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Abstract

We extend the model in Iacoviello (2005) by introducing a stylized banking sector with imperfect competition and endogenous accumulation of bank capital. Banks obtain external funding from both household deposits and the interbank market. While endogenous accumulation of banking capital amplifies the effects of demand shocks, credit market power and sluggishness in bank interest rates dampen the effect of monetary policy shocks on borrowing constraints and hence on real activity, resulting in an 'attenuator' effect opposite in sign with respect to the 'financial accelerator' effect. We calibrate the banking parameters to replicate the observed sluggishness in euro area banking rates and show that this attenuator effect can be sizeable but short-lived. The model also allows analyzing the consequences of a tightening of credit conditions that reduces the supply of credit and increases banks' interest rates independently of monetary policy. In such a scenario the effects on output can be sizable, in particular on capital accumulation.

JEL: E30; E32; E43; E51; E52;

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1 Introduction

Policymakers have often highlighted the importance of financial factors in shaping the business cycle: the possible interactions between credit markets and the real economy are a customary part of the overall assessment on the policy stance. Since the onset of the financial turmoil in August 2007, banks have come again under the spotlight, as losses from subprime credit exposure and from significant write-offs on asset-backed securities raised concerns that a wave of widespread credit restrictions might trigger a severe economic downturn. Past episodes like the U.S. Great Depression, the Savings and Loans crises again in the U.S. in the 1980s or the prolonged recession in Finland and Japan in the 1990s stand as compelling empirical evidence that the banking sector can considerably affect the developments of the real economy.[1]

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

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

In this paper we introduce a banking sector in a DSGE model in order to understand

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

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

We use the model to analyze two issues. First we want to understand what role our banks play in the transmission mechanism of monetary policy. In our model, monetary policy shocks affect the economy through four different channels. Three of them are standard in economies with borrowing constraints: (1) a nominal debt channel, by which realized inflation affects the real ex-post cost of debt service; (2) a borrowing constraint channel, by which an innovation in the policy rate, changing the real rate, alters the value of relaxing the constraint; (3) an asset price channel, by which induced changes in asset prices affect the value of the collateral and hence borrowing. Sluggish (and heterogeneous) pass-through of changes in the monetary policy rate to bank rates brings about a fourth channel, a *banking attenuator effect*. While, absent banks, a change in the policy rate would be transmitted instantaneously and one-for-one into households' and firms' decisions, with sticky bank rates it does so only to the extent, and at the speed, at which banks adjust rates on loans and deposits. Considering the three channels mentioned above, this fact is likely to dampen considerably the effects that work through a change in the real rate or in the value of the collateral. We calibrate the key parameters governing the speed of adjustment of banks interest rates to replicate the average pass-through observed in the euro area banking sector and then use the model to quantify the attenuator effect after a monetary policy shock. Results from impulse response analysis show that the attenuator effect is sizeable on impact but short-lived (3-4 quarters) since bank rates, although sluggish, track quite rapidly changes in the policy rate.

The second issue is related to financial, as opposed to macroeconomic, stability and to the link between the two. Financial shocks can have a relevance of their own for real activity, and banks play a major role in their origin and, probably, in their propagation. The financial turmoil that started in summer 2007 was characterized by a gradual deterioration of banks liquidity and capital positions. Banks report that they reacted by tightening credit standards for lending to the private sector and by increasing both collateral requirements and margins on loans (see, for the euro area, the Bank Lending Surveys published by the ECB). Fears emerged that a "credit crunch" could induce a severe impact on real activity, but exactly how, and to what extent, is still open to debate. As an application of our model we simulate a "financial turmoil" scenario, where banks increase their margins on loans by raising retail rates, independently of monetary policy, and reduce the availability of credit to the private sector, by increasing collateral requirements. Effects on real activity are substantial, particularly on capital accumulation. Most of the adverse impact comes from the restriction on credit to firms, as it quickly spills over and adds up to the household sector, generating a considerable fall in aggregate demand and output.

The rest of the paper is organized as follows. Section 2 reviews the main contributions in the literature on financial frictions in DSGE models. Section 3 outlines the structure of the model, while Section 4 discusses calibration of the main parameters. Section 5 explains the propagation mechanism of the model and presents the results of a monetary policy restriction and a "financial turmoil" experiment. Section 6 concludes.

2 Related literature

Recently, the literature on the role of financial variables in the business cycle has focused on the macroeconomic implications of frictions in the credit market. In order to mitigate the agency costs in lending relations due to asymmetric information, financial agreements usually link the amount or the cost of credit that lenders are willing to grant to borrowers' balance-sheet conditions. Thus, as the financial households and firms income and wealth usually co-move with the business cycle, the conditions at which borrowers can access external financing vary across the cycle. As a result, financial frictions amplify and propagate the conventional transmission mechanism of real and monetary shocks (Bernanke and Gertler, 1995). Shocks originating in financial markets, by affecting borrowers' balance sheets, spill over to the rest of the economy. Beside reinforcing the propagation of exogenous shocks, such a mechanism (the "financial accelerator") endogenously alters the business cycle. For example, with the financial accelerator the dynamics of the fluctuations become highly non-linear, as the intensity of the balance-sheet effects deepens the more the economy moves towards a peak or a trough. Moreover, the distribution of wealth among agents becomes relevant: a transfer of resources towards financially weaker borrowers might increase aggregate investment spending, by improving (average) borrowing terms.

Two main strands can be identified in the literature on the financial accelerator. One has stressed how a strong shocks amplification and propagation mechanism originates from the procyclicality of the external finance premium, i.e. the difference between the cost of external sources of funding and the opportunity cost of funds internal to the borrower (Bernanke and Gertler, 1989 and Carlstrom and Fuerst, 1997).[2] Due to agency problems in lending, which are stronger the lower is borrowers' net worth, such premium rises in bad times and falls in good times, thus amplifying the business cycle and the effects of monetary and financial shocks. Bernanke *et al.* (1999, henceforth BGG) incorporate an external finance premium into a dynamic new-keynesian framework with nominal rigidities and monopolistic competition in goods market. Their model features two groups of agents: households, who consume, work and save, and entrepreneurs, who undertake investment projects by borrowing resources from households. Lending relationships are affected by the presence of asymmetric information and agency costs. In such a framework, at the microeconomic level the optimal financial arrangement prescribes that entrepreneurs demand for capital is proportional to their net worth; in equilibrium, the external finance premium depends inversely on the proportion of the investment that is financed by the entrepreneurs own resources. BGG show that, due to financial frictions, the impact response of output to a monetary policy shocks is around 50 per cent stronger and that of investment is almost twice as large; also the persistence is strongly amplified by the introduction of the financial accelerator.

The second strand of literature has pointed out how financial accelerator effects can

[2] An external finance premium is generated form a costly state verification problem for business projects (Townsend, 1979): in order to obtain repayment from those entrepreneurs who declare bankruptcy, lenders must size up their remaining assets, paying an auditing cost (interpretable as the cost of bankruptcy). The optimal contract, i.e. the one that minimize expected agency costs, features a fixed repayment and auditing only of defaulting entrepreneurs.

be generated by fluctuations in asset prices. Following Kiyotaki and Moore (1995), many authors (e.g., Iacoviello, 2005, and Iacoviello and Neri, 2008) have assumed that agents are constrained in the amount of funds they can borrow by the value of collateral they can pledge as a guarantee to the lenders. In good times, rising asset values allow financially constrained agents to expand their borrowing and increase consumption and investment, thus further stimulating real activity; on the contrary, unfavorable shocks are amplified by ensuing collateral devaluations, which induce agents to additionally cut on their expenditures. Iacoviello (2005) incorporates borrowing constraints into a new-keynesian general equilibrium model. In his model, agents differ in their degree of "impatience" i.e. the utility value they assign to consumption at future dates. In equilibrium, patient households will want to postpone consumption and save, lending funds to more impatient households and entrepreneurs, who nevertheless are constrained in the amount they can borrow by the value of their housing collateral. In the neighborhood of the steady state where such constraint always binds, entrepreneurs' and impatient households' expenditure fluctuates, other things being equal, with the price of the collateral. Since constrained agents have a higher propensity to consume, Iacoviello shows that collateral effects can significantly strengthen the response of the real economy to demand shocks, including those hitting on house prices.[3] Christensen *et al.* (2007) develop and estimate on Canadian data a similar model with capital as entrepreneurs' collateral. They find that including a financial accelerator mechanism does not deliver a significant difference in the fit of the model nor in its ability to replicate the cross correlations of the data.

Despite the important role assigned to credit frictions, the models mentioned so far do not devote much attention to financial intermediaries. Financial transactions are typically assumed to occur through the market; BGG and Carlstrom and Fuerst (1997) mention the existence of a capital mutual fund, collecting resources from lenders and distributing them to borrowers; these intermediary, however, just perform a risk-pooling activity by collecting savings from all households and lending them to all entrepreneurs. Recent contributions to the literature have tried to provide a more realistic and complete model of the banking sector, where intermediaries have an active role in determining the price or the supply of financial assets. An example is the paper by Goodfriend and McCallum (2007), who model a perfectly competitive banking sector which supplies a multiplicity of assets which bear different yields. Banks main activity is the production of loans and deposits, employing work effort and collateral, which consists of risk-free bonds and capital. In this model, the demand for bank loans and deposits is the effect of a deposit-

[3] Iacoviello (2005) assumes that overall supply of housing is fixed. However, Iacoviello and Neri (2008) find similar results in a model in which they allow for endogenous housing investment and variable supply.

in-advance constraint on household consumption and of the timing assumption in the model, according to which households' consumption outlay precedes income cash-flow. The explicit provision of a production function for loans and deposits makes the cost of bank loans higher than the return of a risk free bond; such positive difference is interpreted as an external finance premium originating from the marginal cost of production of loans. Two closer models, in spirit, contents and objectives, to the one presented in this paper, are those by Christiano *et al.* (2007) and by Cúrdia and Woodford(2008). The first paper extends the model in BGG by introducing a perfectly competitive banking sector offering a variety of saving and liquidity services and lending to firms. Each intermediary can be thought of as being comprised of two independent units. One unit collects demand deposits (which provide transaction services but do not transfer resources across periods) from households and issue loans to firms, used to finance working capital expenditure (factors of production must be paid before output sales). The other unit replicates the framework of BGG: it collects time- and saving-deposits (yielding different returns due to differences in their transaction services) and issues loans to entrepreneurs to finance their investment projects. Their model is estimated on euro area data using Bayesian techniques and it is used to study the behavior of the economy under a number of different shocks; consistently with previous results, they show that financial frictions play an important role in the propagation of shocks and that financial factors can be useful to explain past episodes of business cycle fluctuations.

Cúrdia and Woodford (2008) assess the implications of time-varying interest rate spreads for the conduct of monetary policy. They model bank rate spreads in a very stylized way, adopting an agnostic approach on the source of those spreads. Their objective is to investigate whether standard optimal monetary policy prescriptions in a New Keynesian environment are modified by the presence of a wedge between the cost of saving and borrowing. Their main conclusion is that interest rate spreads do not qualitatively change the way that monetary policy should be conducted; however, spreads may make a difference from a quantitative point of view, especially when considering the responses of the real economy to particular shocks.

3 The model

The economy is populated by two types of households and by entrepreneurs. Households consume, work and accumulate housing (which is, on aggregate, provided in fixed supply), while entrepreneurs produce an homogenous intermediate good using capital bought from capital-good producers and labor supplied by households. Agents differ in their degree of impatience, i.e. in the discount factor they apply to the stream of future utility. We assume that patient households' discount factor β_P is higher than those of the impatient households β_I and of the entrepreneurs β_E.

Two types of one-period financial instruments, supplied by banks, are available to agents: saving assets (deposits) and loans. When taking on a bank loan, agents face a borrowing constraint, tied to the value of tomorrow collateral holdings: households can borrow against their stock of housing, while entrepreneurs' borrowing capacity is tied to the value of their physical capital. The heterogeneity in agents' discount factors determines positive financial flows in equilibrium: patient households purchase a positive amount of deposits and do not borrow, while impatient and entrepreneurs borrow a positive amount of loans.

The banking sector operates in a regime of monopolistic competition: banks set interest rates on deposits and on loans in order to maximize profits. The amount of loans issued by each intermediary cna be financed through the amount of deposits that they rise, through reinvested profits (equity or bank capital) or by tapping the interbank market, at an interest rate set by the central bank. Through this channel, policy rate decisions directly affect retail bank interest rates.

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

Two additional producing sectors exist: a monopolistically competitive retail sector and a capital-good producing sector. Retailers buy the intermediate goods from entrepreneurs in a competitive market, brand them at no cost and sell the final differentiated good at a price which includes a markup over the purchasing cost and is subject to adjustment costs. Capital good producers are used as a modeling device to derive an explicit expression for the price of capital, which enters entrepreneurs' borrowing constraint. At the beginning of each period, capital good producers buy the final good (that can be transformed one to one into investment, subject to investment adjustment costs) from retailers and the stock of old depreciated capital from entrepreneurs. Combining the two inputs, they produce new capital, which is again sold to entrepreneurs.

3.1 Households and entrepreneurs

3.1.1 Patient and impatient households

There exist two groups of households: Patients and Impatients, of mass γ_P and γ_I, respectively. The only difference between agents in the two groups is that patients' discount factor (β_P) is higher than impatients' (β_I). Within each group $T = \{P, I\}$, the representative agent i has the following program:

$$\underset{\left\{c_t^T(i), h_t^T(i), l_t^T(i), d_t^T(i), b_t^T(i)\right\}}{max} E_0 \sum_{t=0}^{\infty} \beta_T^t \left[\log(c_t^T(i) - a^T c_{t-1}^T) + \varepsilon_{j,t}^h \log h_t^T(i) - \frac{l_t^T(i)^{1+\phi}}{1+\phi}\right].$$

Utility depends on consumption $c^T(i)$, housing services $h^T(i)$ and hours worked $l^T(i)$. The parameter a^T measures the degree of (external and group-specific) habit formation in consumption; $\varepsilon_{j,t}^h$ captures exogenous shocks to the demand for housing. Household decisions have to match the following budget constraint (in real terms):

$$\begin{aligned} c_t^T(i) + q_t^h \Delta h_t^T(i) + d_t^T(i) + \frac{\left(1 + r_{t-1}^{bh}\right)}{\pi_t} b_{t-1}^T \leq W_t l_t^T(i) + \frac{\left(1 + r_{t-1}^{d}\right)}{\pi_t} d_{t-1}^T(i) + b_t^T(i) \\ -ADJ_t^{wage}(i) + J_t^R(i) + J_t^{CB}(i) \end{aligned}$$

where

$$ADJ_t^{wage}(i) \equiv \frac{\kappa^w}{2} \left[\pi_t^w - \left(\pi_{t-1}^{\zeta} \bar{\pi}^{1-\zeta}\right)\right]^2 W \left(\frac{1}{\gamma^P + \gamma^I}\right)$$

is the lump-sum union-membership fee, which covers the adjustment costs for changing the wage level (see section). The flow of expenses includes current consumption $c_t^T(i)$, accumulation of new housing $\Delta h_t^T(i)$ and of the deposit stock $d_t^T(i)$, and gross real interest paid on last period loans $\frac{\left(1+r_{t-1}^{bh}\right)}{\pi_t} b_{t-1}^T(i)$ (the inflation rate π_t is gross, i.e. it is defined as P_t/P_{t-1}). Resources are composed of wage earnings $W_t l_t^T(i)$, borrowing from banks $b_t^T(i)$, gross interest income on last period deposits $\frac{\left(1+r_{t-1}^{d}\right)}{\pi_t} d_{t-1}^T(i)$ and a number of lump-sum transfers, which include the labor union membership fee, transfers from/to the central bank profits $J_t^{CB}(i)$ and (only for patients, their sole owners) profits from retail firms $J_t^R(i)$.

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

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

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

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

$$m_t^H = \left(1 - \rho^{mh}\right) \bar{m}^H + \rho^{mh} m_{t-1}^H + \eta_t^{mh};$$

where η_t^{mh} is i.i.d., and $\bar{m}^H$ is the (calibrated) steady-state value. We introduce a stochastic LTV because we are interested in studying the effects of credit-supply restrictions on the real side of the economy. At a macro-level, the value of m_t^H determines the amount of credit that banks make available to each type of households, for a given (discounted) value of their housing stock. Thus, exogenous variations in the LTV can be interpreted as outright shocks to loan supply; later in the paper, we exploit this property to simulate a *credit crunch* scenario.

3.1.2 Entrepreneurs

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

$$\max_{\left\{c_t^E(i), k_t^E(i), l_t^E(i), d_t^E(i), b_t^E(i), u_t(i)\right\}} E_0 \sum_{t=0}^{\infty} \beta_E^t \log(c_t^E(i) - a^E c_{t-1}^E)$$

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

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

where A_t^E is an exogenous process for total factor productivity. The intermediate product is sold in a competitive market at wholesale price P_t^w. Entrepreneurs have access to deposit and loan contracts ($d_t^E(i)$ and $b_t^{EE}(i)$, in real terms, respectively) offered by banks, which they use to implement their saving and borrowing decisions. Entrepreneurs' flow budget constraint in real terms is thus the following:

$$\begin{aligned} c_t^E(i) + w_t l_t^E(i) + d_t^E(i) + \frac{(1 + r_{t-1}^{be}) b_{t-1}^{EE}(i)}{\pi_t} + q_t^k k_t^E(i) + k_{t-1}^E(i) \left[\xi_1 (u_t(i) - 1) + \frac{\xi}{2} (u_t(i) - 1)^2\right] \\ = \frac{y_t^E(i)}{x_t} + b_t^{EE}(i) + q_t^k (1 - \delta) k_{t-1}^E(i) + J_t^{CB}(i) + \frac{(1 + r_{t-1}^d) d_{t-1}^E(i)}{\pi_t}. \qquad (2) \end{aligned}$$

In the above, q_t^k is the price of one unit of physical capital in terms of consumption; $J_t^{CB}(i)$ are lump-sum transfers to/from the central bank; $\psi[u_t(i)]k_{t-1}^E(i)$ is the cost, in units of consumption goods, of setting a level $u_t(i)$ of utilization rate, with $\psi(u_t) = \xi_1(u_t - 1) + \frac{\xi_2}{2}(u_t - 1)^2$; $1/x_t$ is the price of the wholesale good produced by the entrepreneur in terms of the consumption good, i.e. x_t is defined as P_t/P_t^W.

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

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

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

$$m_t^E = (1 - \rho^{me})\,\bar{m}^E + \rho^{me} m_{t-1}^E + \eta_t^{me};$$

with η_t^{mh} i.i.d.. The assumption on the discount factor β_E and of "small uncertainty" allows us to solve the model by imposing an always binding borrowing constraint for the entrepreneurs.

In order to shed light on how the presence of borrowing constraints affects capital accumulation, we can rearrange the budget constraint, after replacing borrowing at time t with the expression obtained by solving for $b_t^{EE}(i)$ under equality in (3). The resulting equation is:

$$k_t^E(i) = \frac{1}{\varphi_t} N_t^E(i) \tag{4}$$

where

$$\varphi_t^E \equiv q_t^k - \frac{m_t^E \mathrm{E}_t[q_{t+1}^k \pi_{t+1}(1-\delta)]}{1 + r_t^{be}} \tag{5}$$

φ_t can be interpreted as the downpayment required to buy one unit of physical capital. N_t^E stands for entrepreneur's net worth and it is given by (after imposing the equilibrium result that $d_t^E(i) = 0$ for all t):

$$N_t^E(i) = \frac{y_t^E(i)}{x_t} - c_t^E(i) - w_t l_t^E(i) + q_t^k(1-\delta)k_{t-1}^E(i) - \frac{\left(1 + r_{t-1}^{be}\right) b_{t-1}^{EE}(i)}{\pi_t} - \psi\left[u_t(i)\right] k_{t-1}^E(i) - J_t^{CB}(i).$$

The amount of capital that entrepreneurs will accumulate is a multiple of their net worth at the end of the period: for each unit of own resources, they will be able to obtain $1/\varphi_t$ units of capital. The resource gap between own funds and the cost of purchasing new capital is financed through bank loans, which can easily be shown to satisfy

$$b_t^E = (1/\varphi_t - 1)N_t^E\,. \tag{6}$$

From equation 5 it is clear that the required downpayment is a function of the relevant real interest rate for entrepreneurs $\left(1+r_t^{be}\right)/E_t\pi_{t+1}$ and present and expected future price of capital. In particular, when the real interest rate rises or the future price of capital fall, one unit of own resources is able to rise a smaller amount of capital: such a mechanism is at the heart of the financial accelerator, according to which monetary policy shock or other types of financial shocks have a stronger effect on real activity when borrowers are financially constrained. It is also interesting to observe how the magnitude of such financial accelerator effects crucially depends on the value of m_t^E, which measures the intensity of collateral effects: as m_t^E rises, an increasing portion of capital is collateralizable, so that the impact of changes in the present discounted value of future capital holdings (via changes in the real interest rate or the future price of capital) becomes more and more important.

3.1.3 Labor market

We assume that there exists a continuum of labor types and one union for each labor type n. Each union is representative of the whole household population, i.e. it includes γ^P patients and γ^I impatients. Its discount factor β_U is a weighted average of those of its members. The typical union n sets nominal wages for workers of its labor type by maximizing a weighted average of its members' utility, subject to a constant-elasticity (ϵ_l) demand schedule and to adjustment costs, with indexation to a weighted average of lagged and steady-state inflation. The union equally charges each member household with lump-sum fees to cover adjustment costs. In a symmetric equilibrium, the labor choice for each single household in the economy will be given by the (non-linear) wage-Phillips curve:

$$\begin{aligned}\left(\frac{\gamma^P}{c_t^P - a^P c_{t-1}^P} + \frac{\gamma^I}{c_t^I - a^I c_{t-1}^I}\right)\left[\kappa_w(\pi_t^w - \pi_{t-1}^{\zeta}\pi^{1-\zeta})\pi_t^w - (1-\varepsilon_l)l_t^T\right] = \\ = \left(\gamma^P + \gamma^I\right)\varepsilon_l \frac{l_t^{T\,1+\sigma_l}}{w_t} + \kappa_w \beta_U E_t\left\{\left(\frac{\gamma^P}{c_{t+1}^P - a^P c_t^P} + \frac{\gamma^I}{c_{t+1}^I - a^I c_t^I}\right)(\pi_{t+1}^w - \pi_t^{\zeta}\pi^{1-\zeta})\frac{\pi_{t+1}^{w\;2}}{\pi_{t+1}}\right\}.\end{aligned} \tag{7}$$

We also assume the existence of perfectly competitive "labor packers" who buy the differentiated labor services from unions, transform them into an homogeneous composite labor input and sell it, in turn, to intermediate-good-producing firms. This assumptions yield a demand for each kind of differentiated labor service $l_t(n)$ equal to

$$l_t(n) = \left(\frac{W_t(n)}{W_t}\right)^{-\varepsilon_l} l_t \tag{8}$$

where W_t:

$$W_t = \left[\int_0^1 W_t(n)^{1-\varepsilon_l} di\right]^{\frac{1}{1-\varepsilon_l}}$$

is the aggregate wage in the economy.

3.2 Banks

3.2.1 Deposit and loan demand

We assume that deposits and loans to households and to entrepreneurs are in fact a composite CES basket of slightly differentiated products, each supplied by a single bank with elasticities of substitution equal to ε_t^d, ε_t^{bh} and ε_t^{be}, respectively. Thus (as in the standard Dixit-Stiglitz framework for goods markets), agents have to purchase deposit (loan) contracts by each bank in order to save (borrow) one unit of resources. Although this assumption might seem unrealistic, it is just a useful modeling device to capture the existence of market power in the banking industry.[4]

Following Smets and Wouters (2003), we assume that the elasticity of substitution in the banking industry is stochastic. Like for the LTV, this choice again arises from our interest in studying how exogenous shocks hitting the banking sector transmit to the real economy. As will appear clear below, ε_t^d, ε_t^{bh}, ε_t^{be} affect the value of the spreads between the policy rate (r_t^{IB}) and the retail banking rates (r_t^d, r_t^{bh} and r_t^{be}), pinning-down the value of those spreads in steady-state. Innovations to the elasticities of substitution can thus be interpreted as changes to the banking interest rate spreads arising independently of monetary policy; it is evident that such a framework is particularly appealing to analyze exogenouse increases in loan spreads such as those observed since the onset of the financial turmoil in the summer of 2007. More in detail, the elasticities of substituion for deposit, loans to households and loans to firms are given by the AR(1) processes:

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

$$\varepsilon_t^d = (1 - rho^{\varepsilon^d})\bar{\varepsilon}^d + rho^{\varepsilon^d}\varepsilon_{t-1}^d + \eta_t^{\varepsilon^d}$$
$$\varepsilon_t^{bh} = (1 - rho^{\varepsilon^{bh}})\bar{\varepsilon}^{bh} + rho^{\varepsilon^{bh}}\varepsilon_{t-1}^{bh} + \eta_t^{\varepsilon^{bh}}$$
$$\varepsilon_t^{be} = (1 - rho^{\varepsilon^{be}})\bar{\varepsilon}^{be} + rho^{\varepsilon^{be}}\varepsilon_{t-1}^{be} + \eta_t^{\varepsilon^{be}}.$$

As regards the deposit contract, a given amount of (real) savings $d_t^T(i)$ that agent i of type $T = \{P, I, E\}$ wants to deposit will be distributed across banks so as to maximize the revenue of total savings. More precisely, agent i will choose how much to deposit at the bank j by solving the following expression

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

subject to the aggregation technology

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

The first-order condition of this problem gives agent i's demand for deposit contracts at bank j. Aggregating across all households and entrepreneurs, we obtain aggregate deposit demand for bank j as

$$d_t^B(j) = \left(\frac{r_t^d(j)}{r_t^d}\right)^{-\varepsilon_t^d} d_t \tag{9}$$

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

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

Note that $\varepsilon_t^d < 0$, otherwise the household problem would be unbounded. So, the demand curve for the individual has a positive slope: when the interest rate that the bank offers on its deposits is higher relatively to the average rate prevailing in the market, households will want to deposit a higher proportion of their savings in that bank.

A similar approach is used to derive the demand for household and firm loans faced by an individual bank j. Households and entrepreneurs seeking an amount of borrowing equal to $b_t^T(i)$ (with $T = \{P, I\}$) and $b_t^{EE}(i)$, respectively, would allocate their borrowing among different banks so as to minimize the due total repayment. For hoseholds i:

$$\min_{\{b_t^T(i,j)\}} \int_0^1 r_t^{bh}(j) b_t^H(i,j) dj$$

subject to

$$\left[\int_0^1 b_t^T(i,j)^{\frac{\varepsilon_t^{bh}-1}{\varepsilon_t^{bh}}}dj\right]^{\frac{\varepsilon_t^{bh}}{\varepsilon_t^{bh}-1}} \geq b_t^T(i)$$

Analogously, for entrepreneurs:

$$\min_{\left\{b_t^{EE}(i,j)\right\}} \int_0^1 r_t^{be}(j) b_t^{EE}(i,j) dj$$

subject to

$$\left[\int_0^1 b_t^{EE}(i,j)^{\frac{\varepsilon_t^{be}-1}{\varepsilon_t^{be}}}dj\right]^{\frac{\varepsilon_t^{be}}{\varepsilon_t^{be}-1}} \geq b_t^{EE}(i)$$

The first-order conditions for these problems give household i's and entrepreneur i's demand for loan contracts at bank j. Aggregating across all households and across all entrepreneurs, we obtain aggregate housheold and firm loan demand for bank j as

$$b_t^H(j) = \left(\frac{r_t^{bh}(j)}{r_t^{bh}}\right)^{-\varepsilon_t^{bh}} b_t^H \tag{10}$$

and

$$b_t^E(j) = \left(\frac{r_t^{be}(j)}{r_t^{be}}\right)^{-\varepsilon_t^{be}} b_t^E \tag{11}$$

where $b_t^H \equiv \left(\gamma^P b_t^P(i) + \gamma^I b_t^I(i)\right)$ and $b_t^E \equiv \left(\gamma^E b_t^{EE}(i)\right)$ indicate aggregate demand for household and entrepreneurial loans, respectively, and r_t^{bh} and r_t^{be} are average interest rates on loans, defined as:

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

and

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

3.2.2 Optimal interest rate setting

The banking sector comprises a continuum of monopolistically competitive "commercial" banks (henceforth, just "banks"). Banks' balance sheet is highly stylized but it captures the basic element of financial intermediation. On the liability side, each bank j obtains funding by raising deposits $d_t(j)$, by tapping the interbank market for an amount $m_t(j)$ or by raising equity $(k_t^B(j))$; on the asset side, bank j provides loans to households $b_t^H(j)$ and to entrepreneurs $b_t^E(j)$. Given the assumption that the banking sector operates in a regime of monopolistic competition, each bank j faces an upward sloping demand curve for deposits and a downward sloping one for loans, as shown before. This market power allows each individual bank to set its own interest rates $r_t^d(j)$, $r_t^{bh}(j)$ and $r_t^{be}(j)$ so as to maximize profits; we will show that optimality requires to set rates on deposits as a mark-down over the interest rate prevailing in the interbank market (r_t^{IB}) and that the rates on loans will be set as a markup over the marginal cost of funding for banks, which depends on the interbank interest rate and on the cost of equity. Banks face quadratic adjustment costs when changing their rates; the parameters determining the speed of adjustment to changes in the policy rate are κ_d, κ_h and κ_e, for deposits, household loans and entrepreneurial loans, respectively, and are calibrated in order to match the stickiness in banking rates observed in the data (see section 4).

In order to understand the interest-rate setting mechanism, it is useful to think of a single bank as consisting of two different branches: a "deposit-collecting unit" and a "loan-issuing unit". Every unit is managed independently with the objective of maximizing their individual profits; total bank profits consist of the sum of the profits of the two different branches, and are equal to (in real terms):

$$\begin{aligned} j_t^B(j) = & \left[r_{t-1}^{bh} b_{t-1}^H(j) + r_{t-1}^{be} b_{t-1}^E(j) - mc_{t-1}^B(j)\left[b_{t-1}^H(j) + b_{t-1}^E(j)\right] + \left[r_{t-1}^{ib} - r_{t-1}^d\right] d_{t-1}^B(j) \right. \\ & \left. - \frac{\kappa_d}{2}\left(\frac{r_{t-1}^d}{r_{t-2}^d} - 1\right)^2 r_{t-1}^d d_{t-1} - \frac{\kappa_e}{2}\left(\frac{r_{t-1}^{be}}{r_{t-2}^{be}} - 1\right)^2 r_{t-1}^{be} b_{t-1}^E - \frac{\kappa_h}{2}\left(\frac{r_{t-1}^{bh}}{r_{t-2}^{bh}} - 1\right)^2 r_{t-1}^{bh} b_{t-1}^H\right] \frac{1}{\pi_t}. \end{aligned} \tag{12}$$

The first unit's only task is collecting deposits; the amount of deposits actually raised is influenced by the choice of the return it offers to the depositors, who have a positive-sloping demand curve for an individual bank's deposits, as shown before. We assume that, for a unit of deposits, the amount of profits attributed to this unit of the bank is equal to the diffence between the interbank rate and the deposit rate. In practical terms, one can think of the interbank rate as the figurative value at which transfers of cash between the two branches are registered.

Thus, when optimally choosing the deposit rate, bank j solves the following problem:

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

s.t.

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

where $r_t^d(j)$ is the choice variable, r_t^d is taken as given by the individual bank , $d_t^B(j)$ is the demand for this bank's deposits at time t and d_t is the economy-wide demand for deposits. The term containing κ_d determines the quadratic adjustment cost incurred by the bank if it sets $r_t^d(j)$ to a level different from $r_{t-1}^d(j)$.

After imposing a symmetric equilibrium, the first-order condition for optimal interest rate setting is

$$-1 + \varepsilon_t^d - \varepsilon_t^d \frac{r_t^{IB}}{r_t^d} - \kappa_d \left(\frac{r_t^d}{r_{t-1}^d} - 1 \right) \frac{r_t^d}{r_{t-1}^d} + \beta_B E_t \left\{ \frac{\lambda_{t+1}^B}{\lambda_t^B} \kappa_d \left(\frac{r_{t+1}^d}{r_t^d} - 1 \right) \left(\frac{r_{t+1}^d}{r_t^d} \right)^2 \frac{d_{t+1}}{d_t} \right\} = 0 \ . \quad (13)$$

β_B and λ^B, respectively, denote the discount factor and the marginal utility of consumption of bankers (see section 3.2.3), who are the owners of the banks. The linearized version of 13 is

$$\hat{r}_t^d = \frac{\kappa_d}{1 + \varepsilon_t^d + (1 + \beta_B)\kappa_d} \hat{r}_{t-1}^d + \frac{\beta_B \kappa_d}{1 + \varepsilon_t^d + (1 + \beta_B)\kappa_d} E_t \hat{r}_{t+1}^d + \frac{1 + \varepsilon_t^d}{1 + \varepsilon_t^d + (1 + \beta_B)\kappa_d} \hat{r}_t^{IB} \quad (14)$$

The equation above shows that the deposit interest rate is set by the banks in the model according to a sort of "interest-rate Phillips curve" (hatted values denote percentage deviations from the steady-state). Solving the equation forward, it can be easily shown that the deposit interest rate is set taking into account the expected future level of the policy rate; the speed of adjustment to changes in the policy rate depends inversely on the intensity of the adjustment costs (as measured by κ_d) and positively on the degree of competition in the banking sector (as measured by the inverse of ε_t^d).

It is also useful to observe that, with fully flexible rates, r_t^d is determined as a markdown on the policy rate:

$$r_t^d = \frac{\varepsilon_t^d}{\varepsilon_t^d - 1} r_t^{IB} = \frac{|\varepsilon_t^d|}{|\varepsilon_t^d| + 1} r_t^{IB} \quad (15)$$

where the last equality follows from the fact that $\varepsilon_t^d < 0$. Deposits are essentially an input for banks and in this factor market the intermediaries are price makers, while they take the (figurative) “output” price r_t^{IB} as given; banks thus exploit their market power to lower their marginal cost (and increase profits) as much as possible given the demand constraint. The spread between the policy rate and the cost of deposits thus depends on the elasticity of substitution among deposit varieties; later in the paper, we use this relation to calibrate the steady-state value of ε_t^d ($\bar{\varepsilon}^d$; see section 4).

The loan-issuing branch of the bank faces a somewhat more complex problem. Given the downward-sloping demand curve, its task is that of setting the loan interest rate on household and firm loans so as to maximize profits. In order to issue loans, banks must have a sufficient level of funding, which can be obtained via either external or internal financing. External funding is constituted by the deposits collected by the first unit of the bank $\left(d_t^B(j)\right)$, which are transferred to this unit at the (figurative) cost of r_t^{IB} (see the discussion above), and by additional (illimited) funds obtained from the central bank ($m_t(j)$), at the same (but effective) rate as for deposits.[5] Internal funds consist instead of capital $\left(k_t^B(j)\right)$. As a modeling device, we assume that banks rent (at the cost r_t^{kb}) the amount of capital that they desire, while another category of agents (*bankers*) accumulates that capital; in fact, as will be clear in section 3.2.3, bank capital is reinvested profits from intermediation activity and can thus be considered as internal bank resources. External funding and equity are combined to produce loans according to the following technology:

$$b_t^H(j) + b_t^E(j) = A_t^B \left[{k^B}_{t-1}^{\chi^b}(j) [m_t(j) + d_t^B(j)]^{1-\chi^b} \right] \tag{16}$$

where A_t^B is a shock to the productivity in the banking sector.

Given the production technology for loans, the marginal cost of producing a unit of loans $\left(mc^B(j)\right)$ is independent on the amount of loans, and equal to:

$$mc_t^B(j) = \frac{\left(r_t^{kB}\right)^{\chi^B} \left(r_t^{IB}\right)^{1-\chi^B}}{A_t^B \left(\chi^B\right)^{\chi^B} \left(1-\chi^B\right)^{(1-\chi^B)}} \tag{17}$$

while the optimal input ratio for the bank is given by:

$$\frac{m_t(j) + d_t^B(j)}{k_t^B(j)} = \frac{r_t^{kB}}{r_t^{IB}} \frac{\left(1-\chi^B\right)}{\chi^B} \tag{18}$$

Thus, the profit-maximimzation problem for the loan-producing unit of the bank is

[5] The assumption that unlimited funding can be obtained by the central bank allows us to separate the profit-maximization problem of the two branches of the bank, as it makes the decisions on loan and deposit interest rates independent to each other.

$$\max_{\left\{r_t^{bh}(j), r_t^{be}(j)\right\}} E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^P \left[r_t^{bh} b_t^H(j) + r_t^{be} b_t^E(j) - mc_t^B(j) \left(b_t^H(j) + b_t^E(j) \right) - \right.$$

$$\left. \frac{\kappa_{bh}}{2} \left(\frac{r_t^{bh}(j)}{r_{t-1}^{bh}(j)} - 1 \right)^2 r_t^{bh} b_t^H - \frac{\kappa_{be}}{2} \left(\frac{r_t^{be}(j)}{r_{t-1}^{be}(j)} - 1 \right)^2 r_t^{be} b_t^E \right]$$

subject to demand schedules

$$b_t^H(j) = \left(\frac{r_t^{bh}(j)}{r_t^{bh}} \right)^{-\varepsilon_t^{bh}} b_t^H \tag{19}$$

and

$$b_t^E(j) = \left(\frac{r_t^{be}(j)}{r_t^{be}} \right)^{-\varepsilon_t^{be}} b_t^E \tag{20}$$

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

$$1 - \varepsilon_t^{be} + \varepsilon_t^{be} \frac{mc_t^B}{r_t^{be}} - \kappa_e \left(\frac{r_t^{be}}{r_{t-1}^{be}} - 1 \right) \frac{r_t^{be}}{r_{t-1}^{be}} + \beta_B E_t \left\{ \frac{\lambda_{t+1}^B}{\lambda_t^B} \kappa_e \left(\frac{r_{t+1}^{be}}{r_t^{be}} - 1 \right) \left(\frac{r_{t+1}^{be}}{r_t^{be}} \right)^2 \frac{b_{t+1}^E}{b_t^E} \right\} = 0 \tag{21}$$

$$1 - \varepsilon_t^{bh} + \varepsilon_t^{bh} \frac{mc_t^B}{r_t^{bh}} - \kappa_h \left(\frac{r_t^{bh}}{r_{t-1}^{bh}} - 1 \right) \frac{r_t^{bh}}{r_{t-1}^{bh}} + \beta_B E_t \left\{ \frac{\lambda_{t+1}^B}{\lambda_t^B} \kappa_h \left(\frac{r_{t+1}^{bh}}{r_t^{bh}} - 1 \right) \left(\frac{r_{t+1}^{bh}}{r_t^{bh}} \right)^2 \frac{b_{t+1}^H}{b_t^H} \right\} = 0 \tag{22}$$

The log-linearized version of the loan-rate setting equations is

$$\hat{r}_t^{Bj} = \frac{\kappa_j}{\varepsilon_t^{bj} - 1 + (1+\beta_B)\kappa_j} \hat{r}_{t-1}^{Bj} + \frac{\beta_B \kappa_j}{\varepsilon_t^{bj} - 1 + (1+\beta_B)\kappa_j} E_t \hat{r}_{t+1}^{Bj} + \frac{\varepsilon_t^{bj} - 1}{\varepsilon_t^{bj} - 1 + (1+\beta_B)\kappa_j} \hat{mc}_t^B \tag{23}$$

where $j = h, e$. Loan rates are set by banks taking into account the expected future path of marginal costs. The hybrid nature (both backward- and forward-looking) of interest rate-fixation catches the real-world features that variable-rate loan contracts adjust with lags to changes in the funding cost of banks and in the policy rate in particular, as they are reviewed only at periodic intervals and that fixed-rate contracts take into account also expectations on future financing conditions.

With perfectly flexible rates, the pricing equations become:

$$r_t^{be} = \frac{\varepsilon_t^{be}}{\varepsilon_t^{be} - 1} mc_t^B \tag{24}$$

$$r_t^{bh} = \frac{\varepsilon_t^{bh}}{\varepsilon_t^{bh} - 1} mc_t^B \tag{25}$$

As expected, in this case interest rates on loans are set as mark-up a over the marginal cost.

3.2.3 Bankers

As mentioned in the previous section, in order to introduce bank capital (k_t^b) we resort to the modeling device of assuming the existence of a new category of agents, *Bankers*, that accumulate and rent bank equity to banks. This choice, which allows to make the cost of capital explicit, does not prevent us from considering bank capital as an internal source of funding for banks. The reason for this is that bankers get all profits from intermediation activity, as they are the sole owners of banks, and can only invest in bank capital. Thus, the change in equity in each period corresponds to reinvested bank earnings, i.e. profits net of the part of them which is distributed and consumed by bankers.

Banker j's problem is to choose consumption ($c_t^B(j)$) and the level of next period bank capital ($k_t^B(j)$) so as to solve:

$$\max_{c_t^B(j), k_t^B(j)} E_0 \sum_{t=0}^{\infty} \beta_B^t \log(c_t^B(j) - a^B c_{t-1}^B)$$

subject to the budget constraint:

$$c_t^B(j) + k_t^B(j) \leq \left(1 + r_{t-1}^{kb} - \delta^b\right) k_{t-1}^B(j) + j_t^B(j) \tag{26}$$

where r_{t-1}^{kb} is the rental rate of bank capital and $j_t^B(j)$ is given by equation (12).

3.3 Retailers

Following BGG (1999), we introduce sticky price in the production sector by assuming monopolistic competition at the retail level and quadratic price adjustment costs. Retailers are just "branders" : they buy the intermediate good from entrepreneurs at the wholesale price P_t^W and differentiate the goods at no cost. Each retailer j then sales their unique variety at a mark-up over wholesale price. We assume that retailers' prices are indexed to a combination of past and steady-state inflation, with relative weights equal to ζ and $(1-\zeta)$ respectively; if they want to change their price by more than indexation they have to pay a proportional adjustment cost. In a symmetric equilibrium, the (non-linearized) Phillips curve is given by the retailers' problem first-order condition:

$$1-\varepsilon_y+\frac{\varepsilon_y}{x_t}-\kappa_p(\pi_t-\pi_{t-1}^{\zeta}\pi^{1-\zeta})\pi_t+\beta_P E_t\left[\frac{c_t^P-a^P c_{t-1}^P}{c_{t+1}^P-a^P c_t^P}\kappa_p(\pi_{t+1}-\pi_t^{\zeta}\pi^{1-\zeta})\pi_{t+1}\frac{y_{t+1}}{y_t}\right]=0 \tag{27}$$

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

3.4 Capital goods producers

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

$$k_t(j) = (1-\delta)k_{t-1}(j) + \left[1 - \frac{\kappa_i}{2}\left(\frac{i_t(j)}{i_{t-1}(j)} - 1\right)^2\right] i_t(j) \tag{28}$$

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

3.5 Monetary policy

A central bank is able to exactly set the interest rate prevailing in the interbank market r_t^{IB}, by supplying all the demanded amount of funds in excess of the net liquidity position in the interbank market.[7] We assume that profits made by the central bank on seignorage are evenly rebated in a lump-sum fashion to households and entrepreneurs. In setting the policy rate, the monetary authority follows a Taylor rule of the type

$$\left(1+r_t^{IB}\right) = \left(1+r^{IB}\right)^{(1-\rho^{IB})}\left(1+r_{t-1}^{IB}\right)^{\rho^{IB}}\left(\frac{\pi_t}{\pi}\right)^{\phi_\pi(1-\rho^{IB})}\left(\frac{Y_t}{Y_{t-1}}\right)^{\phi_y(1-\rho^{IB})} \varepsilon_t^{r^{IB}} \tag{29}$$

where ϕ_π and ϕ_y are the weights assigned to inflation and output stabilization, respectively, r^{IB} is the steady-state nominal interest rate and $\varepsilon_t^{r^{IB}}$ is an exogenous shock to monetary

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

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

policy. The transfers from/to the central bank equal:

$$J_t^{CB} = \left(1 + r_{t-1}^{IB}\right) M_{t-1}, \tag{30}$$

where M is the aggregate (net) liquidity immission to the banking sector.

3.6 Aggregation and market clearing

Equilibrium in the goods market is expressed by the resource constraint

$$Y_t = C_t + q_t^k \left[C_t - (1-\delta)K_{t-1}\right] + K_t\psi\left[u_t\right] + adj_t \tag{31}$$

where C_t denotes aggregate consumption and is given by

$$C_t = c_t^P + c_t^I + c_t^E + c_t^B = \gamma^P c_t^P(i) + \gamma^I c_t^I(i) + \gamma^E c_t^E(i) + \gamma^B c_t^B(i)\,, \tag{32}$$

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

Equilibrium in the housing market is given by

$$\bar{h} = \gamma^P h_t^P(i) + \gamma^I h_t^I(i) \tag{33}$$

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

4 Calibration

Standard parameter values are calibrated within the range considered in the New Keynesian/RBC literature, in order to obtain reasonable values for some key steady-state ratios, such as consumption and business investment to GDP (taking into account that the model does not include a public sector; see Tables 1A and 1B). We set the patients' discount factor at 0.9943, in order to obtain a steady-state interest rate on deposits slightly above 2 per cent on an annual basis, in line with the average monthly rate on M2 deposits in the euro area between January 1998 and March 2008.[8] As for impatient households' and

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

entrepreneurs' discount factors β_I and β_E, we set them at 0.975, in the range suggested by Iacoviello (2005) and Iacoviello and Neri (2008). Bankers' discount factor β_B is chosen equal to those of patient agents. The mean value of the weight of housing in households' utility function ε_j^h is set at 0.2, close to the value in Iacoviello and Neri (2008). The parameters measuring the degree of habits in consumption are calibrated to 0.6 in line with the available estimates for the euro area (see Smets and Wouters, 2003). The parameter governing price stickiness in the retail sector κ_p is set at 100, in order to obtain the same degree of stickiness as in Iacoviello (2005).[9] In the labor market we assume the same degree of nominal rigidities, so we set also κ_w at 100. As for the loan-to-value (LTV) ratios, we set $\bar{m}^I$ at 0.7 in line with evidence for mortgages in the main euro area countries (0.7 for Germany, 0.5 for Italy and 0.8 for France and Spain), as pointed out by Calza *et al.* (2007). The calibration of $\bar{m}^E$ is somewhat more problematic: Iacoviello (2005) estimates a value of 0.89, but, in his model, only commercial real estate can be collateralized; Christensen *et al.* (2007), estimate a much lower value (0.32), in a model for Canada where firms can borrow against business capital. Using data over the period 1999-2007 for the euro area we estimate an average ratio of long-term loans to the value of shares and other equities for the non financial corporations sector of around 0.41; using short-term instead of long-term loans we obtain a smaller value of around 0.2. Based on this evidence, we decided to set $\bar{m}^E$ at 0.25 in the benchmark model and to conduct in the next Section a sensitivity analysis to study how this and other parameter choices modify the transmission of a monetary policy shock. These LTV ratios imply a steady-state shares of household and entrepreneur loans equal to 49 and 51 per cent, respectively.

For the banking parameters, no corresponding estimates are available in the literature. Thus, we calibrate them so as to replicate some statistical properties of bank interest rates and spreads. Equation (15) shows that the steady-state spread between the deposit rate and the interbank rate depends on ε_t^d; thus, to calibrate $\bar{\varepsilon}^d$ we calculate the average monthly spread between banking rates in our sample and the 3-month Euribor, which corresponds to around 150 basis points on an annual basis, implying that $\bar{\varepsilon}^d = -1.3$. Analogously, we calibrate ε_t^{bh} and ε_t^{be} by exploiting the steady-state relation between the marginal cost of loan production and household and firm loan rates, implicit in equations (24) and (25); the values obtained are 5.1 and 3.5, respectively. The parameter χ^B, entering the production function for loans, is set at 0.09, so as to obtain a steady-state ratio of bank capital to loans equal to 7.9 percent.

[9] Iacoviello (2005) employs a Calvo-specification for nominal rigidities and he calibrates a 25 per cent probability for firms to adjust prices in each quarter; we set κ_p so as to obtain the same slope for the Phillips curve.

As for the parameters governing interest rate stickiness, their calibration is based on the impact response of the corresponding variables obtained using a small scale VAR. The model includes the banks interest rates on deposits, loans to households and loans to firms, the three-month money market rate and a monthly interpolation of the output gap. The latter variables is constructed using real-time estimates of the output gap from the IMF and the OECD interpolated to the monthly frequency using a set of economic indicators including the survey of the European Commission, the Purchasing Managers' Index and the Bank of Italy/CEPR Eurocoin. The VAR, in which the variables enter in levels, has three lags and is estimated using data for the period 1999:1 2008:3. Figure 1 reports the impulse responses to an innovation in the money market rate and the 0.68 and 0.90 probability intervals computed with Monte Carlo methods. The impact response of the interest rate on deposits to an exogenous increase of 25 basis points in the three-month rate is equal to 3.3 basis points. For the interest rates on loans to households and firms the corresponding numbers are, respectively, 7.8 and 10.5 basis points. These results are broadly in line with the findings in de Bondt (2005) for the euro area. The impact responses obtained from our VAR are then used to calibrate the adjustment costs parameter for banks interest rates. These values turn out to be equal to 11 for deposits (κ_d), 6 for loans to households (κ_H) and 5 for the loans to firms (κ_E). The implied response on impact in the model are equal to respectively, 3.3, 7.9 and 10.4 basis points.

5 The propagation mechanism

In this Section we study the dynamics of the linearized model using impulse responses. To this end we focus on a contractionary monetary policy shock, on an expansionary technology innovation and on a combined experiment in which banks increase interest rates on loans to firms and households and contemporaneously reduce the quantity of credit (a *credit crunch scenario*). Our aim is twofold. First, we want to assess whether and how the transmission mechanism of monetary and technology shocks is affected by the presence of financial frictions and financial intermediation and how different our findings are from those of other papers that share some of our features, such as Iacoviello (2005), Christiano *et al.* (2007) or Goodfriend and McCallum (2007); we also want to analyze the impact of this type of shocks on the profitability and capital position of financial intermediaries, a task that our model is well suited to accomplish since it features an optimizing banking sector with endogenous capital accumulation. Secondly, we want to study the propagation mechanism of shocks originating in credit markets and study the possible implications for real activity of a crunch in lending, i.e. a contemporaneous restriction in the cost and quantity of credit supplied, operated by banks via an increase in lending margins and a reduction in the amount of loans issued.

5.1 Monetary policy shock

The transmission of a monetary policy shock is first studied by analyzing the benchmark model impulse responses to an unanticipated 25 basis points increase in the policy rate (r_t^{IB}; see Fig. 2). The transmission mechanism in our model is affected by the presence of a real rate effect (here working also through a change in the net present value of the collateral), of a financial accelerator effect (working through a change in asset prices), of a nominal debt effect (working through a wealth redistribution effect that originates from the presence of nominal contracts) and, finally, by the presence of monopolistically competitive banks with sticky interest rate setting and endogenous capital accumulation. The first three factors have already been analyzed in the literature and they have been shown to contribute to amplify and propagate the initial impulse of a monetary policy restriction (Iacoviello, 2005; Calza *et al.*, 2007); the importance of banks' decisions has instead been almost ignored: our results suggest that the slow adjustment of retail interest rates attenuates the impact response of real variables to a monetary shock, while the presence of bank capital amplifies them.

After an official rate rise, since prices are sticky, inflation does not rise on impact and thus real rates rise too. This triggers an interest rate channel modified by the presence of borrowing constraints: aggregate consumption falls, due to the standard response of patient agents, who decide to pospone consumption in the face of higher interest rates (constrained agents, instead, are not induced to pospone consumption, as in the local equilibrium that we analyze they are eager for consuming more immediately if endowed with more resources).Entrepreneurs respond to the decrease in demand by cutting production and investment, which in turn depresses labor and capital income for households. House prices face a downward pressure from the fall in housing demand (supply is fixed); the value of installed capital (Tobin's q) falls, given the lower expected future production.

A second channel works through a debt-deflation effect. The contraction spurred by the increase in real rates induces a fall in the general price level and this puts additional strain on borrowers' balance-sheets by raising the real cost of current debt obligations ($\left(1 + r_{t-1}^{B}\right)/\pi_t$). The opposite effect occurs on patient agents, since their real remuneration on savings rises. The net effect of this redistribution of wealth (from impatients and entrepreneurs to patients) is a further contraction in aggregate demand since impatients and entrepreneurs have, by construction, a higher propensity to consume.

Moreover, a financial accelerator is at work in the model. On impact, the rise of real interest rates reduces the net present value of tomorrow's housing and capital holdings, causing banks to cut the amount of loans they are willing to supply to impatients and entrepreneurs. As we see from the figure (fifth and sixth subplots), both household and firm lending fall. The contraction in borrowing, by reducing resources available to constrained agents, puts additional downward pressure on aggregate demand. As a consequence, the fall in house and capital prices accentuates, triggering what can be seen as a 'second round' effect on impatients' and entrepreneurs' borrowing ability, stemming from the expected reduction in the price of their collateral.

Finally, the presence of banks also has an impact on the impulse responses to the monetary impulse. The overall effect is however ambiguous. On the one hand, there is a *banking attenuator* effect, stemming from the fact that, following the official rate increase, banks raise the remuneration of deposits and the cost of loans only gradually and by a lower amount (overall, bank rates, i.e. the rates which are relevant for agents' decisions, rise by around five times less than the policy rate); thus, compared to a model without banks, financial intermediation introduces a moderating effect on each of the channels listed above, and hence on the responses of real and financial variables after a monetary policy shock. On the other hand, the presence of banking capital as an input in the production of loans widens the spread between the loan rates and the policy rate, thus magnifying the impact of monetary tightening. In order to understand which of the two effects prevails when financial intermediation is introduced and to quantitatively assess the relevance of the different channels in shaping the dynamic properties of the economy, we compare the impulse responses of the benchmark model (henceforth, BK) after a monetary policy shock with those coming from four alternative models:

1. Quasi-New Keynesian model (QNK), i.e. a model whose responses very closely resemble those of a standard NK model. Starting from BK, in order to obtain this model, we first eliminate banks, i.e. we force all banking rates equal to the policy rate, so that financial intermediation has no more role; secondly, we assume that the yields on loans and deposits are index-linked, so as to mute the debt-deflation channel; finally, we assume that the assets posted as collateral are evaluated at their steady-state price (and thus the real values of loans and deposits are fixed to their respective steady-state levels).

2. Financial Friction model (FF), i.e. a model where the role of intermediation is shut down (by setting all retail rates equal to r_t^{IB}), but which features both a financial accelerator and a debt-deflation channel. The impulse responses of this model are

strictly comparable to those in Iacoviello (2005).

3. Flexible Rate model (FR), i.e. a model with financial frictions and a simplified banking sector. As opposed to the BK model, the loan-production technology is linear, e.g. one unit of deposits and central bank money can be converted into one unit of loans: thus, the marginal cost of loans is equal to the policy rate. In addition, we assume that banks can costlessly adjust interest rates to changes in the marginal cost (which, in this case, equals the policy rate).

4. No-bank-capital model (noBK), i.e. a model with all the features of BK except the presence of bank capital, in order to single out by comparison with BK the role of this feature in the propagation of the shock.

The results of the exercise are shown in Figure 3. The standard New Keynesian model is nested in BK as a special case (green line, QNK); the corresponding impulse responses are in line with the main findings in the literature. When we move on to the FF model, we appreciate the contribution of financial frictions to the propagation mechanism of the monetary shock. In particular, the amplifying effect of the financial accelerator is clearly evident in the responses of all the main variables: on impact, both consumption and investment decline more than in QNK, causing output to drop sharply, by around 0.4 percentage points.

The role of banks begins to appear when we take into account the responses of the FR and of the noBK models, which add a (simplified) banking sector to the FF framework; in these models, there is a wedge between active and passive rates as a consequence of the pricing power of banks. The main result that emerges (from comparison with the FF model) is that financial intermediation attenuates the response of output and consumption, both in the case of flexible and sticky bank rates. However, as expected, the attenuation effect is more pronounced in the model with sticky rates (noBK; black line), because adjustment costs prevent banks to fully pass on the policy rate increase to retail rates. In the noBK model, the 25-basis point increase in the policy rate raises active bank rates by about 15 basis points on impact (the passive rate, not shown in the picture, raises by less than 5 basis points) whereas in the FF model model all rates jump by exactly the full 25 basis points, i.e. almost three times more. This initial difference in responses vanishes quite rapidly, in about three quarters, after which active banking rates from the two models almost overlap. The initially smaller increase in active rates in the benchmark model is enough to induce a smaller reduction in loan demand, actually quite persistent in the case of household loans. The implied reaction of the real economy is correspondingly attenuated. Consumption declines on impact by 0.10 percentage points (instead of more than 0.15 in FF); output drops by less than 0.20 percentage points, compared to almost 0.40 in FF. Inflation is only marginally altered. Overall, the transmission of monetary policy shocks is not qualitatively modified by the presence of monopolistic banks that set rates sluggishly; from a quantitative point of view, however, the attenuator effect resulting from banks can be sizeable on impact.

Finally, when we compare the noBK and the BK model, we disentangle the effect on real variables of the introduction of endogenous bank capital accumulation. The result is that model responses are significantly magnified. The presence of bank capital has an impact on the banks' intermediation spread, which rises by more than in noBK. The highger spread (and thus the higher loan rates) determines a bigger drop in the price of assets and in loan demand, which causes a greater fall in the real variables; investment is particularly affected, as the fall in entrepreneurs' loans is more than doubled. The monetary tightening is, for banks, an increase in the cost of one of their two inputs for issuing loans; in response to this increase, banks substitute deposits and central bank money with bank capital, which as a result increases in equilibrium. The impact on inflation is, again, very marginal.

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

A further sensitivity exercise is to check how the overall transmission mechanism of monetary policy is affected by different levels of collateral requirements (loan-to-value ratios) on either households or firms (see Figures 4 and 5). When households and firms can collateralize a low share of their housing or capital stock (low values for m^I and m^E), the monetary tightening has, in general, less severe consequences on real variables. Low values of m^I and m^E imply low "leverage" on the part of households and firms, i.e. a low amount of borrowing compared to their own resources. As highlighted by Iacoviello and Neri (2008) and Calza *et al.* (2007), and as described in Section 3.1.2, in this case the absolute amount of borrowing is less sensitive to changes in the net present value of the collateral. Therefore, the amplifying role of the debt-deflation channel and of the financial accelerator is dampened. In the extreme case of non-collateralizable asset ($m^E, m^I = 0$), a monetary restriction would have no effect on the real economy via those financial channels.

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. Starting with a simple "Quasi-New Keynesian" model (QNK), we first add financial frictions (collateral constrained borrowers) á la Iacoviello (2005) (FF); then a simplified banking sector operating under flexible rates and a linear loan-production technology (FR); then we introduce sticky rates (noBK); and finally we add a role for bank capital in the production of loans resulting in the benchmark model (BK). The positive technology shock has been calibrated to give rise to a peak response of output equal to 1% in the benchmark model. The results are shown in Figure 6. The main message is that adding our banks to the picture substantially improves the endogenous propagation mechanism after a technology shock. In the QNK and FF models the responses are similar and can be rationalized in terms of standard substitution and wealth effects: firms are more productive after the shock and tend to increase production, factor demands and prices (partially rigid). The extra-profits earned under monopolistic competition are rebated to (patient) HHs which enjoy more consumption and leisure (a strong wealth effect); impatient HHs enjoy higher labor wages as well and expand their consumption; overall output, consumption and investment go up, while inflation is only moderately affected. Demand for housing increases both for patients and for impatients, resulting in higher equilibrium prices (not shown in the figure). When we introduce a monopolistically competitive banking sector, the steady state markups (and markdown) with respect to the policy rate amplify any given movement of the policy rate (this is true for the *absolute* deviation from steady state even in the flex rate model). This adds a powerful propagation mechanism: as the policy rate starts to decrease, rates on loans decrease even more, giving a strong incentive to expand the demand for loans. Patient HHs and entrepreneurs therefore postpone consumption in order to accumulate houses and physical capital (used as collateral). As a result, on impact consumption and output go *down*, the policy reacts by lowering rates and this reinforces the initial negative stimulus.

When we add to this basic mechanism sticky bank rates (the FR model) the picture does not change substantially. When instead we add a role for banking capital, there are additional amplification channels working through bank profits and the production function for loans. On the one hand, a reduction in bank profits (driven mainly by a reduction in the interest margin earned by banks) induces a proportional reduction in the accumulation of bank capital, leaving banks with less capital to be used in the production for loans and thus pushing the "loan supply" curve upward. On the other hand, the marginal cost for a unit of loan now depends on two terms: the policy rate and the "cost of bank capital". And the rates on loans are set as a markup over this marginal cost. Since in equilibrium the cost of capital is positively correlated with the policy rate, any movement in the latter now has a bigger effect on both the interest and the volume of loans.

5.3 The effects of a tightening of credit conditions

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

Our model is well-suited to analyze the effects of a tightening in credit conditions on the real activity and to give indications (at least qualitatively) on the appropriate response of a central bank following a Taylor-type monetary policy rule. In this section, we outline a financial turmoil scenario in which bank loans to both households and firms are interested unexpectedly and simultaneously by a restriction in supply and an increase in interest rates (independent of monetary policy). We do not attempt to outline a quantitatively realistic scenario; this would be indeed very difficult, given the conflicting indications coming from hard and survey evidence on the tightening of credit standards, in particular in the euro area, and the uncertainty on the effects that have already occurred and on those that might still be in the pipeline. Our experiment consists of a contemporaneous combination of five persistent shocks: an increase in banks collateral requirements for loans to both households and firms and, contemporaneously, one in active and passive bank rates, implemented through an increase in banks market power in loan and deposit markets. Figure 7 shows the effect of this credit crunch experiment, with the overall response obtained by summing up the responses to the five shocks.[10]

As for the calibration of the shock, collateral requirements are increased by 1 percentage point in the first period: since all loans in our model last one period, and given that in the euro area new loans amount to 2% of outstanding loans, the shock would correspond to a 50 p.p. LTV increase on new loans. The magnitude of the shocks on bank rates on loans is such that, absent any general equilibrium feedback, they would increase by 100 basis points: due to the policy reaction to the abrupt downturn, they increase by approximately half that amount. The shock to the deposit rate is of 50 b.p. ex-ante, and slightly less given feedbacks.

By construction, the credit tightening brings about an increase in bank rates, a decrease in the effective net present value of collateral to borrowers and a reduction in the amount of borrowing from banks. Less resources available restrain both demand components and savings. Given nominal rigidities, the real rate increases, reducing patients' consumption. Aggregate demand and output fall. As expected returns from investing in physical capital also fall, investment and the price of capital drop, driving down the value of the collateral in the hands of entrepreneurs and thus reinforcing the leverage restriction. Limitations

[10] The assumption of independently distributed shocks allows simulating the 'financial market turmoil' scenario by adding the impulse responses to each of the shock.

to access to credit put an additional burden on aggregate demand, which, impinging on the constrained part of the economy, is magnified as for the negative consequences on activity. More factors contribute to this result. As inflation falls following a decline in marginal costs, it induces an increase in the real cost of servicing debt and a negative wealth effect on the part of borrowers. Real ex-post return to lenders increases instead. As loan rates are driven down fast by policy reaction and decreased demand, a diminishing intermediation spread decreases banks profits, causing a gradual reduction in banking capital. Together with normalizing policy rates, this puts new pressure on loan rates by increasing marginal costs of loan activity.

Looking at individual agents, the rate shock unfavorably hits borrowers. Higher bank rates induce them to reduce loan demand. Nevertheless, as reflected in the shadow values of borrowing, the restraints have more severe consequences for entrepreneurs: on the one hand, they cannot partially recover from the negative wealth effects by working more (as they are assumed not to work); on the other hand, their net worth gets reduced, limiting borrowing for either one of the two possible uses that they have at hand, consumption and production. Entrepreneurs' demand for goods and inputs harshly falls. Constrained households do instead become more willing to supply labor in order to offset, at least in part, the overall negative wealth effect and sustain consumption. Nevertheless, equilibrium labor and wages fall, as the decline in labor demand prevails. A positive support to consumption of impatients comes from dismissing some real estate, but this further diminishes collateral value in their hands.

Taken in isolation, the effect of a tightening of credit to firms spills over to the household sector through a negative effect on labor income and a deflation-driven increase in the real value of households' debt. Spill-overs to firms from a credit crunch to households are, instead, minor.

A decomposition of the overall response of investment, consumption and output shows that the effect of the increase in collateral requirements is larger than the effect of the increase in interest rate on loans. Similarly the decline in loans to firms reflects primarily the negative shock to the loan-to-value ratio of entrepreneurs. The decline in loans to households, instead, is driven by the interest rate shock.

6 Concluding remarks

The paper has presented a model in which both entrepreneurs and impatients households face borrowing constraints and loans are supplied by imperfectly competitive banks intermediating funds from both patient households deposits and a stylized interbank market.

Together with banking capital, these funds are used as input in the intermediation technology to produce loans to households and firms. Bank interest rates on these distinct loans and on deposits adjust slowly to changes in the policy rate because of adjustment costs.

The presence of financial intermediaries exerts some attenuation of the negative effects of a monetary policy tightening on the real net present value of agents' collateral. On the contrary, endogenous accumulation of banking capital exerts some amplification effect. A shock that reduces the availability of credit and increases the interest rates on loans ("credit crunch shock") can have significant effects on economic activity.

References

[1] Andrés, J. and O. Arce (2008), Banking Competition, Housing Prices and Macroeconomic Stability, mimeo, Bank of Spain.

[2] Aslam, A. and E. Santoro (2008), Bank Lending, Housing and Spreads, University of Copenhagen, Department of Economics Discussion Papers, No. 08-27.

[3] Benes, J. and K. Lees (2007), Monopolistic Banks and Fixed Rate Contracts: Implications for Open Economy Inflation Targeting, mimeo, Reserve Bank of New Zealand.

[4] Bernanke, B.S. and M. Gertler (1995), "Inside the Black Box: The Credit Channel of Monetary Policy Transmission." *Journal of Economic Perspectives*, Vol. 9(4), pp. 27-48.

[5] Bernanke, B.S., M. Gertler and S. Gilchrist (1999), "The Financial Accelerator in a Quantitative Business Cycle Framework", in J.B. Taylor and M. Woodford, eds., Handbook of Macroeconomics, North-Holland, pp. 1341-1393.

[6] Calza, A., T. Monacelli and L. Stracca (2007), "Mortgage Markets, Collateral Constraints, and Monetary Policy: Do Institutional Factors Matter?", Center for Financial Studies, Working paper No. 10.

[7] Carlstrom, T.C. and T.S. Fuerst (1997), "Agency costs, net worth, and business fluctuations: a computable general equilibrium analysis", *American Economic Review*, Vol. 87(5), pp. 893-910.

[8] Carlstrom, T.C. and Fuerst T.S. (2006), "Co-Movement in Sticky Price Models with Durable Goods", Federal Reserve Bank of Cleveland Working Paper 06-14.

[9] Christensen, I., P. Corrigan, C. Mendicino and S. Nishiyama (2007), "An Estimated Open-Economy General Equilibrium Model with Housing Investment and Financial Frictions", mimeo, Bank of Canada.

[10] Christiano, L., M. Eichenbaum and C. Evans (2005), "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy" *Journal of Political Economy*, Vol. 113(1), pp. 1-46.

[11] Christiano, L., R. Motto and M. Rostagno (2007), "Financial Factors in Business Cycle" mimeo, European Central Bank and Northwestern University.

[12] Cúrdia, V. and M. Woodford (2008), "Credit Frictions and Optimal Monetary Policy" mimeo, October.

[13] de Bondt, G. (2005), "Interest rate pass-through: Empirical results for the Euro Area", *German Economic Review*, Vol. 6(1), pp. 37-78.

[14] Goodfriend, M. and B.T. McCallum (2007). "Banking and interest rates in monetary policy analysis: A quantitative exploration" *Journal of Monetary Economics*, vol. 54(5), pp. 1480-1507.

[15] Iacoviello, M. (2005), "House Prices, Borrowing Constraints and Monetary Policy in the Business Cycle" *American Economic Review*, Vol. 95(3), pp. 739-764.

[16] Iacoviello, M. and Neri S. (2008), "Housing market spillovers: evidence from an estimated DSGE model", Banca d'Italia Discussion papers, no. 659.

[17] Kiyotaki, N. and J. Moore (1997) "Credit Cycles", *Journal of Political Economy*, Vol. 105(2), pp. 211-248.

[18] Kok Sorensen, C. and T. Werner (2006), "Bank interest rate pass-through in the euro area: a cross country comparison", Working paper series, no. 580, European Central Bank.

[19] Smets, F. and R. Wouters (2003), "An Estimated Dynamic Stochastic General Equilibrium Model Of The Euro Area", *Journal Of The European Economic Association*, Vol. 1(5), pp. 1123-1175.

Table 1A. Calibrated parameters

Parameter	Value	Parameter	Value
β_P	0.9943	a^P	0.6
β_I	0.975	a^I	0.6
β_E	0.975	a^E	0.6
β_B	0.9943	χ^b	0.09
ε^h	0.2	ϕ	1.5
α	0.25	$\bar{\varepsilon}^d$	-1.3
δ	0.025	$\bar{\varepsilon}^{bh}$	5.1
ε_y	6	$\bar{\varepsilon}^{be}$	3.5
ε_l	5	κ_d	11
κ_i	2.5	κ_h	6
κ_p	100	κ_e	5
κ_w	100	$\bar{m}^I$	0.7
ζ	0.25	$\bar{m}^E$	0.25
ρ^{mh}	0.95	ρ^{ib}	0.75
ρ^{me}	0.95	ϕ_π	1.85
$\rho^{\varepsilon be}$	0.6	ϕ_y	0.0
$\rho^{\varepsilon bh}$	0.6	γ^P	0.25
$\rho^{\varepsilon d}$	0.6	γ^I	0.25
γ^E	0.25	γ^B	0.25
a^B	0.6		

Table 1B. Steady state ratios

Variable	Interpretation	Value
c/y	Ratio consumption to GDP	0.89
i/y	Ratio business investment to GDP	0.11
k/y	Ratio business capital to GDP	4.4
B/y	Ratio of loans to GDP	2.1
B^H/B	Share of loans to households over total loans	0.49
B^E/B	Share of loans to firms over total loans	0.51
K^B/B	Ratio of bank capital to loans (per cent)	7.9
$4 \times r^d$	Annualized bank rate on deposits (per cent)	2.3
$4 \times r^{bh}$	Annualized bank rate on loans to households (per cent)	5.0
$4 \times r^{be}$	Annualized bank rate on loans to firms (per cent)	5.6

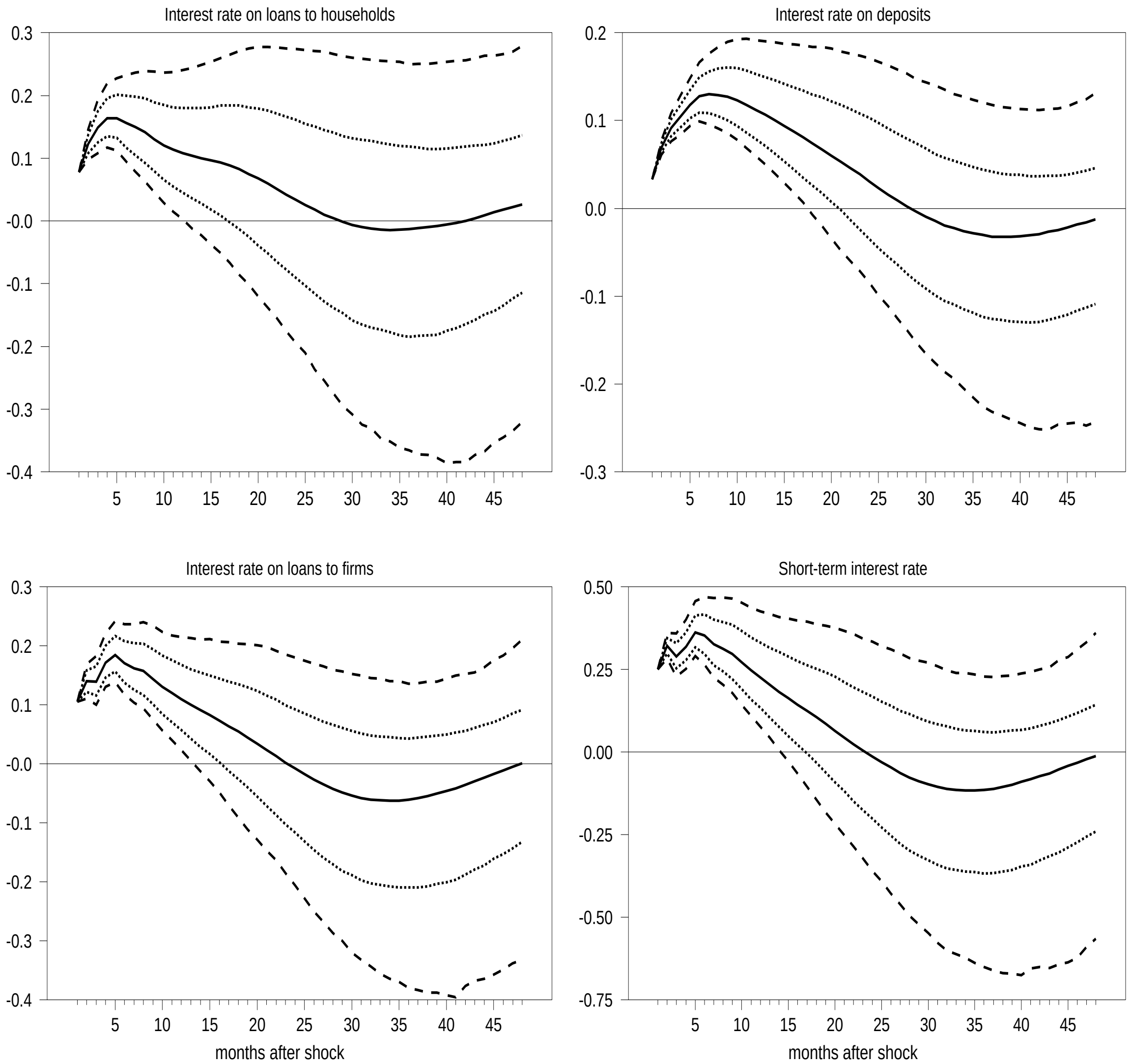

Figure 1: The effects of an exogenous change in the 3-month money market rate on banks rates on loans and deposits. Solid lines represent median values of the posterior distribution of the impulse responses. Dotted lines denote the 0.68 per cent probability intervals, while dashed lines represent the 0.90 per cent probability interval.

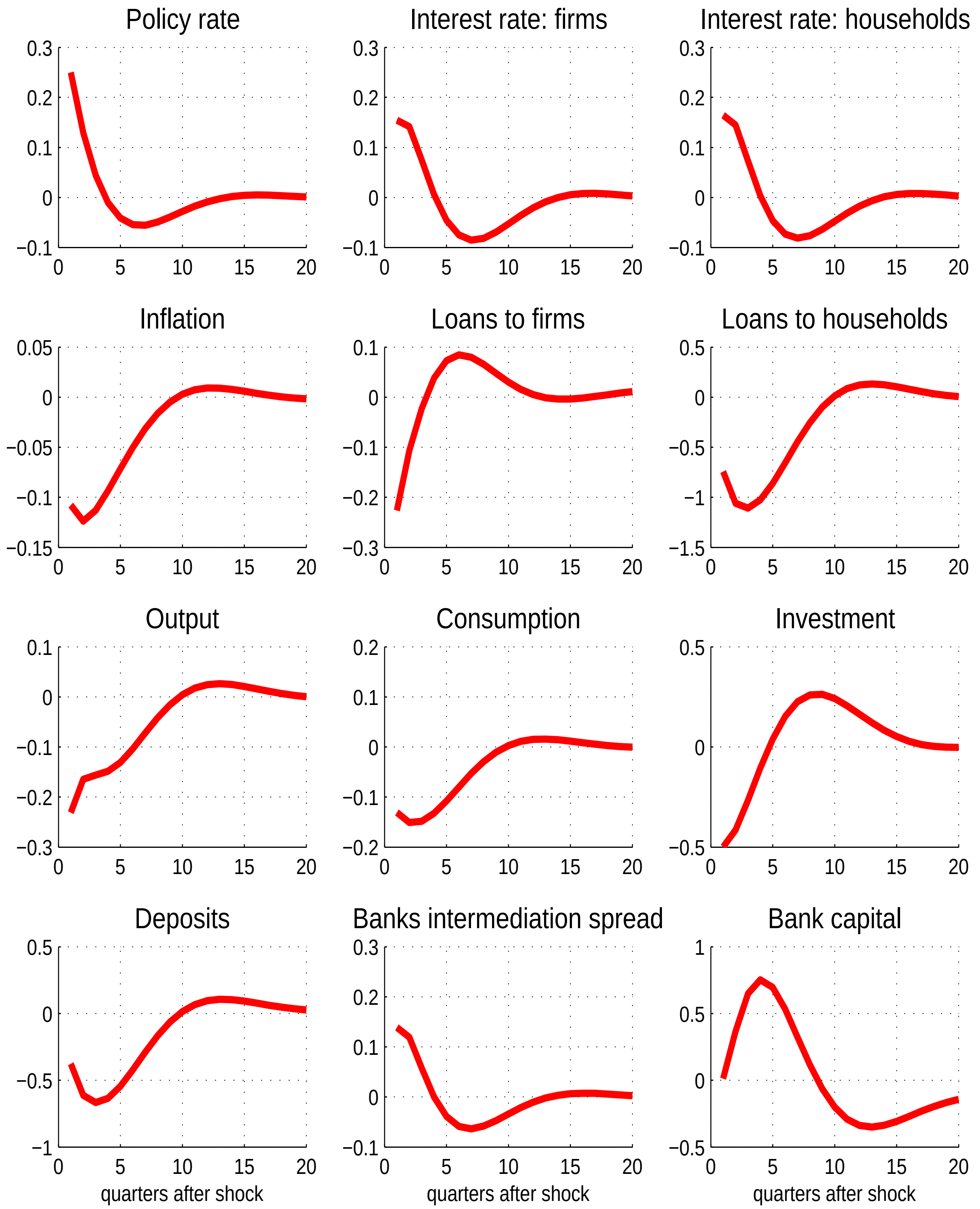

Figure 2: The effects of a contractionary monetary policy shock. Interest rates and banks spreads are shown as absolute deviations from steady state (expressed in percentage points). All others are percentage deviations from steady state.

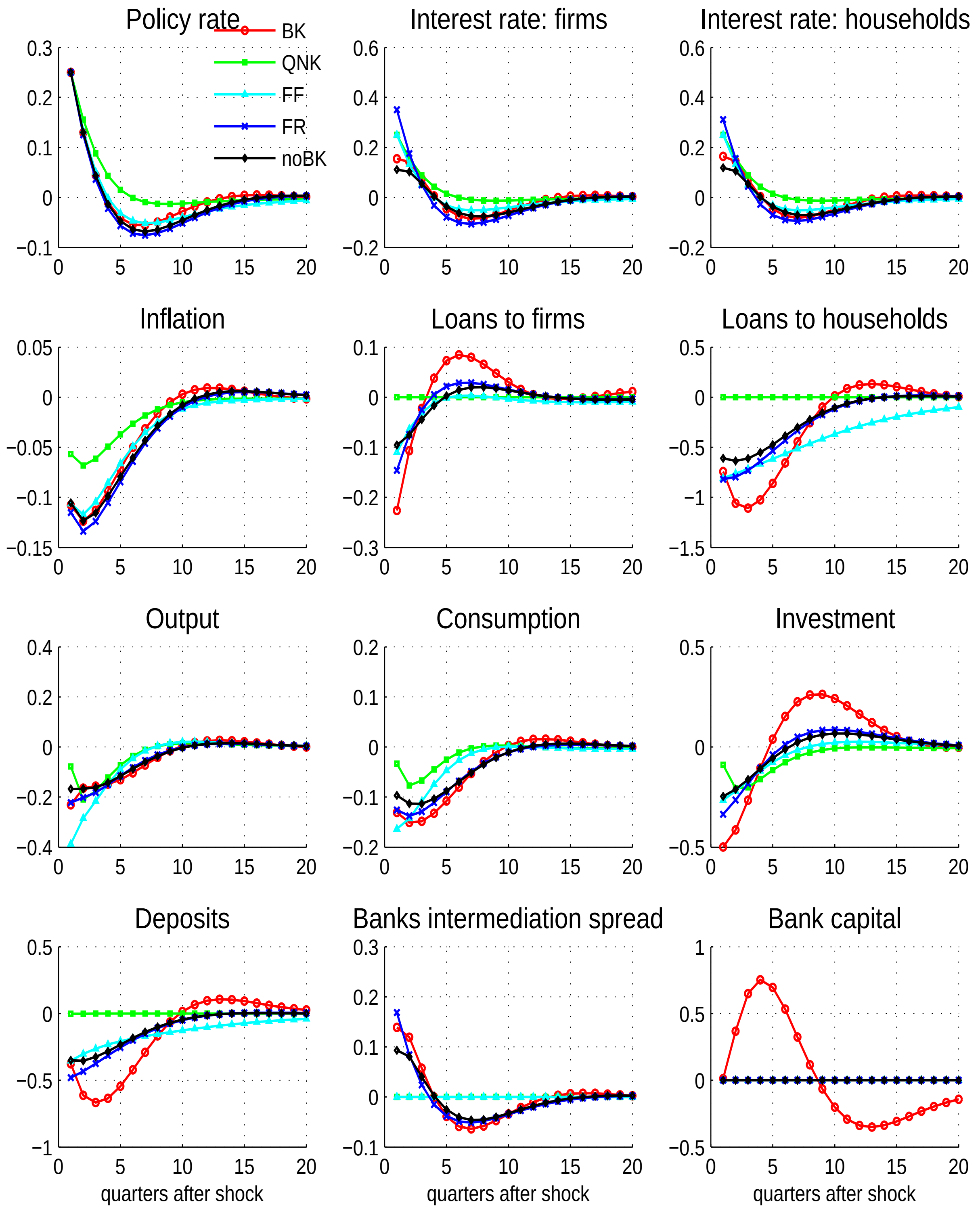

Figure 3: The role of banks and financial frictions after a contractionary monetary policy shock. The red dotted line is from the benchmark model. The green squared line is from the model corresponding to the New Keynesian standard model. The cyan triangled line is from the model with financial frictions but without banks. The blue crossed line is from the model with banks, but with flexible rates and without bank capital. The black line is from the model without bank capital but with sticky rates.

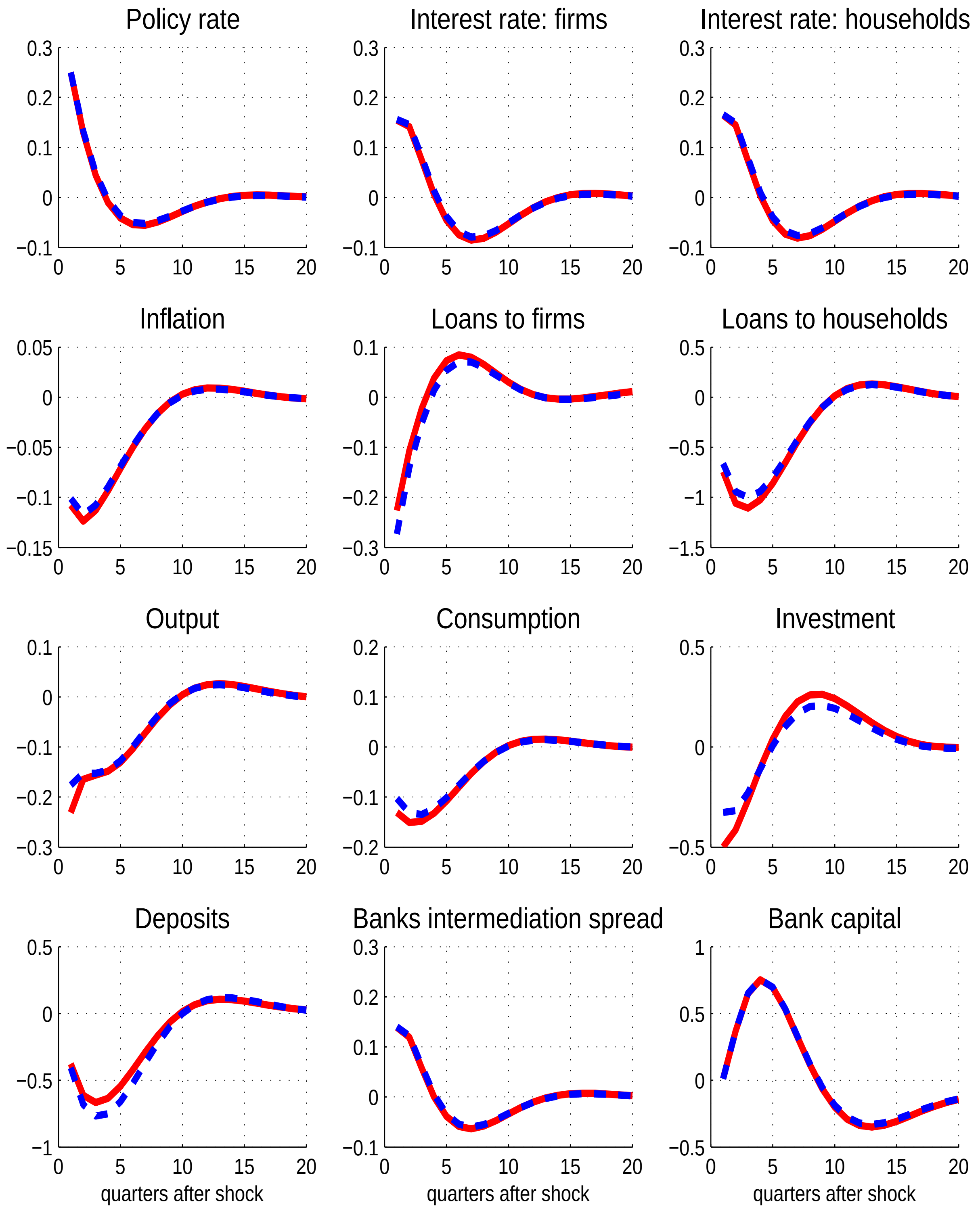

Figure 4: The effects of halfening entrepreneurs' loan-to-value ratio m^E (dashed blue line) against benchmark (red solid line). Interest rates and banks spreads are shown as absolute deviations from steady state (expressed in percentage points). All others are percentage deviations from steady state.

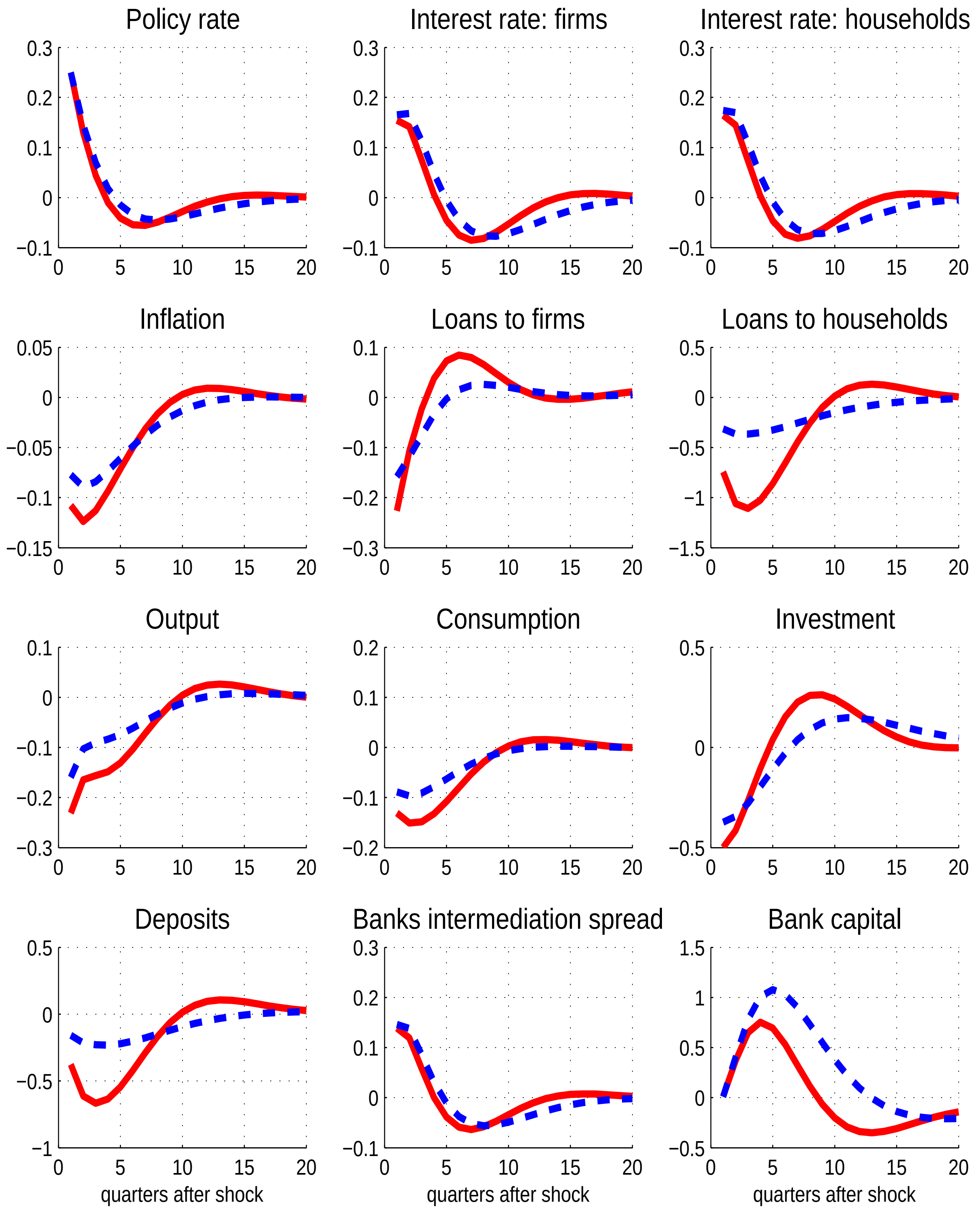

Figure 5: The effects of halfening households' loan-to-value ratio m^I (dashed blue line) against benchmark (red solid line). Interest rates and banks spreads are shown as absolute deviations from steady state (expressed in percentage points). All others are percentage deviations from steady state.

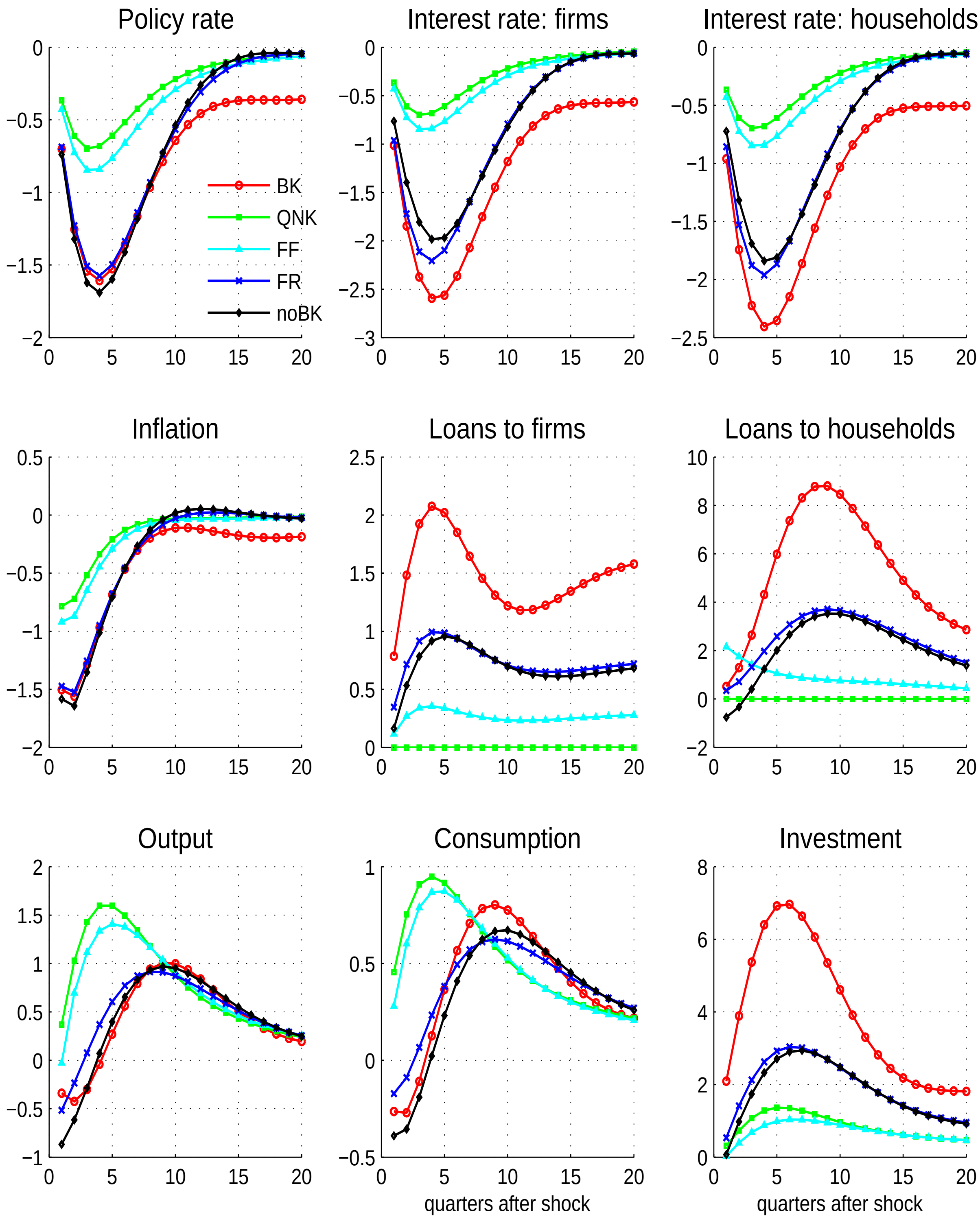

Figure 6: The role of banks and financial frictions after an expansionary technology shock. The red dotted line is from the benchmark model. The green squared line is from the model corresponding to the New Keynesian standard model. The cyan triangled line is from the model with financial frictions but without banks. The blue crossed line is from the model with banks, but with flexible rates and without bank capital. The black line is from the model without bank capital but with sticky rates.

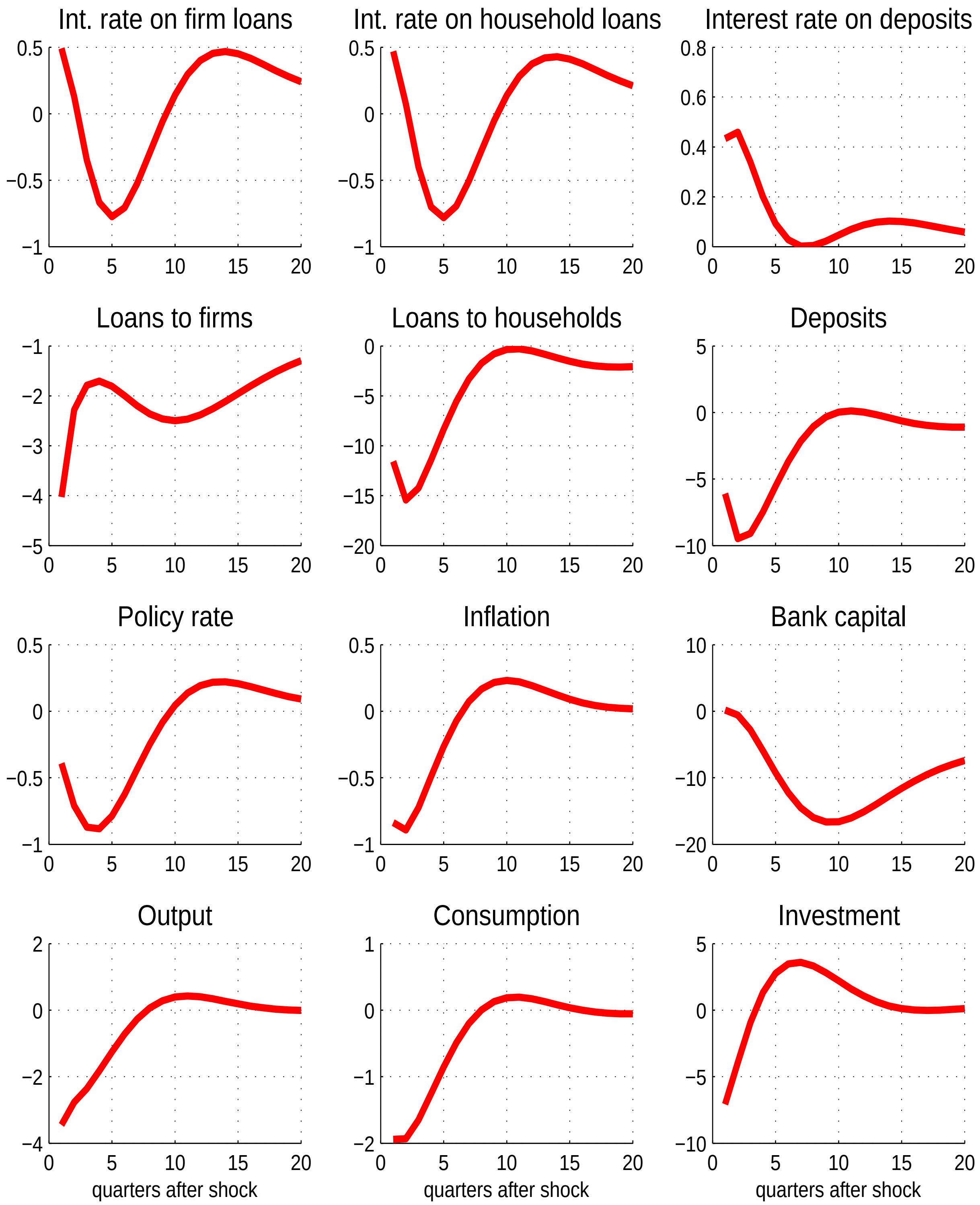

Figure 7: A credit crunch. Interest rates and banks spreads are shown as absolute deviations from steady state (expressed in percentage points). All others are percentage deviations from steady state.