BANCA D'ITALIA
EUROSISTEMA

Temi di Discussione

(Working Papers)

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number 740

January 2010

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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. For this purpose, we introduce an imperfectly competitive banking sector into a DSGE model with financial frictions. Banks issue collateralized loans to both households and firms, obtain funding via deposits and accumulate capital from retained earnings. Margins charged on loans depend on bank capital-to-assets ratios 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 cost of loans. The model is estimated with Bayesian techniques using data for the euro area. The analysis delivers the following results. First, the existence of a banking sector partially attenuates the effects of demand shocks, while it helps propagate supply shocks. Second, shocks originating in the banking sector explain the largest share of the fall of output in 2008 in the euro area, while macroeconomic shocks played a limited role. Third, an unexpected destruction of bank capital has a substantial impact on the real economy and particularly on investment.

JEL Classification: E30, E32, E43, E51, E52.
Keywords: collateral constraints, banks, banking capital, sticky interest rates.

Contents

* Bank of Italy, Economics, Research and International Relations.

1 Introduction[1]

This paper seeks to understand the role of financial frictions and banking intermediation in shaping business-cycle dynamics. To this end, we formulate and estimate a dynamic general equilibrium model incorporating a banking sector that enjoys some degree of market power (on both sides of the balance sheet) and that accumulates bank capital subject to a capital adequacy requirement. We use our model to investigate, first, how the transmission mechanisms of monetary and technology impulses are modified by the introduction of banking and, second, how shocks that originate in credit markets are transmitted to the real economy. Moreover, we estimate the contribution of shocks originating within the banking sector to the slowdown in euro area economic activity during 2008.

Our main motivation comes from the recent financial crisis. Policy-makers have traditionally 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 monetary policy stance. Since the onset of the financial turmoil in August 2007, the potential strength of these interlinkages has become particularly evident. Banks came 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.

Despite its importance for policy-making, most quantitative macromodels employed in academia and policy institutions until recently contained only a very primitive treatment of the interaction between financial and credit markets, on the one hand, and the rest of the economy, on the other. Seminal contributions from Bernanke *et al.* (1999) and Iacoviello (2005) have started to fill this gap by introducing credit and collateral requirements in quantitative general equilibrium models. Since in these models credit transactions take place only through the market, more recent models have begun to study the role of financial intermediaries (Christiano *et al.*, 2008; Goodfriend and McCallum, 2007). Most of these models, however, emphasize the *demand* side of credit. The credit spread that

[1] The views expressed in this paper are those of the authors alone and do not necessarily reflect those of the Bank of Italy. We benefited of comments from Tobias Adrian, Oscar Arce, Jaromír Benes, Vasco Cúrdia, Harris Dellas, Grégory de Walque, Joris de Wind, Eugenio Gaiotti, Jordi Galí, Leonardo Gambacorta, Matteo Iacoviello, John Leahy, Jesper Lindé, Fernando López Villaverde, Caterina Mendicino, Fabio Panetta, Anti Ripatti, Argia Sbordone, Skander van den Heuvel, Mike Woodford and Tack Yun. We also thank participants at the Bank of Italy June '08 "DSGE in the Policy Environment" conference, the Macro Modeling workshop '08, the WGEM and CCBS July '08 workshop at the Bank of England, the ECB Dec. '08 "Financial Markets and Macroeconomic Stability" conference, the Federal Reserve Board June '09 "Financial Markets and Monetary Policy" conference, the DNB Oct. '09 "Housing and Credit Dynamics: Causes and Consequences" conference, the SNB Sept. '09 "Financial Markets, Liquidity, and Monetary Policy" conference, the Riksbank Nov. '09 "Financial Markets and the Macroeconomy: Challenges for Central Banks" workshop, the SED and EEA '09 meetings, and at seminars at NY Fed, DG EcFin and CREI-Univ. Pompeu Fabra. Contacts: andrea.gerali@bancaditalia.it; stefano.neri@bancaditalia.it; luca.sessa@bancaditalia.it; federicomaria.signoretti@bancaditalia.it.

arises in equilibrium (called the external finance premium) is a function of the riskiness of the entrepreneurs' investment projects and/or their net wealth. Banks, operating under perfect competition, simply accommodate the changing conditions from the demand side.

We, instead, believe that conditions from the *supply* side of credit markets – such as the degree of competition prevailing in the banking sector, rate-setting strategies or banks' financial soundness – are at least as important in shaping business cycle dynamics, especially in the euro area where banks are the primary source of funds for households and firms.[2] This relation is apparent in the responses of the banks to the euro area quarterly Bank Lending Survey. In Figure 1, separately for entrepreneurs' and households' loans, we reproduce two charts showing the behavior of the synthetic indexes of loan supply restriction (i.e. the net percentage of responding banks indicating a tightening in lending standards in any given quarter), of lending margins (as reported by the responding banks) and of the impact of competitive pressure and costs related to banks' capital position on lending standards (again, as reported by banks). These figures document how supply factors like those related to the degree of competition among banks or to the costs of banking capital positions are strongly correlated, over different periods, with rates and conditions for access to credit. Our model is designed to capture supply side aspects of this kind. Starting from 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) or Smets and Wouters (2003), we add a stylized banking sector characterized by three distinctive features.

First, our banks set different rates for households and firms and, in so doing, they enjoy some degree of market power. The recognition that a degree of monopolistic power exists in both the loan and the deposit markets generates in the model markups (and a markdown) with respect to the policy rate, which adjust along the cycle. Since the seminal contributions of Monti (1972) and Klein (1971) the microliterature on banking has recognized the importance of studying models of monopolistic competition in the banking sector. Theoretical justifications range from asymmetric information to long-term customer relationships or the presence of switching costs and other nominal frictions. In this paper, we do not try to investigate the source of the market power we attribute to banks. Instead, we calibrate the rate elasticities of loan and deposit demands in the model to reproduce the degree of market power empirically observed in the euro area.

Second, our monopolistic banks face costs of adjusting their retail rates, and the pass-through of changing financing conditions is incomplete on impact. This is an important ingredient if the model is to capture the different speeds at which the variety of banks' rates react to changing conditions in money markets. The empirical evidence in favor of a partial and heterogenous adjustment of bank rates is overwhelming (see, for the euro

[2] In 2008, bank deposits in the euro area accounted for around 95% of household short-term financial assets, while bank loans equaled around 90% of total household liabilities; similarly for firms, in 2008 bank lending accounted for almost 90% of corporate financial debt (i.e. loans plus debt securities) (ECB, 2009a).

area, de Bondt, 2005 and Kok Sørensen and Werner, 2006).

Third, banks accumulate capital (from retained earnings), as they try to keep their capital-to-assets ratio as close as possible to an (exogenously given) target level. This target level might derive from mandatory capital requirements for banking activity (like those set forth explicitly in the Basel Accords) or, in a deeper structural model, might be the equilibrium outcome from optimally balancing the higher costs of internal sources of funding and the benefits of having more "skin in the game" to mitigate typical agency problems in credit markets. Through this leverage ratio and the bank balance sheet identity, bank capital influences both the amounts issued and the rate setting of loans and deposits. This introduces important feedback loops between the real and financial sides of the economy. On the one hand, we can model some shocks that originate in credit markets as "financial" shocks; on the other hand, macro shocks are amplified and/or propagated to a different extent depending on the "soundness" of the financial sector, i.e. depending on whether or not the banking sector is at the optimal leverage ratio when the macro shock hits.

Other authors have studied dynamic general equilibrium models with a banking sector or economies where several financial instruments co-exist. In independent works, Cúrdia and Woodford (2008), Andrés and Arce (2009), Benes and Lees (2007), Aliaga-Díaz and Olivero (2007) and Aslam and Santoro (2008), have developed models with financial intermediaries and a time-varying spread between deposits and lending rates. Markovic (2006), de Walque *et al.* (2008), van den Heuvel (2008) and Meh and Moran (2008), have instead studied the role of equity and bank capital for the transmission of macroeconomic shocks. Neither of them includes (heterogeneous) rate stickiness, or the kind of capital requirements that we consider. Therefore our model combines the main insights from these strands of literature and adds to them. Moreover, by taking the model to the data we provide a careful quantitative evaluation of our model results.

In fact, we estimate the model with Bayesian techniques and data for the euro area over the period 1998:Q1-2009:Q1 and use the estimated model to analyze two sets of issues.

First, we want to understand how financial intermediation modifies the transmission mechanism of monetary policy and technology shocks. Our model features an intermediation spread due to the interest-rate setting behavior of banks. Movements in this spread alter the pass-through of changes in the policy rate to bank rates, which are the relevant rates for consumption and investment decisions. This mechanism modifies the effectiveness of the transmission channels that are usually at work in standard models with endogenous borrowing constraints and no active financial intermediation (see Section 5). In particular, credit market power and the ensuing markup between lending rates and the policy rate amplify changes in the policy rate for borrowers (i.e. impatient households and entrepreneurs), while the markdown between the policy and the deposit rate implies an attenuating effect for lenders (i.e. patient agents). Sticky interest rates, instead, unambiguously induce an attenuation effect (with respect to a flexible-rate setup), as banks translate changes in the policy rate to borrowing and lending rates only partially. Finally, the impact of bank capital depends on the correlation between bank leverage (i.e. the inverse of the capital-to-assets ratio) and the policy rate: if bank leverage increases when policy is tightened, then the transmission of shocks to the real economy is amplified; on the contrary, a fall in leverage during periods of policy tightening smooths fluctuations in the real economy. Given these facts, the overall impact of financial intermediation on the transmission mechanism depends on the relative importance and the mutual interactions of the heterogenous effects on the various agents. As regards monetary policy, overall we find that the attenuating effect of banking prevails, muting the response of both consumption and investment and mainly reflecting the presence of sticky bank rates. Also, after a technology shock financial intermediation induces some attenuation on output, mainly due to the impact of monopolistic power on consumption; in this case, however, banking also enhances the endogenous propagation mechanism of the model, inducing higher persistence in the response of real variables.

Secondly, we analyze how financial shocks are transmitted to the real economy and how they contribute to business cycle fluctuations. In the model, we assume that bank rate margins, as well as credit supply, are subject to exogenous innovations. Thus, the model is an appropriate environment to study how those shocks affect households' and entrepreneurs' consumption and investment decisions. To this end, we perform two exercises. In the first one, we use the model to quantify (ex-post) the contribution of shocks originating in the banking sector to the slowdown experienced in the euro area in 2008. The results suggest that almost all the contraction of real GDP was due to factors that either pushed up the cost of credit or reduced the amount of credit available to the private sector. In the second exercise, we simulate a "credit crunch" scenario, instrumented through an exogenous and persistent destruction of bank capital. Banks' need to handle the capital loss, by re-balancing assets and liabilities and minimizing costs from deviation from a target leverage ratio, triggers an increase in lending margins and a contraction in credit volumes. The ensuing negative effects on real activity are substantial: the restriction on credit severely affects firms' investment, while despite a temporary improvement in labor income aggregate consumption is also hit, generating a considerable fall in aggregate demand and output.

Our model admittedly omits some elements of the current financial crisis (e.g., the increase in risk in financial markets and the freezing up of money markets). However, we think that our analysis constitutes an important step in the direction of quantifying the effects of credit sector shocks on the business cycle.

The rest of the paper is organized as follows. Section 2 reviews some arguments and empirical evidence justifying our key modeling choices. Section 3 describes the model. Section 4 presents the results of the estimation of the model. Section 5 studies the dynamic properties of the model, focusing on monetary policy and technology shocks. Section 6 quantifies the role of shocks originating in the banking sector in the recent downturn of economic activity in the euro area and studies the effects of a fall in bank capital on the economy. Section 7 concludes.

2 Market power and sluggish rates in the banking sector

In this section we discuss the key assumptions that we make about the banking sector, namely the presence of monopolistic power in the deposit and loan markets, as well as the stickiness of bank rates with respect to movements in the corresponding market rates, reviewing both theoretical and empirical arguments in their support.

As regards monopolistic competition, there seems to be an undisputed consensus in the microeconomic theory of financial intermediation about the existence of market power in banking.[3] One often cited reason is the presence of switching costs, for both customers and lenders, which generate a "lock-in" effect that gives banks market power. The banking industry is typically characterized by long-term relationships between banks and borrowers, as a result of asymmetric information problems which induce banks to devote resources to monitor their customers.[4] Given this market structure, switching banks is normally costly for customers: changing financier entails the loss of the capitalized value of an established relationship and the associated cost of signaling creditworthiness to the new lender (or of having the value of collateral re-assessed). Similarly, potential competitors wishing to attract customers from incumbent banks face the additional cost of screening the new customers. Switching costs might also arise due to the presence of pure "menu costs", like technical fees charged to close or to open a bank account, or fees incurred to apply for a loan or to renegotiate the terms of an outstanding debt.[5] Another frequently cited source of bank rents is market structure. The traditional SCP (*structure-conduct-performance*) approach links market concentration (as measured by the Herfindal-Hirschman Index or by the n-bank concentration rate) to market power and interest rate-setting behavior (Berger *et al.*, 2004). Other studies highlight the importance of market contestability and regulatory restrictions as a source of market power (Demirguc-Kunt *et al.*, 2004; Levine, 2003). Regardless of the source, market power in loan and deposit markets allows banks to set interest rates at a spread with respect to the relevant market rates, i.e. a markup in the case of loans and a markdown for deposits.

Several empirical studies have confirmed the presence of market power in the banking sector and studied its determinants over the business cycle. Berger *et al.* (2004) and

[3] See the classical treatment in Freixas and Rochet (1997).

[4] For some early seminal contributions see Diamond and Dybvig (1983), and Diamond (1984); for later models Greenbaum *et al.* (1989), and Sharpe (1990).

[5] Von Thadden (2004) discusses switching costs due to information asymmetries between lenders. See Miles (2004) for a detailed description of debt renegotiation costs for the UK or Kim *et al.* (2003) for an estimate of the importance of switching costs in banking.

Degryse and Ongena (2008) provide extensive surveys of the empirical literature on this topic and, overall, conclude that the degree of competition - measured via different indicators - does indeed influence interest rate spreads and banks' profitability. Among the papers surveyed in these studies, Mandelman (2006), using data for 124 countries for the years 1990-2000, documents how cyclical fluctuations in bank markups are related to changes in the concentration and competitive pressure within the sector. Claessens and Laeven (2004), using bank-level data, estimate the Panzar and Rosse's (1987) *H-statistic*[6] for 50 countries for the period 1994-2001; they show that most banking markets can be classified as monopolistically competitive, with a *H-statistic* ranging from 0.6 to 0.8. For the euro area, De Bandt and Davis (2000) find that banks in the three largest economies of the area (Germany, France and Italy) operate under monopolistic competition, with the degree of market power being higher for small banks in all three countries in their sample, perhaps since they cater more to local markets.

In our model, the measure of banks' market power is the (steady-state) interest rate elasticities of deposit and loan demands: the lower the elasticities (in absolute value), the higher the monopoly power. These elasticities equal 1,5 for the deposit rate and around -3,0 for both loan rates.[7] These numbers are pretty much in line with estimates from empirical studies.[8] For example, Dick (2002) estimates an interest-rate demand elasticity for deposits at U.S. commercial banks over the period 1993-1999 of between 5.8 and 1.5; Neven and Röller (1999), using data for seven European countries for the period 1981-1989, report a demand elasticity of -8.7 for mortgages and -6.8 for corporate loans. Other possible indicators of market power are (steady-state) spreads between the loan and the policy rate and between the policy rate and the deposit rate, which equal 1.7 and 1.2 percent (annual rates) in the model, and the loan-deposit rate margin (i.e. the sum of the two spreads, equal to 2.9 percent). Similar numbers are found in empirical studies for European countries. For example, Corvoisier and Gropp (2002), analyzing ten European countries between 1991 and 1999, compute an average spread with the money market rate, for both deposit and loan rates, of 2.4 per cent; Claeys and Vander Vennet (2008) calculate an average loan-deposit rate margin for 18 Western European countries between 1994 and 2001 – obtained as a ratio of the difference between interest income and interest expenses with respect to total earning assets – of 2.7 percent.[9]

[6] The H-statistic is an widely used empirical measure of industry market power, allowing a distinction to be made between monopoly ($H \leq 0$), monopolistic competition ($0 < H < 1$) and perfect competition ($H = 1$). In banking, it can be computed as the sum of the elasticities of interest revenues with respect to factor input prices.

[7] As explained in Section 4, demand elasticities pin down the (steady-state) spreads between the loans and the policy rate and between the latter and the deposit rate. Thus, we calibrate elasticities so as to replicate the empirical margins observed between those rates in the euro area over our sample period.

[8] Our calibration is actually likely to overstate the effect of market power as we disregard liquidity and/or risk premia that might be embedded in retail bank rates. This implies that we regard our calibrated elasticities as lower bounds when we compare them to estimates from the literature.

[9] In order to quantify the degree of market power that we assume in the model and to assess how

The second "unconventional" assumption we make about the banking sector is that bank interest rates are "sticky", i.e. they react slowly to changes in the corresponding market rates (or in the policy rate). Both theoretical and empirical findings strongly support this assumption. From a theoretical point of view, for example, a bank could find it optimal to adjust rates only infrequently if customers' demand is inelastic in the short run due to switching costs (Calem *et al.*, 2006) or if there are fixed ("menu") costs of adjusting rates (Berger and Hannan, 1991). Moreover, the importance of preserving customer relationships could lead banks to smooth rates over the business cycle, in order to shield borrowers from market rate fluctuations; this kind of "implicit interest rate insurance" enables banks to enjoy higher profits by charging higher interest rates during periods of low market interest rates (Berger and Udell, 1992). From an empirical standpoint, in addition to the bankers' practice of indexing bank rates to past values of some corresponding market rate – which in principle can generate sluggishness by itself – the empirical evidence in favor of bank rate stickiness is overwhelming. This is confirmed by several recent analyses of the euro area, including that by Kok Sørensen and Werner (2006) comparing interest rate pass-through across euro-area countries for various loan and deposit instruments, which finds that, even in the country with the highest speed of adjustment, only 23% of the disequilibrium is adjusted after one period. In a related paper, Gropp *et al.* (2007) report that deposit rates adjust more slowly than lending rates and that, in general, the speed of adjustment is influenced by the degree of competition, both from other banks and from financial markets. De Bondt (2005) reports area-wide evidence of limited impact and first-year pass-through both from official rates to market rates and from market rates to bank rates.[10] Nakajima and Teranishi (2009) estimate loan rate curves using a structural model which is similar to ours, insofar as it features monopolistic competition in the banking sector with Calvo-adjustment of loan rates. Their results confirm that loan rates adjust slowly to changes in the policy rate in euro-area countries for all loan maturities in their sample.

In order to introduce sticky rates we assume in our model that banks face quadratic adjustment costs *à la* Rotemberg whenever they change the level of retail rates. We are aware that this assumption is somewhat *ad hoc* and leaves the issue of the microfoundation of stickiness basically unresolved. However, there is no difference between this and the standard assumption of costly price adjustment in goods markets, which is crucial in New Keynesian DSGE models: assuming these adjustment costs is just a modeling short-cut to capture a stylized fact in a tractable way. In addition, we do not impose a sticky

reasonable this assumption is, we calculated the H-statistic implied by the estimated version of our model, simulating 10,000 observations for loan interest revenues and loan input prices. We obtain a value of 0.54, which is very similar to the standard findings in the empirical literature (see Claessens and Laeven, 2004, or Bikker and Haaf, 2002).

[10] The paper also contains a survey of results from several studies on interest rate pass-through in individual euro-area countries, all delivering the same message of vastly incomplete pass-through over the same horizon.

rate adjustment *a priori*, but the parameters pinning down the degree of stickiness (κ_{bH}, κ_{bE} and κ_d, for household and entrepreneur loans, and for deposits, respectively) are estimated based on euro area data (see Section 4 and Appendix B). This procedure leaves us confident with the assumption of Rotemberg pricing, as it is useful to reconcile model dynamics with observed data. And the data tell us that rates are indeed sticky: our estimates imply a short-run pass-through of policy rates to bank interest rates within the range of the estimates obtained by ECB (2009b).[11]

The estimated stickiness is "genuine" in the sense that it does not reflect compositional issues or the choice of a particular type of bank rates for the estimation. The data employed refer to new-business coverage, i.e. they are average rates on *newly-issued* loans in a given quarter, both for deposits and for loans. These rates do *not* embed sluggishness just by construction, as would have been the case if we had used rates on outstanding loans that are heavily influenced by rates set in the past. In this sense it seems that the rate stickiness we found in the data mostly reflects banks' optimizing behavior.

3 The model economy

The economy is populated by two types of households and by entrepreneurs. Households consume, work and accumulate housing (in fixed supply), while entrepreneurs produce a homogenous intermediate good using capital bought from capital-good producers and labor supplied by households. The three types of 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 out a bank loan, agents face a borrowing constraint, tied to the value of tomorrow's 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 households 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 so as to maximize profits. The amount of loans issued by each intermediary can be financed through the amount of deposits that they raise and through bank capital (accumulated out of reinvested profits).

On the production side, workers supply their differentiated labor services through unions which set wages to maximize members' utility subject to adjustment costs. In addition to entrepreneurs producing the intermediate good, there are two additional pro-

[11] In ECB (2009b), the immediate pass-through (defined as the ratio of the impact change in bank rate to the impact change in the policy rate after a monetary policy) is estimated (depending on the maturity) at between 0.17 and 0.36 for household mortgages and between 0.30 and 0.72 for firm loans, and (depending on the specific instrument) between 0.06 and 0.50 for deposits.

ducing sectors: a monopolistically competitive retail sector and a capital good producing sector. Retailers buy the intermediate goods from entrepreneurs in a competitive market, differentiate and price them subject to nominal rigidities. Capital good producers are used as a modeling device to derive a market price for capital, which determines the value of entrepreneurs' available collateral, against which banks grant loans.

In the following sections we describe in detail the banking setup and the problems of households and entrepreneurs. The rest of the model is set out in Appendix A.

3.1 Households and entrepreneurs

There are two groups of households, patient (P) and impatient (I), and one of entrepreneurs (E). Each of these groups has unit mass. The only difference between the first two is that the discount factor of patient households (β_P) is higher than that of the impatient ones (β_I, assumed to be equal to entrepreneurs β_E). This difference makes savers the agents with a low discount factor, and borrowers the others.

3.1.1 Patient households

The representative patient household maximizes the expected utility

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

which depends on current individual (and lagged aggregate) consumption c_t^P, housing services h_t^P and hours worked l_t^P. There are external and group-specific habits in consumption; premultiplication by one minus the habit coefficient a^P mutes their impact on the steady-state marginal utility of consumption. Preferences are subject to two disturbances: one affecting consumption (ε_t^z) and one housing demand (ε_t^h).[12] Household choices have to match the following budget constraint (in real terms, with multiplier λ_t^P):

$$c_t^P(i) + q_t^h \Delta h_t^P(i) + d_t(i) = w_t^P l_t^P(i) + \left(1 + r_{t-1}^d\right) d_{t-1}(i)/\pi_t + t_t^P(i)$$

The flow of expenses includes current consumption, accumulation of housing services (with real price q_t^h) and deposits to be made this period d_t. Resources are composed of wage earnings $w_t^P l_t^P$ (where w_t^P is the real wage rate for the labor input of each patient household), gross interest income on last period deposits $(1 + r_{t-1}^d) d_{t-1}/\pi_t$ (where $\pi_t \equiv P_t/P_{t-1}$ is the gross inflation) and a number of lump-sum transfers t_t^P, which include a

[12] With the exception of a white noise for monetary policy, we assume that any generic shock ε_t in the model follows a stochastic AR(1) process of the type

$$\varepsilon_t = (1 - \rho_\varepsilon)\,\bar{\varepsilon} + \rho_\varepsilon\ \varepsilon_{t-1} + \eta_t^\varepsilon$$

where ρ_ε is the autoregressive coefficient, $\bar{\varepsilon}$ is the steady-state value and η_t^ε is an i.i.d. zero mean normal random variable with standard deviation equal to σ_ε.

labor union membership net fee and dividends from firms and banks (of which patient households are the only owners).

3.1.2 Impatient households

The representative impatient household maximizes the expected utility

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

which depends on consumption c_t^I, housing services h_t^I and hours worked l_t^I. The parameter a^I measures consumption habits; ε_t^h and ε_t^z are the same shocks that affect the utility of patient households. Household decisions have to match the budget constraint

$$c_t^I(i) + q_t^h \Delta h_t^I(i) + (1 + r_{t-1}^{bH})\, b_{t-1}^I(i)/\pi_t = w_t^I l_t^I(i) + b_t^I(i) + t_t^I$$

in which resources spent for consumption, accumulation of housing services and reimbursement of past borrowing b_{t-1}^I (at rate r_{t-1}^{bH}) have to be financed with labor income (w_t^I is the impatients' wage) and new loans b_t^I (t_t^I only includes net union fees).

In addition, households face a borrowing constraint: the expected value of their collateralizable housing stock at period t must be high enough 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 in case default should occur. At a macro-level, the value of m_t^I determines the amount of credit that banks make available to households, for a given (discounted) value of their housing stock. We assume that variations of LTV ratios do not depend on individual bank choices: rather, we model LTV ratios as exogenous stochastic processes, whose innovations will allow us to study the effects of credit-supply restrictions on the real side of the economy.

3.1.3 Entrepreneurs

Each entrepreneur i only cares about deviations of his own consumption $c_t^E(i)$ from aggregate lagged group habits (parameterized by a^E) and maximizes the utility function

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

by choosing consumption, physical capital k_t^E, loans from banks b_t^E, the degree of capacity utilization u_t and the desired amount of labor input l_t^E. His decisions are subject to the budget constraint

$$c_t^E(i)+w_t^P l_t^{E,P}(i)+w_t^I l_t^{E,I}(i)+\frac{1+r_{t-1}^{bE}}{\pi_t}b_{t-1}^E(i)+q_t^k k_t^E(i)+\psi(u_t(i))k_{t-1}^E(i)=\frac{y_t^E(i)}{x_t}+b_t^E(i)+q_t^k(1-\delta)k_{t-1}^E(i)$$

where δ is depreciation, q_t^k is the price of one unit of physical capital in terms of consumption, $\psi(u_t)k_{t-1}^E$ is the real cost of setting a level u_t of utilization rate, $P_t^W/P_t = 1/x_t$ is the relative competitive price of the wholesale good produced by each entrepreneur according to the technology

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

with a_t^E being a stochastic process for total factor productivity. Aggregate labor l_t^E combines inputs from patient and impatient households according to $l_t^E = (l_t^{E,P})^\mu (l_t^{E,I})^{1-\mu}$.

Symmetrically with respect to households, we assume that the amount of resources that banks are willing to lend 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 entrepreneurs also borrow against housing (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

$$(1 + r_t^{bE})b_t^E(i) \leq m_t^E \mathrm{E}_t[q_{t+1}^k \pi_{t+1}(1-\delta)k_t^E(i)] \tag{2}$$

where m_t^E is the stochastic entrepreneurs' LTV ratio. Our assumption on discount factors is such that, in the absence of uncertainty, the borrowing constraints of both impatient households and entrepreneurs are binding in a neighborhood of the steady state. As in Iacoviello (2005), we assume that the size of the shocks in the model is "sufficiently small"to remain in this neighborhood, and we can thus solve our model imposing that the borrowing constraints always bind.

3.1.4 Loans and deposits demand

To model market power in the banking industry, we assume a Dixit-Stiglitz framework for the credit market.[13] In particular, we assume that units of deposits and of 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. We assume that these elasticities of substitution among contracts offered by different banks are stochastic. This choice arises from our interest in studying how exogenous shocks hitting the banking sector are transmitted 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, consequently, the value of the spreads between the

[13] A similar shortcut is taken by Benes and Lees (2007). Andrés and Arce (2009) set up a general equilibrium model featuring a finite number of imperfectly competitive banks whereby the greater the customers' distance from a bank the more costly the services from that bank.

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 take account of their effects on the real economy.

The demands for loans to households $b_t^I(j)$, loans to entrepreneurs $b_t^E(j)$ and deposits $d_t(j)$ at bank j will depend on overall volumes and on the interest rates charged by bank j relative to the average rates in the economy

$$b_t^I(j) = \left(\frac{r_t^{bH}(j)}{r_t^{bH}}\right)^{-\varepsilon_t^{bH}} b_t^I \qquad b_t^E(j) = \left(\frac{r_t^{bE}(j)}{r_t^{bE}}\right)^{-\varepsilon_t^{bE}} b_t^E \tag{3}$$

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

3.2 Banks

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

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

Another key feature of our banks is that each has to obey a balance sheet identity

$$B_t = D_t + K_t^b$$

stating that each bank can finance loans B_t using either deposits D_t or bank equity (hereinafter also called bank capital) K_t^b.[14] The two sources of finance are perfect substitutes from the point of view of the balance sheet. Banks' choice will be pinned down by a further assumption of an (exogenously given) "optimal" capital-to-assets (i.e. leverage) ratio from which it is costly to deviate, 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. Furthermore, since we assume that bank capital is accumulated out of retained earnings, banks in the model are at the center of a feedback loop between the real and the financial side of

[14] When taking the model to the data we add a shock ε_t^{kb} to liabilities in order to avoid near-stochastic singularity in the estimation.

the economy. As macroeconomic conditions deteriorate, banks profits and hence capital might be negatively hit; depending on the nature of the shock that hits 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 extend to the private sector, thus exacerbating the original contraction. The model might 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 positions and the ensuing credit restriction.

Modeling banks' leverage position and rate-setting activity on loans subject to collateral requirements 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 or LTV ratios.

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

3.2.1 Wholesale branch

Each wholesale branch operates under perfect competition and 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 (parameterized by a coefficient κ_{Kb} and proportional to outstanding bank capital) whenever the capital-to-assets ratio K_t^b/B_t moves away from an "optimal" or target 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, and which is also meant to strike a balance among the various trade-offs involved when deciding how much own resources a bank should hold.

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

$$K_t^b = \left(1 - \delta^b\right) K_{t-1}^b + \omega^b j_{t-1}^b$$

where j_t^b are overall profits made by the three branches of each bank, $(1-\omega^b)$ summarizes the dividend policy of the bank, and δ^b measures resources used in managing bank capital.

The dividend policy is assumed to be exogenously fixed, so that bank capital is not a choice variable for the bank. The problem for the wholesale bank is thus to choose loans and deposits so as to maximize the discounted sum of cash flows, subject to a balance sheet constraint[15]

$$\max_{\{B_t,D_t\}} E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^{P} \left[\left(1+R_t^b\right) B_t - B_{t+1} + D_{t+1} - \left(1+R_t^d\right) D_t + \Delta K_{t+1}^b - \frac{\kappa_{Kb}}{2} \left(\frac{K_t^b}{B_t} - \nu^b \right)^2 K_t^b \right]$$

$$\text{s.t.} \qquad B_t = D_t + K_t^b \,, \tag{5}$$

where R_t^b (the net wholesale loan rate) and R_t^d (the net wholesale deposit rate) are taken as given. Using the balance sheet identity (5) twice (at date t and $t+1$), the objective function boils down to period profits

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

The FOCs deliver a condition linking the spread between wholesale rates on loans and on deposits to the degree of leverage B_t/K_t^b, i.e.

$$R_t^b = R_t^d - \kappa_{Kb} \left(\frac{K_t^b}{B_t} - \nu^b \right) \left(\frac{K_t^b}{B_t} \right)^2 \tag{6}$$

in order to close the model, we assume that banks have access to unlimited finance at the policy rate r_t from a lending facility at the central bank: hence, by arbitrage the deposit rate is pinned down in the interbank market and $R_t^d \equiv r_t$. Therefore, equation (6) becomes a condition linking the rate on wholesale loans prevailing in the interbank market to the official rate, on one hand, and to the leverage of the banking sector on the other

$$R_t^b = r_t - \kappa_{Kb} \left(\frac{K_t^b}{B_t} - \nu^b \right) \left(\frac{K_t^b}{B_t} \right)^2 \tag{7}$$

The above equation highlights the role of capital in determining loan supply conditions. Rewriting it in terms of the spread between wholesale loan and deposit rates yields

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

The spread is inversely related to the overall capital-to-assets ratio of banks: in particular, when banks are scarcely capitalized and leverage increases, margins become wider. On the one hand, the higher the leverage, the wider (i.e. more positive) the spread between the wholesale loan rate and the policy rate, the more the bank wants to lend, increasing profits per unit of capital (or return on equity). On the other hand, as leverage increases further, the deviation from ν becomes more costly, reducing bank profits. In this case, the FOC commands that the optimal choice for banks is to choose a level of loans (and thus of leverage, given a level of K_t^b) such that the marginal cost of reducing the capital-to-assets ratio exactly equals the deposit-loan spread.

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

3.2.2 Retail banking

Retail banks are monopolistic competitors on both the loan and deposit markets.

Loan branch: The retail loan branch of bank j obtains wholesale loans $B_t(j)$ from the wholesale unit at rate R_t^b, differentiates them at no cost and resells them to households and firms applying two different markups. In order to introduce stickiness and to study the implication of an imperfect bank pass-through, we assume that each retail bank faces quadratic adjustment costs for changing the rates it charges on loans; these costs are parameterized by κ_{bE} and κ_{bH} and are proportional to aggregate returns on loans. Retail loan bank j solves

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

subject to demand schedules (3) and with $B_t(j) = b_t(j) = b_t^I(j) + b_t^E(j)$. For rates to households and firms (indexed by s), the first order conditions yield, after imposing a symmetric equilibrium,

$$1 - \varepsilon_t^{bs} + \varepsilon_t^{bs}\frac{R_t^b}{r_t^{bs}} - \kappa_{bs}\left(\frac{r_t^{bs}}{r_{t-1}^{bs}} - 1\right)\frac{r_t^{bs}}{r_{t-1}^{bs}} + \beta_P E_t\left\{\frac{\lambda_{t+1}^P}{\lambda_t^P}\kappa_{bs}\left(\frac{r_{t+1}^{bs}}{r_t^{bs}} - 1\right)\left(\frac{r_{t+1}^{bs}}{r_t^{bs}}\right)^2 \frac{b_{t+1}^s}{b_t^s}\right\} = 0 \quad (9)$$

with λ_t^P denoting the Lagrange multiplier for the budget constraint of a patient household. For the simplified case in which $\varepsilon_t^{bs} = \varepsilon^{bs}$, the log-linearized version of the loan-rate setting equations is (hats denote percent deviations from steady-state)

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

By solving the equation forward, one could see that loan rates are set by banks based on current and expected future values of the wholesale bank rate, which is the relevant marginal cost for this type of bank and which depends on the policy rate and the capital position of the bank, as highlighted in the previous section. The adjustment to changes in the wholesale rate depends inversely on the intensity of the adjustment costs (as measured by κ_{bs}) and positively on the degree of competition in the bank loans sector (as measured by the inverse of ε^{bs}).

Under perfectly flexible rates the pricing equation (9) becomes

$$r_t^{bs} = \frac{\varepsilon_t^{bs}}{\varepsilon_t^{bs} - 1} R_t^b \quad (10)$$

and interest rates on loans are set as a simple markup over the marginal cost. We can also calculate the spread between the loan and the policy rate under flexible rates

$$S_t^{bs} \equiv r_t^{bs} - r_t = \frac{\varepsilon_t^{bs}}{\varepsilon_t^{bs} - 1} S_t^W + \frac{1}{\varepsilon_t^{bs} - 1} r_t \quad (11)$$

with the last equality obtained by combining (10) with the expression in (7). The spread on retail loans is thus increasing in the policy rate, and is proportional to the wholesale spread S_t^W, determined by the bank's capital position. In addition, the degree of monopolistic competition also plays a role, given that an increase in market power (i.e. a reduction in the elasticity of substitution ε_t^{bs}) determines – *ceteris paribus* – a wider absolute 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: Similarly, the retail deposit branch of bank j collects deposits $d_t(j)$ from households and then passes the raised funds to the wholesale unit, which remunerates them at rate r_t. The problem for the deposit branch is

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

subject to deposits demand (4) and with $D_t(j) = d_t(j)$. Quadratic adjustment costs for changing the deposit rate are parameterized by the coefficient κ_d and are proportional to aggregate interest paid on deposits. After imposing a symmetric equilibrium, the first-order condition for optimal deposit interest rate setting is

$$-1 + \varepsilon_t^d - \varepsilon_t^d \frac{r_t}{r_t^d} - \kappa_d \left(\frac{r_t^d}{r_{t-1}^d} - 1 \right) \frac{r_t^d}{r_{t-1}^d} + \beta_P E_t \left\{ \frac{\lambda_{t+1}^P}{\lambda_t^P} \kappa_d \left(\frac{r_{t+1}^d}{r_t^d} - 1 \right) \left(\frac{r_{t+1}^d}{r_t^d} \right)^2 \frac{d_{t+1}}{d_t} \right\} = 0 \tag{12}$$

For a simplified case in which ε^d is non-stochastic, the linearized version of (12) is

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

The deposit rate is set by banks taking into account the expected future level of the policy rate. The adjustment to changes in the policy rate depends inversely on how severe are the adjustment costs (i.e. on κ_d) and positively on the degree of competition in banks fund raising (as measured by the inverse of ε^d).

With fully flexible rates, r_t^d is determined as a static markdown over the policy rate

$$r_t^d = \frac{\varepsilon_t^d}{\varepsilon_t^d - 1} r_t \tag{13}$$

Overall the real profits of a bank are the sum of net earnings (intermediation margins minus other costs) from the wholesale unit and the retail branches. After deleting the intra-group transactions, their expression is

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

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

4 Estimation

4.1 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 Adolfson *et al.*, 2007).[16] We use twelve observables: real consumption, real investment, real house prices, real deposits, real loans to households and firms, overnight rate, interest rates on deposits, loans to firms and households, wage inflation and consumer price inflation. For a description of the data see Appendix B. The sample period runs from 1998:Q1 to 2009:Q1. We remove the trend from the variables using the HP filter with smoothing parameter set at 1,600 (while all rates are simply demeaned). We also estimated the model with linearly detrended data and obtained very similar results in terms of the posterior distribution of parameters.

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

4.2 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 over the sample period. 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 (2009). The mean value of the weight of housing in households' utility function ε^h is set at 0.2, close to the value in Iacoviello and Neri (2009). As for the loan-to-value (LTV) steady-state ratios, we set m^I at 0.7 in line with evidence for mortgages in the main euro-area countries (typically, 0.7 in Germany and Spain, 0.75 in France and 0.5 in Italy), as pointed out by Calza *et al.* (2009). The calibration of m^E is somewhat more problematic: Iacoviello (2005) estimates a value of 0.89 for the U.S., 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 our data set, we compute for the euro area 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 lower value of around 0.2.

[16] Our estimation is done with Dynare 4.0.

Based on this evidence, and given that in our estimation we use rates on loans to firms with original rate fixation above 1 year, we decide to set m^E at 0.35.

The capital share is set at 0.25 and the depreciation rate at 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. We specify $\psi(u_t) = \xi_1(u_t - 1) + \frac{\xi_2}{2}(u_t - 1)^2$ as in Schmitt-Grohé and Uribe (2006): ξ_1 is constrained by the model to be equal to the steady-state marginal product of capital divided by the markup, while nonlinearity is limited by setting $\xi_2 = 0.1\,\xi_1$. The labor inputs Cobb-Douglas parameter μ is calibrated at 0.8 so to approximate the labor income share of unconstrained households as in Iacoviello and Neri (2009).

For the banking parameters, no corresponding estimate is available with precision in the literature. Thus, we calibrate them so as to replicate some statistical properties of bank interest rates and spreads. Equation (13) shows that the steady-state spread between the deposit rate and the interbank rate depends only on ε_t^d; thus, to calibrate ε^d we calculate the average monthly spread between retail deposit rates in our sample and the Eonia, which corresponds to around 125 basis points in annualized terms, implying that $\varepsilon^d = -1.46$. Similarly, we calibrate ε_t^{bH} and ε_t^{bE} to 2.79 and 3.12 by exploiting the steady-state relation between the marginal cost of loan production and households and firms loan rates. The steady-state ratio of bank capital to total loans $(B_t^H + B_t^E)$ is set at 0.09, slightly above the capital requirements imposed by the Basel Accords. The parameter δ^b is set at the value (0.1049), which 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 parameters, we choose a beta-distribution with a prior mean of 0.8 and a 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 at 50 with a standard deviation of 20. 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 parameters governing interest rates adjustment costs, their prior means are set at values between 3 and 10, chosen so that the coefficients in the loglinearized rate-setting equations imply immediate pass-throughs of the magnitude documented in ECB (2009b); the standard deviations are set at 2.5. The prior on the banking regulatory parameter (κ_{Kb}) is harder to set and we assume a rather widespread distribution, with a mean of 10 and a standard deviation of 5. We have estimated the model imposing a prior mean for κ_{Kb} of 100 and obtained a posterior median of 40. Similarly when we set the prior mean at 2.5 the posterior median increased to 4. These results may suggest that the parameter is somehow identified in the data and that the overlap between the prior and posterior distribution (see Figure 2) is not the result of lack of identification.

4.3 Posterior estimates

Tables 2A and 2B also report the posterior mean, median and 95 percent probability intervals for the structural parameters. Draws from the posterior distribution of the parameters are obtained using the random walk version of the Metropolis algorithm. We ran ten parallel chains, each with a length of 100,000. The scale factor was set in order to deliver acceptance rates of between 20 and 30 percent. Convergence was assessed by means of the multivariate convergence statistics taken from Brooks and Gelman (1998) and also computing recursive means of the model's parameters. 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. The posterior mean of the parameter measuring the degree of consumption habits is estimated to be high, at 0.85. For monetary policy, our estimation confirms the weak identification of the response to inflation (see Figure 3) and the relatively large degree of policy rate inertia; moreover, the posterior median of the coefficient measuring the response to output growth is more than three times 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 0.16) and confirms the finding of Benati (2008) who documents a low degree of indexation in the euro area in the single currency period. Concerning the parameters measuring the degree of stickiness in bank rates, we find that deposit rates adjust more rapidly than the rates on loans to changes in the policy rate. This result is not surprising given that our measure of deposits include time deposits, whose interest rates are typically highly reactive to changes in money market rates. We have estimated a version of the model with flexible bank rates and found that the log of the marginal density is substantially lower than the corresponding one for the benchmark model (by around 50), suggesting that stickiness is a key feature of bank rates in the euro area. Finally, the posterior distribution for κ_{Kb} stays very close to the chosen prior. As already mentioned, we experimented with larger and smaller values for the mean of the prior distribution. These experiments suggest that this parameter is partially identified in the data, in the sense that in these cases the posterior distribution moves away from the prior one.

5 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.

The benchmark model, described in Section 3, introduces financial intermediation in a framework that already features a number of transmission channels for monetary impulses, which are usually at work in models with heterogeneous agents and borrowing constraints. In that category of models, the traditional interest rate channel is modified by the fact that only a fraction of the population (patient agents) are willing to postpone consumption when the real rate rises, and is accompanied by three additional channels, as listed, for example, in Calza *et al.* (2009): (i) a nominal-debt channel, whereby, as interest and principal payments are in nominal terms, changes in inflation affect the ex-post distribution of resources across borrowers and lenders; (ii) a collateral-constraint channel, whereby an innovation in the policy rate changes the shadow value of borrowing and therefore impacts on consumption; (iii) an asset-price effect, whereby induced changes in asset prices alter the value of the collateral that agents can pledge. Iacoviello (2005), among others, has shown that these channels can amplify and propagate the transmission of monetary impulses, when compared to standard models with representative agents and frictionless financial markets. Due to the interest-rate setting behavior of banks, our model features an intermediation spread, whose movements alter the pass-through of changes in the policy rate to bank rates, which are the relevant rates for consumption and investment decisions. This mechanism modifies the effectiveness of the abovementioned transmission channels. In particular, credit market power and the ensuing markup between lending rates and the policy rate amplify changes in the policy rate for borrowers (i.e. impatient households and entrepreneurs), while the markdown between the policy and the deposit rate implies an attenuating effect for lenders (i.e. patient agents). Sticky interest rates, instead, unambiguously induce an attenuation effect (with respect to a flexible-rate setup), as banks translate changes in the policy rate to borrowing and lending rates only partially. Finally, the impact of bank capital depends on the correlation between bank leverage (i.e. the inverse of the capital-to-asset ratio) and the policy rate: if bank leverage increases when policy is tightened, then the transmission of shocks to the real economy is amplified; on the contrary, a fall in leverage during periods of policy tightening smooths fluctuations in the real economy. Given these facts, the overall impact of financial intermediation on the transmission mechanism depends on the relative importance and the mutual interactions of the heterogenous effects on the various agents.

Overall, we find that after a monetary policy shock financial intermediation attenuates the response of real variables, mainly reflecting the presence of sticky bank rates. Also after a technology innovation banking somewhat dampens the response of output, mainly due to the impact of monopolistic power on consumption; in this case, however, banking also enhances the endogenous propagation mechanism of the model.

5.1 Monetary policy shock

The transmission of a monetary policy shock is studied first by analyzing the impulse responses to an unanticipated 50 basis points exogenous shock to the policy rate (r_t). Figure 4 shows the impulse responses, with parameter values set at the estimated posterior median. The red line (BK in the figure) plots impulse responses of the benchmark model, described in Section 3. In order to decompose the contribution of each distinctive feature of banking at work in that model, in the charts we compare the BK model with a number of other models, where we progressively shut down those features:[17] (i) a model with sticky bank rates (SR model) where we get rid of bank capital, i.e. a model with a simplified balance sheet for banks that includes only deposits on the liability side;[18] (ii) a model where we also remove stickiness in bank rate setting, i.e. we allow for flexible rates (FR in the figure); [19] (iii) a model where we eliminate market power for banks, i.e. where we assume that financial intermediaries operate in perfect competition; this model can be interpreted as a standard financial frictions framework, like Iacoviello (2005; FF in the figure);[20] (iv) a model where we also remove the assets-price and nominal-debt channels, in order to obtain a setup as similar as possible to the New Keynesian standard (a "Quasi-New Keynesian" model - QNK).[21]

In our benchmark model (BK), 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 (QNK) or in a model with financial frictions (FF). Therefore, our model continues to be able to replicate stylized business cycle facts while having the advantage of introducing new elements which realistically enrich the set of inter-linkages between macroeconomic and financial variables. In the face of a policy tightening, output and inflation contract (inducing a partial endogenous unwinding of the policy rate). Real interest rates for households and entrepreneurs go up, reflecting the increase in bank interest rates, and asset prices decline, determining a reduction in the present discounted value of collateral and a fall in lending, to both households and firms. On impact, bank profits get pushed up by the increase in banks' intermediation spread, which more than offsets the reduction in the amount of

[17] Thus, the contribution of the various features is obtained as the difference in the responses among the models. It would be possible to re-estimate each model and perform the same comparison. However, in this case, all the parameters would change in order to fit the data and, therefore, it would not be possible to attribute any change in the propagation mechanism of shocks to a specific feature of the model.

[18] 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.

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

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

[21] It is quasi NK since agents are still constrained in borrowing, although it is assumed that there is no effect of price fluctuations on the value of the collateral (which is kept fixed at the steady state level) and that loans and deposits (plus interests) are repaid in real terms.

intermediated funds; after a few quarters, however, profits turn negative as bank margin increases unwind while loans and deposits remain negative for longer. Following profits, bank capital initially increases but it then turns negative after about ten quarters.

From a quantitative point of view, however, the BK model differs substantially from the FF model where a single interest rate exists. In particular, the contractionary effect of the policy tightening is attenuated in the BK model. This effect is due to the presence of sticky bank rates, which dampen the response of retail loan rates, thus reducing the contraction in loans, consumption and investment (see the difference between the SR and the FR lines in Figure 4). The impact of market power (i.e. the difference between the FR and FF lines) on output is rather limited, reflecting the differentiated effects on borrowers and lenders, which almost mutually offset each other in the aggregate. In particular, the loan-interest rate markup determines a bigger increase of the relevant rates for impatient households and entrepreneurs in the FR model, while the markdown for the deposit rate attenuates the restriction for patient households. As a consequence, borrowers' consumption and investment decline by more (in FR with respect to FF), while savers' consumption decreases by less. Finally, 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 (as represented by the differences between the BK and the SR lines); this partly reflects the small value estimated for the parameter κ_{Kb}, which – as mentioned before – we use to perform this exercise.[22]

Our findings on the presence of an overall attenuating effect of banking after a monetary policy shock are in line with the results obtained by Goodfriend and McCallum (2007). In their model, the attenuation effect stems from the presence of procyclical marginal costs and occurs only when the monetary impulse is very persistent. 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 also arises in Andrés and Arce (2009) and Aslam and Santoro (2008). In these models, this effect is mainly the result of a steady-state spread in the banking sector due to imperfectly competitive financial intermediation: we share the same result, but we highlight that it is the outcome of an amplification effect on borrowers and an attenuation effect on savers. Christiano *et al.* (2008) present a model with financial intermediaries. Their banks are rather different compared to ours, as they operate under perfect competition and therefore cannot set retail interest rates. Regarding the monetary transmission mechanism, they find that the presence of banks and financial frictions magnifies the response of output and induces higher persistence; however, they also find that banks play a marginal role in propagating the monetary impulse while the financial accelerator is more important.

[22] For example, our parameters imply that a reduction of the capital-to-assets ratio by half (from its steady state-value of 9%) would increase the spread between the wholesale loan rate and the policy rate by around 10 basis points only.

5.2 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 line with the basic financial frictions setup *à la* Iacoviello (2005; FF), in our benchmark model the expansion which follows a positive technology shock is boosted by a financial acceleration mechanism and, at the same time, dampened by a debt deflation effect. With respect to Iacoviello's model, the presence of imperfectly competitive financial intermediation amplifies both of these channels, while sticky rates and bank capital alter the picture only marginally. Overall, a dampening effect prevails on impact, so that consumption and output in the three models with banking (FR, SR, BK) feature a common attenuation in the first few quarters, more intense than the one prevailing in the FF case; but, as policy and loan rates decrease more in response, real variables display a higher persistence: output reaches a peak after about ten quarters, as compared to seven in the FF model.

With respect to the financial acceleration mechanism, the existence of markups on loan rates provides an amplifying contribution to the expansion following the technology shock. The usual downward pressure on prices determined by the shock induces a policy rate cut: with imperfectly competitive banking, interest rates on loans fall even more, by a measure of the markup. Thus, investment is boosted both by the technological improvement and by a particularly eased access to credit. The accumulation of physical capital (and also of housing by impatient households) pushes asset prices up, so that borrowers also benefit from the wider access to credit that higher collateral value affords.

With respect to the debt deflation mechanism, this expansionary effect is somewhat dampened by the fact that debt contracts are signed in nominal terms and with rate-setting banks. In fact, deflation increases the real value of debt obligations and limits resources available to borrowers, both directly and through second-round asset-price effects on the collateral value. In our models where the banking sector is imperfectly competitive, markups applied on loan rates raise the cost of debt servicing: a given deflation leaves debtors with a higher burden of real debt obligations which weigh more on their resources and on their spending, so that the dampening of the supply shock due to the existence of nominal debt is initially stronger.

The market power enjoyed by banks also plays a role in the delayed propagation of a technological improvement. The initially stronger attenuation of demand exerts additional downward pressure on prices, triggering a more aggressive reduction of the policy rate in the first year, and the existence of markups induces an even stronger reduction of loan rates, which reach a minimum by the end of the first year. This improvement in credit conditions boosts real activity: in particular, it allows entrepreneurs to expand investment further, which in turn induces a higher price of capital and hence higher collateral valuations, reinforcing the initial effect. As labor becomes more productive, entrepreneurs increase labor demand too. Wages set by impatient households, initially moderated by the adverse wealth effect, also increase with a lag, and so does consumption for this group of agents. Overall, the dynamics of consumption and investment are delayed with respect to the FF setup, and this translates into a higher persistence in output.

The presence of sticky interest rates limits the reduction of bank rates, and hence the expansion of lending and aggregate demand, but overall it only marginally affects the impulse responses of the main real variables (see the difference between the SR and the FR lines). Finally, the presence of bank capital mainly affects the behavior of investment (see the difference between the BK and the SR lines), by establishing a link between the amount of credit available to firms and bank profits. In fact, investment peaks at around 40% below the level achieved under the SR model, mainly because lending is now restrained by the fall in bank capital that follows a contraction of bank profits. In turn, the decline in profits is related to the endogenous countercyclical response of the interest rate margin (the differential between loan and deposit rates), which is the main source of bank profits.[23]

6 Applications

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

6.1 The role of financial shocks in the business cycle

In order to quantify the relative importance of each shock in the model we perform a 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 median 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 it. On the other hand, to the extent that the overall story told by the model is consistent with the conventional wisdom that has emerged so far about the origins and causes of the current crisis, we can use this experiment as an indirect misspecification test for our model.

[23] Empirically, the differential between loan and deposit rates is countercyclical. See, for example, Aliaga-Díaz and Olivero (2008) for evidence on the U.S.

For this exercise we have divided the 13 shocks that appear in the model into three groups. First, there is a "macroeconomic"group, which pools shocks to production technology, to intertemporal preferences, to housing demand, to investment-specific technology, and to price and wage markups. Next, the "monetary policy" group isolates the contribution of the non-systematic conduct of monetary policy. Finally, the "financial" group consists of shocks originating in the credit sector: these are the shocks to the loan-to-value ratios on loans to firms and households, the shocks to the markup on bank interest rates and the shock to balance sheets.

Figure 6 shows the results of the exercise for some key macro variables. Concerning output (defined as the sum of consumption and investment) the results of the historical decomposition suggest that macro and financial shocks were primary drivers behind the rise of 2006-2007, while the sharp slowdown of 2008 was essentially caused by financial shocks.[24] These affected the real economy mainly through their effect on investment and the decomposition of that variable confirms how unusually large (positive) shocks, mainly related to firms' LTV ratios, 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. Macroeconomic shocks also played a role in the slowdown of 2008, in that their positive contribution to the dynamics of output fell to almost nothing during 2008, after having been quite high the year before. A closer inspection of that category reveals that an important contributor in this group were price markup shocks. The reason why these shocks are estimated to be so important at the current juncture is that they are probably 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 made a positive contribution in 2008, although the contribution of price markup shocks turned negative starting in the last quarter; on the other hand, monetary policy shocks are found to have exerted negative effects on the policy rate between the end of 2007 and the third quarter of 2008. In order to understand these results, one must remember that over this period, which was characterized by great uncertainty over the consequences of the financial crisis, the ECB kept the interest rate on its 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. In the second half of 2008, the contribution of credit sector shocks became predominant, and accounted for the bulk of the rapid reduction in the policy rate.

In Figure 7 we collect the results of the historical decomposition of loans to households and firms and the corresponding bank rates. In this case we found it convenient to divide the "financial" group in three sub-categories: shocks directly related to loans to

[24] We obtain quite similar results using linearly detrended data. In this case, only the last two quarters of the sample show a significant contribution of financial shocks to the downturn in economic activity in the euro area.

households (i.e., shocks to households' LTV ratios and to interest rate markups on their loans), shocks directly related to loans to firms, and all other financial shocks (deposit rate markup and bank balance sheet shocks). The dynamics of the interest rates on loans to firms and households were mainly driven by macroeconomic shocks. However, shocks related to the supply of credit to firms have 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. Loans to firms were driven almost exclusively by shocks related directly to credit to firms, with the notable exception of 2008 when a negative contribution came from macroeconomic shocks, among which a significant role was played, again, by price markup shocks until the third quarter and, subsequently, by shocks to the marginal efficiency of investment. Concerning loans to households, a main driver of its dynamics turns out to be the housing demand shock (within the macro group), since it explains most of the strong rise in 2006 and, at a decreasing pace, in 2007, as well as the subsequent decline in 2008, tracking the house prices cycle. Consistent with the indications from the Bank Lending Survey for that period, our results explain with lower loan-to-value ratios the early deceleration of loans to households in the year before the outbreak of the crisis.

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

6.2 The effects of a bank capital loss

Starting in the summer of 2007, financial markets in advanced economies entered a protracted period of considerable strain. The initial deterioration in the U.S. 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. Since the October 2007 round, banks participating in the euro area Bank Lending Survey reported to have considerably tightened their credit standards and, at the same time, to have strongly increased the margins charged on average loans to households and firms (Figure 1). When asked about the motivations behind these developments, banks pointed predominantly to the role played by the costs incurred in managing their capital position (right panels in Figure 1). These survey results therefore vividly picture a situation in which a negative shock in the US financial markets generated conditions for real effects in the euro area via its impact on the capital positions of banks, and on the availability and cost of bank credit. Against this background, it is of the essence for policymakers, when evaluating the appropriateness of the monetary policy stance, to be able to reckon the impact of such bank balance sheets effects as to the availability and cost of credit.

As our model is particularly well suited to analyze such a question, in this section we use it to study what happens if bank capital suffers a strong negative shock. In order to run the simulation, we modify the model introducing the possibility of an unexpected and persistent contraction in bank capital K^b. We do not attempt to construct a quantitatively realistic scenario; this would indeed be very difficult, given the conflicting indications coming from hard and survey evidence on realized and latent bank capital losses and on the tightening of credit standards, in particular in the euro area, and given the uncertainty on the effects that have already occurred and on those that might still be in the pipeline. Instead, we mostly want to study the transmission and amplification mechanisms that account for the macroeconomic effects of bank capital losses. We calibrate the shock so as to obtain, on impact, a fall of bank capital equal to 5 percent of its pre-shock level. The persistence of the shock is set at 0.95 in order to obtain a persistent fall of the capital-to-assets ratio below its steady state value (9 percent). Figure 8 shows the effects of this experiment using the median of the posterior distribution of the parameters and under an alternative calibration in which the only difference is that it is particularly difficult (and costly) to raise new capital, i.e. we increase by a factor of 10 the coefficient on the adjustment costs on the capital-to-assets ratio κ_{Kb} (from an estimate that is slightly below 10).

In the benchmark case, the decline in bank liabilities following the shock leaves banks too leveraged, and with a burden of costs due to their deviation from capital requirements. It is then optimal for banks to try to re-balance assets and liabilities by reducing loans and increasing deposits: they do so by increasing all retail rates, which weakens demand for loans and stimulates that for deposits. The reduction in loans is of major concern for banks since they need to approach rapidly the capital/loans target: therefore, loan rates undergo a higher increase than the deposit rate. Loan volumes decrease both for entrepreneurs and for impatient households, reducing resources available to them. Entrepreneurs cut investment substantially and move to a larger capital utilization, given that its relative cost has decreased and that physical capital is less useful as collateral; at the same time they increase labor demand. Labor is more productive and becomes more costly: wages are set higher if demand by firms has to be met. The initial increase in labor income sustains consumption of households, in particular of impatient agents, and limits the fall in output, at least on impact: later on, in the beginning of the third year, the contraction in output is three times the one on impact, at almost 0.3 percent. Monetary policy is quite unaffected by the exogenous change in bank capital positions: the policy rate increases only slightly in response to some upward movements in prices which reflect the increase in labor and capacity costs only.[25] Banks balance their books and capital positions independently of any monetary stimulus. A rapid increase in the intermediation margin contributes to this re-balancing by building back bank capital stock.

Increasing the cost of deviating from the target capital-to-assets ratio does not change the dynamics substantially. Obviously, all responses to the capital loss shock are harshened. The most significant variation relates to the fact that, with a higher deviation cost, banks' optimal adjustment strategy assigns a greater importance to deleveraging, with respect to a plain squaring of the balance sheet: in fact, while in the benchmark case the capital loss was also countered via an increase in deposits, with a higher cost of deviating from the target K^b/B ratio banks aim mainly at decreasing loans and increasing capital (through higher loan rates and intermediation margins) and accordingly stop raising rates on deposits (whose volumes actually fall). In this case, these dynamics are key to a much faster recovery of the banking capital position and of leverage, which is almost complete after just one and a half year.

7 Concluding remarks

The paper has presented a model in which entrepreneurs and impatient households contract loans subject to borrowing constraints. Loans are supplied by imperfectly competitive banks using both deposits collected from savers and bank capital that they have accumulated out of reinvested earnings. Margins charged on loans depend on the interest rate elasticities of loan and deposit demands, on the degree of interest rate stickiness and on the banks' capital-to-assets ratio. Banks' 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 has been estimated using Bayesian techniques and data for the euro area over the period 1998:Q1-2009:Q1, in order to analyze three important issues. First, we study how financial intermediation modifies the transmission mechanism of monetary policy and technology shocks. Overall, after a monetary shock, the presence of financial intermediation induces an attenuation effect on real variables, mainly reflecting the presence of sticky bank rates. In the case of a technology shock, imperfect competition in banking generates some attenuation as well, specially of consumption, but it also determines additional persistence in the response of real activity. The quantitative impact of the presence of a bank capital requirement on responses to a monetary policy shock turns out to be negligible; however, the link between loan margins and the capital-to-assets ratio significantly dampens the response of investment following a technology innovation.

Secondly, we analyze the transmission of financial shocks to the real economy and their contribution to business cycle fluctuations. In particular, we show that shocks in

[25] A mild increase in inflation together with a fall in output is also found by Meh and Moran (2008) in an analogous experiment of bank capital loss.

the banking sector explain the largest fraction of the fall of output in the euro area in 2008, while macroeconomic shocks played a smaller role.

Finally we simulate a “credit crunch” scenario via an unexpected and exogenous destruction of banking capital and find that the effects of this shock can be sizeable, particularly on investment.

Together with results in papers like Christiano *et al.* (2008), our findings suggest the need to include explicitly financial and credit shocks when building general equilibrium models to analyze business cycle fluctuations: neglecting them, not only on the demand but also on the supply side of credit, could lead one to miss important drivers of the cycle.

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Appendix

A The rest of the model

A.1 Loan and deposit demand

The demand function for household i seeking an amount of real loans equal to $\bar{b}_t^I(i)$ can be derived from minimizing the due total repayment

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

subject to

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

with $\varepsilon_t^{bH} > 1$. Aggregating FOCs across all impatient households, aggregate impatient households' demand for loans at bank j is obtained as

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

where $b_t^I \equiv \gamma^I b_t^I(i)$ indicates aggregate demand for household loans and the aggregate interest rates on loans to households is $r_t^{bH} = [\int_0^1 r_t^{bH}(j)^{1-\varepsilon_t^{bH}} dj]^{\frac{1}{1-\varepsilon_t^{bH}}}$.

Demand for entrepreneurs' loans is obtained analogously and is equal to

$$b_t^E(j) = \left(\frac{r_t^{bE}(j)}{r_t^{bE}} \right)^{-\varepsilon_t^{bE}} b_t^E$$

Demand for deposits at bank j of impatient household i, seeking an overall amount of real savings $\bar{d}_t(i)$, is obtained by maximizing the revenue of total savings

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

subject to the aggregation technology (with $\varepsilon_t^d < -1$)

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

and is given by (aggregating across households)

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

where $d_t \equiv \gamma^P d_t^P(i)$ and the aggregate deposit rate is $r_t^d = [\int_0^1 r_t^d(j)^{1-\varepsilon_t^d} dj]^{\frac{1}{1-\varepsilon_t^d}}$.

A.2 The labor market

We assume that workers provide slightly differentiated labor types, sold by unions to perfectly competitive labor packers who assemble them in a CES aggregator with parameter ε_t^l (modeled as an exogenous process) and sell the homogeneous labor input to entrepreneurs. For each labor type m there are two unions, one for patient households and one for impatient households (indexed by s). Each union (s, m) sets nominal wages $\{W_t^s(m)\}_{t=0}^{\infty}$ for the work efforts of its members by maximizing their utility subject to a downward sloping demand 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. The union equally charges each member household lump-sum fees to cover adjustment costs. It maximizes the following objective expressed in terms of utils for each of its members

$$E_0 \sum_{t=0}^{\infty} \beta_s^t \left\{ U_{c_t^s(i,m)} \left[\frac{W_t^s(m)}{P_t} l_t^s(i,m) - \frac{\kappa_w}{2} \left(\frac{W_t^s(m)}{W_{t-1}^s(m)} - \pi_{t-1}^{\iota_w} \pi^{1-\iota_w} \right)^2 \frac{W_t^s}{P_t} \right] - \frac{l_t^s(i,m)^{1+\phi}}{1+\phi} \right\}$$

subject to demand from labor packers

$$l_t^s(i,m) = l_t^s(m) = \left(\frac{W_t^s(m)}{W_t^s} \right)^{-\varepsilon_l} l_t^s$$

In a symmetric equilibrium, the labor choice for a household of type s will be given by an ensuing (non-linear) wage-Phillips curve

$$\kappa_w (\pi_t^{w^s} - \pi_{t-1}^{\iota_w} \pi^{1-\iota_w}) \, \pi_t^{w^s} = \beta_s E_t \left[\frac{\lambda_{t+1}^s}{\lambda_t^s} \kappa_w (\pi_{t+1}^{w^s} - \pi_t^{\iota_w} \pi^{1-\iota_w}) \frac{\pi_{t+1}^{w^s \, 2}}{\pi_{t+1}} \right] + (1-\varepsilon_l) l_t^s + \frac{\varepsilon_l l_t^{s\,1+\phi}}{w^s{}_t \lambda_t^s}$$

A.3 Capital goods producers

In the capital goods producing (CGP) sector, at the beginning of period t zero-profit perfectly competitive firms buy at price P_t^k last period undepreciated capital $((1-\delta)k_{t-1})$ from entrepreneurs (who also own CGP firms); at the same time, they buy at price P_t an amount i_t of final goods from retailers. With these inputs in hand, the activity of CGP firms increases the stock of effective capital $\bar{x}_t$, which is then sold back to entrepreneurs at the end of the period, still at 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 costs. CGP firms therefore solve the following problem

$$\max_{\{\bar{x}, i_t\}} E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^E \left(q_t^k \Delta \bar{x}_t - i_t \right)$$

subject to

$$\bar{x}_t = \bar{x}_{t-1} + \left[1 - \frac{\kappa_i}{2} \left(\frac{i_t \varepsilon_t^{qk}}{i_{t-1}} - 1 \right)^2 \right] i_t$$

where $\Delta\bar{x}_t = k_t - (1-\delta)k_{t-1}$ is the flow output, κ_i is the parameter measuring the cost for adjusting investment and ε_t^{qk} is a shock to the productivity of investment goods.

From FOCs (see technical appendix), the real price of capital q_t^k is determined by a dynamic equation similar to that in Christiano *et al.* (2005) and Smets and Wouters (2003).[26]

A.4 Goods retailers

The retail goods market is assumed to be monopolistically competitive. Retailers are just "branders": they buy the intermediate good from entrepreneurs at the wholesale price P_t^W and differentiate it at no cost. Each retailer then sells his unique variety, applying a markup over the wholesale price, taking into account the demand that he faces characterized by a stochastic price-elasticity ε_t^y. Retailers' prices are sticky and are indexed to a combination of past and steady-state inflation, with relative weights parameterized by ι_p; if retailers want to change their price beyond what indexation allows, they face a quadratic adjustment cost parameterized by κ_p. They must choose $\{P_t(j)\}_{t=0}^{\infty}$ to maximize profits (accruing to patient households) given by

$$E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^P \left[P_t(j)y_t(j) - P_t^w y_t(j) - \frac{\kappa_p}{2}\left(\frac{P_t(j)}{P_{t-1}(j)} - \pi_{t-1}^{\iota_p}\pi^{1-\iota_p}\right)^2 P_t y_t \right]$$

subject to a downward sloping demand coming from consumers maximization of a consumption aggregator

$$y_t(j) = \left(\frac{P_t(j)}{P_t}\right)^{-\varepsilon_t^y} y_t$$

A.5 Monetary policy

A central bank is able to set exactly the interest rate prevailing in the interbank market r_t. In setting the policy rate, the monetary authority follows a Taylor rule of the type

$$(1+r_t) = (1+r)^{(1-\phi_R)}(1+r_{t-1})^{\phi_R}\left(\frac{\pi_t}{\pi}\right)^{\phi_\pi(1-\phi_R)}\left(\frac{y_t}{y_{t-1}}\right)^{\phi_y(1-\phi_R)}\varepsilon_t^r \qquad (14)$$

where ϕ_π and ϕ_y are the weights assigned to inflation and output stabilization, respectively, r is the steady-state nominal interest rate, $y_t = \gamma^E y_t^E(i)$ is aggregate output and ε_t^r is an i.i.d. shock to monetary policy with normal distribution and standard deviation σ_r.

A.6 Aggregation and market clearing

In the final goods market, the equilibrium condition is given by the following resource constraint

$$y_t = c_t + q_t^k\left[k_t - (1-\delta)k_{t-1}\right] + k_{t-1}\psi(u_t) + \delta^b k_{t-1}^b + Adj_t \qquad (15)$$

[26] 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.

where $c_t = c_t^P + c_t^I + c_t^E$ is aggregate consumption, $k_t = \gamma^E k_t^E(i)$ is the aggregate stock of physical capital and k_t^b is aggregate bank capital (γ^s, $s \in P, I, E$, is the measure of each subset of agents). The term Adj_t includes real adjustment costs for prices, wages and interest rates.

In the housing market, equilibrium is given by

$$\bar{h} = \gamma^P h_t^P(i) + \gamma^I h_t^I(i) \tag{16}$$

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

B 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. Sources: ECB and Eurostat.

Wages: Hourly labor cost index - wages and salaries, whole economy excluding agriculture, fishing and government sectors, seasonally and working day 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: ECB.

Nominal interest rate (policy): Eonia rate. Source: ECB.

Nominal interest rate on loans to households: Annualized agreed rate (AAR) on loans for house purchases, total maturity, new business coverage, euro area (changing composition). Source: ECB.

Nominal interest rate on loans to firms: AAR on loans other than bank overdrafts to non-financial corporations with maturity of over one year, total amount, new business coverage, euro area (changing composition). Source: ECB.

Nominal interest rate on deposits: Weighted average (with weights proportional to outstanding amounts) of AARs on overnight deposits (total maturity), on deposits with agreed maturity of up to two years, and on deposits redeemable at notice of up to three months, households and non-profit institutions serving households, new business coverage, euro area (changing composition). Source: ECB.

Loans to households: Outstanding amounts of loans to households for house purchasing, total maturity, euro area (changing composition), neither seasonally nor working day adjusted. Source: ECB.

Loans to firms: Outstanding amounts of loans to non-financial corporations, total maturity, euro area (changing composition), neither seasonally nor working day adjusted. Source: ECB.

Deposits: Outstanding amounts of overnight deposits (total maturity), deposits with agreed maturity of up to two years and deposits redeemable at notice of up to three months, households and non-profit institutions serving households, euro area (changing composition). Source: ECB.

For bank retail interest rates, we join two ECB data sets. From 2003:Q1, we use harmonized monthly data from the MFI Interest Rate statistics – or MIR statistics –, in new business coverage as it reflects better than the outstanding amounts the extent to which the policy rate impulse is transmitted to retail bank rates. Data from MIR are extended back to 1998:Q1 resorting to the euro area Retail Interest Rate (RIR) data set, compiled by the ECB until 2003:Q9. Since original national data in RIR are neither harmonized in coverage nor in nature (nominal or effective), we check the stability of the relation between comparable MIR-RIR rates series over the nine-month overlapping period of 2003 before using monthly variations in comparable series from RIR to backcast MIR rates.

Volumes of loans and deposits are taken in outstanding amounts: in fact, if taken in new business coverage (available from 2003:Q1 in MIR) the high volatility of these series would, first, not allow a safe backcasting of volumes data and, second, induce undue instability when used as weights for aggregating the various existing interest rate series into our level of breakdown.

Table 1. 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 Frisch elasticity	1.0
μ	Share of unconstrained households	0.8
ε^h	Weight of housing in 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
m^I	Households' LTV ratio	0.7
m^E	Entrepreneurs' LTV ratio	0.35
ν^b	Target capital-to-loans ratio	0.09
ε^d	$\frac{\varepsilon^d}{\varepsilon^d-1}$ markdown on deposit rate	-1.46
ε^{bH}	$\frac{\varepsilon^{bH}}{\varepsilon^{bH}-1}$ markup on rate on loans to households	2.79
ε^{bE}	$\frac{\varepsilon^{bE}}{\varepsilon^{bE}-1}$ markup on rate on loans to firms	3.12
δ^b	Cost for managing the bank's capital position	0.1049

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

		Prior distribution		Posterior distribution			
Parameter	distr.	Mean	Std.dev.	Mean	2.5 percent	Median	97.5 percent
κ_p	Gamma	50.0	20.0	30.57	10.68	28.65	49.89
κ_w	Gamma	50.0	20.0	102.35	70.29	99.90	133.81
κ_i	Gamma	2.5	1.0	10.26	7.57	10.18	12.81
κ_d	Gamma	10.0	2.5	3.62	2.28	3.50	4.96
κ_{bE}	Gamma	3.0	2.5	9.51	6.60	9.36	12.31
κ_{bH}	Gamma	6.0	2.5	10.22	7.47	10.09	12.88
κ_{Kb}	Gamma	10.0	5.0	11.49	4.03	11.07	18.27
ϕ_π	Gamma	2.0	0.5	2.01	1.72	1.98	2.30
ϕ_R	Beta	0.75	0.10	0.77	0.72	0.77	0.81
ϕ_y	Normal	0.10	0.15	0.35	0.15	0.35	0.55
ι_p	Beta	0.50	0.15	0.17	0.06	0.16	0.28
ι_w	Beta	0.50	0.15	0.28	0.16	0.28	0.39
a^h	Beta	0.50	0.10	0.85	0.81	0.86	0.90

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

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

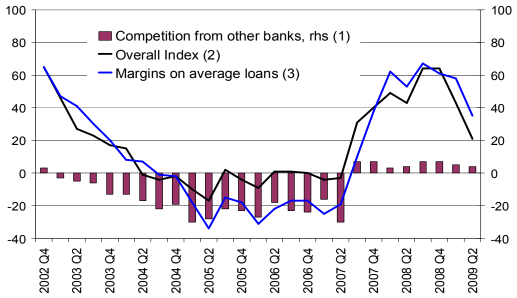
		Prior distribution		Posterior distribution			
Parameter	distr.	Mean	Std.dev.	Mean	2.5 percent	Median	97.5 percent
ρ_z	Beta	0.8	0.10	0.396	0.260	0.393	0.531
ρ_a	Beta	0.8	0.10	0.936	0.899	0.939	0.974
ρ_j	Beta	0.8	0.10	0.916	0.858	0.921	0.975
ρ_{mE}	Beta	0.8	0.10	0.892	0.839	0.894	0.945
ρ_{mI}	Beta	0.8	0.10	0.925	0.875	0.929	0.979
ρ_d	Beta	0.8	0.10	0.830	0.739	0.838	0.917
ρ_{bH}	Beta	0.8	0.10	0.808	0.675	0.819	0.949
ρ_{bE}	Beta	0.8	0.10	0.820	0.688	0.834	0.960
ρ_{qk}	Beta	0.8	0.10	0.543	0.395	0.548	0.694
ρ_y	Beta	0.8	0.10	0.306	0.205	0.305	0.411
ρ_l	Beta	0.8	0.10	0.636	0.510	0.640	0.769
ρ_{Kb}	Beta	0.8	0.10	0.810	0.718	0.813	0.906
σ_z	Inv. gamma	0.01	0.05	0.027	0.019	0.026	0.035
σ_a	Inv. gamma	0.01	0.05	0.006	0.004	0.006	0.007
σ_j	Inv. gamma	0.01	0.05	0.076	0.022	0.070	0.129
σ_{mE}	Inv. gamma	0.01	0.05	0.007	0.005	0.007	0.009
σ_{mI}	Inv. gamma	0.01	0.05	0.003	0.003	0.003	0.004
σ_d	Inv. gamma	0.01	0.05	0.033	0.024	0.032	0.043
σ_{bH}	Inv. gamma	0.01	0.05	0.067	0.035	0.066	0.115
σ_{bE}	Inv. gamma	0.01	0.05	0.063	0.034	0.063	0.096
σ_{qk}	Inv. gamma	0.01	0.05	0.019	0.013	0.019	0.025
σ_R	Inv. gamma	0.01	0.05	0.002	0.001	0.002	0.002
σ_y	Inv. gamma	0.01	0.05	0.634	0.274	0.598	0.985
σ_l	Inv. gamma	0.01	0.05	0.577	0.378	0.561	0.760
σ_{Kb}	Inv. gamma	0.01	0.05	0.031	0.026	0.031	0.037

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

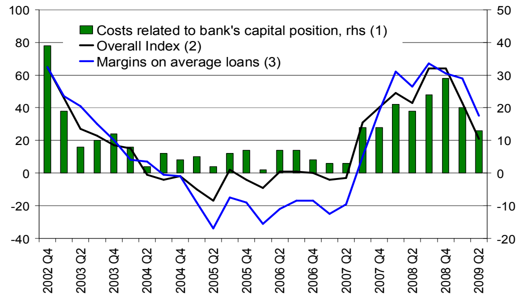
Figure 1. Bank Lending Survey of the euro area (net percentages)

Loans and credit lines to enterprises

The impact of competition

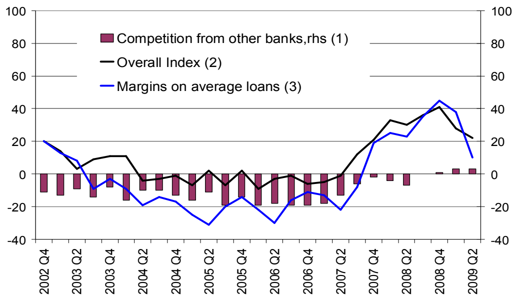


The impact of bank capital costs

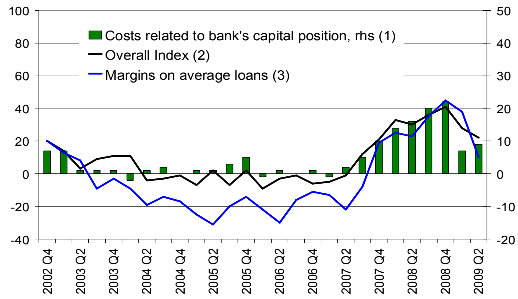


Loans to households for house purchase

The impact of competition

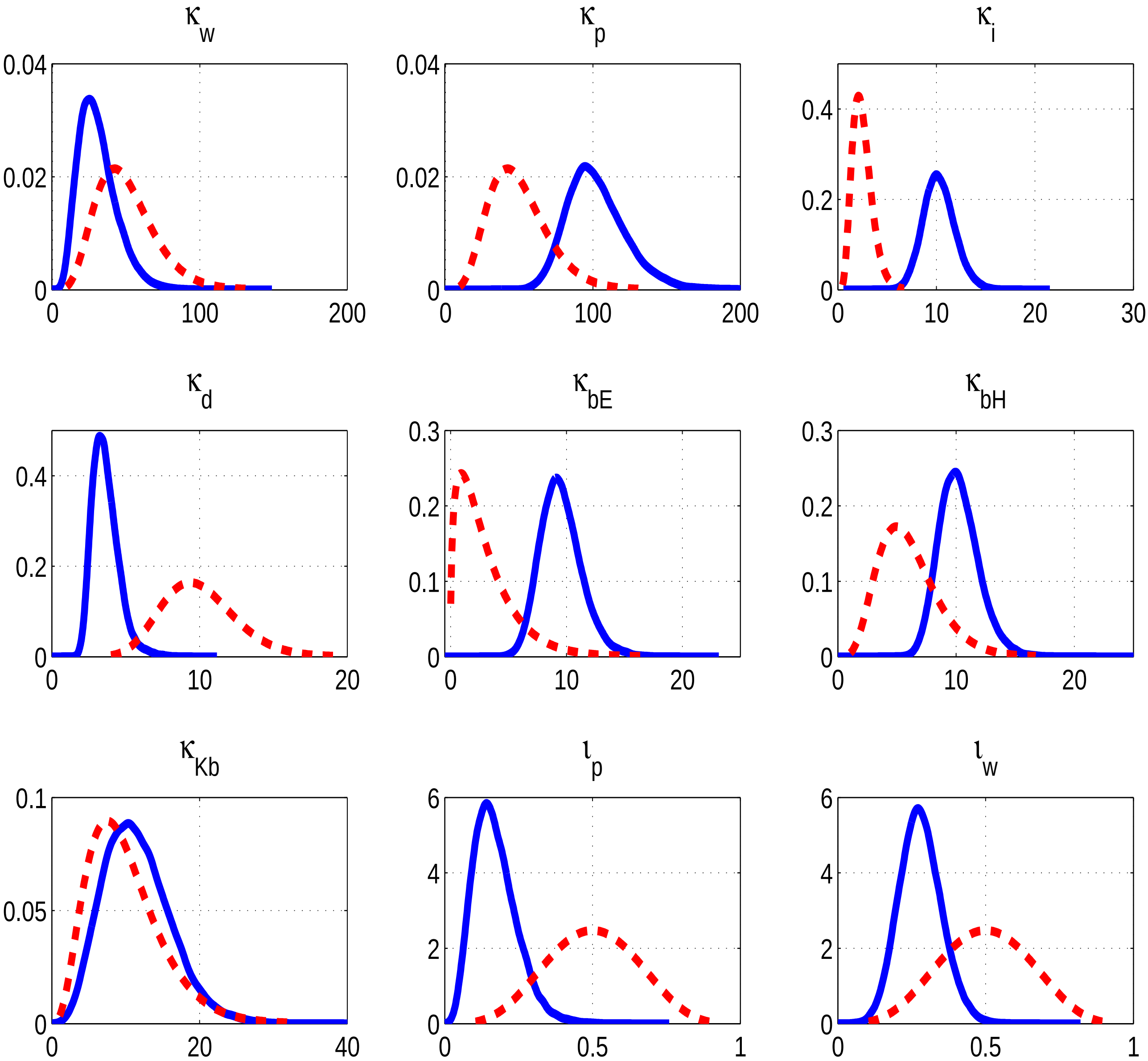


The impact of bank capital costs



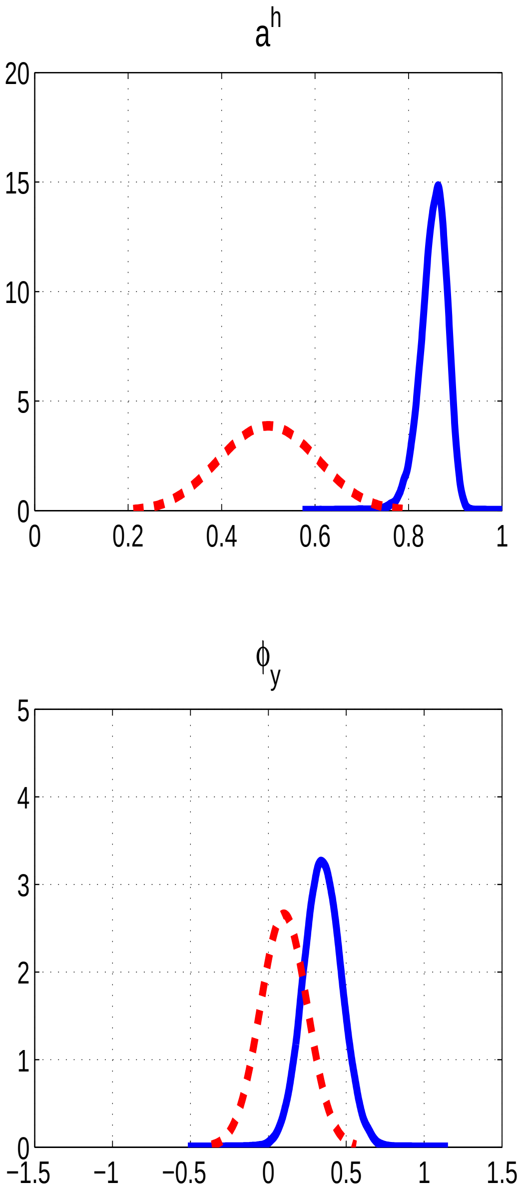
(1) Net percentage of banks reporting the factor as contributing to tightening of lending standards.
(2) Net percentage of banks reporting an overall tightening in lending standards.
(3) Net percentage of banks reporting to have increased margin.

Figure 2. Prior and posterior marginal distributions



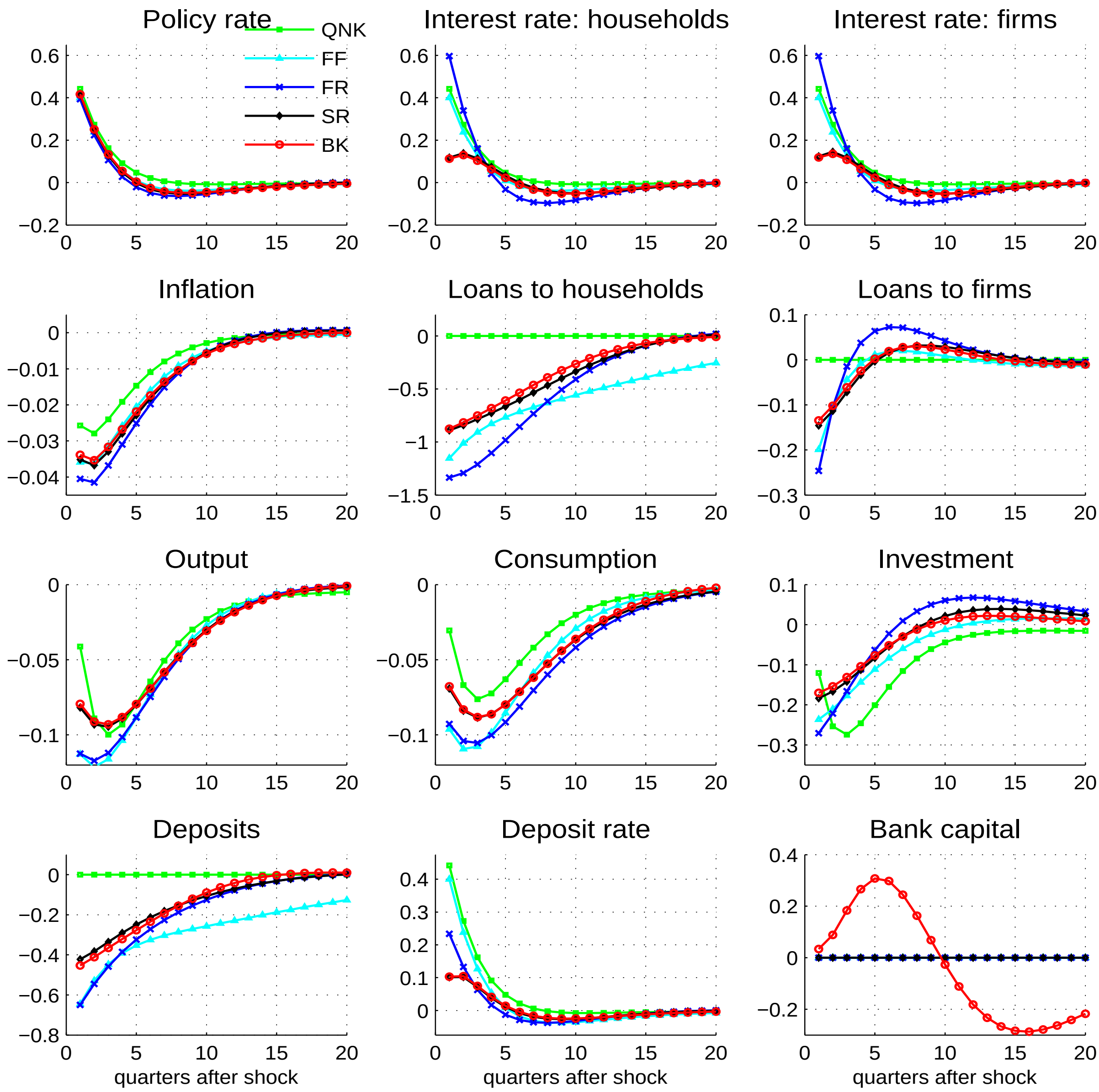
Note: The marginal posterior densities are based on 10 chains, each with 100,000 draws based on the Metropolis algorithm. Blue solid lines denote the posterior distribution, red dashed lines the prior distribution.

Figure 3. Prior and posterior marginal distributions



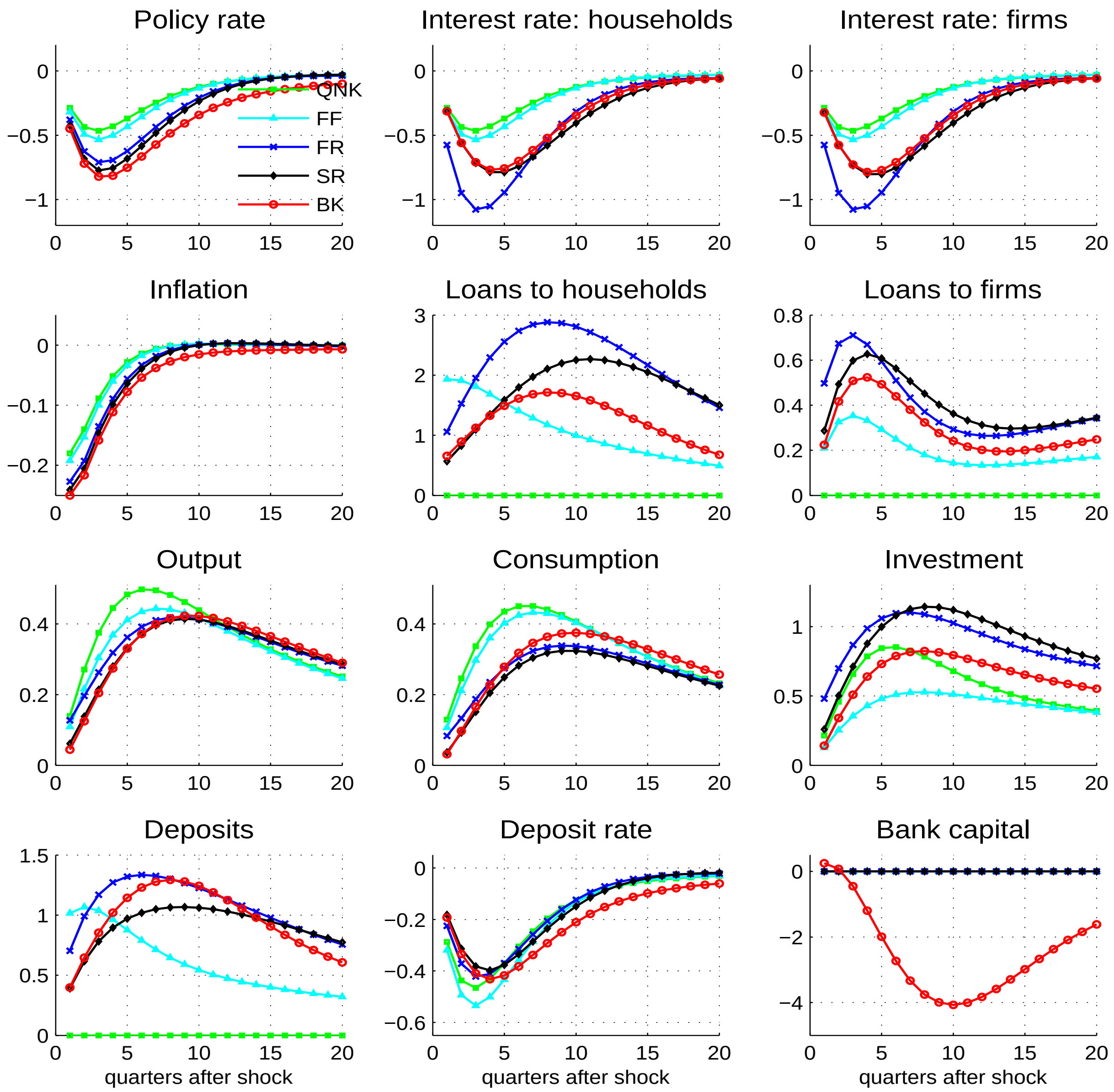
Note: The marginal posterior densities are based on 10 chains, each with 100,000 draws based on the Metropolis algorithm. Blue solid lines denote the posterior distribution, red dashed lines the prior distribution.

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



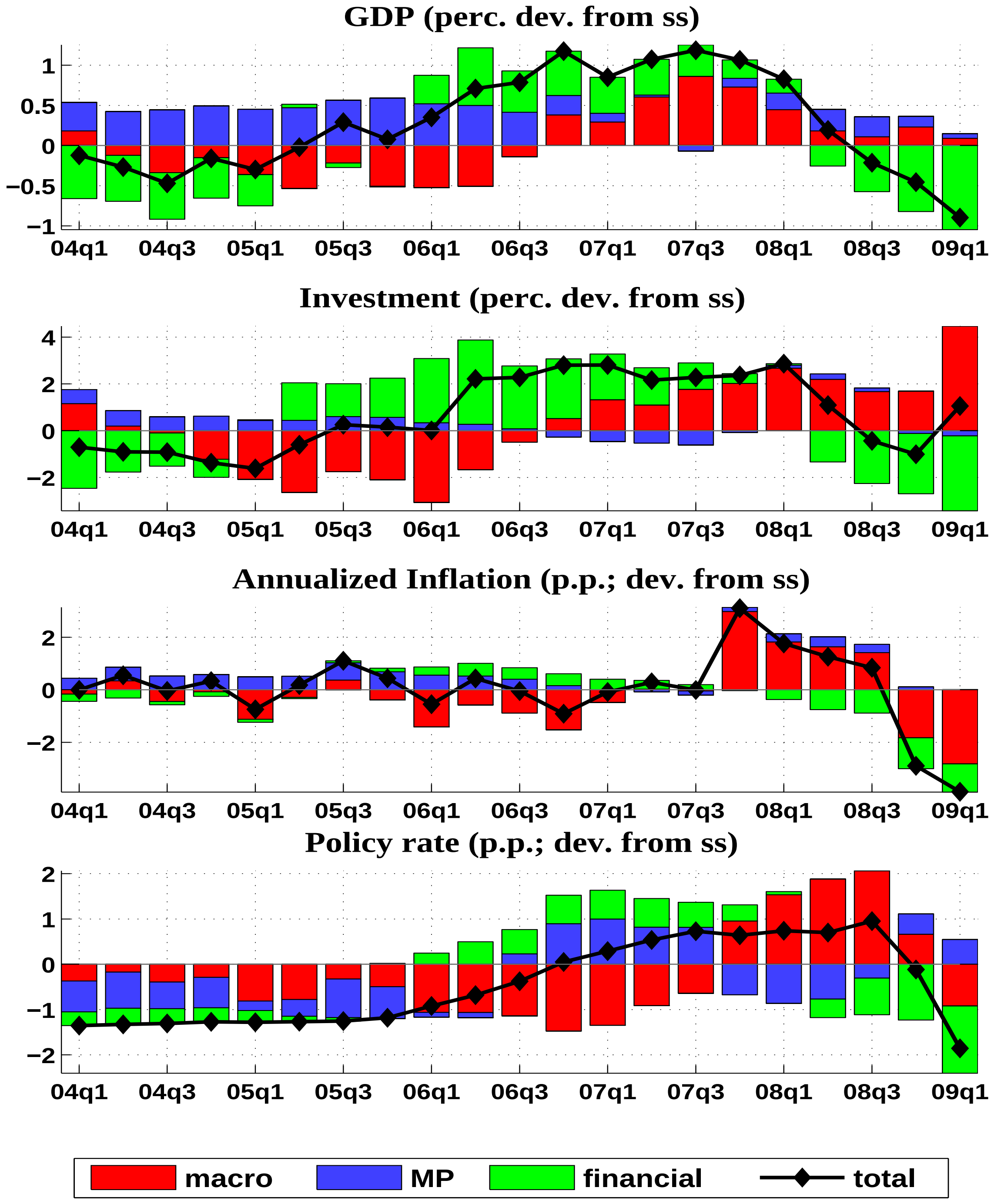
Note: The impulse responses are computed using the median of the posterior distribution of the benchmark model (BK). All rates are shown as absolute deviations from steady state, expressed in percentage points. All others graphs report percentage deviations from steady state. The red circled line is from the benchmark model (BK). The green squared line is from the quasi-NK model (QNK). The light blue line with triangles 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 (SR).

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



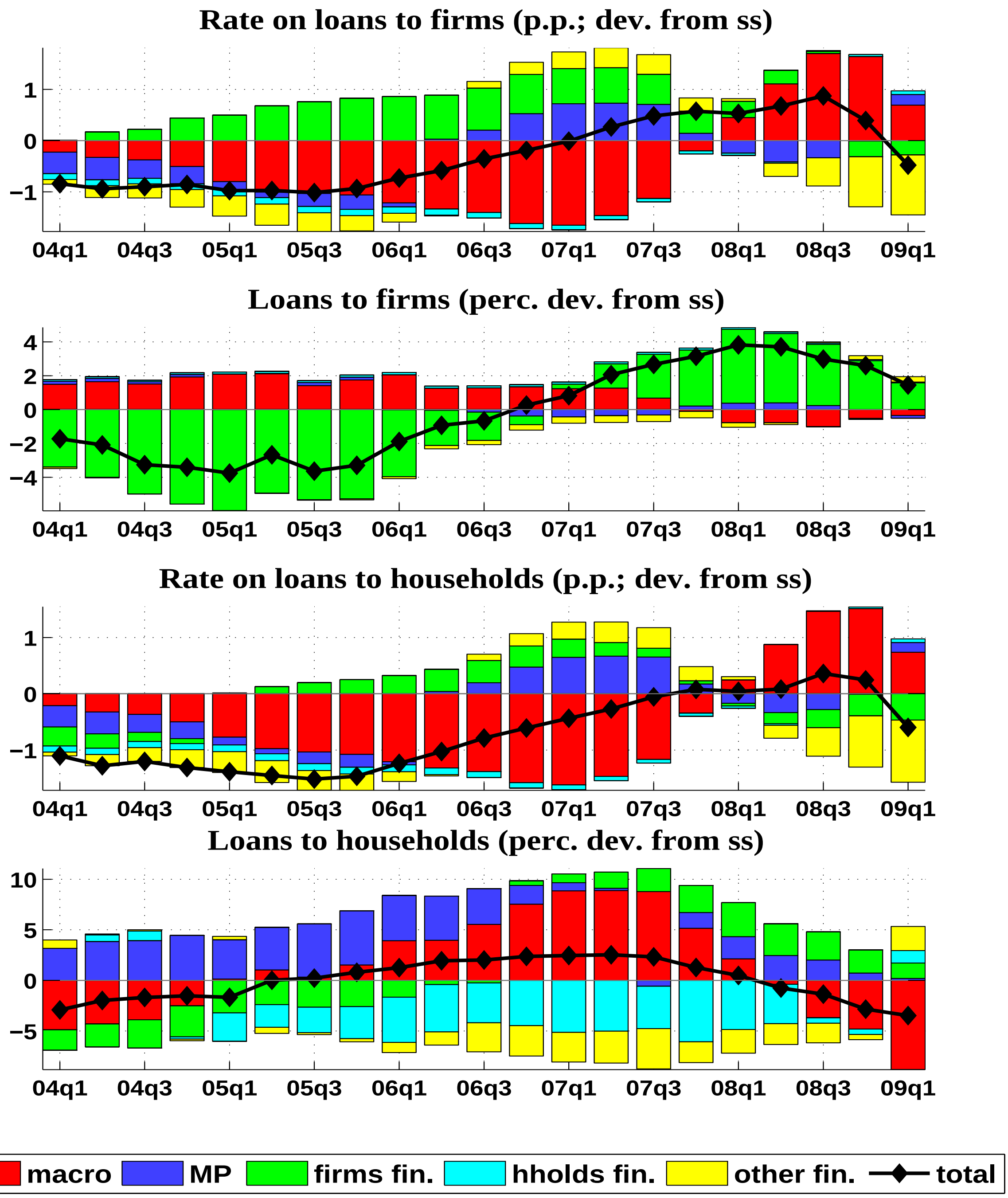
Note: The impulse responses are computed using the median of the posterior distribution of the benchmark model (BK). All rates are shown as absolute deviations from steady state, expressed in percentage points. All others graphs report percentage deviations from steady state. The red circled line is from the benchmark model (BK). The green squared line is from the quasi-NK model (QNK). The light blue line with triangles 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 (SR).

Figure 6. Historical decomposition of the main macro variables: 2004:Q1 - 2009:Q1



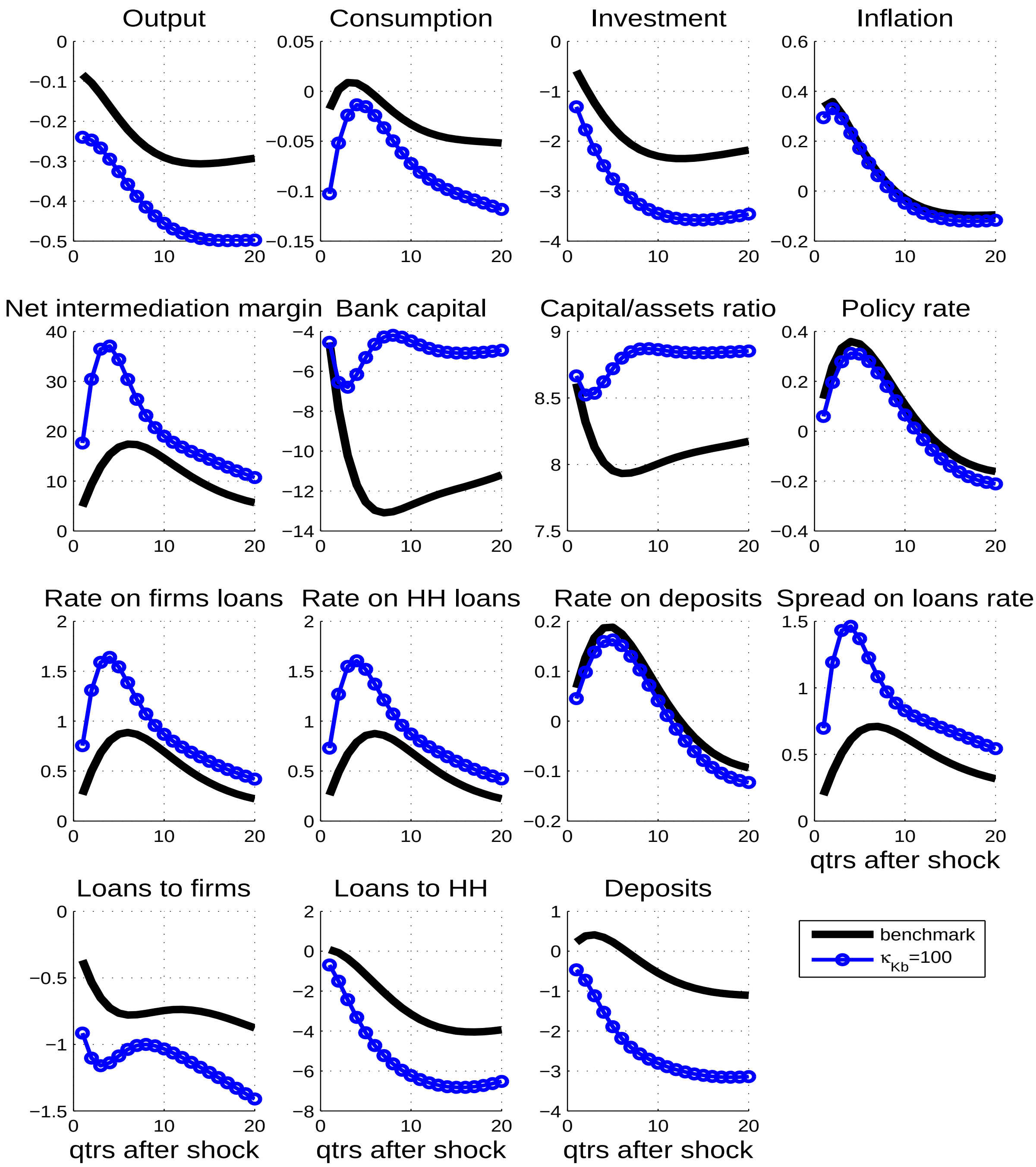
Note: The decomposition is computed using the median of the posterior distribution of the benchmark model. Macro shocks include shocks to: price and wage markups, technology, consumption preferences, housing demand, and investment-specific technology. MP refers to monetary policy shocks. Financial shocks include shocks to the loan-to-value ratios on loans to firms and households, shocks to the markup on bank interest rates and balance sheet shocks.

Figure 7. Historical decomposition of the main financial variables: 2004:Q1 - 2009:Q1



Note: The decomposition is computed using the median of the posterior distribution of the benchmark model. Macro shocks include shocks to: price and wage markups, technology, consumption preferences, housing demand, and investment-specific technology. MP refers to monetary policy shocks. The firms financial category includes shocks to LTV ratios for loans to firms and shocks to the interest rate markup on their loans. The households financial category includes shocks to LTV ratios for loans to households and shocks to the interest rate markup on their loans. Finally, other financial shocks include shocks to the interest rate markdown on deposits and shocks to banks' balance sheets.

Figure 8. Impulse responses to a negative shock to capital



Note: The impulse responses are computed using the median of the posterior distribution of the benchmark model (black solid line), and replacing $\kappa_{Kb} = 100$ (blue circled line), respectively. All rates are shown as absolute deviations from steady state, expressed in percentage points. The capital-to-assets ratio is expressed in percentage points. All others graphs report percentage deviations from steady state.

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