monetary authority or by collecting deposits from patient households, at a rate set by the banks themselves with a mark-down over the interbank rate.

We estimate the model with Bayesian techniques and data for the euro area over the period 1999-2008. The model is used to understand the role of banks and imperfect competition in the banking sector in the transmission mechanism of monetary policy and technology shocks. We use it to quantify the contribution of shocks originating within the banking sector to the slowdown in economic activity during 2008 and to study the consequences of tightening of credit conditions induced by a reduction in bank capital.

The analysis delivers the following results. First, while financial frictions amplify the effects of monetary policy compared to a standard new keynesian model, sticky bank rates dampen (attenuator effect) the effects on the economy that work through a change in the real rate or in the value of the collateral. Second, shocks in the banking sector explain the largest fraction of the fall output in 2008 in the euro area while macroeconomic shocks played a smaller role. Finally, shocks to credit supply can have substantial effects on the economy and particularly on investment. A fall in bank capital forces bank to raise interest rates resulting in lower demand for loans by households and firms who are forced to cut on consumption and expenditure.

The rest of the paper is organized as follows. Section 2 describes the model. Section 3 presents the results of the estimation of the model. Section 4 studies the dynamic properties of the model focusing on monetary policy and technology shocks. Section 5 quantifies the role of shocks originating in the banking sector in the downturn in economic activity in the euro area during 2008 and studies the effects of a fall in bank capital on the economy. Section 6 offers some concluding remarks.

2 The model

The economy is populated by two types of households and by entrepreneurs. Households consume, work and accumulate housing (in fixed supply), while entrepreneurs produce an homogenous intermediate good using capital bought from capital-good producers and labor supplied by households. Agents differ in their degree of impatience, i.e. in the discount factor they apply to the stream of future utility.

Two types of one-period financial instruments, supplied by banks, are available to agents: saving assets (deposits) and loans. When taking on a bank loan, agents face a borrowing constraint, tied to the value of tomorrow collateral holdings: households can borrow against their stock of housing, while entrepreneurs' borrowing capacity is tied to the value of their physical capital. The heterogeneity in agents' discount factors determines positive financial flows in equilibrium: patient households purchase a positive amount of deposits and do not borrow, while impatient and entrepreneurs borrow a positive amount of loans. The banking sector operates in a regime of monopolistic competition: banks set interest rates on deposits and on loans in order to maximize profits. The amount of loans issued by each intermediary can be financed through the amount of deposits that they rise and through reinvested profits (bank capital).

Workers supply their differentiated labor services through unions which set wages to maximize members' utility subject to adjustment costs: services are sold to a competitive labor packer which supplies a single labor input to firms.

Two additional producing sectors exist: a monopolistically competitive retail sector and a capital-good producing sector. Retailers buy the intermediate goods from entrepreneurs in a competitive market, brand them at no cost and sell the final differentiated good at a price which includes a markup over the purchasing cost and is subject to further adjustment costs. Physical capital good producers are used as a modeling device to derive an explicit expression for the price of capital, which enters entrepreneurs' borrowing constraint.

2.1 Households and entrepreneurs

There exist two groups of households, patients and impatiens, and entrepreneurs. Each of these group has unit mass. The only difference between these agents is that patients' discount factor (β_P) is higher than impatients' (β_I) and entrepreneurs (β_E).

2.1.1 Patient households

The representative patient household maximizes the expected utility:

$$E_0 \sum_{t=0}^{\infty} \beta_P^t \ \varepsilon_t^z \left[\log(c_t^P(i) - a^P c_{t-1}^P) + \varepsilon_t^h \log h_t^P(i) - \frac{l_t^P(i)^{1+\phi}}{1+\phi} \right]$$

which depends on current individual consumption $c_t^P(i)$, lagged aggregate consumption c_{t-1}^P, housing services $h^P(i)$ and hours worked $l^P(i)$. The parameter a^P measures the degree of (external and group-specific) habit formation in consumption; ε_t^h captures exogenous shocks to the demand for housing while ε_t^z is an intertemporal shock to preferences. These shocks have an AR(1) representation with i.i.d normal innovations. The autoregressive coefficients are, respectively, ρ_z and ρ_j and the standard deviations are σ_z and σ_j. Household decisions have to match the following budget constraint (in real terms):

$$c_t^P(i) + q_t^h \Delta h_t^P(i) + d_t^P(i) + \leq W_t^P l_t^P(i) + \frac{\left(1 + r_{t-1}^d\right)}{\pi_t} d_{t-1}^P(i) + T_t^P$$

The flow of expenses includes current consumption, accumulation of housing services and deposits to be made this period d_t^P. Resources are composed of wage earnings $W_t^P l_t^P$, gross interest income on last period deposits $\frac{\left(1+r_{t-1}^d\right)}{\pi_t} d_{t-1}^P$ (the inflation rate π_t is gross, i.e. it is defined as P_t/P_{t-1}) and a number of lump-sum transfers T_t^P , which include the labor union membership net fee, dividends from the retail firms J_t^R and the banking sector dividends $\left(1 - \omega^b\right) \frac{J_{t-1}^b}{\pi_t}$.

2.1.2 Impatient households

Impatient households do not hold deposits and do not own retail firms but receive dividends from labor unions. The representative impatient household maximizes the expected utility:

$$E_0 \sum_{t=0}^{\infty} \beta_I^t \ \varepsilon_t^z \left[\log(c_t^I(i) - a^I c_{t-1}^I) + \varepsilon_t^h \log h_t^I(i) - \frac{l_t^I(i)^{1+\phi}}{1+\phi} \right]$$

which depends on consumption $c^I(i)$, housing services $h^I(i)$ and hours worked $l^I(i)$. The parameter a^I measures the degree of (external and group-specific) habit formation in consumption; ε_t^h and ε_t^z are the same shocks that affect the utility of patient households. Household decisions have to match the following budget constraint (in real terms):

$$c_t^I(i) + q_t^h \Delta h_t^I(i) + \frac{\left(1 + r_{t-1}^{bH}\right)}{\pi_t} b_{t-1}^I \leq W_t^I l_t^I(i) + b_t^I(i) + T_t^I$$

in which resources spent for consumption, accumulation of housing services and reimboursement of past borrowing have to be financed with the wage income and new borrowing (T_t^I only includes net union fees to be paid).

In addition, households face a borrowing constraint: the expected value of their collateralizable housing stock at period t must be sufficient to guarantee lenders of debt repayment. The constraint is:

$$\left(1 + r_t^{bH}\right) b_t^I(i) \leq m_t^I E_t \left[q_{t+1}^h h_t^I(i) \pi_{t+1}\right] \tag{1}$$

where m_t^I is the (stochastic) loan-to-value ratio (LTV) for mortgages. From a microeconomic point of view, (1-m_t^I) can be interpreted as the proportional cost of collateral repossession for banks given default. Our assumption on households' discount factors is such that, absent uncertainty, the borrowing constraint of the impatien is binding in a neighborhood of the steady state. As in Iacoviello (2005), we assume that the size of shocks in the model is "small enough" so to remain in such a neighborhood, and we can thus solve our model imposing that the borrowing constraint always binds.

We assume that the LTV follows the stochastic AR(1) process

$$m_t^I = (1 - \rho_{mI}) \bar{m}^I + \rho_{mI} \; m_{t-1}^I + \eta_t^{mI}$$

where η_t^{mI} is an i.i.d. zero mean normal random variable with standard deviation equal to σ_{mI} and $\bar{m}^I$ is the (calibrated) steady-state value. We introduce a stochastic LTV because we are interested in studying the effects of credit-supply restrictions on the real side of the economy. At a macro-level, the value of m_t^I determines the amount of credit that banks make available to each type of households, for a given (discounted) value of their housing stock.

2.1.3 Entrepreneurs

In the economy there is an infinity of entrepreneurs of unit mass. Each entrepreneur i only cares about his own consumption $c^E(i)$ and maximizes the following utility function:

$$E_0 \sum_{t=0}^{\infty} \beta_E^t \log(c_t^E(i) - a^E c_{t-1}^E)$$

where a^E, symmetrically with respect to households, measures the degree of consumption habits. Entrepreneurs' discount factor β_E is assumed to be strictly lower than β_P, implying that entrepreneurs are, in equilibrium, net borrowers. In order to maximize lifetime consumption, entrepreneurs choose the optimal stock of physical capital $k_t^E(i)$, the degree of capacity utilization $u_t(i)$, the desired amount of labor input $l^E(i)$ and borrowing $b_t^E(i)$. Labor and effective capital are combined to produce an intermediate output $y_t^E(i)$ according to the production function

$$y_t^E(i) = a_t^E[k_{t-1}^E(i)u_t(i)]^\alpha l_t^E(i)^{1-\alpha}$$

where a_t^E is an exogenous AR(1) process for total factor productivity with autoregressive coefficient equal to ρ_a and i.i.d. normal innovations η_t^a with standard deviation equal to σ_a. Labour of the two households are combined in the production function in a Cobb-Douglas fashion as in Iacoviello and Neri (2008). The parameter μ measures the labor income share of unconstrained households.

The intermediate product is sold in a competitive market at wholesale price P_t^w. Entrepreneurs have access to loan contracts ($b_t^E(i)$, in real terms) offered by banks, which they use to implement their borrowing decisions. Entrepreneurs' flow budget constraint in real terms is thus the following:

$$\begin{aligned} c_t^E(i) + W_t l_t^E(i) + \frac{(1+r_{t-1}^{bE})b_{t-1}^E(i)}{\pi_t} + q_t^k k_t^E(i) + \psi(u_t(i))k_{t-1}^E(i) \\ = \frac{y_t^E(i)}{x_t} + b_t^E(i) + q_t^k(1-\delta)k_{t-1}^E(i). \end{aligned} \tag{2}$$

In the above, W_t is the aggregate wage index, q_t^k is the price of one unit of physical capital in terms of consumption; $\psi(u_t(i))k_{t-1}^E(i)$ is the real cost of setting a level $u_t(i)$ of utilization rate, with $\psi(u_t) = \xi_1(u_t - 1) + \frac{\xi_2}{2}(u_t - 1)^2$ (following Schmitt-Grohe and Uribe, 2005); $1/x_t$ is the price in terms of the consumption good of the wholesale good produced by each entrepreneur, i.e. x_t is defined as P_t/P_t^W.

Symmetrically with respect to households, we assume that the amount of resources that banks are willing to lend to entrepreneurs is constrained by the value of their collateral, which is given by their holdings of physical capital. This assumption differs from Iacoviello (2005), where also entrepreneurs borrow against housing (interpretable as commercial real estate), but it seems a more realistic modeling choice, as overall balance-sheet conditions give the soundness and creditworthiness of a firm. The borrowing constraint is thus

$$(1 + r_t^{bE})b_t^E(i) \leq m_t^E \mathrm{E}_t(q_{t+1}^k \pi_{t+1}(1-\delta)k_t^E(i)) \tag{3}$$

where m_t^E is the entrepreneurs' loan-to-value ratio; similarly to households, m_t^E follows the stochastic process

$$m_t^E = (1 - \rho_{mE})\,\bar{m}^E + \rho_{mE}\, m_{t-1}^E + \eta_t^{mE}$$

with η_t^{mE} being a zero mean normal random i.i.d. variable with standard deviation equal to σ_{mE}. The assumption on the discount factor β_E and of "small uncertainty" allows us to solve the model by imposing an always binding borrowing constraint for the entrepreneurs.

The presence of the borrowing constraint implies that the amount of capital that entrepreneurs will be able to accumulate each period is a multiple of their net worth.[2] In particular, capital is inversely proportional to the down payment that banks require in order to make one unit of loans, which is in turn a function of the LTV ratio, of the expected future price of capital and of the real interest rate on loans. It is this feature that gives rise - in a model with a borrowing constraint - to a financial accelerator, whereby changes in interest rates or asset prices modify the transmission of shocks, amplifying - for instance - monetary policy shocks.

2.1.4 Loan and deposit demand

We assume that units of deposit and loan contracts bought by households and entrepreneurs are a composite CES basket of slightly differentiated products -each supplied by a branch of a bank j- with elasticities of substitution equal to ε_t^d, ε_t^{bH} and ε_t^{bE}, respectively. As in the standard Dixit-Stiglitz framework for goods markets, in our credit market agents have to purchase deposit (loan) contracts from each single bank in order to save (borrow) one unit of resources. Although this assumption might seem unrealistic, it is just a useful modeling device to capture the existence of market power in the banking industry.[3]

We assume that the elasticity of substitution in the banking industry is stochastic. This choice arises from our interest in studying how exogenous shocks hitting the banking sector transmit to the real economy. ε_t^{bH} and ε_t^{bE} (ε_t^d) affect the value of the markups (markdowns) that banks charge when setting interest rates and, thus, the value of the spreads between the policy rate and the retail loan (deposit) rates. Innovations to the loan (deposit) markup (markdown) can thus be interpreted as innovations to bank spreads arising independently of monetary policy and we can analyze their effects on the real economy.

Given the Dixit-Stiglitz framework, demand for an individual bank's loans and deposits depends on the interest rates charged by the bank - relative to the average rates in the economy. The demand function for household i seeking an amount of borrowing equal to $b_t^H(i)$ can be derived from minimizing the due total repayment:

$$\min_{\left\{b_t^H(i,j)\right\}} \int_0^1 r_t^{bH}(j) b_t^I(i,j) dj$$

[2] The same reasoning applies to the accumulation of housing by impatient households.

[3] A similar shortcut is taken by Benes and Lees (2007). Arce and Andrés (2008) set up a general equilibrium model featuring a finite number of imperfectly competitive banks in which the cost of banking services is increasing in customers' distance.

subject to

$$\left[\int_0^1 b_t^H(i,j)^{\frac{\varepsilon_t^{bH}-1}{\varepsilon_t^{bH}}} dj\right]^{\frac{\varepsilon_t^{bH}}{\varepsilon_t^{bH}-1}} \geq b_t^I(i) \ .$$

Aggregating f.o.c.'s across all impatient households, aggregate impatient households' demand for loans at bank j is obtained as:

$$b_t^H(j) = \left(\frac{r_t^{bH}(j)}{r_t^{bH}}\right)^{-\varepsilon_t^{bH}} b_t^I$$

where $b_t^I \equiv \gamma^I b_t^I(i)$ indicates aggregate demand for household loans in real terms (γ^s, $s \in [P, I, E]$ indicates the measure of each subset of agents) and r_t^{bH} is the average interest rates on loans to households, defined as:

$$r_t^{bH} = \left[\int_0^1 r_t^{bH}(j)^{1-\varepsilon_t^{bH}} dj\right]^{\frac{1}{1-\varepsilon_t^{bH}}} \ .$$

Demand for entrepreneurs' loans is obtained analogously, while demand for deposits at bank j of impatient household i, seeking an overall amount of (real) savings $d_t^P(i)$, is obtained by maximizing the revenue of total savings

$$\max_{\left\{d_t^P(i,j)\right\}} \int_0^1 r_t^d(j) d_t^P(i,j) dj$$

subject to the aggregation technology

$$\left[\int_0^1 d_t^P(i,j)^{\frac{\varepsilon_t^d-1}{\varepsilon_t^d}} dj\right]^{\frac{\varepsilon_t^d}{\varepsilon_t^d-1}} \geq d_t^P(i)$$

and is given by (aggregating across households):

$$d_t^P(j) = \left(\frac{r_t^d(j)}{r_t^d}\right)^{-\varepsilon_t^d} d_t \tag{4}$$

where $d_t \equiv \gamma^P d_t^P(i)$ and r_t^d is the aggregate (average) deposit rate, defined as

$$r_t^d = \left[\int_0^1 r_t^d(j)^{1-\varepsilon_t^d} dj\right]^{\frac{1}{1-\varepsilon_t^d}} \ .$$

2.1.5 Labor market

We assume that there exists a continuum of labor types and two unions for each labor type n, one for patients and one for impatients. Each union sets nominal wages for workers of its labor type by maximizing a weighted average of its members' utility, subject to a constant elasticity (ϵ_t^l) demand schedule and to quadratic adjustment costs (premultiplied by a coefficient κ_w), with indexation ι_w to a weighted average of lagged and steady-state inflation. Each union equally charges each member household with lump-sum fees to cover adjustment costs. In a symmetric equilibrium, the labor choice for each single household in the economy will be given by the ensuing (non-linear) wage-Phillips curve. We also assume the existence of perfectly competitive "labor packers" who buy the differentiated labor services from unions, transform them into an homogeneous composite labor input and sell it, in turn, to intermediate-good-producing firms. These assumptions yield a demand for each kind of differentiated labor service $l_t(n)$ equal to

$$l_t(n) = \left(\frac{W_t(n)}{W_t}\right)^{-\varepsilon_t^l} l_t \tag{5}$$

where W_t is the aggregate wage in the economy. The stochastic elasticity of labour demand implies a time-varying AR(1) markup process with innovations η_t^l normally distributed with zero mean and standard deviation equal to σ_l.

In the adjustment cost function for nominal wages, the parameter denotes the parameters measuring the size of these costs, while measures the degree of indexation to past prices.

2.2 Banks

The banks play a central role in our model since they intermediate all financial transactions between agents in the model. The only saving instrument available to patient households is bank deposits, the only way to borrow, for impatient households and entrepreneurs, is by applying for a bank loan.

The first key ingredient in how we model banks is the introduction of monopolistic competition at the banking retail level. Banks enjoy some market power in conducting their intermediation activity, which allows them to adjust rates on loans and rates on deposits in response to shocks or other cyclical conditions in the economy. The monopolistic competition setup allows us to study how different degrees of interest rate pass-through affect the transmission of shocks, in particular monetary policy.

The second key feature of our banks is that they have to obey a balance sheet identity

$$B_t = D_t + K_t^b$$

stating that banks can finance their loans B_t using either deposits D_t or bank equity (also called bank capital in the following) K_t^b.[4] The two sources of finance are perfect

[4] When taking the model to the data we introduce a shock ε_t^b into the balance sheet condition. This shock has an AR(1) representation with autoregressive coefficient ρ_b and innovations η_t^b which are normally distributed with zero mean and variance equal to σ_b.

substitutes from the point of view of the balance sheet, and we need to introduce some non-linearity (i.e. imperfect substitutability) in order to pin down the choices of the bank. We assume that there exists an (exogenously given) "optimal" capital-to-assets (i.e. leverage) ratio for banks, which can be thought of as capturing the trade-offs that, in a more structural model, would arise in the decision of how much own resources to hold, or alternatively as a shortcut for studying the implications and costs of regulatory capital requirements. Given this assumption, bank capital will have a key role in determining the conditions of credit supply, both for quantities and for prices. In addition, since we assume that bank capital is accumulated out of retained earnings, the model has a built-in feedback loop between the real and the financial side of the economy. As macroeconomic conditions deteriorate, banks profits are negatively hit, and this weaken the ability of banks to raise new capital; depending on the nature of the shock that hit the economy, banks might respond to the ensuing weakening of their financial position (i.e. increased leverage) by reducing the amount of loans they are willing to give, thus exacerbating the original contraction. The model can thus potentially account for the type of "credit cycle" typically observed in recent recession episodes, with a weakening real economy, a reduction of bank profits, a weakening of banks' capital position and the ensuing credit restriction.

The presence of both ingredients, bank capital and the ability of banks to set rates, allows us to introduce a number of shocks that originate from the *supply side of credit* and thus to study their effects and their propagation to the real economy. In particular we can study the effects of a drastic weakening in the balance sheet position of the banking sector, or the effect of an exogenous rise in loans rates.

To better highlight the distinctive features of our banking sector and to facilitate exposition, we can think of each bank j in the model ($j \in [0,1]$) as actually composed of three parts, two "retail" branches and one "wholesale" unit. The two retail branches are responsible for giving out differentiated loans to entrepreneurs and raising differentiated deposits from households, respectively. These branches set rates in a monopolistic competitive fashion, subject to adjustment costs. The wholesale unit manages the capital position of the group and, in addition, raises wholesale loans and wholesale deposits in the interbank market.

2.2.1 Wholesale branch

The wholesale branch combines net worth, or *bank capital* (K_t^b), and wholesale deposits (D_t) on the liability side and issues wholesale loans (B_t) on the asset side. We impose a cost on this wholesale activity related to the capital position of the bank. In particular, the bank pays a quadratic cost whenever the capital-to-assets ratio (K_t^b/B_t) moves away from an "optimal" value ν^b. This parameter is usually set equal to 0.09 in our numerical experiments, a level consistent with much of the regulatory capital requirements for banks, which in turn tries to strike a balance between various trade-offs involved when deciding how much own resources a bank should keep.

Bank capital is accumulated each period out of retained earnings according to:

$$K_t^{b,n}(j) = \left(1 - \delta^b\right) K_{t-1}^{b,n}(j) + \omega^b J_{t-1}^{b,n}(j)$$

where $K_t^{b,n}(j)$ is bank equity of bank j in nominal terms, $J_t^{b,n}(j)$ are overall profits made by the three branches of bank j in nominal terms, $(1-\omega^b)$ summarizes the dividend policy of the bank, and δ^b measures resources used in managing bank capital and conducting the overall banking intermediation activity.

The dividend policy is assumed to be exogenously fixed, so that bank capital is not a choice variable for the bank. The problem for wholesale bank is thus to choose loans $B_t(j)$ and deposits $D_t(j)$ so as to maximize profits, subject to a balance sheet constraint[5]:

$$\max E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^p \left[\left(1 + R_t^b\right) B_t(j) - \left(1 + R_t^d\right) D_t(j) - K_t^b(j) - \frac{\kappa_{Kb}}{2} \left(\frac{K_t^b(j)}{B_t(j)} - \nu^b \right)^2 K_t^b(j) \right] \tag{6}$$

$$s.t. \qquad B_t(j) = D_t(j) + K_t^b(j)\,, \tag{7}$$

where R_t^b - the net wholesale loan rate - and R_t^d - the net deposit rate - are taken as given.

The first order conditions of the problem deliver a condition linking the spread between wholesale rates on loans and on deposits to the degree of leverage $B_t(j)/K_t^b(j)$ of bank j, i.e.:

$$R_t^b = R_t^d - \kappa_{Kb} \left(\frac{K_t^b(j)}{B_t(j)} - \nu^b \right) \left(\frac{K_t^b(j)}{B_t(j)} \right)^2$$

In order to close the model we assume that banks can invest any excess fund they have in a deposit facility at the Central bank remunerated at rate r_t (or, alternatively, can purchase any amount of a riskless bond remunerated at that rate), so that $R_t^d \equiv r_t$ in the interbank market. As the interbank market is populated by many (identical) wholesale banks, in a symmetric equilibrium the equation above states a condition that links the rate on wholesale loans prevailing in the interbank market R_t^b to the official rate r_t, on one hand, and to the leverage of the banking sector B_t/K_t^b on the other:

$$R_t^b = r_t - \kappa_{Kb} \left(\frac{K_t^b}{B_t} - \nu^b \right) \left(\frac{K_t^b}{B_t} \right)^2 \tag{8}$$

The above equation highlights the role of capital in determining loan supply conditions. On the one hand - as far as there exists a spread between loan and the policy rate - the bank would like to extend as many loans as possible, increasing leverage and thus profit

[5] Banks value the future stream of profits using the patient households discount factor $\Lambda_{0,t}^p$ since they are owned by patients.

per unit of capital (or return on equity). On the other hand, when leverage increases, the capital-to-asset ratio moves away from ν and banks pay a cost, which reduces profits. The optimal choice for banks (from the first order condition) is to choose a level of loans (and thus of leverage, given K_t^b) such that the marginal cost for reducing the capital-to-asset ratio exactly equals the deposit-loan spread. The equation (8) can also be rearranged to highlight the spread between (wholesale) loan and deposit rates:

$$S_t^W \equiv R_t^b - r_t = -\kappa_{Kb}\left(\frac{K_t^b}{B_t} - \nu^b\right)\left(\frac{K_t^b}{B_t}\right)^2 \tag{9}$$

The spread is inversely related to overall leverage of the banking system: in particular, when banks are scarcely capitalized and capital constraints become more binding (i.e. when leverage increases) margins become tighter.

2.2.2 Retail banking

Retail banking activity is carried out in a regime of monopolistic competition.

Loan branch: Retail loan branches obtain wholesale loans $B_t(j)$ from the wholesale unit at the rate R_t^b, differentiate them at no cost and resell them to households and firms applying two distinct mark-ups. In order to introduce stickiness and study the implication of an imperfect bank pass-through, we assume that banks face quadratic adjustment costs for changing the rates they charge on loans; these costs are parametrized by κ_{bE} and κ_{bH} and proportional - as standard in the literature - to aggregate deposits. The problem for retail loan banks is to choose $\{r_t^{bH}(j), r_t^{bE}(j)\}$ to maximize:

$$\max_{\{r_t^{bH}(j), r_t^{bE}(j)\}} E_0 \sum_{t=0}^{\infty} \lambda_{0,t}^P \Big\{ r_t^{bH}(j) b_t^H(j) + r_t^{bE}(j) b_t^E(j) - R_t^b B_t(j) -$$
$$-\frac{\kappa_{bH}}{2}\left(\frac{r_t^{bH}(j)}{r_{t-1}^{bH}(j)} - 1\right)^2 r_t^{bH} b_t^H - \frac{\kappa_{bE}}{2}\left(\frac{r_t^{bE}(j)}{r_{t-1}^{bE}(j)} - 1\right)^2 r_t^{bE} b_t^E \Big] \tag{10}$$

subject to demand schedules

$$b_t^H(j) = \left(\frac{r_t^{bH}(j)}{r_t^{bH}}\right)^{-\varepsilon_t^{bH}} b_t^H, \quad \text{and} \quad b_t^E(j) = \left(\frac{r_t^{bE}(j)}{r_t^{bE}}\right)^{-\varepsilon_t^{bE}} b_t^E$$

with $b_t^H(j) + b_t^E(j) = B_t(j)$.

The first order conditions yield, after imposing a symmetric equilibrium,

$$1 - \varepsilon_t^{bs} + \varepsilon_t^{bs}\frac{R_t^b}{r_t^{bs}} - \kappa_{bs}\left(\frac{r_t^{bs}}{r_{t-1}^{bs}} - 1\right)\frac{r_t^{bs}}{r_{t-1}^{bs}} + \beta_P E_t\left\{\frac{\lambda_{t+1}^P}{\lambda_t^P}\kappa_{bs}\left(\frac{r_{t+1}^{bs}}{r_t^{bs}} - 1\right)\left(\frac{r_{t+1}^{bs}}{r_t^{bs}}\right)^2 \frac{b_{t+1}^E}{b_t^E}\right\} = 0\ , \tag{11}$$

with $s = H, E$. For the simplified case with non-stochastic ε_t^{bs}, the log-linearized version of the loan-rate setting equations is

$$\hat{r}_t^{bs} = \frac{\kappa_{bs}}{\varepsilon_t^{bs} - 1 + (1+\beta_P)\kappa_{bs}}\hat{r}_{t-1}^{bs} + \frac{\beta_P \kappa_{bs}}{\varepsilon_t^{bs} - 1 + (1+\beta_P)\kappa_{bs}} E_t \hat{r}_{t+1}^{bs} + \frac{\varepsilon_t^{bs} - 1}{\varepsilon_t^{bs} - 1 + (1+\beta_P)\kappa_{bs}}\hat{R}_t^b$$

Loan rates are set by banks taking into account the expected future path of the wholesale bank rate, which is the relevant marginal cost for this type of banks and which depends on the policy rate and the capital position of the bank, as highlighted in equation (8) in previous section.

With perfectly flexible rates, the pricing equation (11) becomes:

$$r_t^{bs} = \frac{\varepsilon_t^{bs}}{\varepsilon_t^{bs} - 1} R_t^b \tag{12}$$

As expected, in this case interest rates on loans are set as mark-up a over the marginal cost. We can also calculate the spread between the loan and the policy rate with flexible rates:

$$S_t^{bs} \equiv r_t^{bs} - r_t = \frac{\varepsilon_t^{bs}}{\varepsilon_t^{bs} - 1} S_t^W + \frac{1}{\varepsilon_t^{bs} - 1} r_t \tag{13}$$

with the last equality obtained by combining (12) with the expression in (8). The spread on retail loans is thus proportional to the wholesale spread S_t^W, which is determined by the bank capital position, and is increasing in the policy rate. In addition, the degree of monopolistic competition also plays a role, as an increase in market power (i.e. a reduction in the elasticity of substitution ε_t^{bs} determines - *ceteris paribus* - a wider spread. This relation between the elasticity and the loan spread allows us to interpret shocks to ε_t^{bs}, which we model as a stochastic process, as exogenous innovations to the bank loan margin.

Deposit branch: Retail deposit branches perform a similar, but reversed, operation with respect to deposits. They collect deposits $d_t(j)$ from households and then pass the raised funds to the wholesale unit, which pays them at rate r_t. The problem for the deposit branch is to choose the retail deposit rate $r_t^d(j)$, applying a monopolistically competitive mark-down to the policy rate r_t, in order to maximize:

$$\max_{\{r_t^d(j)\}} E_0 \sum_{t=0}^{\infty} \lambda_{0,t}^P \left[r_t D_t(j) - r_t^d(j) d_t(j) - \frac{\kappa_d}{2} \left(\frac{r_t^d(j)}{r_{t-1}^d(j)} - 1 \right)^2 r_t^d D_t \right] \tag{14}$$

subject to deposits demand

$$d_t(j) = \left(\frac{r_t^d(j)}{r_t^d} \right)^{\varepsilon_t^d} D_t$$

with $d_t(j) = D_t(j)$; the term containing κ_d is the quadratic adjustment costs for changing the deposit rate. After imposing a symmetric equilibrium, the first-order condition for optimal deposit interest rate setting is

$$-1 + \varepsilon_t^d - \varepsilon_t^d \frac{r_t}{r_t^d} - \kappa_d \left(\frac{r_t^d}{r_{t-1}^d} - 1 \right) \frac{r_t^d}{r_{t-1}^d} + \beta_P E_t \left\{ \frac{\lambda_{t+1}^P}{\lambda_t^P} \kappa_d \left(\frac{r_{t+1}^d}{r_t^d} - 1 \right) \left(\frac{r_{t+1}^d}{r_t^d} \right)^2 \frac{d_{t+1}}{d_t} \right\} = 0 \ . \tag{15}$$

For a simplified case in which ε^d is non-stochastic, the linearized version of the previous equation is

$$\hat{r}_t^d = \frac{\kappa_d}{1+\varepsilon^d+(1+\beta_P)\kappa_d}\hat{r}_{t-1}^d + \frac{\beta_P\kappa_d}{1+\varepsilon^d+(1+\beta_P)\kappa_d}E_t\hat{r}_{t+1}^d + \frac{1+\varepsilon^d}{1+\varepsilon^d+(1+\beta_P)\kappa_d}\hat{r}_t$$

which shows that banks set the deposit interest rate according to a sort of "interest-rate Phillips curve" (hatted values denote percentage deviations from the steady-state). By solving the equation forward, one could see that the deposit interest rate is set taking into account the expected future level of the policy rate. The speed of adjustment to changes in the policy rate depends inversely on the intensity of the adjustment costs (as measured by κ_d) and positively on the degree of competition in the banking sector (as measured by the inverse of ε^d). With fully flexible rates, r_t^d is determined as a static mark-down over the policy rate:

$$r_t^d = \frac{\varepsilon_t^d}{\varepsilon_t^d - 1} r_t = \frac{\left|\varepsilon_t^d\right|}{\left|\varepsilon_t^d\right| + 1} r_t \tag{16}$$

where the last equality follows from the fact that $\varepsilon_t^d < 0$.

Overall profits of bank j are the sum of earnings from the wholesale unit and the retail branches. After deleting the intra-group transactions, their expression is:

$$J_t^b(j) = r_t^{bH}(j)b_t^H(j)+r_t^{bE}(j)b_t^E(j)-r_t^d(j)d_t(j)-\frac{\kappa_{Kb}}{2}\left(\frac{K_t^b(j)}{B_t(j)}-\nu^b\right)^2 K_t^b(j)-Adj_t^B(j) \tag{17}$$

where $Adj_t^B(j)$ indicates adjustment costs for changing interest rates on loans and deposits.

2.3 Retailers

At the retail level, we assume monopolistic competition and quadratic price adjustment costs, which make prices sticky. In the adjustment cost function for prices, the parameter κ_p denotes the parameters measuring the size of these costs, while ι_p measures the degree of indexation to past prices.

Retailers are just "branders": they buy the intermediate good from entrepreneurs at the wholesale price P_t^W and differentiate the goods at no cost. Each retailer then sales their unique variety at a mark-up over the wholesale price. The elasticity of substitution ε_t^y faced by retailers is assumed to follow and AR(1) process with autoregressive coefficient ρ_y and i.i.d. normal innovations with standard deviation σ_y. We also assume that retailers' prices are indexed to a combination of past and steady-state inflation, with relative weights parametrized by ζ; if they want to change their price beyond what indexation allows, they face a proportional adjustment cost. In a symmetric equilibrium, the (non-linearized)

Phillips curve is given by the retailers' problem first-order condition:

$$1-\varepsilon_t^y+\frac{\varepsilon_t^y}{x_t}-\kappa_p(\pi_t-\pi_{t-1}^{\zeta}\pi^{1-\zeta})\pi_t+\beta_P E_t\left[\frac{c_t^P-a^P c_{t-1}^P}{c_{t+1}^P-a^P c_t^P}\kappa_p(\pi_{t+1}-\pi_t^{\iota_P}\pi^{1-\iota_P})\pi_{t+1}\frac{y_{t+1}}{y_t}\right]=0 \tag{18}$$

where $x_t = P_t/P_t^W$ is the gross markup earned by retailers.

2.4 Capital goods producers

Introducing capital good producers (CGPs) is a modeling device to derive a market price for capital, which is necessary to determine the value of entrepreneurs' collateral, against which banks concede loans. We assume that, at the beginning of each period, each capital good producer buys an amount $i_t(j)$ of final good from retailers and the stock of old undepreciated capital $(1-\delta)k_{t-1}$ from entrepreneurs (at a nominal price P_t^K). Old capital can be converted one-to-one into new capital, while the transformation of the final good is subject to quadratic adjustment cost; the amount of new capital that CGPs can produce is given by

$$k_t(j)=(1-\delta)k_{t-1}(j)+\left[1-\frac{\kappa_i}{2}\left(\frac{\varepsilon_t^{qk}\ i_t(j)}{i_{t-1}(j)}-1\right)^2\right]i_t(j) \tag{19}$$

where κ_i is the parameter measuring the cost for adjusting investment and ε_t^{qk} is a shock to the productivity of investment goods. This shock has an AR(1) representation with autoregressive coefficient ρ_{qk} and i.i.d normally distributed with zero mean innovations with standard deviation equal to σ_{qk}.

The new capital stock is then sold back to entrepreneurs at the end of the period at the nominal price P_t^k. Market for new capital is assumed to be perfectly competitive, so that it can be shown that CPGs' profit maximization delivers a dynamic equation for the real price of capital $q_t^k = P_t^k/P_t$ similar to Christiano *et al.* (2005) and Smets and Wouters (2003). [6]

2.5 Monetary policy

A central bank is able to exactly set the interest rate prevailing in the interbank market r_t, by supplying all the demanded amount of funds in excess of the net liquidity position in the interbank market.[7] We assume that profits made by the central bank on seignorage

[6] As pointed out by BGG (1999), a totally equivalent expression for the price of capital can be obtained by internalizing the capital formation problem within the entrepreneurs' problem; the analogous to our q_t^k is nothing but the usual Tobin's q. In using a decentralized modeling strategy, we follow Christiano *et al.* (2005).

[7] From an operational point of view, we are assuming that monetary policy is conducted as in the Eurosystem, but with a zero-width policy-rate corridor.

are evenly rebated in a lump-sum fashion to households and entrepreneurs. In setting the policy rate, the monetary authority follows a Taylor rule of the type

$$(1 + r_t) = (1 + r)^{(1-\phi_R)} (1 + r_{t-1})^{\phi_R} \left(\frac{\pi_t}{\pi}\right)^{\phi_\pi(1-\phi_R)} \left(\frac{Y_t}{Y_{t-1}}\right)^{\phi_y(1-\phi_R)} \varepsilon_t^R \tag{20}$$

where ϕ_π and ϕ_y are the weights assigned to inflation and output stabilization, respectively, r is the steady-state nominal interest rate and ε_t^R is an exogenous shock to monetary policy with normal distribution and standard deviation σ_r.

2.6 Aggregation and market clearing

Equilibrium in the goods market is expressed by the resource constraint

$$Y_t = C_t + q_t^k \left[C_t - (1-\delta)K_{t-1}\right] + K_t\psi\left(u_t\right) + Adj_t \tag{21}$$

where C_t denotes aggregate consumption and is given by

$$C_t = c_t^P + c_t^I + c_t^E \tag{22}$$

$Y_t = \gamma^E y_t^E(i)$ is aggregate output and $K_t = \gamma^E k_t^E(i)$ is the aggregate stock of physical capital. The term Adj_t includes real adjustment costs for prices, wages and interest rates. Equilibrium in the housing market is given by

$$\bar{h} = \gamma^P h_t^P(i) + \gamma^I h_t^I(i) \tag{23}$$

where $\bar{h}$ denotes the exogenous fixed housing supply stock.

3 Estimation

3.1 Methodology and data

We linearize the equations describing the model around the steady state. The solution takes the form of a state-space model that is used to compute the likelihood function. We use a Bayesian approach and choose prior distributions for the parameters which are added to the likelihood function; the estimation of the implied posterior distribution of the parameters is done using the Metropolis algorithm (see Smets and Wouters, 2007 and Linde at al. 2007). We use ten observables: real consumption, real investment, real house prices, real deposits, real loans to households and firms, the minimum bid rate on the main refinancing operations, the interest rates on deposits, loans to firms and households, wage inflation and consumer price inflation. For a description of the data see appendix A. The sample period runs from 1998:1 to 2008:4. We remove the trend from the variables using the HP filter. We also estimated the model with linearly detrended and obtained very similar results in terms of the posterior distribution of the parameters of the model.

We estimate the parameters that affect the dynamics of the model and calibrate those determining the steady state in order to obtain reasonable values for some key steady-state values and ratios. Table 1 reports the values of the calibrated parameters.[8]

3.2 Calibrated parameters and prior distributions

Calibrated parameters We set the patients' discount factor at 0.9943, in order to obtain a steady-state interest rate on deposits slightly above 2 per cent on an annual basis, in line with the average monthly rate on M2 deposits in the euro area between January 1998 and December 2008.[9] As for impatient households' and entrepreneurs' discount factors β_I and β_E, we set them at 0.975, in the range suggested by Iacoviello (2005) and Iacoviello and Neri (2008). The mean value of the weight of housing in households' utility function ε_j^h is set at 0.2, close to the value in Iacoviello and Neri (2008). As for the loan-to-value (LTV) ratios, we set $\bar{m}^I$ at 0.7 in line with evidence for mortgages in the main euro area countries (0.7 for Germany, 0.5 for Italy and 0.8 for France and Spain), as pointed out by Calza *et al.* (2007). The calibration of $\bar{m}^E$ is somewhat more problematic: Iacoviello (2005) estimates a value of 0.89, but, in his model, only commercial real estate can be collateralized; Christensen *et al.* (2007), estimate a much lower value (0.32), in a model for Canada where firms can borrow against business capital. Using data over the period 1999-2008 for the euro area we estimate an average ratio of long-term loans to the value of shares and other equities for the non financial corporations sector of around 0.41; using short-term instead of long-term loans we obtain a smaller value of around 0.2. Based on this evidence, we decide to set $\bar{m}^E$ at 0.25. These LTV ratios imply a steady-state shares of household and entrepreneur loans equal to 49 and 51 per cent, respectively.

The capital share is set to 0.25 and the depreciation rate to 0.025. In the labor market we assume a markup of 15 per cent and set ϵ_l at 5. In the goods market, a value of 6 for ϵ_y in steady state delivers a markup of 20 percent, a value commonly used in the literature.

For the banking parameters, no corresponding estimates are available in the literature. Thus, we calibrate them so as to replicate some statistical properties of bank interest rates and spreads. Equation (16) shows that the steady-state spread between the deposit

[8] Estimation is done with Dynare 4.0.

[9] The rate on M2 deposits was constructed by taking a weighted average of the rates on overnight deposits, time deposits up to 2 years and saving deposits up to 3 months, with the respective outstanding amounts in each period as weights. Data on interest rates were obtained from the official MIR statistics by the ECB, starting from January 2003; previous to that date, we used monthly variations of non-harmonized interest rates for the EMU-12, provided by the BIS, to reconstruct back the series. Similarly, for loan rates we used ECB official interest rates on new-business loans to non-financial corporations and on loans for house purchase to households since January 2003, and we reconstructed back the series by using variations of non-harmonized rates before that date.

rate and the interbank rate depends on ε_t^d; thus, to calibrate $\bar{\varepsilon}^d$ we calculate the average monthly spread between banking rates in our sample and the 3-month Euribor, which corresponds to around 150 basis points on an annual basis, implying that $\bar{\varepsilon}^d = -1.3$. Analogously, we calibrate ε_t^{bH} and ε_t^{bE} by exploiting the steady-state relation between the marginal cost of loan production and household and firm loan rates. The steady state ratio of bank capital to total loans $(B_t^H + B_t^E)$ is set to 0.09, slightly above the capital requirements imposed by Basel II. The parameter δ^b is set at the value (0.0982) that ensures that the ratio of bank capital to total loans is exactly 0.09.

Prior distributions Our priors are listed in Tables 2A and 2B. Overall, they are either consistent with the previous literature or relatively uninformative. For the persistence, we choose a beta-distribution with a prior mean of 0.8 and standard deviation of 0.1. We set the prior mean of the habit parameters in consumption $a^h = a^P = a^I = a^E$ at 0.5 (with a standard error of 0.1). For the monetary policy specification, we assume prior means for ϕ_R, ϕ_π and ϕ_Y equal, respectively, to 0.75, 2.0 and 0.1. We set the prior mean of the parameters measuring the adjustment costs for prices κ_p and wages κ_w to, respectively, 50 and 100 with standard deviations of 50. The priors for the indexation parameters ι_p and ι_w are loosely centered around 0.5, as in Smets and Wouters (2007). As for the mean of the adjustment costs for interest rates, their mean is set to 20 and the standard deviation to 10. These priors include the values that have been estimated using a small scale VAR, which included the bank interest rates on deposits, loans to households and loans to firms, the three-month money market rate and a monthly measure of output, estimated over the period 1999:1 2008:12. The impact response to an exogenous increase of 25 basis points in the three-month rate is equal to 3 basis points for the interest rate on deposits, and to 17 and 15 basis points for the interest rates on loans to households and to firms, respectively. These responses imply adjustment costs equal to 11 for deposits (κ_d), 6 for loans to households (κ_{bH}) and 5 for the loans to firms (κ_{bE}).

3.3 Posterior estimates

Tables 2A and 2B report the posterior mean, median and 95 probability intervals for the structural parameters, together with the mean and standard deviation of the prior distributions. Draws from the posterior distribution of the parameters are obtained using the random walk version of the Metropolis algorithm. We run 10 parallel chains each of length 200,000. The scale factor was set in order to deliver acceptance rates between 20 and 30 percent. Convergence was assessed by means of the multivariate convergence statistics taken from Brooks and Gelman (1998). Figures 2 and 3 report the prior and posterior marginal densities of the parameters of the model, excluding the standard deviation of the innovations of the shocks.

All shocks are quite persistent with the only exception of the price markup shock. As far as monetary policy is concerned our estimation confirm the weak identification of the response to inflation (see Figure 3) and the relatively large degree of interest rate inertia. The posterior median of the coefficient measuring the response to output growth is larger (3) than the prior mean. Concerning nominal rigidities, we find that wage stickiness is more important than price stickiness. The degree of price indexation is relatively low (the median is 0.15) and confirms the finding of Benati (2008) who documents a reduction in indexation in the euro area in the post-1999 sample. Concerning the parameters measuring the degree of stickiness in bank rates, we find that deposit rates adjustment more rapidly than the rates on loans to changes in the policy rate. This results is not surprising given that our measure of deposits include also time and saving deposits. The interest rates on these instruments, indeed, is typically more responsive to changes in money market rates than those on overnight deposits. In all the cases the median is smaller than the mean of the prior distribution.

The median values of the marginal posterior distribution of the parameters We set the prior mean of the parameters measuring the adjustment costs for prices κ_p and wages κ_w to, respectively, 50 and 100 with standard deviations of 50. The priors for the indexation parameters ι_P and ι_W are loosely centered around 0.5, as in Smets and Wouters (2007). As for the mean of the adjustment costs for interest rates, their mean is set to 20 and the standard deviation to 10.

4 Properties of the estimated model

In this Section we study the dynamics of the linearized model using impulse responses, focusing on a contractionary monetary policy shock and on an expansionary technology innovation. Our aim is to assess whether and how the transmission mechanism of monetary and technology shocks is affected by the presence of financial frictions and financial intermediation and how different our findings are from those of other papers that share some of our features, such as Iacoviello (2005), Christiano *et al.* (2007) or Goodfriend and McCallum (2007). At the same time we want to analyze the impact of this types of shocks on the profitability and capital position of financial intermediaries, a task that our model is suited to accomplish.

4.1 Monetary policy shock

The transmission of a monetary policy shock is first studied by analyzing the impulse responses to an unanticipated 50 basis points exogenous shock to the policy rate (r_t) (see Figure 4). The benchmark model, described in the previous sections, features a number of transmission channels for monetary impulses. Besides the traditional interest rate channel, modified by the presence of agents with an heterogeneous degree of patience, there exist three more channels: a borrowing constraint channel by which an innovation in the policy rate, by changing the net present value of the collateral, changes how binding agents' constraints are; moreover, there exist a financial accelerator effect, by which induced changes in asset price alter the value of the collateral agents can pledge. Finally, the assumption that interest and principal payments on loans and deposits are in nominal terms introduces a nominal debt channel, whereby changes in inflation affect the ex-post distribution of resources across borrowers and lenders. All these last three factors have been shown to contribute to amplify and propagate the initial impulse of a monetary tightening (see, e.g., Iacoviello, 2005, or Calza et al., 2007). Adding to their effects, the presence of a banking sector affects the monetary transmission mechanism by impinging on each of them. In particular, credit market power, sluggishness in bank rates and the presence of bank capital might dig wedges between rates set by the policymaker and rates which are relevant for the decisions of each agent in the economy. The overall effect on the transmission mechanism of monetary policy could in principle be ambiguous.

In order to highlight how the various channel affect the transmission of monetary policy, in figure 4 we compare our (benchmark) model (BK in the figure) with a number of other models, where we progressively shut down a number of features: (i) a model where we shut down the bank-capital channel, i.e. a model with a simplified balance-sheet for banks, including only deposits on the liability side (noBK in the figure);[10] (ii) a model where we also remove stickiness in bank-interest rate setting and allow for flexible rates (FR in the figure); [11] (iii) a model with perfectly competitive banks, i.e. most resembling to the single interest rate model with financial frictions in Iacoviello (2005) (FF inthe figure);[12] (iv) a model where we also remove the financial accelerator and debt-deflation effects, in order to obtain a model similar to the standard New Keynesian DSGE.[13]

In the benchmark model, the presence of financial intermediation and capital constraints does not qualitatively alter the responses of the main macroeconomic variables, when compared to standard results in the New Keynesian literature. Therefore, our model has the advantage to introduce new elements, thus enriching the inter-linkages between macroeconomic and financial variables, while remaining able to replicate stylized facts in business cycle theory. In the face of a policy tightening, output and inflation contract and the policy rate does not rise one-to-one with the exogenous shock, because it endogenously responds to the fall in output and inflation. Loans to both households and firms fall, reflecting the decline in asset prices, i.e. the price of housing and the value of firms'

[10] In order to do so, we force the parameter κ_{Kb} to be equal to 0 and we rebate banking profits to patient households in a lump-sum fashion.

[11] Operationally, we set the costs to change rates κ_{bH}, κ_{bE} and κ_d to zero.

[12] This model is obtained by assuming that the elasticities of substitution for loans and deposits all equal infinity.

[13] Here agents are assumed to be still constrained in borrowing but at the steady state value of the collateral, and loans and deposits (plus interest) are repaid in real terms.

capital, and the increase in the real interest rate. Bank loan rates increase less than the policy rate (on impact, the increase is around one fourth) but they remain above steady state for longer, reflecting the imperfect pass-through of lending rates; the loan-deposit interest margin also goes up, as the increase in the deposit rate is even less pronounced. The response of bank capital is initially positive, reflecting the increase in bank margins and thus profit, but it subsequently falls as spreads reduce and financial activity remains subdued.

From a quantitative point of view, however, a number of differences arises from the the introduction of financial intermediation. In general, our banking sector *attenuates* the responses with respect to a model featuring a single interest rate (FF model in the figure). This is because monopolistic competition in banking introduces a steady-state wedge between retail bank rates and the policy rates, on the one hand, and also allows for imperfect pass-through on bank rates (due to adjustment costs) which mutes the response of retail rates to the increase in the official rate. The introduction of a link between the capital position of banks and the spread on loans has, instead, virtually no effect on the dynamics of the real variables; this partly reflects the small value estimated for the parameter κKb, which - as mentioned before - we use to perform this exercise. To give an example, our calibration implies that a reduction of the capital-to-asset ratio by half (from its steady state value of 9%) would increase the spread between loan rates and the policy rate by only 20 basis points.

Analyzing more in detail the differences between the various models, the presence of the financial accelerator is clearly evident when comparing the model with financial frictions (and no banks; FF model) with the model where this channel is shut down (QNK model). The role of banks begins to appear when we take into account the responses of the FR and of the noBK models, which add a (simplified) banking sector to the FF framework; in both these models, there is a wedge between active and passive rates as a consequence of the market power of banks and pass-through on bank rates is imperfect. The FR model isolates the attenuating effect coming from imperfect competition in the credit market. This comes from a steady state effect according to which a given (absolute) monetary tightening impinges on a loan rate which is already higher, by a measure of the markup, than the policy rate, therefore determining a smaller percent variation of the former rate. Sticky bank rates (noBK model) add to this, preventing banks to fully pass on the policy rate increase to retail rates. From the figure, it is evident that the attenuator effect resulting from the presence of banks can be sizeable on impact. Finally, when we compare the noBK and the BK model, we disentangle the effect on real variables of the presence of banking capital. Bank capital rises substantially following the shock but turns negative after 10 quarters; overall, the impact of the shock is very persistent, suggesting that the introduction of this feature can potentially add much to the propagation mechanism. Movements in bank capital follow the dynamics of bank profits (which in our model correspond to interest margin): these rise on impact, when the increase in rate spreads more than offsets the fall in intermediated funds, but later become negative (after around 5 quarters), when spreads reduce to zero (and intermediation activity remains subdued). The increase in equity seems to determine some substitution effect with deposits, whose relative cost has increased; such substitution prevents movements in equity to have any significant impact on credit and, thus, on the real economy.

Our findings about the relative strength of the effects coming from the financial frictions and the banking sector are in line with much of the available literature. Christensen *et al.* (2007) find that financial frictions boost the response of output after an increase in policy rates by about a third, mainly on account of a stronger response of both consumption and investment. As for the role of banks, Christiano *et al.* (2007) find that, in general, the presence of banks and financial frictions strengthens significantly the propagation mechanism of monetary policy: the output response is both bigger and more persistent compared to a model that does not feature these channels. Although their banks, compared to ours, are rather different intermediaries that operate under perfect competition, they also find that banks play a marginal role in propagating the monetary impulse while the financial accelerator is more important. An attenuation effect coming from banks similar to ours has been found in Goodfriend and McCallum (2007) banking model. In their model, the effect occurs only when the monetary impulse is very persistent, since marginal costs in the banking sector become procyclical in that case (otherwise the effect is of opposite sign). The attenuation effect in our model is more general, as bank rate adjustment is sluggish irrespective of the persistence of monetary shocks. A similar attenuator effect from the presence of a steady-state spread in the banking sector, due to imperfectly competitive financial intermediation, arises also in Andrés and Arce (2008) and Aslam and Santoro (2008).

4.2 Technology shock

The transmission of a technology shock is studied by looking at the impulse responses coming from the same set of models illustrated in the previous paragraph. Figure 5 shows the simulated responses of the main macroeconomic and financial variables following a shock to a_t^E equal in size to the estimated standard deviation of TFP.

In the case of a technology shock the presence of financial intermediation substantially enhances the endogenous propagation mechanism after the shock, with output peaking higher and 2 to 4 quarters later than in the model with financial frictions and without banks (FF). This effect reflects mainly the behavior of investment, whose response is significantly magnified by the presence of financial intermediaries.

In all models, the shock makes production more efficient, bringing inflation down. Monetary policy accommodates the fall in inflation bringing down also loan rates, and therefore increasing loans, aggregate demand and output. When we introduce a monopolistically competitive banking sector (with flexible rates, FR), the reduction in the policy rate translates into a reduction of credit spreads, which increases the demand for loans. Both impatient households and entrepreneurs, benefitting from the greater availability of credit, accumulate housing and physical capital, which allows them to borrow even more and to enjoy a persistent expansion of consumption. As a result, there the effects of the shock on both consumption and investment is more persistent: the peak increase in consumption is reached in the beginning of the third year, i.e. one year later with respect to the model without banks; the rise in investment is very pronounced and also its peak is delayed.

When we add to this basic mechanism sticky bank rates (the noBK model) the picture does not change substantially, although the reduction of spreads is dampened by the imperfect pass-through, determining a smaller impact reaction of lending and, thus, of consumption and investment. The introduction of bank capital has a relevant impact on investment, going mainly through the reduction of the availability of credit to entrepreneurs. In addition, the reduction in capital - by affecting the bank capital position - also affects the loan margin, dampening the reduction described above.

5 Applications

Once the model has been estimated and its propagation mechanism studied, we can use it to address the two questions raised in the Introduction. First, what role did the shocks originating in the banking system played in the dynamics of the main variables since the burst of the financial crisis? Second, what are the effects of a credit crunch originating from a fall in bank capital?

5.1 The role of financial shocks in the business cycle

In order to quantify the relative importance of each shock in the model we perform an historical decomposition of the dynamics of the main macro and financial variables of the euro area. This decomposition was obtained by fixing the parameters of the model at the posterior mode and then using the Kalman smoother to obtain the values of the innovations for each shock. The aim of the exercise is twofold: on the one hand, we want to investigate how our financially-rich model interprets the slowdown in 2008 and thus learn from the model which shocks were mainly responsible for the current slowdown. On the other hand, to the extent that the overall story told by the model is consistent with the common wisdom emerged so far about the origins and causes of the current crises, we can use this experiment as an indirect misspecification test for our model.

For this exercise we have divided the 13 shocks that appear in the model in three groups.

First there is a “macroeconomic” group, which pulls together shocks to the production technology, to intertemporal preferences, to housing demand, to the investment-specific technology, and to price and wage markups. Then, the “monetary policy” group isolates the contribution coming from the non-systematic conduct of the monetary policy. Finally, the “financial” group consists of shocks originating in the banking system: those are the shocks to the loan-to-value ratios on loans to firms and households, the shocks to the markup on the bank interest rates and the shock to the balance sheet.

Figure 6 shows the results of the exercise for some macro variables. Concerning output (defined as the sum of consumption and investment) the results of the historical decomposition suggest that financial shocks were primary drivers behind *both* the rise of 2006-2007 and the sharp slowdown of 2008. In particular, these shocks explain about 60 per cent of the slowdown in economic activity in the last three quarters of 2008. The financial shocks affect the real economy mainly through their effect on investment and the decomposition of that variable confirms how unusually large (positive) shocks were responsible for the positive performance of investment in 2006 and 2007 and how these same shocks turned negative in 2008, accounting for the fall in investment. The other main culprit behind the slowdown of 2008 are, obviously, negative macroeconomic shocks. Looking a bit closer into that category, it turns out that an important contributor in this group were price markup shocks. The reason why these shocks are estimated to be so important in the current juncture is that they are likely to be capturing the effects of the sharp increase in commodity prices that occurred in the first half of 2008. The large contribution of these shocks to inflation confirms this hypothesis.Turning to the policy rate, the macroeconomic shocks exerted a positive contribution during most of 2008. According to the model monetary policy shocks had negative effects on the policy rate between the end of 2007 and the third quarter of 2008. In order to understand this result, one has to recall that over this period, which was characterized by great uncertainty on the consequences of the financial crisis, the ECB kept the interest rate on the main refinancing operations fixed at 4.0 per cent until July 2008 when it was raised by 25 basis points in order to counteract inflationary pressures stemming from the surge in commodity prices. Since mid-2008, the contribution of the banking shocks become predominant and fully account for the rapid reduction in the policy rate in the last quarter of 2008.

In Figure 7 we collect the results of the historical decomposition for some credit variables. In this case we find convenient to divide the “financial” group in three subcategories: shocks directly related to loans to households (loan-to-value ratio for HH and interest rate markup shock on loans to HH), shocks directly related to loans to firms, and the rest of financial shocks (markup shock on deposit rate and bank balance sheet shock). The dynamics of the interest rates on loans to firms and households were mainly driven by macroeconomic shocks. However, shocks related to the firms side of credit played an important role in driving up the rate on loans to firms since 2005, while monetary policy shocks were relatively important drivers between 2006 and 2007, when the ECB raised the policy rate from the very low levels reached in June 2003. Concerning loans to households, a main driver of its dynamics turned out to be the housing shock (within the macro group), since it explains most of the strong rise in 2006 and 2007 and of the subsequent decline in 2008. This is not surprising given the role of housing as collateral for the households in obtaining credit. Beside the housing shock, a important role in the recent fall is played by the high price markup shocks (within the macro group) estimated in 2008, which, as we said earlier, are likely to be capturing the sharp increase in commodity prices that occurred in the first half of 2008. Loans to firms are driven almost exclusively by shocks related directly to the firms side of credit, with the notable exception of 2008 when a sizable negative contribution comes from the macroeconomic shocks (in particular, again, the price markups).

To sum up, the exercise taught us that the banking shocks introduced in our model have played an important role in shaping the dynamics of the euro area in the last business cycle and, more importantly, according to the model they did so in a way that nicely squares with our prior knowledge and expert judgement of macroeconomists about what has happened.

5.2 The effects of a tightening of credit conditions

Starting in the summer of 2007, financial markets in a number of advanced economies fell under considerable strain. The initial deterioration in the US sub-prime mortgage market quickly spread across other financial markets, affecting the valuation of a number of assets. Banks, in particular, suffered losses from significant write-offs on complex instruments and reported increasing funding difficulties, in connection with the persisting tensions in the interbank market and with the substantial hampering of securitization activity. A number of them were forced to recapitalize and improve their balance sheets. In addition, intermediaries reported that concerns over their liquidity and capital position induced them to tighten credit standards for the approval of loans to the private sector. In the euro area, since the October 2007 round, banks participating to the Eurosystem's quarterly Bank Lending Survey reported to have strongly increased the margins charged on average and riskier loans and to have implemented a restriction on collateral requirements both for households and firms; in each 2008 Survey release, 30% of respondent banks reported to have reduced the loan-to-value ratio for house purchase mortgages in the previous three months. Against this background, policymakers have been particularly concerned with the impact that a restriction in the availability and cost of credit might have on the real economy. The potential consequences on economic activity of the financial turmoil have been given considerable attention when evaluating the appropriateness of the monetary policy stance.

In light of the importance of understanding the consequences of a tightening of credit standards by banks, in this section we try to answer the following question: What would happen if bank capital were to suffer a strong negative shock? Would it trigger a contraction in loan supply, an increase in bank rates and a contraction in economic activity?

Our model is well-suited to analyze the effects of a tightening in credit conditions on the real activity and to give indications (at least qualitatively) on the appropriate response of a central bank following a Taylor-type monetary policy rule. The experiment we carry out involves implementing an unexpected and persistent contraction in bank capital K_b. We do not attempt to construct a quantitatively realistic scenario; this would be indeed very difficult, given the conflicting indications coming from hard and survey evidence on the tightening of credit standards, in particular in the euro area, and the uncertainty on the effects that have already occurred and on those that might still be in the pipeline. We calibrate the shock in a way that it determines a fall of bank capital by 5 percent on impact. The persistence of the shock is set to 0.95 in order to obtain a persistent fall of the capital/asset ratio below its steady state value (9 percent). In the exercise we assess the role of the adjustment costs on the capital/asset ratio by computing the impulse responses under different calibration of the parameters κ_{Kb}. We consider as benchmark a value of 10, the prior mean of the parameters, and then a higher one, corresponding to 50, and a lower one equal to 2. Figure 8 shows the effect of this credit crunch experiment.

By construction, the credit tightening brings about a fall in bank capital. In order to compensate for the loss in equity, banks increase the rate on deposits to attract them and increase their liabilities. At the same time, they increase the rates on loans to increase profits. At this point, the larger is the cost for adjusting the capital ratio, the larger is the increase in banks' interest rates. Higher rates reduce the demand for loans by households and firms which are forced to cut back on consumption and investment expenditure. The effect is larger on investment; the size of the response of consumption depends largely on the persistence of the shock to bank capital (see Figure 8). When the persistence of the shock is reduced to 0.5, consumption marginally increases while investment still falls substantially. Output contracts only when the adjustment costs on the capital ratio is sufficiently large. In this scenario, interest rates on loans and deposits still increase and loan demand falls; profits increase and compensate the fall in equity. The capital ratio converges faster to its steady state.

Looking at individual agents, the rate shock unfavorably hits impatient households, through the increase in the real interest rate they face on loans, who are forced to sell their housing in order to support consumption. House prices fall and patient households start investing in housing by reducing consumption. Entrepreneurs reduce the accumulation of capital and consumption. Aggregate demand falls considerably and output contracts significantly.

6 Concluding remarks

The paper has presented a model in which both entrepreneurs and impatients households face borrowing constraints and loans are supplied by imperfectly competitive banks that collect deposits from patient households. Deposits and bank capital are used to produce loans that are granted to households and firms. Bank interest rates on these distinct loans and on deposits adjust slowly to changes in the policy rate. The model is estimated using Bayesian techniques and data for the euro area over the period 1999-2008.

We find that in the face of demand shocks, like a monetary policy shock, the presence of financial intermediaries diminishes the business cycle acceleration effects deriving from a change of the real net present value of agents' collateral. The presence of bank capital does not alter the effects of monetary policy shocks on the main macroeconomic variables. On the contrary, banks intermediation increases the propagation of supply shock like technological improvements.

The model is then used to quantify the contribution of shocks originating within the banking sector to the slowdown in economic activity during 2008 and to study the consequences of tightening of credit conditions induced by a reduction in bank capital. Shocks in the banking sector explain the largest fraction of the fall output in 2008 while macroeconomic shocks played a smaller role. The effects of a credit supply shock can be substantial particularly on investment. A fall in bank capital forces bank to raise interest rates resulting in lower demand for loans by households and firms who are forced to cut on consumption and expenditure.

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Table 1A. Calibrated parameters

Parameter	Description	Value
β_P	Patient households' discount factor	0.9943
β_I	Impatient households' discount factor	0.975
β_E	Entrepreneurs' discount factor	0.975
ϕ	Inverse of the Frish's elasticity	1.5
μ	Share of unconstrained households	0.8
ε^h	Weight of housing in the households' utility function	0.2
α	Capital share in the production function	0.25
δ	Depreciation rate of physical capital	0.025
ε_y	$\frac{\varepsilon_y}{\varepsilon_y-1}$ is the markup in the goods market	6
ε_l	$\frac{\varepsilon_l}{\varepsilon_l-1}$ is the markup in the labour market	5
$\bar{m}^I$	LTV households	0.7
$\bar{m}^E$	LTV entrepreneurs	0.25
ν^b	Capital/loans ratio in steady state	0.09
$\bar{\varepsilon}^d$	$\frac{\varepsilon^d}{\varepsilon^d-1}$ markdown on deposit rate	-1.3
$\bar{\varepsilon}^{bH}$	$\frac{\varepsilon^{bH}}{\varepsilon^{bH}-1}$ markup on rate on loans to HHs	5.1
$\bar{\varepsilon}^{bE}$	$\frac{\varepsilon^{bE}}{\varepsilon^{bE}-1}$ markup on rate on loans to firms	3.5

Table 1B. Steady state ratios

Variable	Interpretation	Value
c/y	Ratio of consumption to GDP	0.87
i/y	Ratio of investment to GDP	0.11
k/y	Ratio of capital stock to GDP	4.4
B/y	Ratio of loans to GDP	1.9
B^H/B	Share of loans to households over total loans	0.46
B^E/B	Share of loans to firms over total loans	0.54
K^b/B	Ratio of bank capital to loans (per cent)	0.09
K^b/y	Ratio of bank capital to GDP (per cent)	0.18
$4 \times r^d$	Annualized bank rate on deposits (per cent)	2.3
$4 \times r$	Annualized policy rate (per cent)	4.0
$4 \times r^{bH}$	Annualized bank rate on loans to households (per cent)	5.6
$4 \times r^{bE}$	Annualized bank rate on loans to firms (per cent)	5.6

Table 2A. Prior and posterior distribution of the structural parameters

	Prior Distribution			Posterior Distribution			
Parameter	Distr.	Mean	St.Dev	Mean	2.5 percent	Median	97.5 percent
κ_p	Gamma	50.0	20.0	31.24	10.97	29.19	51.76
κ_w	Gamma	50.0	20.0	88.18	54.38	84.71	121.46
κ_i	Gamma	2.5	1.00	6.86	4.95	6.74	8.82
κ_d	Gamma	20.0	10.0	10.13	6.41	9.83	13.59
κ_{bE}	Gamma	20.0	10.0	14.10	10.32	13.89	17.67
κ_{bH}	Gamma	20.0	10.0	13.95	8.52	13.58	19.19
κ_{Kb}	Gamma	10.0	5.00	10.82	5.29	10.63	16.02
ϕ_π	Gamma	2.0	0.25	2.02	1.76	1.99	2.25
ϕ_R	Beta	0.7	0.15	0.81	0.77	0.81	0.84
ϕ_Y	Normal	0.1	0.15	0.24	0.05	0.24	0.42
ι_p	Beta	0.5	0.15	0.15	0.05	0.14	0.25
ι_w	Beta	0.5	0.15	0.19	0.09	0.19	0.29
a^h	Beta	0.5	0.10	0.74	0.65	0.74	0.83

Note: Results based on 10 chains, each with 100,000 draws Metropolis algorithm.

Table 2B. Prior and posterior distribution of the structural parameters

	Prior Distribution			Posterior Distribution			
Parameter	Distr.	Mean	St.Dev	Mean	2.5 percent	Median	97.5 percent
ρ_a	Beta	80	10	0.93	0.89	0.93	0.97
ρ_z	Beta	80	10	0.54	0.39	0.54	0.68
ρ_j	Beta	80	10	0.91	0.85	0.91	0.96
ρ_{mE}	Beta	80	10	0.91	0.85	0.91	0.96
ρ_{mI}	Beta	80	10	0.94	0.89	0.94	0.98
ρ_d	Beta	80	10	0.86	0.81	0.86	0.90
ρ_{bE}	Beta	80	10	0.79	0.67	0.78	0.88
ρ_{bH}	Beta	80	10	0.77	0.63	0.81	0.95
ρ_{ak}	Beta	80	10	0.44	0.31	0.44	0.57
ρ_p	Beta	80	10	0.26	0.16	0.26	0.35
ρ_l	Beta	80	10	0.67	0.56	0.68	0.79
ρ_b	Beta	80	10	0.81	0.72	0.81	0.90
σ_a	Inv. gamma	0.01	0.05	0.005	0.005	0.004	0.007
σ_z	Inv. gamma	0.01	0.05	0.016	0.015	0.011	0.020
σ_j	Inv. gamma	0.01	0.05	0.070	0.067	0.027	0.113
σ_{mE}	Inv. gamma	0.01	0.05	0.003	0.003	0.002	0.004
σ_{mI}	Inv. gamma	0.01	0.05	0.002	0.002	0.002	0.003
σ_d	Inv. gamma	0.01	0.05	0.031	0.030	0.023	0.039
σ_{bE}	Inv. gamma	0.01	0.05	0.128	0.123	0.096	0.164
σ_{bH}	Inv. gamma	0.01	0.05	0.010	0.007	0.002	0.019
σ_{ak}	Inv. gamma	0.01	0.05	0.013	0.013	0.010	0.017
σ_R	Inv. gamma	0.01	0.05	0.002	0.002	0.001	0.002
σ_p	Inv. gamma	0.01	0.05	0.655	0.620	0.287	1.020
σ_l	Inv. gamma	0.01	0.05	0.452	0.435	0.290	0.600
σ_b	Inv. gamma	0.01	0.05	0.008	0.008	0.007	0.010

Note: Results based on 10 chains, each with 100,000 draws Metropolis algorithm.

Figure 1. Bank Lending Survey of the Eurosystem and Senior Loan Officer Survey of the Federal Reserve

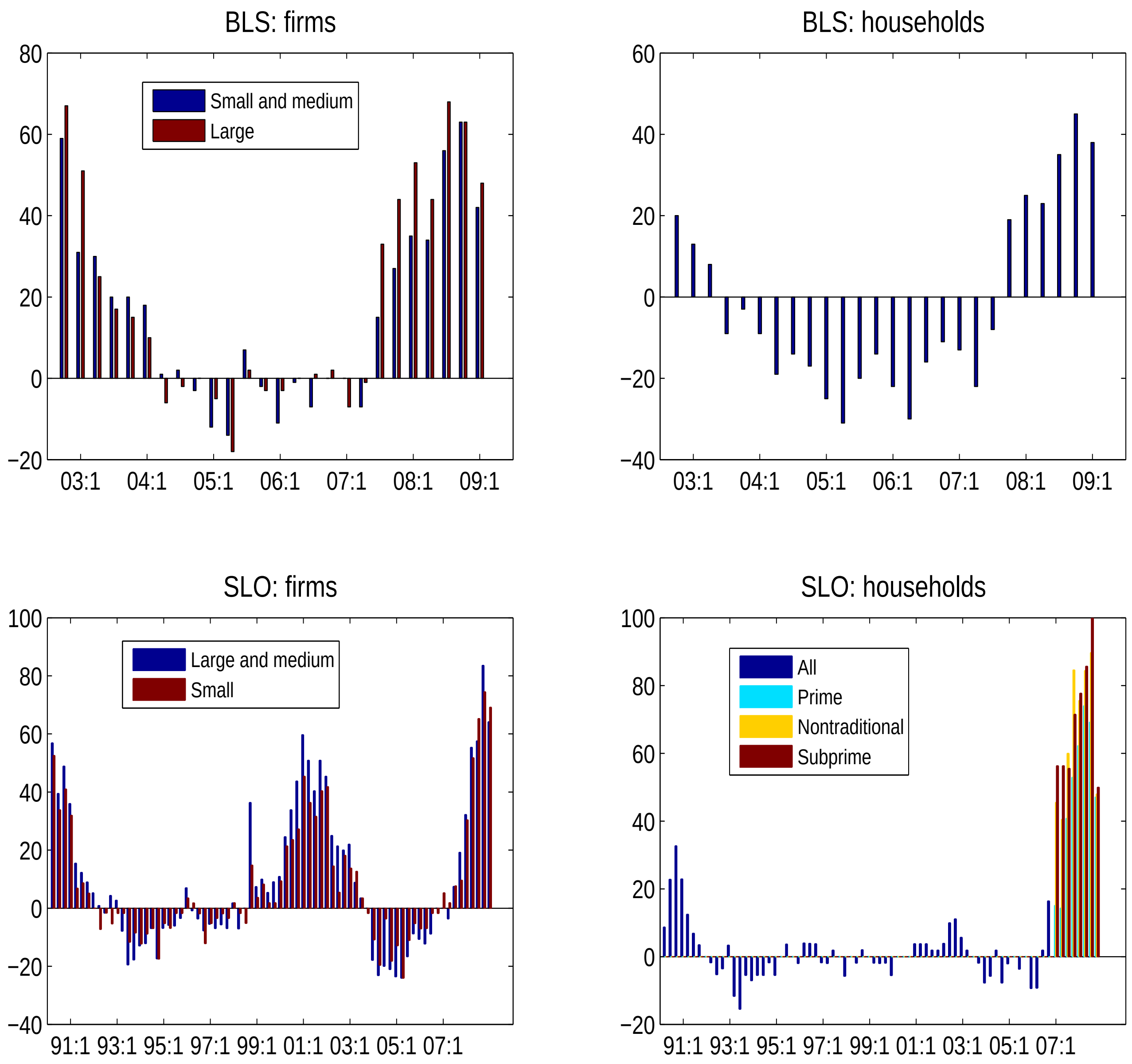
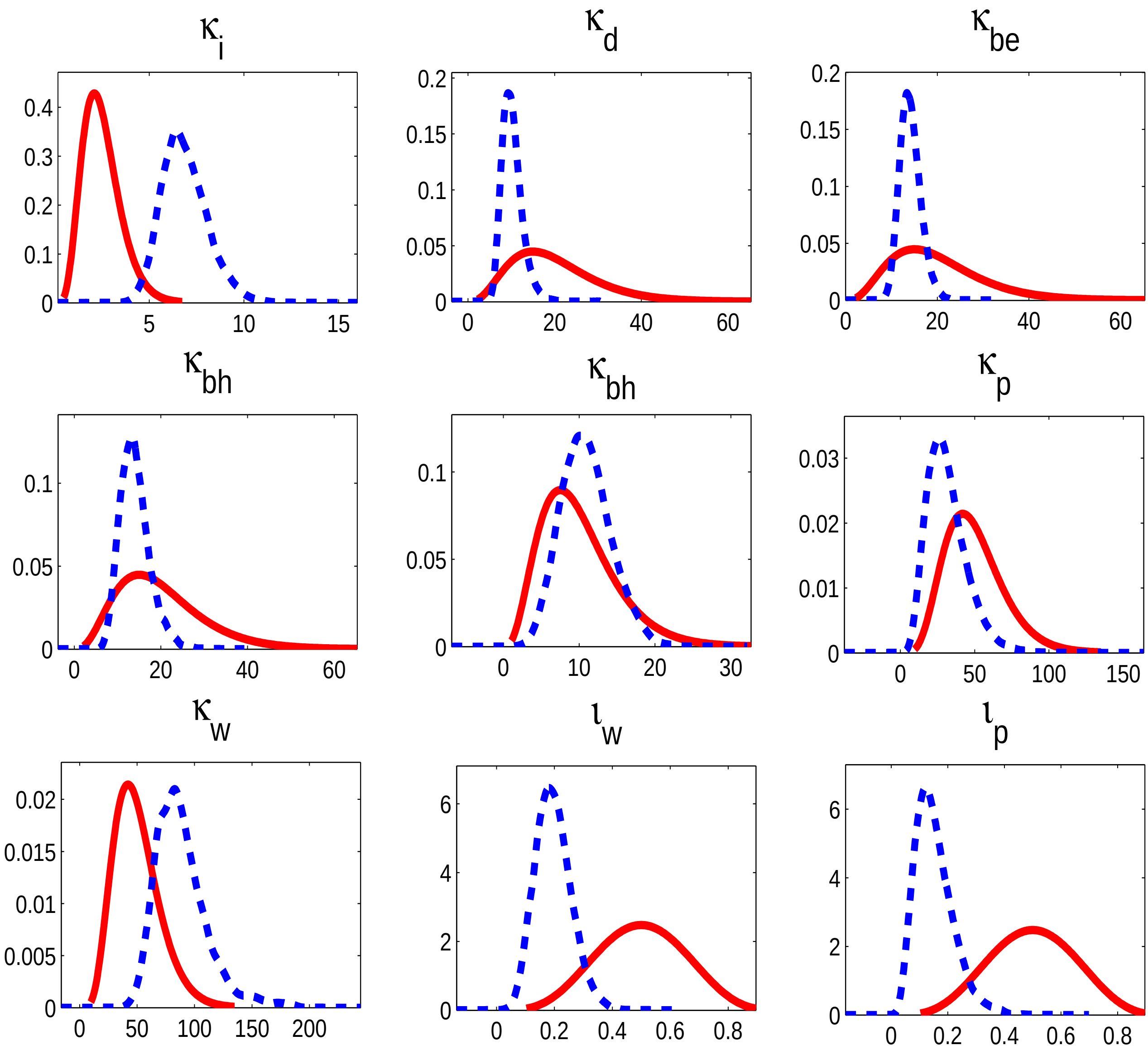
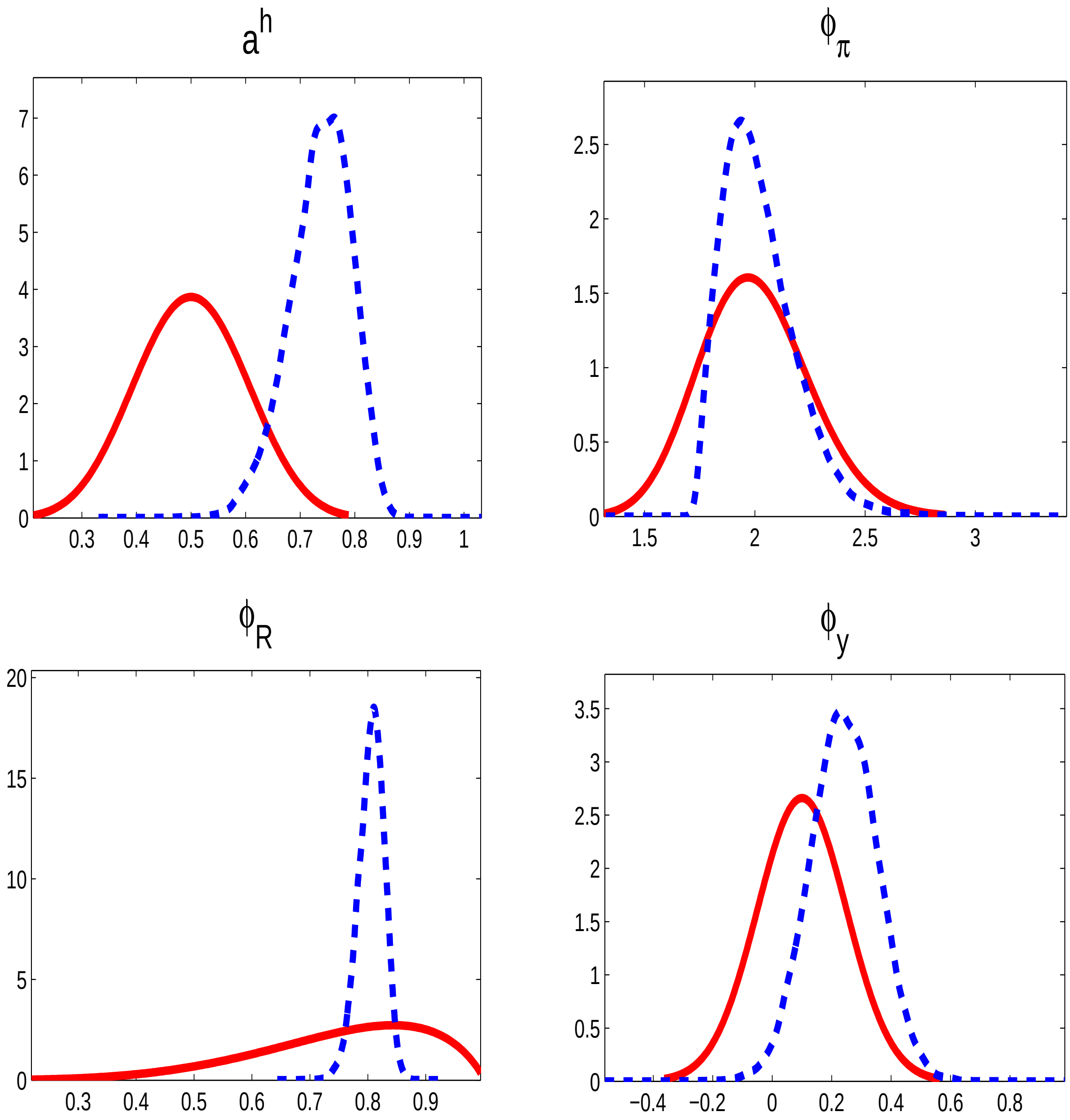


Figure 2. Prior and posterior marginal distributions



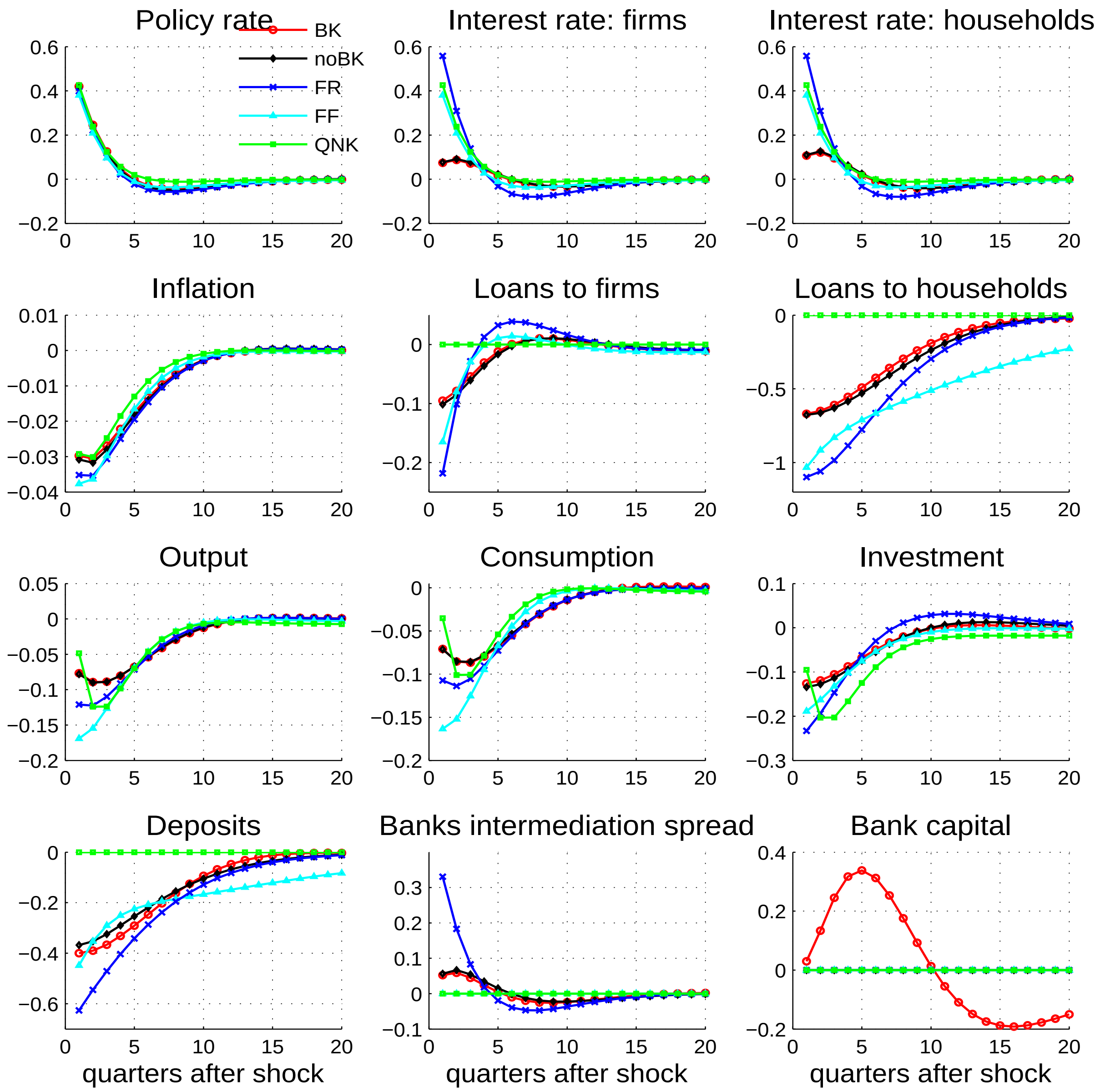
Note: The marginal posterior densities are based on 10 chains, each with 100,000 draws Metropolis algorithm.

Figure 3. Prior and posterior marginal distributions



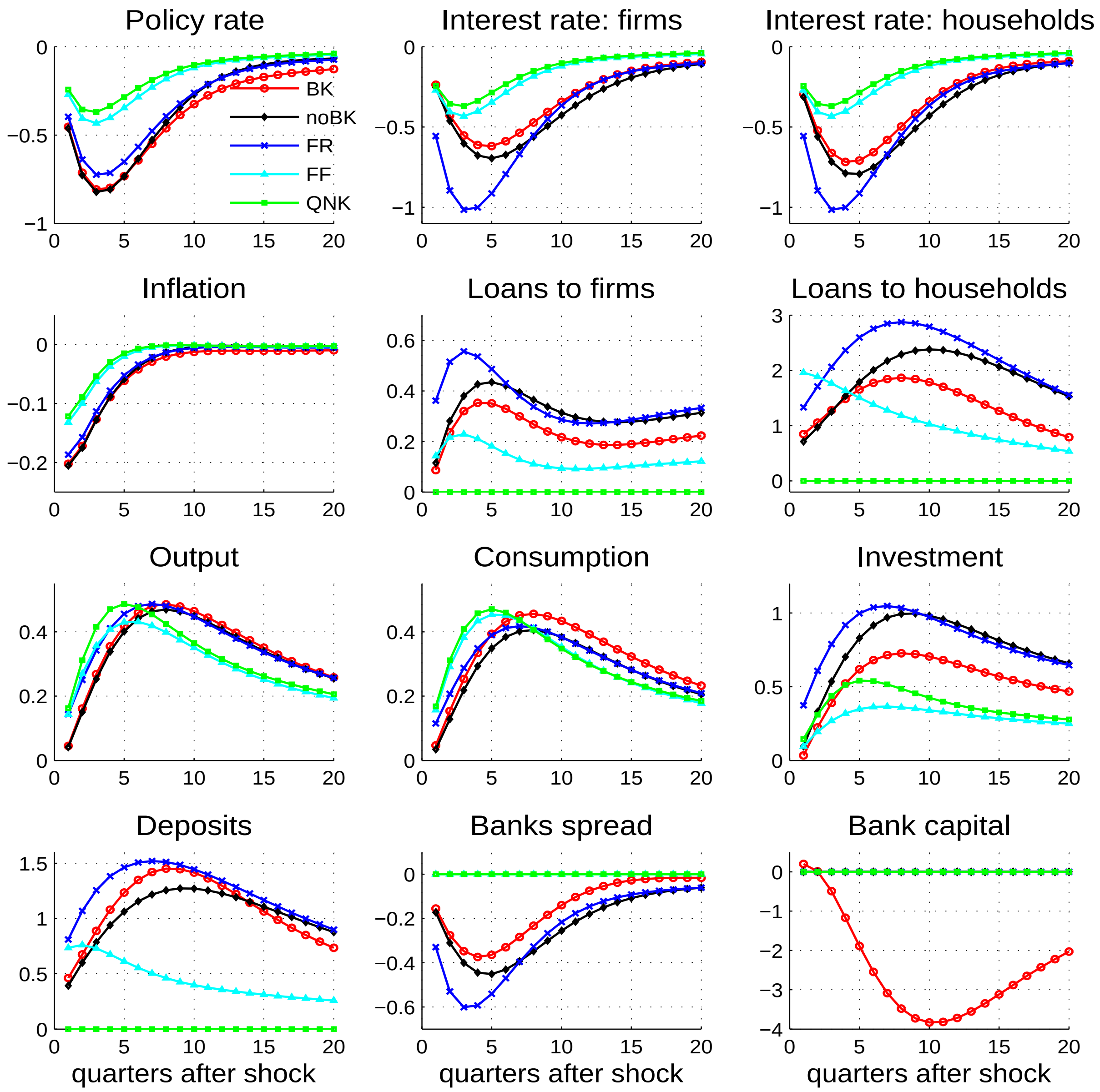
Note: The marginal posterior densities are based on 10 chains, each with 100,000 draws Metropolis algorithm.

Figure 4 The role of banks and financial frictions in the transmission of a contractionary monetary policy shock



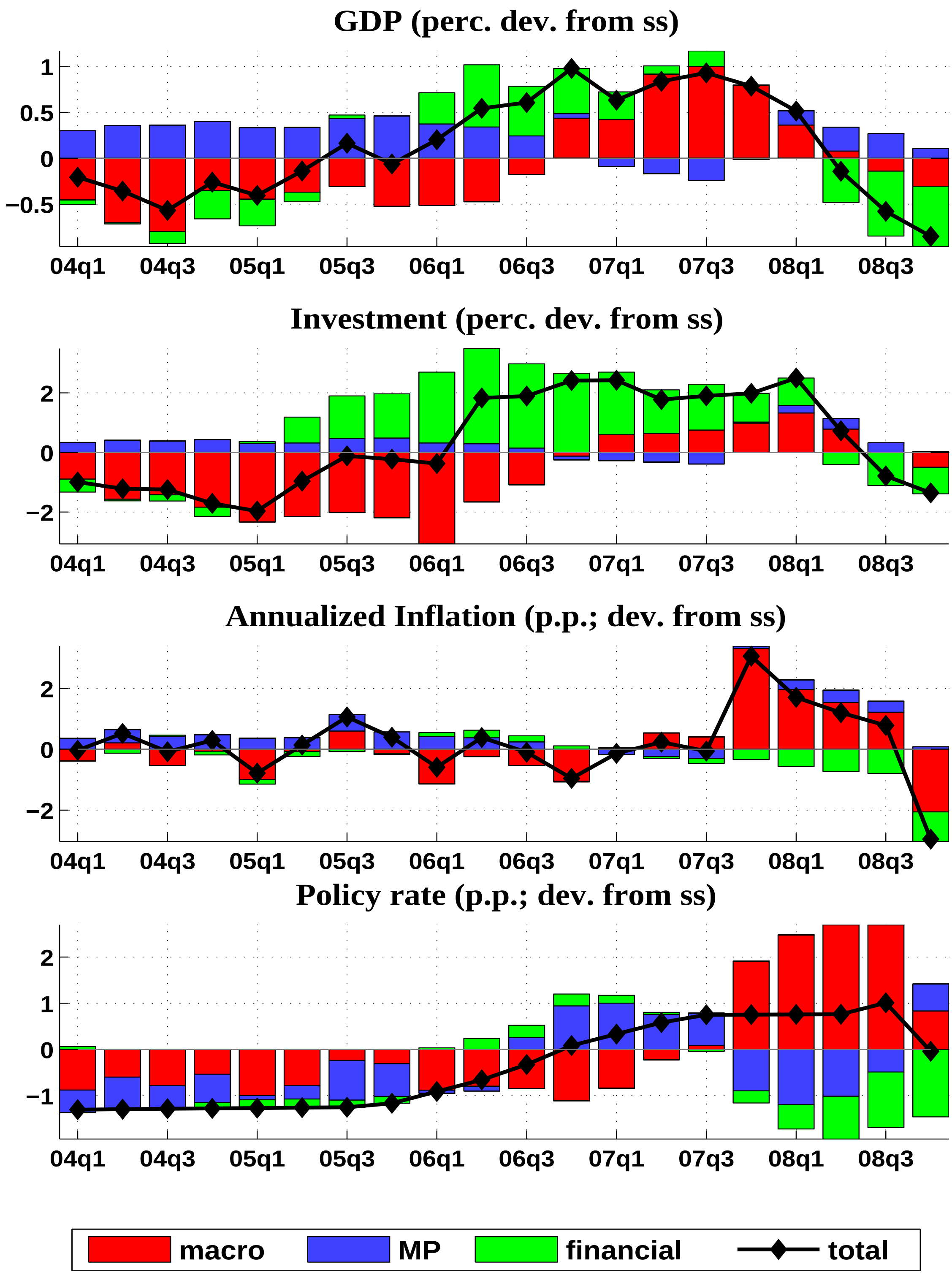
Note: The impulse responses are computed using the mode of the posterior distribution of the benchmark model (BK). Interest rates and banks spreads are shown as absolute deviations from steady state, expressed in percentage points. All others are percentage deviations from steady state. The red circled line is from the benchmark model (BK). The green squared line is from the quasi-NK model (QNK). The light blue with triangles line is from the model with financial frictions but without banks (FF). The dark blue crossed line is from the model with banks, but with flexible rates and without bank capital (FR). The black line is from the model without bank capital but with sticky rates (noBK).

Figure 5 The role of banks and financial frictions in the transmission of a positive technology shock



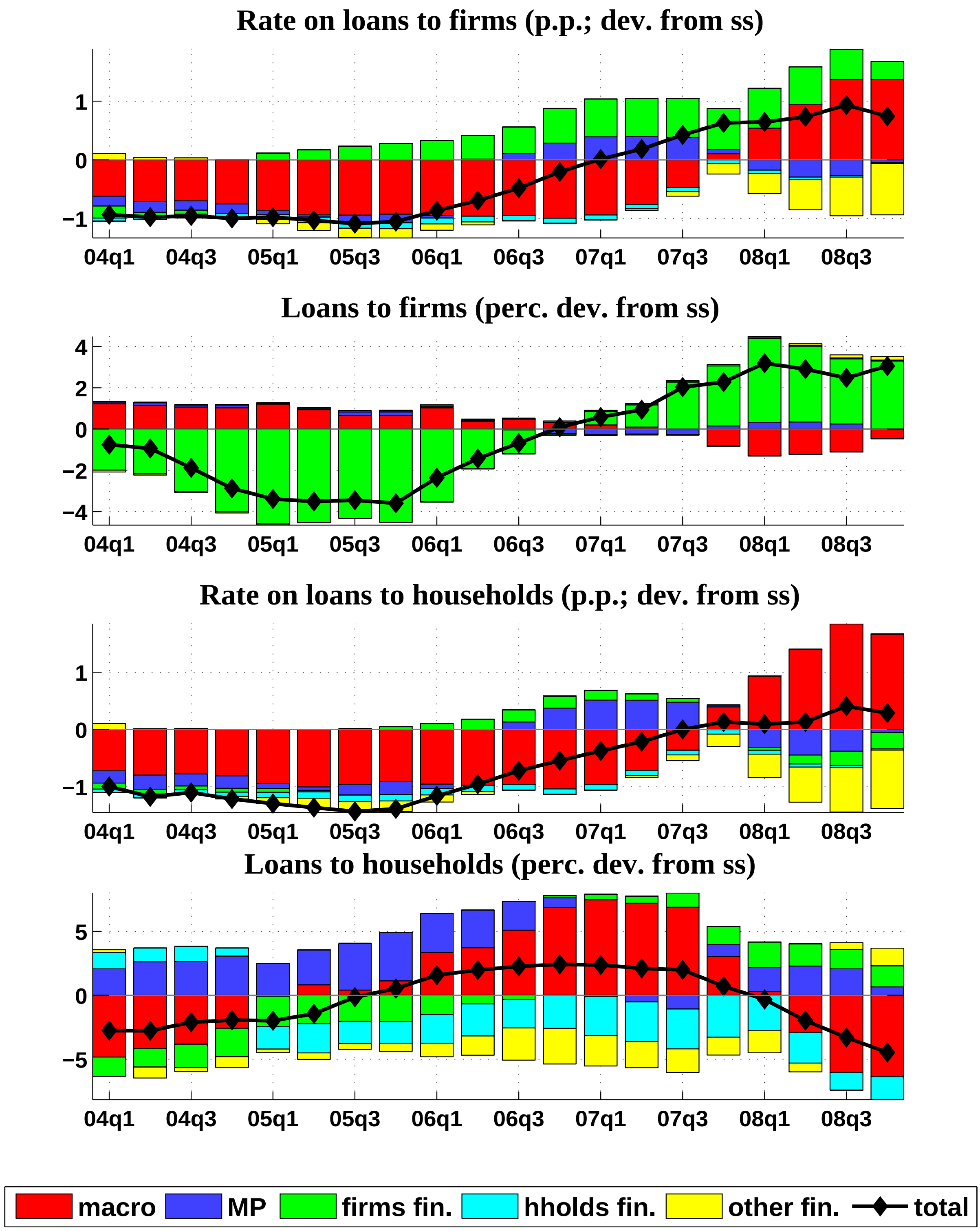
Note: The impulse responses are computed using the mode of the posterior distribution of the benchmark model (BK). Interest rates and banks spreads are shown as absolute deviations from steady state, expressed in percentage points. All others are percentage deviations from steady state. The red circled line is from the benchmark model (BK). The green squared line is from the quasi-NK model (QNK). The light blue with triangles line is from the model with financial frictions but without banks (FF). The dark blue crossed line is from the model with banks, but with flexible rates and without bank capital (FR). The black line is from the model without bank capital but with sticky rates (noBK).

Figure 6. Historical decomposition of main macro variables: 2004q1 - 2008q4



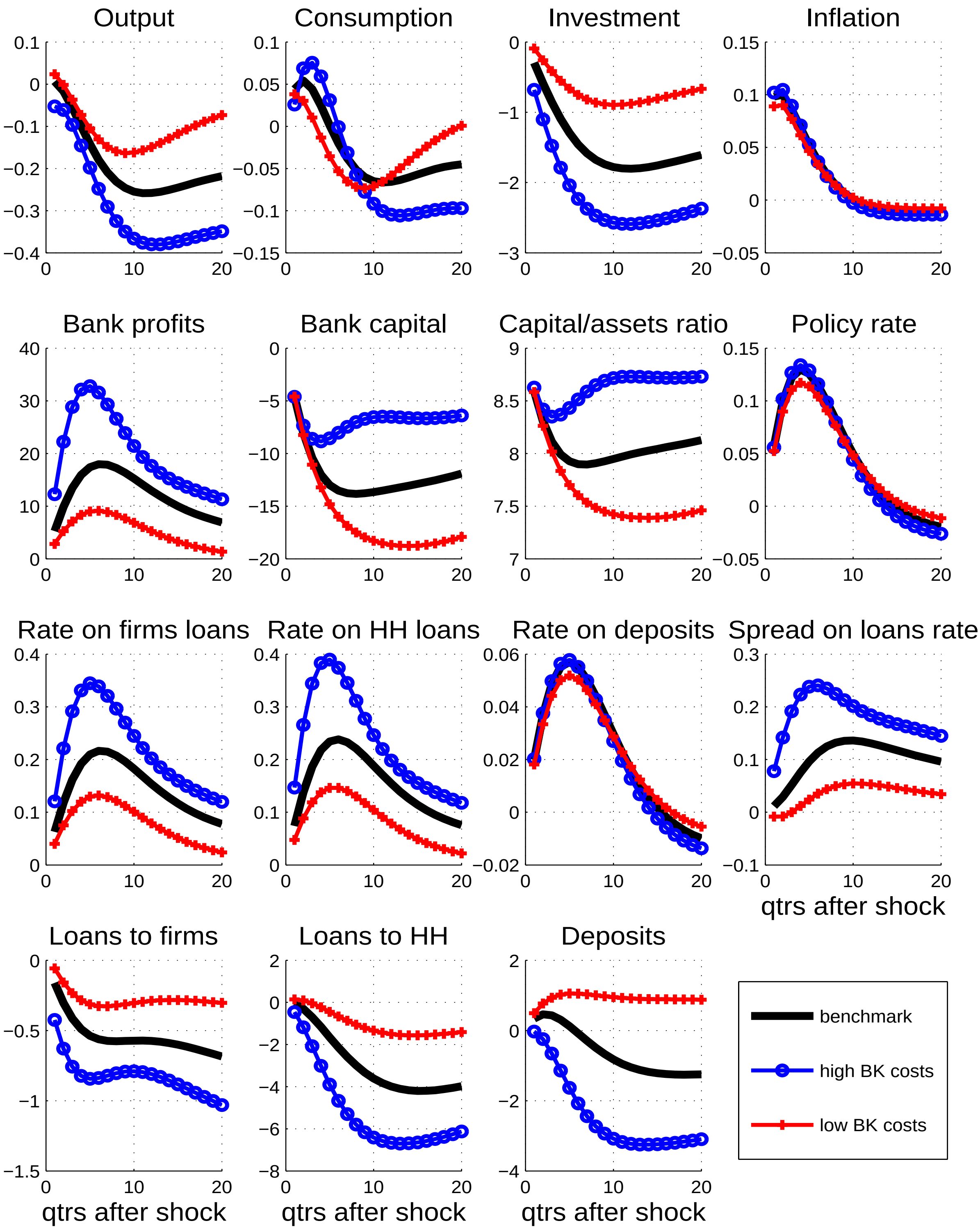
Note: The decomposition is computed using the mode of the posterior distribution of the BK model.

Figure 7. Historical decomposition of main financial variables: 2004q1 - 2008q4



Note: The decomposition is computed using the mode of the posterior distribution of the BK model.

Figure 8. Impulse responses to a negative shock to capital



Note: The impulse responses are computed using the mode of the posterior distribution of the BK model.

Appendix A. Data and Sources

Real consumption: Final consumption of households and NPISH's, constant prices, seasonally adjusted, not working day adjusted, Euro area 15 (fixed composition). Source: Eurostat

Real investment: Gross fixed capital formation, constant prices, seasonally adjusted, not working day adjusted, Euro area 15 (fixed composition). Source: Eurostat

Real house prices: nominal residential property prices deflated with the harmonized index of consumer prices. Source: ECB and Eurostat.

Nominal interest rate: Mimimum/fixed rate on the Main Refinancing Operations of the Eurosystem. Source: European Central Bank.

Nominal interest rate on loans to households: Annualized agreed rate (AAR) on loans for house purchases excl. bank overdrafts, total maturity, Outstanding amounts coverage, Euro area (changing composition). Source: European Central Bank for the period from 1999:1 to 2008:12 and Bank for International Settlements (BIS) for the period 1998:1 1998:12.

Nominal interest rate on loans to firms: Annualized agreed rate (AAR) on loans to non-financial corporation over 1 year maturity, outstanding amount, Euro area (changing composition). Source: European Central Bank and (BIS).

Nominal interest rate on deposits: weighted average (with weights proportional to outstanding amounts) of annualized agreed rates (AAR) on overnight deposits (total maturity), on deposits with agreed maturity up to two years and deposits redeemable at notice up to 3 months maturity. Households and individual businesses, Euro area (changing composition). Source: European Central Bank and (BIS).

Loans to households: outstanding amounts of loans for house purchasing, total maturity, Euro area (changing composition), neither seasonally or working day adjusted.

Loans to firms: outstanding amounts of loans to non-financial corporations up to 5 years maturity, Euro area (changing composition), neither seasonally or working day adjusted.

Deposits: outstanding amounts of annualized agreed rates (AAR) on overnight deposits (total maturity), on deposits with agreed maturity up to two years and deposits redeemable at notice up to 3 months maturity. Households and individual businesses, Euro area (changing composition). Source: European Central Bank and (BIS).

Wages: Hourly Labour cost index - wages and salaries, whole economy excluding agriculture, fishing and government sectors, working day and seasonally adjusted. Source: Eurostat.

Inflation: Quarter on quarter log differences in the Harmonized Index of Consumer Prices (HICP). Overall index, seasonally adjusted, not working day adjusted, Euro area 15 (fixed composition). Source: European Central Bank.