Macroeconomic Propagation under Different Regulatory Regimes: Evidence from an Estimated DSGE Model for the Euro Area*

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This article analyzes the role of credit market frictions in business-cycle fluctuations and in the transmission of monetary policy. We estimate a closed-economy dynamic stochastic general equilibrium (DSGE) model for the euro area with financially constrained households and firms and embedding an oligopolistic banking sector facing capital constraints. Using this setup we examine the monetary policy implications of the various financial frictions to credit supply and demand and furthermore examine the real economic implications of increasing capital requirements and of introducing risk-sensitive capital requirements. Moreover, the potential for introducing countercyclical bank capital rules and aligning macroprudential tools with standard monetary policy tools is examined. In particular, the model results highlight the importance of operating with a protracted implementation schedule of new regulatory requirements for smoothing out the transitional costs to the economy arising from a more capital-constrained banking sector.

JEL Codes: E4, E5, F4.

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1. Introduction

The financial crisis which started in 2007 brought to the fore the importance of the financial sector and its potential amplifying effects on business-cycle fluctuations. The massive write-downs and losses that banks had to incur over this period significantly impaired their liquidity and capital positions, which in turn forced many banks to cut back on activities and to shed assets. This deleveraging process in the banking sector may have hampered the access to financing for some bank-dependent borrowers and thereby reduced their ability to consume and invest, potentially reinforcing the economic downturn. Whereas in the macroeconomic literature it has long been recognized that financial intermediation may play a role in economic fluctuations through the financial accelerator mechanism relating to the banks' borrowers,[1] the possible amplifying impact on the business cycle of shocks directly hitting the financial intermediaries has only recently been taken up by the literature.[2] The importance of the banks' balance sheet situation in transmitting shocks to monetary policy (and other types of shocks) has, however, long been recognized in the empirical literature. For example, it has been pointed out that more liquid and well-capitalized banks are better able to absorb shocks hitting the macroeconomic environment (including changes in monetary policy) than more capital- and liquidity-constrained

[1]Financing frictions arising in the context of asymmetric information between borrowers and lenders are often suggested as a prime candidate for endogenously amplifying and increasing the persistence of even small transitory exogenous shocks. The basic idea, often called the financial accelerator, is that in the presence of credit constraints exogenous shocks can generate a positive feedback effect between the financial health of borrowing firms or households and output; see, e.g., Carlstrom and Fuerst (1997), Kiyotaki and Moore (1997), and Bernanke, Gertler, and Gilchrist (1999) (BGG hereafter). Recent work by Christiano, Motto, and Rostagno (2007), Christensen and Dib (2008), and Liu, Wang, and Zha (2009) quantifies the interlinkages between the financial and real sectors using a financial accelerator mechanism.

[2]For some recent studies modeling the banking sector in a DSGE modeling framework, see, e.g., Meh and Moran (2008), Van den Heuvel (2008), Agenor and Alper (2009), Agenor and Pereira da Silva (2009), Aguiar and Drumond (2009), Angeloni and Faia (2009), Covas and Fujita (2009), de Walque, Pierrard, and Rouabah (2009), Dib (2009), Gertler and Karadi (2009), Christiano, Motto, and Rostagno (2010), and Gerali et al. (2010).

banks.[3] In addition to the attention on the role of financial intermediaries brought forward by the financial crisis, the introduction of more risk-sensitive capital requirements (i.e., the Basel II capital adequacy framework; see Basel Committee on Banking Supervision 2006) has reinforced the concerns that financial intermediation by itself might have substantial feedback effects on the real economy. Moreover, as a consequence of the financial crisis, at the end of 2010 the Basel Committee on Banking Supervision (BCBS) introduced amendments to the bank regulatory framework (i.e., Basel III) with the aim of strengthening capital requirements. The new requirements will be gradually phased in as of 2013 and are scheduled to be fully implemented by 2019.[4] Our model is also well suited for analyzing the potential costs (and benefits) of moving towards higher capital ratio targets and the role of monetary policy during such a transition. Furthermore, the financial crisis has reinforced interest in macroprudential tools and policies that might be applied by policymakers to reduce the risks of financial boom and bust cycles and thereby lead to a more stable path of real economic growth. A general equilibrium framework, such as ours, is also useful for analyzing the potential for macroprudential tools and their interaction with other macroeconomic and monetary policy instruments.

Against this background, in this article we propose a closed-economy DSGE model with financial frictions including a banking sector which faces monopolistic competition and is subject to capital constraints. The latter may owe both to market disciplining forces (i.e., banks operate with a capital buffer) and to regulatory capital adequacy rules (which can be either risk insensitive or risk sensitive). Furthermore, the presence of monopolistic competition in the banking sector gives rise to some degree of stickiness in banks' adjustment of lending and deposit rates to changes in monetary policy rates. From a theoretical viewpoint, a sluggish pass-through of bank loan and deposit rates to policy rate changes is based on the notion of banks having some degree of market power, which may derive from banks being "special" in the sense of being able to reduce (by acting

[3]See, e.g., Bernanke and Lown (1991), Peek and Rosengren (1995), Kashyap and Stein (2000), Van den Heuvel (2002), Gambacorta and Mistrulli (2004), and Kishan and Opiela (2006).

[4]See Basel Committee on Banking Supervision (2011).

as “delegated monitors”) the information gap between savers and borrowers of funds.[5] In general, banks’ interest rate setting behavior can be expected to depend on the degree of bank competition (or market power of banks) and on factors related to the costs of financial intermediation (such as interest rate and credit risk, menu costs and other operational costs, banks’ degree of risk aversion, and the cost of non-deposit funding sources).[6] Hence, by exploiting their market power, banks are able to generate profits and thus to replenish their capital buffers following shocks to their liquidity and capital positions.[7] Under risk-sensitive capital requirements, banks’ capital positions are affected by changes in the risk profile of their borrowers over the business cycle, and the time-varying nature of bank borrower risk profiles is therefore also considered in our modeling of firms and households.

On the real side of the economy, we assume that households and firms are financially constrained in their spending and investment decisions, and we furthermore incorporate some degree of heterogeneity in the household sector. The model has a subset of firms that are financially constrained and can only borrow by using revenue and capital as collateral, and a subset of financially constrained households that use debt collateralized by housing and part of their wage income. Both firms and households are affected by idiosyncratic shocks to their collateral values. Firms and households default on their loans when the value of their collateral is below the repayment promised to the lender. In order to keep the model tractable, we follow other DSGE models of financial frictions in using differences in the level of impatience of agents to generate equilibrium borrowing and lending (e.g., Iacoviello 2005). In equilibrium, more impatient agents (borrowers and entrepreneurs) will borrow from patient savers.

[5]See, e.g., Diamond and Dybvig (1983), Diamond (1984), and Diamond and Rajan (2001).

[6]There is ample empirical evidence for the existence of a sluggish bank interest rate pass-through in the euro area (see, e.g., Mojon 2001, de Bondt 2005, Sander and Kleimeier 2006, Kok Sørensen and Werner 2006, and Gropp, Kok Sørensen, and Lichtenberger 2007).

[7]There are a few recent studies that embed features of an incomplete bank interest rate pass-through into a DSGE model framework; see, e.g., Kobayashi (2008), Agenor and Alper (2009), Hülsewig, Mayer, and Wollmershäuser (2009), and Gerali et al. (2010).

Building on Notarpietro (2007) and Iacoviello and Neri (2010), we define a three-agent, two-sector economy, where the impatient agents face collateral requirements when asking for mortgages or loans. Firms produce non-durable consumption goods and residential goods. The latter serve two purposes: they can be directly consumed, thus providing utility services as any durable good, or they can be used as collateral in the credit market, to obtain extra funds for financing consumption. The role of collateral constraints in closed economies has been estimated in DSGE models by Notarpietro (2007) and Iacoviello and Neri (2010), who report the relevance of housing market shocks in shaping consumption dynamics in the United States. Most existing models of household borrowing in a DSGE framework follow Kiyotaki and Moore (1997) and Iacoviello (2005) in using a hard borrowing constraint and assuming it always binds. The Kiyotaki-Moore model of credit constraints can be seen as a special case of the current model in which there is no uncertainty about the future value of the collateral when the loan is made. The assumption that the constraint always binds makes the leverage ratio in their model constant. Furthermore, they ignore any difference between borrowing rates and the risk-free rate. The model proposed here can at least qualitatively match the typically observed countercyclical leverage ratio of households.[8] The assumption of an always binding borrowing constraint is questionable for large shocks that may be of particular interest to policymakers, and it may severely distort the dynamics of borrowers and the rest of the economy in those circumstances. The soft borrowing constraint in our model (with interest rates rising smoothly as a function of borrowing) will always bind as long as it can be satisfied.

The only other papers that have allowed for financing frictions affecting both households and firms are Iacoviello (2005) and Gerali et al. (2010). Both of these papers rely on hard borrowing constraints, as in Kiyotaki and Moore (1997), to model credit frictions and assume the borrowing constraints always bind. Our model setup provides an alternative perspective by including costs of default and positive lending spreads.

By allowing for frictions concerning both credit demand and supply, the contributions of this paper cover several dimensions. First,

[8]For instance, as found for the United States by Adrian and Shin (2009).

apart from encompassing the traditional financial accelerator mechanism arising in the context of financially constrained borrowers, our model allows for assessing the impact of frictions within the banking sector, such as its price-setting behavior and constraints to its capital management. In particular, we assess the extent to which the presence of bank loan and deposit rate sluggishness affect monetary policy optimization. Moreover, our setup allows for examining the macroeconomic implications of shocks to bank capital (such as those observed during the 2007–10 financial crisis as well as reflected in the proposal to introduce stronger capital requirements under the Basel III agreement) and the implications of introducing risk-sensitive capital requirements or the transitional effects of higher capital requirements. Furthermore, our model can also shed some light on the potential effects of active macroprudential policies over the cycle and their interaction with monetary policy.

At the same time, our current model setup is less suited for analyzing the issues of liquidity and wholesale funding vulnerabilities, which arguably were other main contributing factors to the severity and propagation of the financial crisis. The macroeconomic implications of money market disruptions and the potential role of unconventional monetary policies have been addressed in other recent papers (see, e.g., Gertler and Kiyotaki 2009 and also Christiano, Motto, and Rostagno 2010).

The rest of the article is organized as follows. Section 2 describes the main decision problems of the structural model.[9] Section 3 presents the results of the Bayesian estimation, while section 4 explores the business-cycle implications of the financial frictions; in particular, the optimal monetary policy responses under different regulatory frameworks are investigated, focusing on the introduction of higher and risk-based capital requirements and macroprudential rules. Section 5 concludes.

2. Theoretical Model

The real side of the economy is modeled as a three-agent, two-sector economy, producing residential and non-residential goods.

[9]For the purpose of brevity, many model details can be found in the working paper version of this article, Darracq Pariès, Kok Sørensen, and Rodriguez-Palenzuela (2010).

Residential goods are treated here as *durable* goods. A continuum of entrepreneurs, with unit mass, produce non-residential and residential intermediate goods under perfect competition and face financing constraints. Retailers differentiate the intermediate goods under imperfect competition and staggered price setting, while competitive distribution sectors serve final non-residential consumption as well as residential and non-residential investments. A continuum of infinitely lived households, with unit mass, is composed of two types, differing in their relative intertemporal discount factor. A fraction $(1 - \omega)$ of households are relatively *patient*, the remaining fraction ω being *impatient*. Households receive utility from consuming both non-residential and residential goods, and disutility from labor. Impatient households are financially constrained. The labor market structure is characterized by homogeneous labor supply and monopolistically competitive unions, which gives rise to staggered wage setting.

The banking sector collects deposits from patient households and provides funds to entrepreneurs and impatient households. Three layers of frictions affect financial intermediaries. First, wholesale bank branches face capital requirements (which can be risk insensitive or risk sensitive) as well as adjustment costs related to their capital structure. Second, some degree of nominal stickiness generates some imperfect pass-through of market rates to bank deposit and lending rates. Finally, due to asymmetric information and monitoring costs in the presence of idiosyncratic shocks, the credit contracts proposed to entrepreneurs and impatient households factor in external financing premia which depend indirectly on the borrower's leverage. Figure 1 provides an overview of the financial contracts linking the banking sector to the real economy.

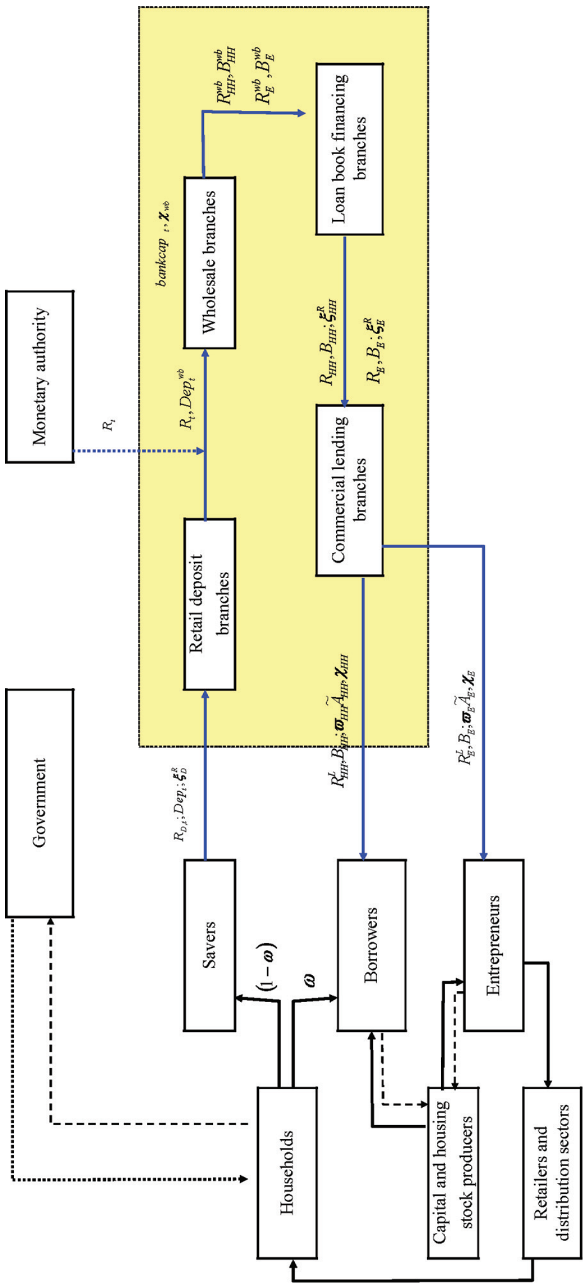
Finally, a government sector collecting taxes and providing lump-sum fiscal transfers and a monetary authority applying a standard Taylor rule close the model.

2.1 Households

2.1.1 The Saver's Program

The patient agents, $s \in [\omega, 1]$, are characterized by a higher intertemporal discount factor than the borrowers, and thus act as net lenders

Figure 1. Structure of the Model



in equilibrium. They own the productive capacities of the economy. Each patient agent receives instantaneous utility from the following instantaneous utility function:

$$\mathcal{W}_t^s = \mathbb{E}_t\left\{\sum_{j\geq 0}\gamma^j\left[\begin{array}{c}\frac{1}{1-\sigma_X}\left(X_{t+j}^s\right)^{1-\sigma_X} - \frac{\varepsilon_{t+j}^L\overline{L}_{S,C}}{1+\sigma_{LC}}\left(N_{Ct+j}^s\right)^{1+\sigma_{LC}}\\ -\frac{\varepsilon_{t+j}^L\overline{L}_{S,D}}{1+\sigma_{LD}}\left(N_{Dt+j}^s\right)^{1+\sigma_{LD}}\end{array}\right]\varepsilon_{t+j}^{\beta}\right\},$$

where X_t^s is an index of consumption services derived from non-residential final goods (C^s) and residential stock (D^s), respectively.

$$X_t^s \equiv \left[\left(1-\varepsilon_t^D\omega_D\right)^{\frac{1}{\eta_D}}\left(C_t^s - h_S C_{t-1}^s\right)^{\frac{\eta_D-1}{\eta_D}} + \varepsilon_t^D\omega_D^{\frac{1}{\eta_D}}\left(D_t^s\right)^{\frac{\eta_D-1}{\eta_D}}\right]^{\frac{\eta_D}{\eta_D-1}},$$

with the parameter h_S capturing habit formation in consumption of non-residential goods. We introduce three stochastic terms in the utility function: a preference shock ε_t^{β}, a labor supply shock ε_t^L (common across sectors), and a housing preference shock ε_t^D. The latter affects the relative share of residential stock, ω_D, and modifies the marginal rate of substitution between non-residential and residential goods consumption. All the shocks are assumed to follow stationary AR(1) processes.

Households receive disutility from their supply of homogenous labor services to each sector, $N_{C,t}^s$ and $N_{D,t}^s$. The real compensation of hours worked in each sector are denoted $w_{C,t}^s$ and $w_{D,t}^s$. The specification of labor supply assumes that households have preferences over providing labor services across different sectors. In particular, the specific functional form adopted implies that hours worked are perfectly substitutable across sectors. $\overline{L}_C$ and $\overline{L}_D$ are level-shift terms needed to ensure that the patient's labor supply is equal to one in the steady state.

The saver maximizes its utility function subject to an infinite sequence of the following budget constraint:

$$\begin{aligned} &C_t^s + Q_{D,t}T_{D,t}\left(D_t^s - (1-\delta)D_{t-1}^s\right) + Dep_t^s \\ &\quad = \frac{(1+R_{D,t-1})}{(1+\pi_t)}Dep_{t-1}^s + (1-\tau_{w,t})\left(w_{C,t}^s N_{C,t}^s + w_{D,t}^s N_{D,t}^s\right) \\ &\qquad + \Pi_t^s + TT_t^s, \end{aligned}$$

where $Q_{D,t}T_{D,t}$ is real price of housing stock in terms of non-residential goods, TT_t^s are real government transfers, and Π_t^s are real distributed profits. $\delta \in (0,1)$ is the residential good depreciation rate. π_t is the non-residential good inflation rate. $R_{D,t-1}$ is the nominal interest rate paid on the one-period real deposits Dep_t^s.

In equilibrium, all savers have identical consumption plans. Therefore, we can drop the superscript s. We also allow for a time-varying labor income tax, given by $1 - \tau_{w,t} = (1 - \overline{\overline{\tau}}_w)\varepsilon_t^W$.

2.1.2 The Borrower's Program[10]

Each impatient agent $b \in [0, \omega]$ receives utility from the same type of function as in the case of patient households but with a lower discount factor $\beta < \gamma$:[11]

$$\mathcal{W}_t^b = \mathbb{E}_t \left\{ \sum_{j \geq 0} \beta^j \left[\begin{array}{c} \frac{1}{1-\sigma_X} \left(\widetilde{X}_{t+j}^b\right)^{1-\sigma_X} - \frac{\varepsilon_{t+j}^L \overline{L}_{B,C}}{1+\sigma_{LC}} \left(N_{C,t+j}^b\right)^{1+\sigma_{LC}} \\ - \frac{\varepsilon_{t+j}^L \overline{L}_{B,D}}{1+\sigma_{LD}} \left(N_{D,t+j}^b\right)^{1+\sigma_{LD}} \end{array} \right] \varepsilon_{t+j}^\beta \right\},$$

where $\widetilde{X}_t^b$ is given by

$$\widetilde{X}_t^b \equiv \left[\left(1 - \varepsilon_t^D \omega_D\right)^{\frac{1}{\eta_D}} \left(\widetilde{C}_t^b - h_B \widetilde{C}_{t-1}^b\right)^{\frac{\eta_D - 1}{\eta_D}} + \varepsilon_t^D \omega_D^{\frac{1}{\eta_D}} \left(\widetilde{D}_t^b\right)^{\frac{\eta_D - 1}{\eta_D}} \right]^{\frac{\eta_D}{\eta_D - 1}}.$$

As regards savers, $\overline{L}_{B,C}$ and $\overline{L}_{B,D}$ are level-shift terms needed to ensure that the impatient's labor supply equals one in the steady state.

Borrowers' incomes and housing stock values are subject to common idiosyncratic shocks $\varpi_{HH,t}$ that are i.i.d. across borrowers and across time. $\varpi_{HH,t}$ has a log-normal cumulative distribution function (CDF) $F(\varpi)$ with $F'(\varpi) = f(\varpi)$, and a mean of $E(\varpi) = 1$. The variance of the idiosyncratic shock $\sigma_{HH,t}$ is time varying. The value of the borrower's house is given by

$$\varpi_{HH,t}\widetilde{Q}_{D,t}T_{D,t}(1-\delta)\widetilde{D}_{t-1}^b.$$

[10]The specification adopted here is broadly similar to Solomon (2011).

[11]Variables related to the saver are denoted with a superscript b, as opposed to s, used for the savers.

Lending in this economy is only possible through one-period state-contingent debt contracts that require a constant repayment of $\frac{(1+R^L_{HH,t})}{1+\pi_t}B_{HH,t-1}$ independent of $\varpi_{HH,t}$ if the borrower is to avoid costly loan monitoring or enforcement, where $R^L_{HH,t}$ is the nominal lending rate.

The borrower can default and refuse to repay the debt. Savers cannot force borrowers to repay. Instead, lending must be intermediated by commercial banks that have a loan enforcement technology allowing them to seize collateral expressed in real terms

$$\varpi_{HH,t}\tilde{A}^b_{HH,t} = (1-\chi_{HH})\varpi_{HH,t}\widetilde{Q}_{D,t}T_{D,t}(1-\delta)\widetilde{D}^b_{t-1}$$

at a proportional cost $\mu_{HH}\varpi_{HH,t}\tilde{A}_{HH,t}$ when the borrower defaults.

$\mu_{HH} \in (0,1)$ determines the deadweight cost of default; $0 < \chi_{HH} \leq 1$ represents housing exemptions. It defines the maximum loan-to-collateral ratio (often called the loan-to-value ratio) that the bank is willing to grant against each component of the collateral. Conditional on enforcement, the law cannot prevent the bank from seizing $\varpi_{HH,t}\tilde{A}_{HH,t}$. Suppose first that the borrower does not have access to any insurance against the $\varpi_{HH,t}$ shock. Whenever $\varpi_{HH,t} < \overline{\varpi}_{HH,t}$, the borrower prefers to default and lose

$$\varpi_{HH,t}\tilde{A}^b_{HH,t} < \frac{\left(1+R^L_{HH,t}\right)}{1+\pi_t}B_{HH,t-1} = \overline{\varpi}_{HH,t}\tilde{A}^b_{HH,t}$$

when the bank enforces the contract. On the other hand, when $\varpi_{HH,t} \geq \overline{\varpi}_{HH,t}$, the borrower prefers to pay $\frac{(1+R^L_{HH,t})}{1+\pi_t}B_{HH,t-1}$ rather than lose $\varpi_{HH,t}\tilde{A}_{HH,t} \geq \frac{(1+R^L_{HH,t})}{1+\pi_t}B_{HH,t-1}$.

To be able to use a representative agent framework while maintaining the intuition of the default rule above, we assume that borrowers belong to a large family that can pool their assets and diversify away the risk related to $\varpi_{HH,t}$ after loan repayments are made. As in Lucas (1990) and Shi (1997), the family maximizes the expected lifetime utility of borrowers with an equal welfare weight for each borrower. The payments from the insurance scheme cannot be seized by the bank. As a result, despite the insurance, the bank cannot force the borrower to repay $\frac{(1+R^L_{HH,t})}{1+\pi_t}B_{HH,t-1}$ when $\varpi_{HH,t} < \overline{\varpi}_{HH,t}$. Like the individual borrowers, the family cannot commit to always repay the loan (or make up for any lack of payment by a borrower), even though from an ex ante perspective it is optimal to do so. Ex post, from the perspective of maximizing the expected welfare of the borrowers, for any given $R^L_{HH,t}$ it is optimal to have borrowers with $\varpi_{HH,t} < \overline{\varpi}_{HH,t}$ default and borrowers with $\varpi_{HH,t} \geq \overline{\varpi}_{HH,t}$ repay $\frac{(1+R^L_{HH,t})}{1+\pi_t} B_{HH,t-1}$.

Given the large family assumption in particular, households' decisions are the same in equilibrium. Therefore, we can drop the superscript b.

By pooling the borrowers' resources, the representative family has the following aggregate repayments and defaults on its outstanding loan:

$$H(\overline{\varpi}_{HH,t})\tilde{A}_{HH,t} = \left[(1 - F_t(\overline{\varpi}_{HH,t}))\overline{\varpi}_{HH,t} + \int_0^{\overline{\varpi}_{HH,t}} \varpi dF_t\right]\tilde{A}_{HH,t}.$$

On the commercial lending bank side, the profit made on the credit allocation is given by

$$G(\overline{\varpi}_{HH,t})\tilde{A}_{HH,t} - \frac{(1 + R_{HH,t-1})}{1 + \pi_t} B_{HH,t-1} \geq 0$$

with

$$G(\overline{\varpi}_{HH,t}) = (1 - F_t(\overline{\varpi}_{HH,t}))\overline{\varpi}_{HH,t} + (1 - \mu_{HH}) \int_0^{\overline{\varpi}_{HH,t}} \overline{\varpi} dF_t.$$

$R_{HH,t-1}$ is the interest rate at which the commercial lending bank gets financing every period, while $R^L_{HH,t}$ is the state-contingent lending rate. Competition among banks will ensure that profits are null in equilibrium. The zero-profit condition could also be seen as the borrowing constraint in this model. Notice that this constraint always binds as long as it can be satisfied.[12] In contrast, the hard borrowing constraint in Kiyotaki and Moore (1997) or Iacoviello (2005) may not bind, even though authors using that framework assume it always binds to allow the use of perturbation methods.[13]

[12] If the constraint were slack, the lender could always reduce the borrower's expected repayments while still respecting the constraint by reducing $\overline{\varpi}_{HH,t}$.

[13] This may be a reasonable assumption for small shocks, but it can be a bad approximation for larger shocks that may be of concern to policymakers.

The caveat is that if a new shock significantly lowers the value of $\tilde{A}_{HH,t}$, it may be impossible to find a default threshold that allows the bank to break even on the loan with the risk-free rate. This should not be a major concern except for very low aggregate shock values.[14]

With the assumption of perfectly competitive banks, we can represent the problem of borrowers as if they choose default thresholds as a function of the aggregate states directly, subject to the bank's participation constraints.

Each borrower maximizes utility function with respect to $(\widetilde{C}_t, \widetilde{D}_t, B_{HH,t}\overline{\varpi}_{HH,t}, N_{C,t}, N_{D,t})$ subject to an infinite sequence of real budget constraints:[15]

$$\widetilde{C}_t + \widetilde{Q}_{D,t}T_{D,t}(\widetilde{D}_t - (1-\delta)\widetilde{D}_{t-1}) + H(\overline{\varpi}_{HH,t})\tilde{A}_{HH,t} = B_{HH,t} + \widetilde{TT}_t + \widetilde{w}_{C,t}\widetilde{N}_{C,t} + \widetilde{w}_{D,t}\widetilde{N}_{D,t}$$

and the zero-profit condition for the commercial lending banks.

2.2 Labor Supply and Wage Setting

The labor market structure is modeled following Schmitt-Grohe and Uribe (2006). In both countries, households of each type (patient, impatient) provide homogeneous labor services, which are transformed by monopolistically competitive unions into differentiated labor inputs. As a result, all households of the same type supply the same amount of hours worked in each sector, in equilibrium.

We assume that in each sector $j \in \{C, D\}$ there exist monopolistically competitive labor unions representing the patient and impatient households. Unions differentiate the homogeneous labor provided by households, N_{jt} from savers and $\widetilde{N}_{jt}$ from borrowers, creating a continuum of measure one of labor services (indexed by $z \in [0, 1]$) which are sold to labor packers.

[14]In our calibrations, the balanced growth path value of the loan-to-value ratio (LTV) $G(\overline{\varpi}_{HH,t})$ is around 0.5. This suggests that we would need shocks that cause extremely large movements in the LTV on impact before we violate the upper bound on the LTV. See the appendix in Bernanke, Gertler, and Gilchrist (1999) for a discussion of the same issue in their model.

[15]We use the non-residential goods price level as a deflator.

Then perfectly competitive labor packers buy the differentiated labor input and aggregate them through a CES technology into one labor input per sector and households type. Finally, the labor inputs are further combined using a Cobb-Douglas technology to produce the aggregate labor resource $L_{C,t}$ and $L_{D,t}$ that enter the production functions of entrepreneurs (see later). Unions set wages on a staggered basis. Every period, each union faces a constant probability $1 - \alpha_{wji}$ of being able to adjust its nominal wage. If the union is not allowed to reoptimize, wages are indexed to past and steady-state inflation. Taking into account that unions might not be able to choose their nominal wage optimally in the future, the optimal nominal wage is chosen to maximize intertemporal utility under the budget constraint and the labor demand function.

2.3 Non-Financial Corporate Sectors

2.3.1 Entrepreneurs

Entrepreneurs are also more impatient than household savers and have a discount factor $\beta_E < \beta$. They receive utility from their consumption of non-residential goods. They are in charge of the production of intermediate residential and non-residential goods, and operate in a perfectly competitive environment. They do not supply labor services. Their intertemporal utility function is given by

$$\mathcal{W}_t^E = \mathbb{E}_t \left\{ \sum_{j \geq 0} (\beta_E)^j \frac{\left(C_{t+j}^E - h_E C_{t+j-1}^E\right)^{1-\sigma_{CE}}}{1 - \sigma_{CE}} \varepsilon_{t+j}^{\beta} \right\}.$$

Non-residential intermediate goods are produced with capital and labor, while residential intermediate goods combine capital, labor, and land. In every period of time, savers are endowed with a given amount of land, which they sell to the entrepreneurs in a fixed quantity. We assume that the supply of land is exogenously fixed and that each entrepreneur takes the price of land as given in its decision problem. Entrepreneurs make use of Cobb-Douglas technology as follows:

$$Z_t(e) = \varepsilon_t^A \left(u_t^C(e) K_{t-1}^C(e)\right)^{\alpha_C} L_t^C(e)^{1-\alpha_C} - \Omega_C \quad \forall e \in [0,1]$$
$$Z_{D,t}(e) = \varepsilon_t^{A_D} \left(u_t^D(e) K_{t-1}^D(e)\right)^{\alpha_D} L_t^D(e)^{1-\alpha_D-\alpha_{\mathcal{L}}} \mathcal{L}_t(e)^{\alpha_{\mathcal{L}}} - \Omega_D,$$

where ε_t^A and $\varepsilon_t^{A_D}$ are exogenous technology shocks and $\mathcal{L}_t(e)$ denotes the endowment of land used by entrepreneur e at time t. Capital is sector specific and is augmented by a variable capacity utilization rate u_t. MC_t and $MC_{D,t}$ denote the selling prices for intermediate non-residential and residential products.

Entrepreneurs' fixed capital is subject to common multiplicative idiosyncratic shocks $\varpi_{E,t}$. As for households, these shocks are independent and identically distributed across time and across entrepreneurs with $E(\varpi_{E,t}) = 1$, and a log-normal CDF $F^E(\varpi_{E,t})$. Here again, the variance of the idiosyncratic shock $\sigma_{E,t}$ is time varying.

As for borrowers, entrepreneurs only use debt contracts in which the loan rates can be made contingent on aggregate shocks but not on the idiosyncratic shock $\varpi_{E,t}$. Entrepreneurs belong to a large family that can diversify the idiosyncratic risk after loan contracts are settled but cannot commit to sharing the proceeds of this insurance with banks. Banks can seize collateral $\varpi_{E,t}\tilde{A}_{E,t}$ when the entrepreneur refuses to pay at a cost of $\mu_E\varpi_{E,t}\tilde{A}_{E,t}$. The value of the collateral that the bank can seize is

$$\varpi_{E,t}\tilde{A}_{E,t} = \varpi_{E,t}(1-\chi_E)(1-\delta_K)\big(Q_t^C K_{t-1}^C + Q_t^D K_{t-1}^D\big).$$

We assume that the capital utilization rate is predetermined with respect to the idiosyncratic shock to facilitate aggregation. χ_E reflects the ability to collateralize capital. This specification relates to models where only capital serves as collateral, as in Kobayashi, Nakajima, and Inaba (2007) or Gerali et al. (2010).

Aggregate repayments or defaults on outstanding loans to entrepreneurs are

$$H^E(\overline{\varpi}_{E,t})\tilde{A}_{E,t} = \left[\big(1 - F_t^E(\overline{\varpi}_{E,t})\big)\overline{\varpi}_{E,t} + \int_0^{\overline{\varpi}_{E,t}} \overline{\varpi} dF_t^E\right]\tilde{A}_{E,t}.$$

On the commercial lending bank side, the profit made on the credit allocation is given by

$$G^E(\overline{\varpi}_{E,t})\tilde{A}_{E,t} - \frac{(1+R_{E,t-1})}{1+\pi_t}B_{E,t-1} \geq 0$$

with

$$G^E(\varpi_{E,t}) = \left(1 - F_t^E(\varpi_{E,t})\right)\varpi_{E,t} + (1-\mu_E)\int_0^{\varpi_{E,t}} \varpi dF_t^E.$$

$R_{E,t-1}$ is the interest rate at which the commercial lending bank gets financing every period, while $R_{E,t}^L$ is the state-contingent lending rate to entrepreneurs.

Overall, each entrepreneur maximizes its utility function with respect to $(C_t^E, K_t^C, K_t^D, u_t^C, u_t^D, B_t^E, \varpi_{E,t}, L_{C,t}, L_{D,t})$ subject to an infinite sequence of real budget constraints

$$\begin{aligned} C_t^E &+ Q_t^C\left(K_t^C - (1-\delta_K)K_{t-1}^C\right) + Q_t^D\left(K_t^D - (1-\delta_K)K_{t-1}^D\right) \\ &\qquad + H^E(\varpi_{E,t})\tilde{A}_{E,t} \\ &= B_{E,t} + MC_tZ_t + MC_{D,t}Z_{D,t} - W_{C,t}^rL_{C,t} - W_{D,t}^rL_{D,t} - p_{lt}\mathcal{L}_t \\ &\qquad - \Phi\left(u_t^C\right)K_{t-1}^C - \Phi\left(u_t^D\right)K_{t-1}^D + TT_t^E \end{aligned}$$

together with the participation constraints for the banks. We assume the following functional form for the adjustment costs on capacity utilization: $\Phi(X) = \frac{\overline{\overline{R^k}}(1-\varphi)}{\varphi}\left(\exp\left[\frac{\varphi}{1-\varphi}(X-1)\right] - 1\right)$. Following Smets and Wouters (2007), the cost of capacity utilization is zero when capacity is fully used ($\Phi(1) = 0$). p_{lt} denotes the relative price of land deflated by non-residential goods price.

2.3.2 Retailers and Distribution Sectors

Retailers differentiate the residential and non-residential goods produced by the entrepreneurs and operate under monopolistic competition. They sell their output to the perfectly competitive distribution sectors which aggregate the continuum of differentiated goods. The elementary differentiated goods are imperfect substitutes, with elasticity of substitution denoted $\frac{\mu_D}{\mu_D-1}$ and $\frac{\mu}{\mu-1}$ for the residential and the non-residential sectors, respectively. The distributed goods are then produced with the following technology: $Y_D = \left[\int_0^1 Z_D(d)^{\frac{1}{\mu_D}} \mathrm{d}d\right]^{\mu_D}$ and $Y = \left[\int_0^1 Z(c)^{\frac{1}{\mu}} \mathrm{d}c\right]^{\mu}$. The corresponding aggregate price indexes are defined as $P_D = \left[\int_0^1 p_D(d)^{\frac{1}{1-\mu_D}} \mathrm{d}d\right]^{1-\mu_D}$

for the residential sector and $P = \left[\int_0^1 p(c)^{\frac{1}{1-\mu}} \mathrm{d}c\right]^{1-\mu}$ for the non-residential sector. The distribution goods serve as final consumption goods for households and are used by capital and housing stock producers.

Retailers are monopolistic competitors which buy the homogenous intermediate products of the entrepreneurs at prices MC_t for the non-residential intermediate goods and $MC_{D,t}$ for the residential intermediate goods. The intermediate products are then differentiated and sold back to the distributors. Retailers set their prices on a staggered basis à la Calvo (1983). In each period, a retailer in the non-residential sector faces a constant probability $1 - \xi_C$ (resp. $1 - \xi_D$ in the residential sector) of being able to reoptimize its nominal price. The demand curves that retailers face in each sector follow $Z_D(d) = \left(\frac{p_D(d)}{P_D}\right)^{-\frac{\mu_D}{\mu_D - 1}} Y_D$ and $Z(c) = \left(\frac{p(c)}{P}\right)^{-\frac{\mu}{\mu-1}} Y$.

2.3.3 Capital and Housing Stock Producers

Using distributed residential and non-residential goods, a segment of perfectly competitive firms, owned by the patient households, produce a stock of housing and fixed capital. At the beginning of period t, those firms buy back the depreciated housing stocks from both households types $(1-\delta)D_{t-1}$ and $(1-\delta)\widetilde{D}_{t-1}$ as well as the depreciated capital stocks $(1-\delta_K)K^C_{t-1}$, $(1-\delta_K)K^D_{t-1}$ at real prices (in terms of consumption goods) $Q_{D,t}T_{D,t}, \widetilde{Q}_{D,t}T_{D,t}, Q^D_t, Q^C_t$, respectively. Then they augment the various stocks using distributed goods and facing adjustment costs. The augmented stocks are sold back to entrepreneurs and households at the end of the period at the same prices.

2.4 The Banking Sector

The banking sector is owned by the patient households and is segmented in three parts. Following Gerali et al. (2010), each banking group is first composed of a wholesale branch which gets financing in the money market and allocates funds to the rest of the group, facing an adjustment cost on the overall capital ratio of the group. The wholesale branch takes the bank capital and the dividend policy as given in its decision problem and operates under perfect competition.

The second segment of the banking group comprises a deposit branch which collects savings from the patient households and places them in the money markets as well as two loan book financing branches which receive funding from the wholesale branch and allocate them to the commercial lending branches. In this second segment, banks operate under monopolistic competition and face nominal rigidity in their interest rate settings. The third segment of the banking group is formed by two commercial lending branches which provide loan contracts to impatient households and entrepreneurs. The commercial lending branches are zero-profit competitive firms.

2.4.1 Wholesale Branch

The perfectly competitive wholesale branches receive deposits Dep_t^{wb}, from the retail deposit banks, with an interest rate set at the policy rate R_t. Taking as given the bank capital $Bankcap_t$ in real terms, they provide loans $B_{E,t}^{wb}$ and $B_{HH,t}^{wb}$ at interest rates $R_{E,t}^{wb}$ and $R_{HH,t}^{wb}$ to the loan book financing branches for lending to entrepreneurs and households, respectively. When deciding on deposits and loans, the wholesale banks are constrained by an adjustment cost on banks' leverage. This friction is meant to capture the capital requirement pressures on the banks' behavior. For this reason, we assume that wholesale banks target a capital ratio of 11 percent and the quadratic cost is supposed to illustrate the various interactions between banks' balance sheet structure, market disciplining forces, and the regulatory framework.[16] On the one hand, this reflects that, owing to pecuniary and reputational costs, banks are keen to avoid getting too close to the regulatory minimum capital requirement and hence tend to operate with a substantial buffer over that minimum capital ratio.[17] On the other hand, bank capital is costly relative to other sources of financing (like deposits and bond issuance),

[16] The 11 percent capital ratio target corresponds to the average (risk-adjusted) total capital ratio of the 100 largest listed euro-area banks for the period 1999–2008 according to Datastream (Worldscope).

[17] There is a rich literature providing evidence that banks operate with substantial capital buffers; for some recent studies see, e.g., Ayuso, Pérez, and Saurina (2004), Bikker and Metzemakers (2004), Berger et al. (2008), Stolz and Wedow (2005), and Gropp and Heider (2010).

implying that banks tend to economize on the amount of capital they hold.[18]

Under the Basel I-like capital requirement regime, the bank's static profit maximization problem can be formulated as follows, where all quantities are expressed in real terms:

$$\max_{B_t^w, Dep_t^w} R_{HH,t}^{wb} B_{HH,t}^{wb} + R_{E,t}^{wb} B_{E,t}^{wb} - R_t Dep_t^{wb} - \frac{\chi_{wb}}{2}\left(\frac{Bankcap_t}{0.5B_{HH,t}^{wb} + B_{E,t}^{wb}} - 0.11\right)^2 Bankcap_t$$

subject to the balance sheet identity

$$B_{HH,t}^{wb} + B_{E,t}^{wb} = Dep_t^{wb} + Bankcap_t.$$

As in Gerali et al. (2010) the derived lending spreads emphasize "the role of bank capital in determining loan supply conditions." Hence, on the one hand, if the spread between the lending rate and the policy rate is positive, the bank would have an incentive to increase profits by raising loan volumes. This, on the other hand, would increase its leverage, which is, however, penalized by regulatory rules and market disciplining forces, as the capital ratio moves away from its target, which poses a cost to the bank. The bank's decision problem is therefore finely balanced between boosting its profits via increased leverage and retaining control of its capital structure. Moreover, a key point to notice for our Basel I type specification is that the bank's target capital ratio is insensitive to changes in borrower risk over time. In addition, reflecting the risk weighting of the Basel I regulatory framework, household loans are given a (fixed) risk weight of 50 percent, whereas the risk weight attached to corporate loans is 100 percent.

[18] For example, the European Central Bank (ECB) estimates of the cost of equity, the cost of market-based debt (i.e., bond issuance), and the cost of deposits for euro-area banks show that the former was on average around 6.7 percent in the period 2003–09. During the same period, banks' cost of raising debt in the capital markets was around 5 percent, while their average cost of deposit funding was close to 2 percent.

The decision problem of the wholesale bank leads to the following condition on the spread between the lending rate and the policy rate:

$$R^{wb}_{HH,t} - R_t = -\chi_{wb}\left(\frac{Bankcap_t}{0.5B^{wb}_{HH,t} + B^{wb}_{E,t}} - 0.11\right) \times \left(\frac{Bankcap_t}{0.5B^{wb}_{HH,t} + B^{wb}_{E,t}}\right)^2 0.5$$

$$R^{wb}_{E,t} - R_t = -\chi_{wb}\left(\frac{Bankcap_t}{0.5B^{wb}_{HH,t} + B^{wb}_{E,t}} - 0.11\right) \times \left(\frac{Bankcap_t}{0.5B^{wb}_{HH,t} + B^{wb}_{E,t}}\right)^2.$$

When the leverage of the bank increases beyond the targeted level, banks increase their loan-deposit margins.

The capital base of the wholesale branch is accumulated out of retained earnings from the bank group profits

$$Bankcap_t = (1 - \delta^{wb})Bankcap_{t-1} + \nu^b \Pi^b_t,$$

where δ^{wb} represents the resources used in managing bank capital, Π^b_t is the overall profit of the bank group, and ν^b is the share of profits not distributed to the patient households.

2.4.2 Imperfect Pass-Through of Policy Rate on Bank Lending Rates

The retail deposit branch and the loan book financing branches are monopolistic competitors and set their interest rates on a staggered basis with some degree of nominal rigidity à la Calvo (1983).

Retail Deposit Branch. The deposits offered to patient households are a CES aggregation of the differentiated deposits provided by the retail deposit branches: $Dep = \left[\int_0^1 Dep(j)^{\frac{1}{\mu^R_D}} \mathrm{d}j\right]^{\mu^R_D}$, expressed in real terms. Retail deposits are imperfect substitutes with elasticity of substitution $\frac{\mu_D^R}{\mu_D^R-1} < -1$. The corresponding average interest rate offered on deposits is $R_D = \left[\int_0^1 R_D(j)^{\frac{1}{1-\mu_D^R}} \mathrm{d}j\right]^{1-\mu_D^R}$.

Retail deposit branches are monopolistic competitors which collect deposits from savers and place them in the money market. Deposit branches set interest rates on a staggered basis à la Calvo (1983), facing each period a constant probability $1-\xi_D^R$ of being able to reoptimize their nominal interest rate. When a retail deposit branch cannot reoptimize its interest rate, the interest rate is left at its previous period level.

The retail deposit branch j chooses $\hat{R}_{D,t}(j)$ to maximize its intertemporal profit.

$$\mathbb{E}_t\left[\sum_{k=0}^{\infty}\left(\gamma\xi_D^R\right)^k\frac{\Lambda_{t+k}}{\Lambda_t}\left(R_{t+k}Dep_{t+k}(j)-\hat{R}_{t,D}(j)Dep_{t+k}(j)\right)\right],$$

where $Dep_{t+k}(j) = \left(\frac{\hat{R}_{D,t}(j)}{R_{D,t}}\right)^{-\frac{\mu_D^R}{\mu_D^R-1}}\left(\frac{R_{D,t}}{R_{D,t+k}}\right)^{-\frac{\mu_D^R}{\mu_D^R-1}} Dep_{t+k}$ and Λ_t is the marginal value of non-residential consumption for the household savers.

A markup shock $\varepsilon_{D,t}^R$ is introduced in the staggered nominal deposit rate setting.

Loan Book Financing Branches. As for the retail deposit branches, loan book financing branches provide funds to the commercial lending branches which obtain overall financing through a CES aggregation of the differentiated loans: $B_{E,t} = \left[\int_0^1 B_{E,t}(j)^{\frac{1}{\mu_E^R}} \mathrm{d}j\right]^{\mu_E^R}$ as regards commercial loans to entrepreneurs and $B_{HH,t} = \left[\int_0^1 B_{HH,t}(j)^{\frac{1}{\mu_{HH}^R}} \mathrm{d}j\right]^{\mu_{HH}^R}$ as regards commercial loans to households. Loans from loan book financing branches are imperfect substitutes with elasticity of substitution $\frac{\mu_E^R}{\mu_E^R-1}$ and $\frac{\mu_{HH}^R}{\mu_{HH}^R-1} > 1$. The corresponding average lending rate is

$$R_E = \left[\int_0^1 R_E(j)^{\frac{1}{1-\mu_E^R}} \mathrm{d}j\right]^{1-\mu_E^R} \quad \text{and}$$

$$R_{HH} = \left[\int_0^1 R_{HH}(j)^{\frac{1}{1-\mu_{HH}^R}} \mathrm{d}j\right]^{1-\mu_{HH}^R}.$$

Loan book financing branches for each segment of the credit market are monopolistic competitors which levy funds from the wholesale branches and set interest rates on a staggered basis à la Calvo (1983), facing each period a constant probability $1-\xi_E^R$ and $1-\xi_{HH}^R$ of being able to reoptimize their nominal interest rate. If a loan book financing branch cannot reoptimize its interest rate, the interest rate is left at its previous period level.

In each sector $i \in \{E, HH\}$, the loan book financing branch j chooses $\hat{R}_{i,t}(j)$ to maximize its intertemporal profit.

$$\mathbb{E}_t\left[\sum_{k=0}^{\infty}\left(\gamma\xi_i^R\right)^k\frac{\Lambda_{t+k}}{\Lambda_t}\left(\hat{R}_{i,t}(j)B_{i,t+k}(j)-R_{i,t}^{wb}(j)B_{i,t+k}(j)\right)\right],$$

where $B_{i,t+k}(j)=\left(\frac{\hat{R}_{i,t}(j)}{R_{i,t}}\right)^{-\frac{\mu_i^R}{\mu_i^R-1}}\left(\frac{R_{i,t}}{R_{i,t+k}}\right)^{-\frac{\mu_i^R}{\mu_i^R-1}}B_{i,t+k}$.

As for deposit rates, we add markup shocks $\varepsilon_{HH,t}^R$ and $\varepsilon_{E,t}^R$ to the staggered nominal lending rate settings.

Commercial Lending Branches. Commercial lending branches deliver credit contracts for entrepreneurs and household borrowers. Those branches are perfectly competitive and in equilibrium have zero profits. Details on the credit contract and the decision problems for the commercial lending branches are provided in the sections on entrepreneurs and household borrowers.

2.5 Government and Monetary Authority

Public expenditures $\overline{\overline{G}}$ are subject to random shocks ε_t^G. The government finances public spending with lump-sum transfers.

Monetary policy is specified in terms of an interest rate rule targeting inflation, output, and their first difference as well as changes in the relative price of housing. Written in deviation from the steady state, the interest rate rule used has the following form:

$$\begin{aligned} r_t &= \rho r_{t-1}+(1-\rho)(r_\pi\pi_{t-1}+r_y y_{t-1})+r_{\Delta\pi}\Delta\pi_t+r_{\Delta y}\Delta y_t \\ &\quad + r_{T_D}\Delta t_{D,t}+\log\left(\varepsilon_t^R\right), \end{aligned}$$

where lowercase letters denote log-deviations of a variable from its deterministic steady state.

3. Bayesian Estimation

The model is estimated on euro-area data using Bayesian likelihood methods. We consider fifteen key macroeconomic quarterly time series from 1986:Q1 to 2008:Q2: output, consumption, non-residential fixed investment, hours worked, real wages, CPI inflation rate, three-month short-term interest rate, residential investment, real house prices, household loans, non-financial corporation loans, household deposits, and bank lending rates on household loans, on non-financial corporation loans, and on household deposits. All real variables and real house prices are linearly detrended prior to estimation. Inflation and nominal interest rates are mean adjusted (see the calibration section for more details). Full description of the data set is provided in appendix 1.

We summarize here the exogenous stochastic shocks that we introduce:

- Efficient shocks: AR(1) technology (ε_t^A) (common to both sectors), AR(1) housing-specific technology ($\varepsilon_t^{A_D}$), AR(1) non-residential investment specific productivity (ε_t^I), AR(1) labor supply (ε_t^L), AR(1) public expenditure (ε_t^G), AR(1) consumption preferences (ε_t^B), and AR(1) housing preferences (ε_t^D)
- Inefficient shocks: i.i.d price markup (ε_t^P), AR(1) interest rate markups on deposits and loans ($\varepsilon_{D,t}^R, \varepsilon_{HH,t}^R, \varepsilon_{E,t}^R$).
- Riskiness shocks: the standard deviation of the idiosyncratic risk for impatient households and entrepreneurs is subject to AR(1) shocks ($\varepsilon_{HH,t}^\sigma, \varepsilon_{E,t}^\sigma$)
- AR(1) bank capital shock ($\varepsilon_t^{Bankcap}$)
- Monetary policy shock (ε_t^R)

As regards behavioral parameters, we chose to limit the number of estimated coefficients by bringing some symmetry across sectors and agents. We estimate the parameters driving the adjustment costs on residential and non-residential investment, ϕ_D, ϕ, which are the same across household types and sectors, respectively. The parameter on capacity utilization adjustment cost φ is also the same for both sectors. Concerning preference parameters, the intertemporal elasticity of substitution, σ_X, is similar for the two household types; the labor supply elasticity, σ_L, is the same across household types and sector-specific labor service; and the habit parameter, h, is equalized across all agents. The Calvo parameters on nominal wage rigidity, α_{wC}, α_{wD}, are the same for both household types, while we introduce a single indexation parameter γ_w. The Calvo parameter on non-residential retail goods price setting, ξ_C, and the associated indexation coefficients, γ_C, are estimated, while in the residential goods sector, we estimate the Calvo parameter, ξ_D, and set the indexation parameter, γ_D, to zero. On the imperfect interest rate pass-through, we draw some inference on the three coefficients driving the staggered rate setting on deposits and loans, ξ_D^R, ξ_{HH}^R, ξ_E^R. The adjustment cost on banks' capital structure, χ_{wb}, is also estimated. Finally, the parameters in the Taylor rule are $\rho, r_\pi, r_y, r_{\Delta\pi}, r_{\Delta y}, r_{T_D}$.

In the benchmark estimation, we do not introduce the share of household borrowers. As argued later on, given the weak identification of the parameter and the lack of observable data on households' heterogenous features, we calibrated this parameter to achieve realistic debt structure in the steady state. At the same, some inference and sensitivity analysis on this coefficient is presented thereafter. Calibrating the share of borrowers is also symmetric to our assumption that all firms are financially constrained.

Some parameters are excluded from the estimation and have to be calibrated. These are typically parameters driving the steady-state values of the state variables, for which the econometric model based on detrended data is almost non-informative. Details about the calibrated parameters, the steady state, and the prior distributions are provided in appendices 2 and 3.

3.1 Posterior Distributions

Tables 1 and 2 report the mode, the mean, and the 10th and 90th percentiles of the posterior distribution of the structural parameters for the model.

In terms of the parameter estimates, emphasizing those features that are more closely related to our modeling framework with respect to the sectoral structure of the economy and financial frictions, among the stochastic exogenous disturbances, the posterior distributions for autoregressive coefficients turned out to be very close to unity for several shocks. Those shocks are, notably, those related to the housing sector, housing preference and productivity shocks,

Table 1. Parameter Estimates 1

Param.	*A priori* Beliefs			Benchmark Specification *A posteriori* Beliefs				Alternative Specification *A posteriori* Beliefs			
	Dist.	Mean	Std.	Mode	Mean	$\mathcal{I}_1$	$\mathcal{I}_2$	Mode	Mean	$\mathcal{I}_1$	$\mathcal{I}_2$
ε_t^A	unif	5	2.89	0.49	0.50	0.42	0.58	0.45	0.46	0.39	0.53
ε_t^I	unif	5	2.89	0.26	0.27	0.20	0.34	0.26	0.28	0.20	0.35
ε_t^L	unif	5	2.89	0.17	0.18	0.13	0.23	0.18	0.19	0.15	0.24
ε_t^G	unif	5	2.89	1.85	1.87	1.64	2.12	1.88	1.92	1.68	2.16
ε_t^B	unif	5	2.89	1.44	1.50	1.24	1.77	2.05	2.02	1.57	2.45
$\varepsilon_t^{A_D}$	unif	5	2.89	2.09	2.15	1.52	2.75	2.08	2.10	1.50	2.65
ε_t^D	unif	5	2.89	2.04	2.47	1.21	3.72	2.77	2.95	1.72	4.10
ε_t^P	unif	5	2.89	0.28	0.30	0.25	0.35	0.28	0.29	0.25	0.34
$\varepsilon_{D,t}^R$	unif	5	2.89	0.06	0.06	0.04	0.08	0.07	0.07	0.05	0.09
$\varepsilon_{HH,t}^R$	unif	5	2.89	0.06	0.06	0.05	0.07	0.06	0.06	0.05	0.07
$\varepsilon_{E,t}^R$	unif	5	2.89	0.12	0.13	0.11	0.15	0.12	0.13	0.11	0.15
$\varepsilon_{HH,t}^\sigma$	unif	5	2.89	0.08	0.08	0.07	0.09	0.03	0.03	0.02	0.04
$\varepsilon_{E,t}^\sigma$	unif	5	2.89	0.06	0.06	0.05	0.07	0.06	0.06	0.05	0.07
$\varepsilon_t^{Bankcap}$	unif	5	2.89	2.32	2.37	2.06	2.66	2.30	2.35	2.06	2.65
ε_t^R	unif	5	2.89	0.10	0.11	0.09	0.12	0.11	0.11	0.10	0.13

(continued)

Table 1. (Continued)

Param.	***A priori* Beliefs**			**Benchmark Specification** *A posteriori* **Beliefs**				**Alternative Specification** *A posteriori* **Beliefs**			
	Dist.	**Mean**	**Std.**	**Mode**	**Mean**	$\mathcal{I}_1$	$\mathcal{I}_2$	**Mode**	**Mean**	$\mathcal{I}_1$	$\mathcal{I}_2$
ρ_A	beta	0.5	0.2	0.92	0.90	0.85	0.95	0.97	0.96	0.93	0.98
ρ_I	beta	0.5	0.2	0.68	0.68	0.58	0.78	0.69	0.68	0.58	0.79
ρ_l	beta	0.5	0.2	0.85	0.83	0.73	0.93	0.79	0.60	0.27	0.89
ρ_G	beta	0.5	0.2	0.91	0.88	0.79	0.97	0.99	0.98	0.97	0.99
ρ_B	beta	0.5	0.2	0.95	0.94	0.91	0.97	0.97	0.97	0.96	0.98
ρ_{A_D}	beta	0.5	0.2	0.89	0.88	0.83	0.94	0.90	0.89	0.84	0.93
ρ_D	beta	0.5	0.2	0.99	0.98	0.97	0.99	0.97	0.97	0.96	0.99
$\rho^R_{D,t}$	beta	0.5	0.2	0.97	0.96	0.93	0.99	0.95	0.95	0.92	0.97
$\rho^R_{HH,t}$	beta	0.5	0.2	0.26	0.26	0.13	0.38	0.25	0.25	0.14	0.37
$\rho^R_{E,t}$	beta	0.5	0.2	0.40	0.41	0.23	0.57	0.37	0.37	0.22	0.52
$\rho^\sigma_{HH,t}$	beta	0.5	0.2	0.98	0.98	0.97	0.99	0.99	0.99	0.98	0.99
$\rho^\sigma_{E,t}$	beta	0.5	0.2	0.98	0.98	0.96	0.99	0.98	0.97	0.96	0.99
$\rho^{Bankcap}_t$	beta	0.5	0.2	0.71	0.70	0.61	0.79	0.72	0.71	0.62	0.80

Table 2. Parameter Estimates 2

Param.	*A priori* Beliefs			Benchmark Specification *A posteriori* Beliefs				Alternative Specification *A posteriori* Beliefs			
	Dist.	**Mean**	**Std.**	**Mode**	**Mean**	$\mathcal{I}_1$	$\mathcal{I}_2$	**Mode**	**Mean**	$\mathcal{I}_1$	$\mathcal{I}_2$
ϕ_D	gamm	1	0.5	0.23	0.23	0.15	0.31	0.23	0.22	0.15	0.30
ϕ	norm	4	1.5	7.72	7.71	5.63	9.74	7.52	7.66	5.54	9.79
φ	beta	0.5	0.15	0.75	0.76	0.63	0.89	0.77	0.76	0.64	0.89
σ_X	gamm	1.5	0.20	0.63	0.65	0.56	0.73	0.71	0.72	0.66	0.79
h	beta	0.75	0.1	0.59	0.58	0.54	0.62	0.53	0.51	0.45	0.58
σ_L	gamm	1.5	0.1	1.32	1.33	1.18	1.47	1.32	1.32	1.18	1.46
α_{wC}	beta	0.85	0.05	0.73	0.73	0.67	0.80	0.73	0.79	0.68	0.89
α_{wD}	beta	0.85	0.05	0.87	0.85	0.79	0.92	0.88	0.86	0.81	0.92
γ_w	beta	0.5	0.15	0.24	0.28	0.10	0.44	0.19	0.26	0.09	0.43
ξ_C	beta	0.75	0.05	0.83	0.83	0.79	0.86	0.84	0.85	0.81	0.88
γ_C	beta	0.5	0.15	0.58	0.61	0.45	0.78	0.55	0.58	0.43	0.73
ξ_D	beta	0.2	0.1	0.81	0.81	0.76	0.86	0.81	0.79	0.75	0.84
ξ_D^R	beta	0.5	0.2	0.32	0.31	0.26	0.37	0.28	0.28	0.23	0.33

(continued)

Table 2. (Continued)

Param.	*A priori* Beliefs			Benchmark Specification *A posteriori* Beliefs				Alternative Specification *A posteriori* Beliefs			
	Dist.	Mean	Std.	Mode	Mean	$\mathcal{I}_1$	$\mathcal{I}_2$	Mode	Mean	$\mathcal{I}_1$	$\mathcal{I}_2$
ξ^R_{HH}	beta	0.5	0.2	0.92	0.92	0.88	0.95	0.90	0.90	0.88	0.92
ξ^R_E	beta	0.5	0.2	0.76	0.75	0.69	0.82	0.77	0.76	0.70	0.82
χ_{wb}	gamm	20	2.5	18.58	18.54	15.08	22.03	19.07	19.34	15.90	22.56
ρ	beta	0.75	0.1	0.84	0.84	0.82	0.87	0.81	0.81	0.78	0.84
r_π	gamm	2.5	0.25	2.37	2.38	2.17	2.59	2.36	2.41	2.22	2.60
r_y	gamm	0.2	0.1	0.03	0.03	0.01	0.05	0.04	0.04	0.02	0.06
$r_{\Delta\pi}$	gamm	0.30	0.10	0.24	0.24	0.18	0.31	0.31	0.31	0.24	0.38
$r_{\Delta y}$	gamm	0.12	0.05	0.07	0.08	0.05	0.11	0.09	0.10	0.06	0.13
r_{T_D}	norm	0.00	1.00	0.03	0.03	0.00	0.06	0.01	0.01	−0.02	0.04
λ_e	beta	0.75	0.05	0.65	0.65	0.61	0.69	0.64	0.63	0.58	0.67
ω	beta	0.45	0.05	—	—	—	—	0.28	0.27	0.22	0.31
$\rho_{B,D}$	unif	0.00	2.89	—	—	—	—	0.89	0.91	0.53	1.26
$\rho_{D,\sigma_{HH}}$	gamm	1.00	0.50	—	—	—	—	1.78	1.76	1.20	2.33
$P_\lambda(\mathcal{Y})$				−432.1				−387.2			

and to loan dynamics, risk shocks on households and entrepreneurs. Visual inspection of detrended real house prices and loan data over the sample indeed suggest very high degrees of persistence which are not well captured by the internal propagation of the model. The markup shocks on bank interest rates also display high autoregressive coefficients, with the notable exception of lending rates to households, for which lower inertia seems to compensate for higher nominal rigidity.

Turning to behavioral parameters, the labor supply elasticity as well as the inflation term in level in the monetary policy rule are weakly identified. The estimation does not support the evidence of meaningful specific reaction of monetary policy to house prices.

The Calvo parameters on the imperfect adjustment of lending rates are estimated to be the lowest for deposit rates, at around 0.3; the highest for lending rates to households, at around 0.9 in the benchmark estimation; and somewhat in between for lending rates to entrepreneurs, at around 0.75. The higher flexibility of deposit rates is also found by Gerali et al. (2010) and is most likely due to differences in the maturity structures of the various composite rates which cannot be accounted for by the one-period loans considered in the DSGE model.

Finally, the posterior distribution for the adjustment cost on banks' capital structure, χ_{wb}, stays very close to its prior distribution. At the same time, having experimented with alternative priors, the posterior distribution could eventually depart significantly from the prior one, therefore suggesting that data are somewhat informative about this parameter.

As regards the real and nominal rigidities for the residential sector, the estimation leads to an adjustment cost parameter for residential investment, ϕ_D, of around 0.2 at the mode. The degree of nominal rigidity is quite elevated, with a posterior mode for the Calvo parameter on residential prices of 0.81. The real rigidities in the residential sector have compounded effects on macroeconomic propagation through households' borrowing constraint and, consequently, households' consumption expenditures. Overall, it seems that data call for some degree of real rigidity in the residential markets. Everything else being equal, this implies that relative prices would react more to economic shocks. In order to limit the volatility of residential prices in the presence of adjustment costs on residential investment, staggered housing price setting is needed.

Tables 1 and 2 show the posterior parameter distributions when introducing correlations between the consumption preference shock and the housing preference shock on the one hand, and between the housing preference shocks and the household risk shock on the other hand. These experiments were guided by the correlations of structural shocks obtained in the estimations.

The innovation on the consumption preference shock, ε_t^B, has been introduced in the AR(1) process of the housing preference shock. Such a positive correlation between both exogenous disturbances is partly correcting for the sharp negative co-movement after a consumption preference shock between consumption and residential investment, which may not be supported by data given the positive unconditional correlation observed in our sample. The introduction of the innovation on the housing preference shock in the AR(1) process of the risk shock on housing loans is limiting the negative co-movement between residential price and residential investment on the one hand and lending rate spreads to households on the other hand. The presence of such correlations is affecting the inference on behavioral parameters.

In the results reported in tables 1 and 2, we also estimated the share of household borrowers, ω, free in the estimation procedure. The prior distribution for this parameter was set with a relatively elevated mean and small variance. The posterior distribution for the household borrowers' share reaches 28 percent at the mode. Overall, ω does not seem to be strongly identified. This confirms the results of Darracq Pariès and Notarpietro (2008). The presence of borrowers is not rejected by the data, as the model specification leads to strictly positive values for such shares.

3.2 Business-Cycle Contribution of Financial Shocks

We also analyze the role of credit market frictions and financial shocks in economic fluctuations. Table 3 reports unconditional variance decomposition of HP-filtered variables, emphasizing the contribution of housing-related structural shocks and shocks to the banking sector. The variance decomposition is computed using the posterior modes of their respective estimation.

Table 3. Shocks Decomposition of Unconditional Variances: HP Filtering

	$\varepsilon_t^{A_D}$	ε_t^{D}	$\varepsilon_{HH,t}^{\sigma}$	$\varepsilon_{E,t}^{\sigma}$	$\varepsilon_{HH,t}^{R}$	$\varepsilon_{E,t}^{R}$	$\varepsilon_{D,t}^{R}$	$\varepsilon_t^{Bankcap}$	**Others** Z_t
Z_t	3.1	19.1	14.9	3.5	1.2	0.1	8.2	0.7	49.1
C_t^{tot}	0.7	7.8	26.8	1.8	1.8	0.1	8.0	0.6	52.6
I_t	0.1	0.8	0.4	40.4	0.4	1.9	0.4	6.3	49.1
$Z_{D,t}$	23.3	42.9	1.4	0.8	0.4	0.1	5.0	0.1	26.1
$T_{D,t}$	3.6	36.5	1.3	3.0	0.0	0.1	1.2	0.5	53.9
L_t^{tot}	2.5	17.6	13.2	3.7	1.1	0.1	7.2	0.8	53.9
W_t^{tot}	0.5	4.3	16.0	1.2	1.1	0.0	6.9	0.4	69.7
Π_t	0.2	1.2	7.6	3.6	0.4	0.1	8.3	0.8	77.9
R_t	0.1	10.9	12.6	8.5	0.9	0.2	13.4	1.8	51.7
$R_{E,t}$	0.0	3.0	4.4	19.6	0.6	35.8	6.6	7.1	23.0
$R_{HH,t}$	0.2	8.5	24.6	2.7	42.9	0.8	5.9	2.6	11.9
$R_{D,t}$	0.1	11.6	14.4	10.5	0.9	0.3	4.7	2.2	55.4
$B_{E,t}$	0.0	1.5	6.3	61.1	0.8	1.0	3.5	3.1	22.7
$B_{HH,t}$	0.3	17.9	53.9	0.9	3.9	0.3	1.1	3.2	18.7
Dep_t	0.1	6.9	18.4	22.4	2.2	1.1	2.0	23.3	23.6

More than 50 percent of unconditional variances of loans to households and entrepreneurs are explained by their respective risk shock. Indeed, looking at zero-profit condition for household loans, for example,

$$G(\varpi_{HH,t})\tilde{A}_{HH,t} - \frac{(1 + R_{HH,t-1})}{1 + \pi_t} B_{HH,t-1} \geq 0,$$

we see that the term $G(\varpi_{HH,t})$ could be interpreted as a time-varying loan-to-value ratio and is directly related to the risk shock on household borrowers. In the empirical exercise, this shock is therefore partly capturing the gap between the dynamics of loans and the dynamics of its collateral value. Household deposits are mainly driven by risk shocks on households and entrepreneurs as well as by bank capital shocks, with a respective contribution of around 20 percent. Those disturbances have a strong impact on bank assets and capital, thereby mechanically affecting bank liabilities. Overall, approximately 20 percent of the unconditional volatility of loans and deposits are driven by disturbances not related to the financial or housing blocks.

On bank lending rates, for each sector, the risk shock and the interest rate markup shock have strong contributions, explaining jointly more than 50 percent of variance. By contrast, the role of financial shocks is more limited as regards the volatility of deposit rates.

Turning to the residential sector, the housing preference shock explains a large part of price and quantity in this sector. The housing-specific productivity shock contributes mainly to residential investment volatility. On balance, 40 percent of residential investment and 60 percent of real housing prices are driven by non-housing-specific disturbances.

For the non-residential sector, the corporate risk shock has a large contribution to non-residential investment fluctuations, whereas the household risk shock contributes significantly to consumption volatility, albeit to a lesser extent. The housing preference shock and the interest rate markup shock on deposits are non-negligible sources of consumption unconditional variance. For GDP, consumption, and non-residential investment, roughly 50 percent of unconditional variances are not explained by financial and housing-specific shocks.

Finally, on consumer prices, the risk shocks and the interest rate shock on deposits have some meaningful contributions, but almost 80 percent of variance is driven by disturbances not related to the financial or the housing blocks.

4. Macroeconomic Propagation and Monetary Policy Stabilization under Different Regulatory Frameworks

In this section we consider the macroeconomic implications of the various types of credit frictions embedded in our model and, in turn, consider how different kinds of regulatory frameworks might affect monetary policy stabilization.

We focus in particular on disturbances to the financial side of our model economy. For a description of propagation of non-financial economic disturbances, please refer to the working paper version of this article (Darracq Pariès, Kok Sørensen, and Rodriguez Palenzuela 2010).

4.1 Bank Capital Shocks and Bank Capital Channel

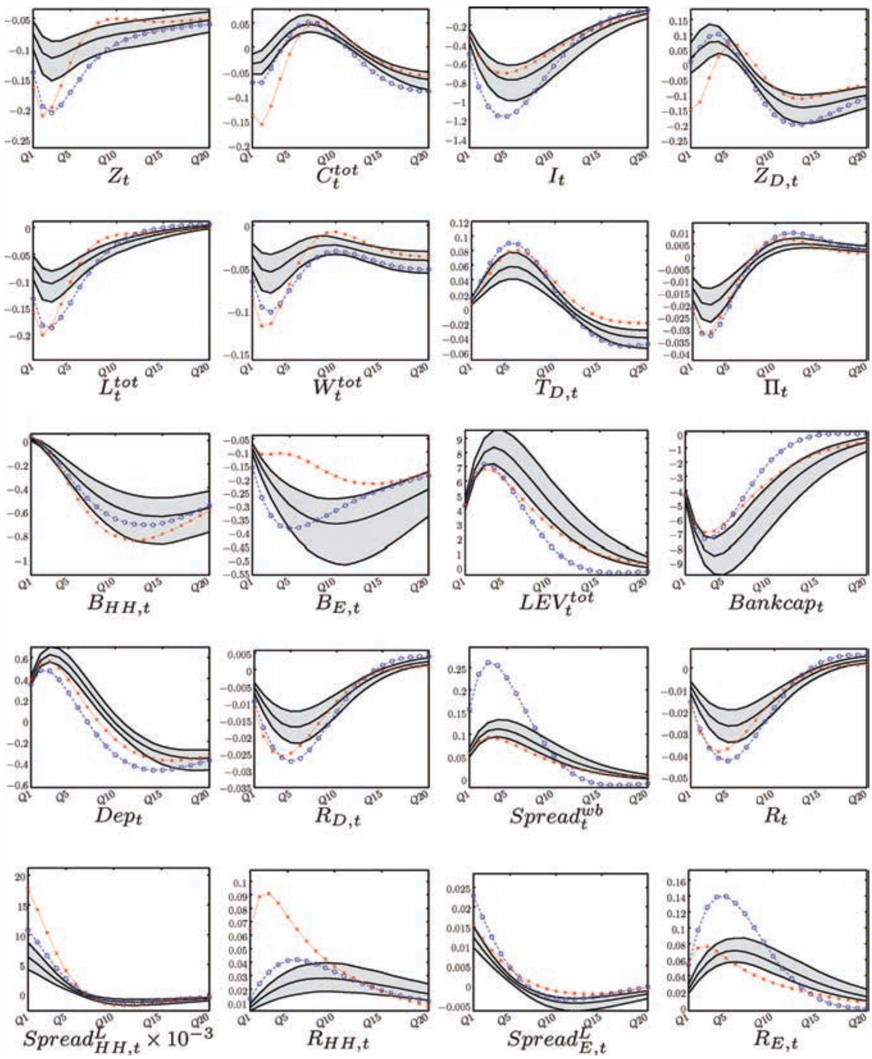
The recent financial crisis led banks to incur substantial losses on their trading and loan books, which in turn put severe pressure on their capital positions. In order to return to a more stable capital situation, and possibly responding to pressures from regulators and market participants to operate with more solid capital buffers, banks have been faced with a trade-off of either raising new capital or adjusting their asset side, or (more likely) a combination of the two. Our model specification can be used to assess the macroeconomic implications of such shocks to bank capital, which in our case will lead banks to replenish their capital position by boosting their retained earnings. This is illustrated in figure 2, which shows the implications of an adverse shock to bank capital, ($\varepsilon_t^{Bankcap}$). The bank capital shock results in an increase in bank leverage which, in order for banks to reestablish their target leverage ratio, leads to an increase in banks' loan-deposit margins. This is driven mainly by higher lending rates, which in turn reduces lending and hence real activity.[19] The negative impact on output of the bank capital shock in the benchmark model is relatively modest but persistent.[20]

The specific role of the bank capital channel in the propagation of economic shocks via the financial sector can be further analyzed by increasing banks' adjustment cost on their leverage (setting $\chi_{wb} = 50$). This is illustrated by the dotted lines with circles in figures 2–4, and it is observed that a more pronounced bank capital channel results in a much stronger propagation of shocks from the banking sector to the real economy. Consequently, the monetary policy response is also more forceful than in the benchmark case, which allows for output to rebound back towards the baseline over time.

[19]This mechanism is corroborated by empirical findings for the United States, which suggests that pressure on bank capital positions induces banks to apply higher lending rates (in particular vis-à-vis their riskier borrowers); see Santos and Winton (2009).

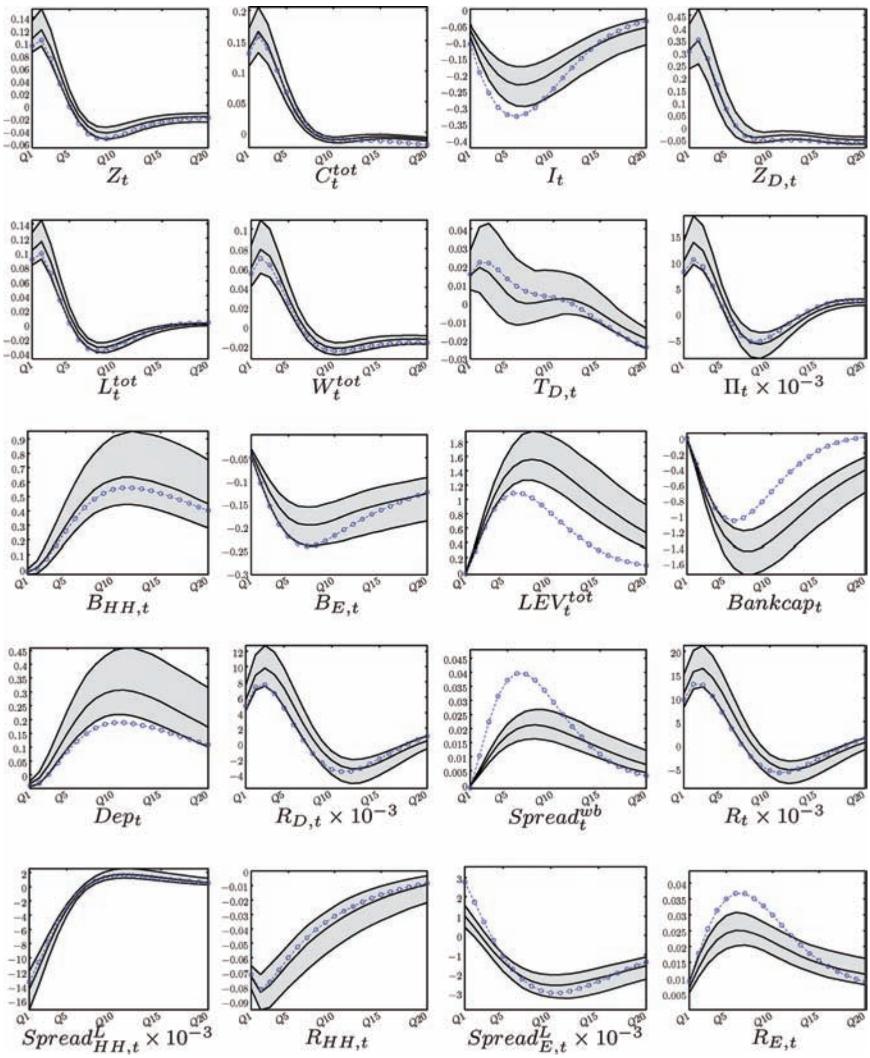
[20]Recent empirical studies suggest an approximate effect of a 1-percentage-point shock to bank capital positions (or loan supply shocks more generally) in the range of an approximately 0.1- to 1.0-percentage-point impact on real economic activity; see, e.g., Van den Heuvel (2008), Ciccarelli, Maddaloni, and Peydró (2009), Francis and Osborne (2009), and Cappiello et al. (2010). Our baseline estimates are at the lower end of this range.

Figure 2. Impulse Response Functions Associated with a Shock on $\varepsilon_t^{Bankcap}$



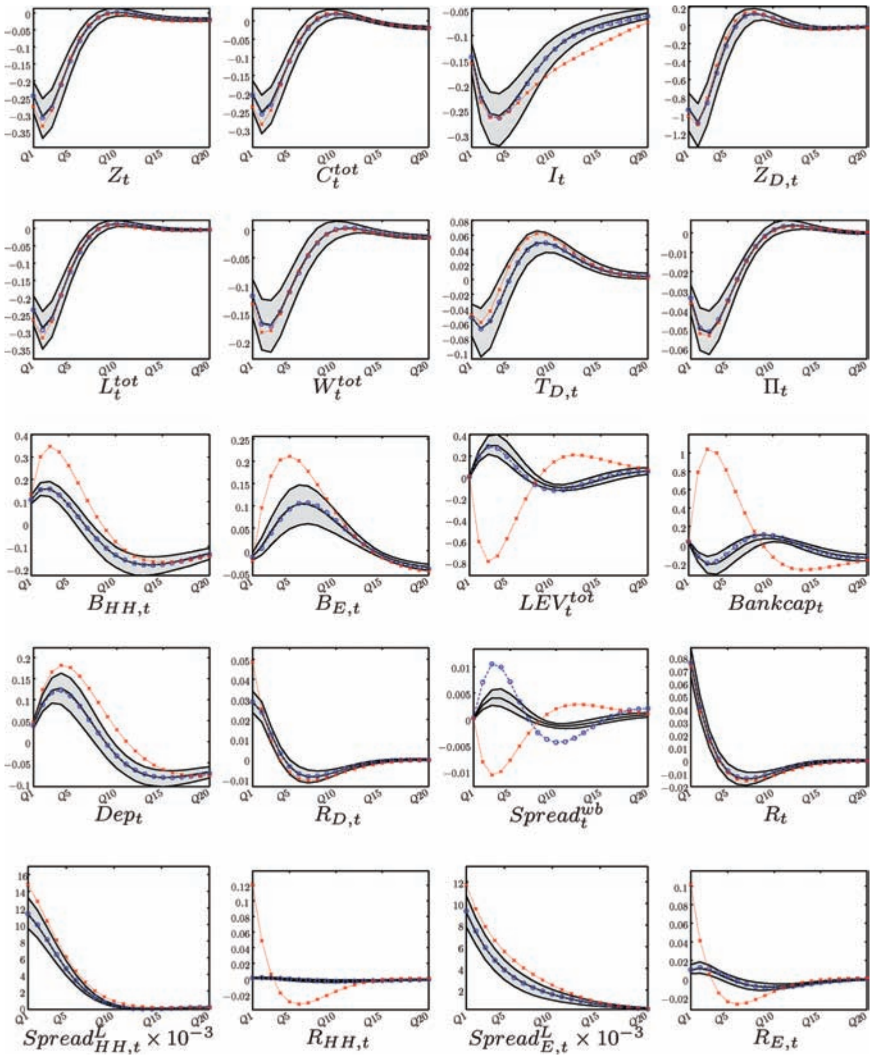
Note: Benchmark model (plain lines for the mode and shaded areas for the 90 percent highest-density interval from the posterior distribution of parameters), model with high bank capital channel (dotted lines with circles), and model without imperfect interest rate pass-through (dashed lines with crosses).

Figure 3. Impulse Response Functions Associated with a Shock on $\varepsilon^{R}_{HH,t}$



Note: Benchmark model (plain lines for the mode and shaded areas for the 90 percent highest-density interval from the posterior distribution of parameters), model with high bank capital channel (dotted lines with circles), and model without imperfect interest rate pass-through (dashed lines with crosses).

Figure 4. Impulse Response Functions Associated with a Shock on ε_t^R



Note: Benchmark model (plain lines for the mode and shaded areas for the 90 percent highest-density interval from the posterior distribution of parameters), model with high bank capital channel (dotted lines with circles), and model without imperfect interest rate pass-through (dashed lines with crosses).

The role of bank capital constraints and the macroeconomic propagation through the bank profit channel can also be illustrated in the case of a negative markup shock to mortgage loan spreads (figure 3), which creates an immediate boost to mortgage lending and consumption. It is observed the ensuing monetary tightening leads to a more pronounced reduction of output, and investment in particular, in the presence of a strong bank capital channel, as banks react to the increase in leverage by more forcefully raising their loan-deposit margin.

The cyclicality of bank profits and its impact on macroeconomic propagation is furthermore accentuated by the sluggishness of bank interest rate setting. A common finding in the empirical literature is that banks only gradually pass on the changes in monetary policy rates to the rates offered to their retail customers. This sluggishness may thus affect the speed and effectiveness of the monetary policy transmission via the interest rate channel. The frictions are furthermore often found to be asymmetric in the sense that bank lending rates tend to adjust quicker as a response to policy rate increases than to policy rate decreases.[21] In other words, the sluggishness of retail bank interest rates is another friction affecting the way shocks are propagated to the real economy. This is best illustrated when considering a monetary policy shock (figure 4). For example, a monetary tightening via its overall more muted impact on lending rates than on deposit rates, in turn, exerts an initial negative impact on bank capital that induces banks to adjust their loan-deposit margins to recoup their profits. This further amplifies the macroeconomic response to the initial monetary policy shock.

The importance of retail bank interest rate rigidities is furthermore considered for the case where banks have no market power when setting rates and where consequently the pass-through of policy rates to bank interest rates is immediate and complete are shown (dashed lines with crosses). Overall, this implies that monetary policy accommodation to the various shocks hitting the economy is transmitted fully and more quickly to the interest rates facing savers and borrowers. Hence, the counterbalancing impact of monetary policy is more powerful in this case. In other words, the common

[21] See, e.g., Mester and Saunders (1995), Mojon (2001), and Gropp, Kok Sørensen, and Lichtenberger (2007).

finding that the bank interest rate pass-through is sluggish implies a somewhat attenuated impact of the policy rate changes through the interest rate channel of monetary policy transmission.

4.2 Transitional Dynamics Towards Higher Capital Requirements

Our model is also well suited to investigate the macroeconomic implications of changes to the regulatory framework. The reform of the financial regulatory landscape enacted in end-2010 (so-called Basel III), following the proposal of the Basel Committee on Banking Supervision (BCBS), will lead to higher required capital for the banking sector.[22] The simulations presented remain illustrative of the transitional costs of introducing higher capital requirements but should not be interpreted as a quantitative economic assessment of the introduction of Basel III.[23] Indeed, the magnitude of the shock is not related to the exact calibration of the reform and to the balance sheet structure of the euro-area system. Moreover, the simulation is silent on the steady-state and cyclical benefits of higher capital requirements.

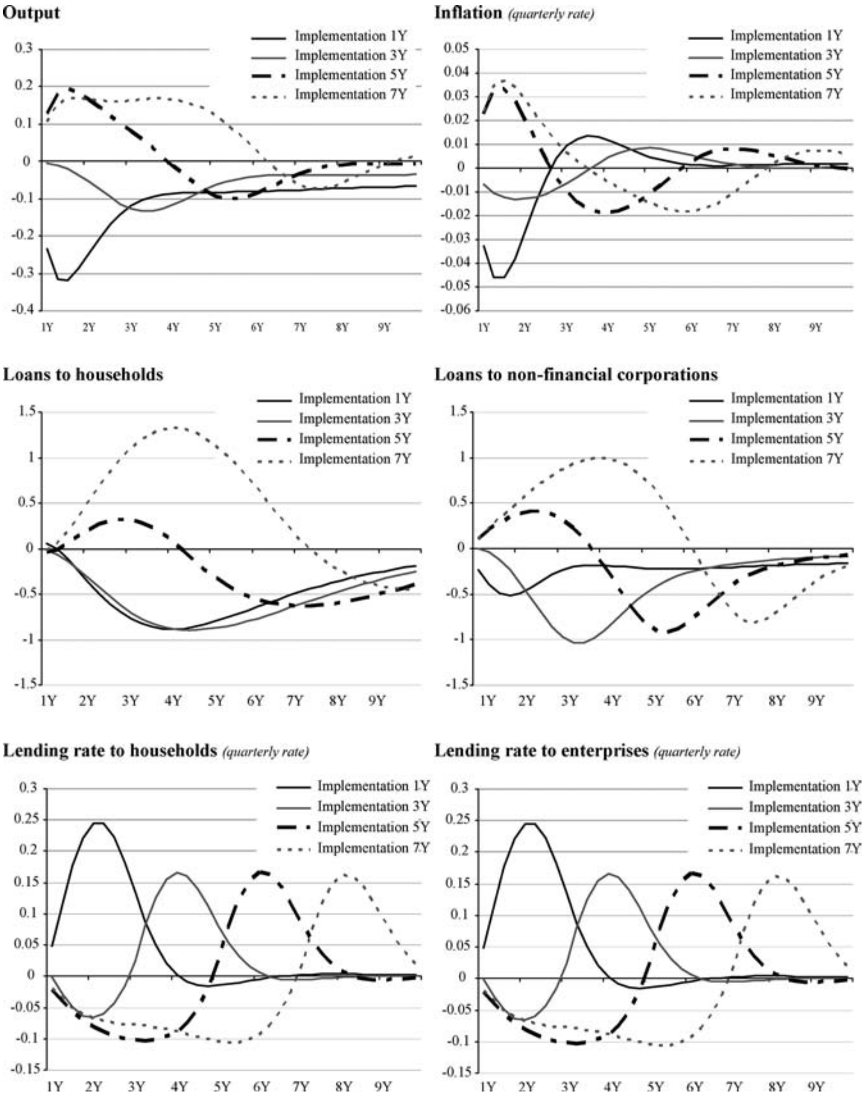
The simulations are presented in figure 5. As regards the timing of the introduction of the higher capital requirements, the experiments assume the implementation of higher capital requirements at different horizons (i.e., immediate implementation, after two, four, and six years, respectively). The model is run under perfect foresight and with endogenous monetary policy, following the estimated Taylor rule. Given the specification of the bank capital frictions and the calibration strategy for the steady state, capital requirements have no tangible impact on the real allocation over the long term. As described above, the required bank balance sheet adjustments take place through higher loan-deposit margins, which curb loan demand and support the internal capital accumulation through higher retained earnings.

The parameter driving the bank capital channel has been set at its highest value found across the various estimation exercises

[22]See Basel Committee on Banking Supervision (2011).

[23]For the macroeconomic impact assessment of introducing the new regulatory framework, see Basel Committee on Banking Supervision (2010).

Figure 5. Transitional Dynamics to Higher Capital Requirement for Different Implementation Dates: Benchmark Model



($\chi_{wb} = 50$). We also experimented with simulations through unexpected capital requirement shocks. This led to somewhat stronger effects which could even be more pronounced by assuming unchanged monetary policy. On balance, the perfect-foresight simulations presented below may be seen as the mid-range effects given possible assumptions on expectations and monetary policy reaction.

In the case of immediate implementation of higher capital requirements (solid black lines in figure 5), the maximum impact on real GDP is obtained after a few quarters. A 2-percentage-point increase in capital requirements leads to a peak decline in real GDP of 0.3 percentage point, the negative effects being rapidly reabsorbed over the medium term. The downward pressures on inflation are relatively short lived, reaching −0.05 percentage point of quarterly inflation after a few quarters and then reverting back to positive territory. As mentioned before, in the long term, the transition towards higher capital requirements leaves the real economy and the outstanding amount of loans unchanged since the adjustment will be fully reflected in higher bank capital. The required increase in bank profits depends on the magnitude of loan-deposit margins' increase compared with loan volume contraction. Figure 5 shows the hump-shaped responses of spreads and loans with opposite signs. Given the more gradual interest rate pass-through on mortgage lending rates, the price and volume adjustments of household credit are more sluggish than in the case of non-financial corporations.

Considering now the announcement of higher capital requirements at more distant horizons, it turns out that the output cost of bank balance sheet consolidation becomes smaller the later the implementation date. For implementation after three years, the peak negative impact on GDP is much more moderate and materializes later than in the previous case. The transition path of GDP even turns positive when higher capital requirements are expected to be implemented after five and seven years, respectively. In the latter cases, GDP only falls below baseline around the year of the implementation. The expansion of GDP in the first years is notably supported by lower bank lending rate spreads and is mainly caused by the forward-looking behavior of economic agents. In other words, borrowers decide to "front load" consumption and investment in view of expected tighter credit conditions in the future. This more benign impact on activity the further into the future the actual implementation of the new requirements is moved can be interpreted as a "smoothing out" of the negative implications of the capital shock. If banks have more time to adjust their activities and balance sheets to the new environment, they will tend to smooth the impact of the shock. The tighter the implementation schedule, the more important non-linearities in credit frictions will be.

4.3 Macroeconomic Propagation under Risk-Sensitive Capital Requirements

Not only has the level of required capital been increased under the Basel III agreement, but another key innovation already being implemented under the existing Basel II framework was the introduction of more risk-sensitive capital requirements. The regulatory interface of our model also allows for analyzing the macroeconomic propagation effects of such a change to the regulatory framework; i.e., moving from "fixed-rate" capital requirements (à la Basel I) to having risk-sensitive risk weights as stipulated under the Basel II and III agreements.

Under the risk-sensitive Basel II-like capital requirement regime, the static profit maximization problem of the bank is as follows:

$$\max_{B_t^w, Dep_t^w} R_{HH,t}^{wb} B_{HH,t}^{wb} + R_{E,t}^{wb} B_{E,t}^{wb} - R_t Dep_t^{wb} - \frac{\chi_{wb}}{2}(RWCap_t - 0.11)^2 Bankcap_t,$$

where

$$RWCap_t = \frac{Bankcap_t}{\left(a_0^E + a_1^E LEV_{E,t}^{wb} + b^E \varepsilon_{E,t}^{\sigma}\right) B_{E,t}^{wb} + \left(a_0^{HH} + a_1^{HH} LEV_{HH,t}^{wb} + b^{HH} \varepsilon_{HH,t}^{\sigma}\right) B_{HH,t}^{wb}}$$

and subject to the balance sheet identity

$$B_{HH,t}^{wb} + B_{E,t}^{wb} = Dep_t^{wb} + Bankcap_t.$$

$LEV_{E,t}^{wb}$ and $LEV_{HH,t}^{wb}$ are leverage ratios for the corporate and household sectors defined as debt over collateralized assets. a_0^E, a_1^E, b^E and $a_0^{HH}, a_1^{HH}, b^{HH}$ represent coefficients in the linearized version of the Basel II formula (see below for details). This formulation leads to the following lending spreads conditioned on the risk-sensitive capital requirements:

$$R^{wb}_{HH,t} - R_t = -\chi_{wb}(RWCap_t - 0.11) \times RWCap_t^2\left(a_0^{HH} + 2a_1^{HH} LEV^{wb}_{HH,t}\right)$$

$$R^{wb}_{E,t} - R_t = -\chi_{wb}(RWCap_t - 0.11) RWCap_t^2\left(a_0^{E} + 2a_1^{E} LEV^{wb}_{E,t}\right).$$

In contrast to the lending spreads derived under the Basel I regulatory regime, the target capital ratio is now dependent on the riskiness of the banks' borrowers, which is dependent on the state of the economy impinging on borrower net worth (via income and housing wealth on the side of households and via the value of the capital stock on the side of corporations).

For calculating the steady-state linear relationship between Basel II risk weights and leverage, we take as a starting point the Basel II risk-weight formulas and subsequently linearize the resulting risk curves for entrepreneurs and households around their respective steady-state leverage ratios.

As a first step, under the Basel II capital adequacy framework, the risk-weighted assets are derived using the following formulas.[24] The capital requirement formula for the corporate exposures is given by

$$CR^E = LGD^E \Phi\left[(1-\tau^E)^{-0.5}\Phi^{-1} PD^E + \left(\frac{\tau^E}{1-\tau^E}\right)^{0.5} \Phi^{-1}(0.999)\right] - PD^E LGD^E,$$

where PD^E and LGD^E refer to probability of default and loss given default on corporate exposures, respectively. Φ denotes the cumulative distribution function for a standard normal random variable.

[24] We focus here on the foundation internal ratings-based approach and assume fixed LGD values provided by the supervisory authority. For corporate exposures (i.e., entrepreneurs) we assume an LGD value of 0.45 and for household exposures we assume an LGD value of 0.35 (retail mortgage exposures are presumably better collateralized, hence the lower LGD). We furthermore, for simplicity, assume a one-year maturity. For more details on the Basel II formulas, see Basel Committee on Banking Supervision (2004).

τ^E denotes the asset-value correlation which parameterizes cross-borrower dependencies and, being a decreasing function of PD, is equal to

$$\tau^E = 0.12\left[\frac{(1-\exp(-50PD^E))}{(1-\exp(-50))}\right] + 0.24\left[1 - \frac{(1-\exp(-50PD^E))}{(1-\exp(-50))}\right].$$

As we assume a fixed LGD (equal to 0.45), the only time-varying component in the risk weighting is the PD, and the resulting risk curve has a concave nature.

For household exposures, we apply the following derivation of the capital requirement:

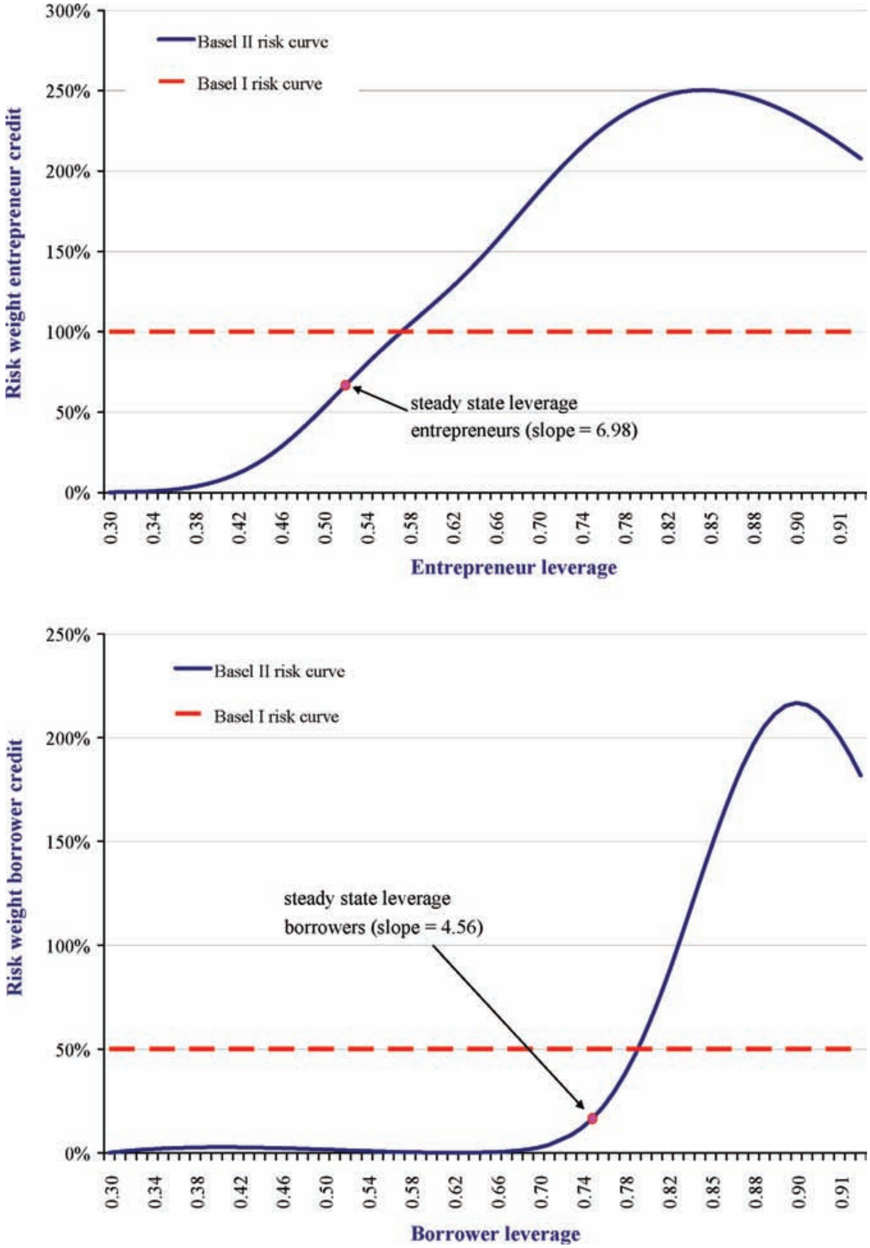
$$CR^{HH} = LGD^{HH}\Phi\left[(1-\tau^{HH})^{-0.5}\Phi^{-1}PD^{HH} + \left(\frac{\tau^{HH}}{1-\tau^{HH}}\right)^{0.5}\Phi^{-1}(0.999)\right] - PD^{HH}LGD^{HH},$$

where τ^{HH} equals 0.15. Also in the case of household exposures, the time variation of the risk curve is a function of PDs only (as LGD^{HH} is fixed at 0.35). The risk-weighted assets are subsequently derived as $RWA^E = CR^E * 12.5 * 1.06 * EAD^E$ and $RWA^{HH} = CR^{HH} * 12.5 * EAD^{HH}$, where EAD denotes exposure at default (i.e., $B^{wb}_{E,t}$ and $B^{wb}_{HH,t}$ for corporate exposures and household exposures, respectively).[25] The time-varying correlation adjustment parameter and the assumed higher LGD for corporate exposures results in higher risk weights and an initially steeper risk curve relative to the risk function with respect to household exposures.

In the next step, the Basel II-based risk-weight functions can be expressed in terms of borrower leverage, $(G(\varpi))$ for households and $(G_E(\varpi_E))$ for entrepreneurs. As can be seen from figure 6, there is a positive and concave relationship between required capital and the leverage of borrowers, which in turn is a positive function of the probability of default, $(\overline{\varpi}_{HH,t})$ and $(\overline{\varpi}_{E,t})$ for households and entrepreneurs, respectively.

[25]The scaling factor of 1.06 in the calculation of the risk-weight function for corporate exposures aims at compensating for the expected overall decline in capital requirements caused by the transition from Basel I to Basel II.

Figure 6. Risk Weights under Basel I and Basel II



Mechanically, owing to the risk-weight functions, it can be conjectured that shocks to borrower credit risk would give rise to higher capital requirements. As credit risk often deteriorates in economic downturns and improves in upturns, it has been argued that the regulatory risk curves as formulated in Basel II could have amplifying procyclical effects on the business cycle (to the extent that bank capital constrains bank lending, which in turn may be an imperfect substitute to other financing sources).[26] At the same time, if banks engage in active management of their loan portfolio, either as a response to or in anticipation of cyclical requirements to their minimum capital levels, the overall effect on the business cycle may not be as mechanical as what the simple transposition of the risk weighting to capital requirements and lending would prescribe.[27]

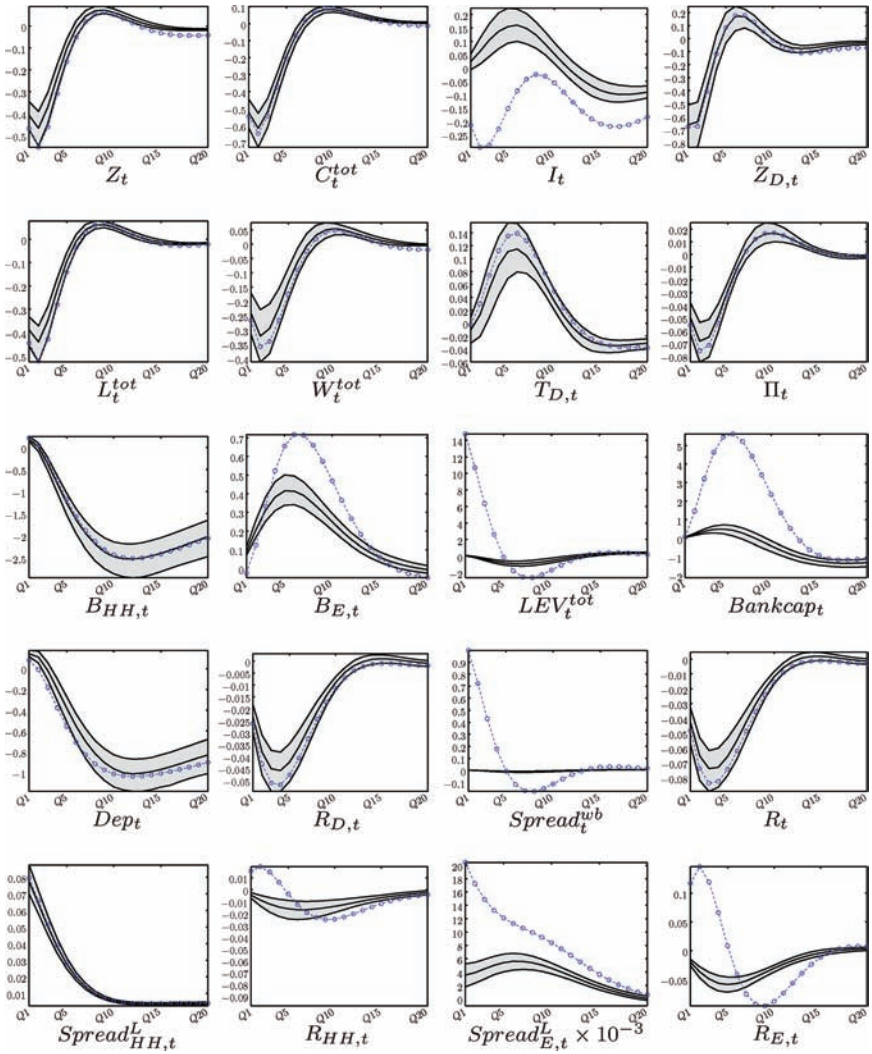
The DSGE model has been estimated on euro-area data, assuming constant capital requirements over the cycle, which is interpreted as consistent with Basel I regulatory framework. Given the estimated sources of business-cycle fluctuations, we simulate a counterfactual economy where capital requirements are risk sensitive according to the Basel II risk-weights formula. The model considers two types of risky assets: loans to households for house purchase and loans to non-financial corporations. The counterfactual economy under Basel II turns out to be marginally more volatile overall, with unchanged monetary policy rule. Compared with economic fluctuations under Basel I, risk-sensitive capital requirements imply 5 percent higher volatility in real GDP growth and 4 percent higher volatility in inflation.

The relatively limited impact on macroeconomic volatility masks more pronounced amplification mechanisms for specific sources of economic disturbances, and notably financial shocks. Figures 7 and 8 illustrate the impact of more risk-sensitive capital requirements on real and financial variables. Focusing on the different shock amplifications in the benchmark model (i.e., Basel I; solid black lines) and the Basel II-based benchmark model (dotted lines with circles), we observe that, for example, a shock to borrower riskiness has a

[26] See, e.g., Danielsson et al. (2001), Kashyap and Stein (2004), and Catarineau-Rabell, Jackson, and Tsomocos (2005).

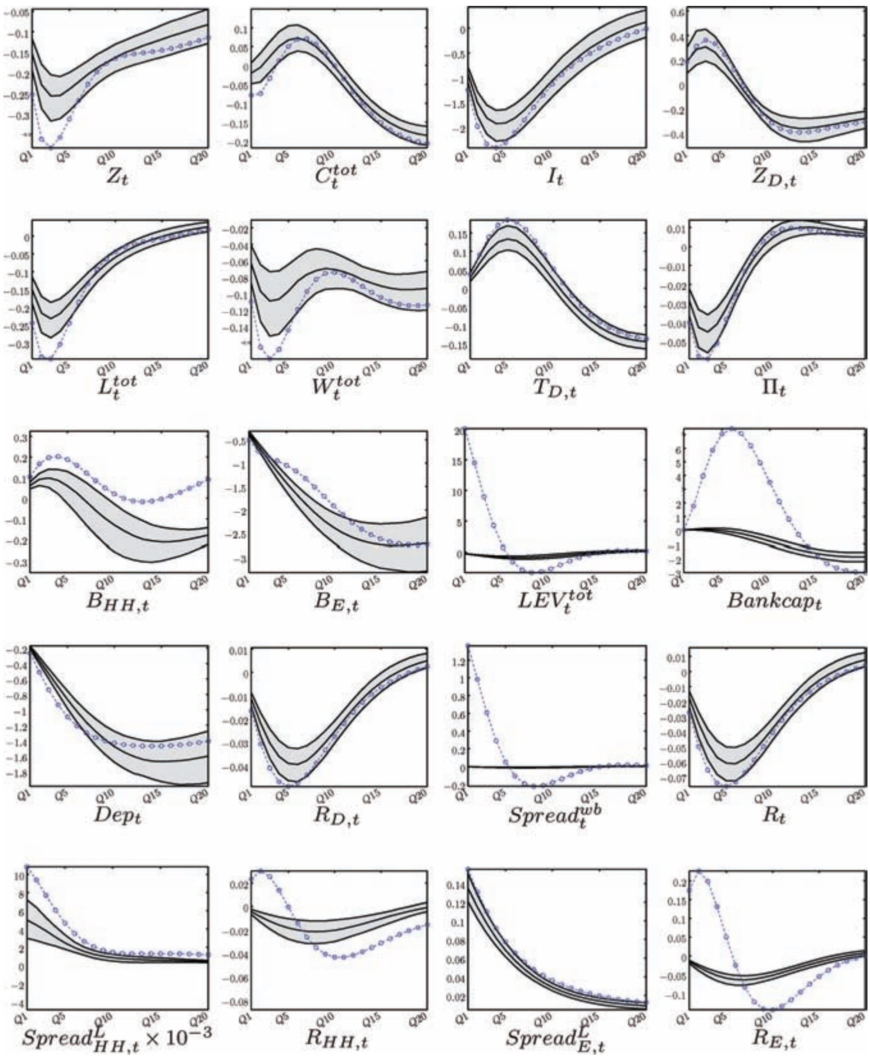
[27] See, e.g., Gordy and Howells (2006), Zhu (2008), Boissay and Kok Sørensen (2009), and Jokivuolle, Kiema, and Vesala (2009).

Figure 7. Impulse Response Functions Associated with a Shock on $\varepsilon^{\sigma}_{HH,t}$



Note: Benchmark model (plain lines for the mode and shaded areas for the 90 percent highest-density interval from the posterior distribution of parameters), and benchmark model under Basel II (dotted lines with circles).

Figure 8. Impulse Response Functions Associated with a Shock on $\varepsilon^{\sigma}_{E,t}$



Note: Benchmark model (plain lines for the mode and shaded areas for the 90 percent highest-density interval from the posterior distribution of parameters), and benchmark model under Basel II (dotted lines with circles).

more pronounced impact on lending spreads when banks are subject to risk-sensitive capital requirements. In contrast to the benchmark case, bank lending rates increase, allowing banks to rebuild their capital in response to the higher (risk-weighted) leverage. In the case of a negative shock to corporate riskiness, investment is more adversely affected under the Basel II framework, and the positive spillover impact on consumption is more muted relative to the baseline (Basel I). Likewise, in the case of an adverse shock to household default risk, the need for banks to accumulate more capital results in a negative spillover effect on the corporate sector (via higher corporate lending spreads). Overall, we observe that changes in credit risk across time, especially in the case of a shock to corporate creditworthiness, amplifies the impact on output compared to the situation with flat-rate capital requirements. This underlines the importance of banks' risk perception in guiding their lending behavior and stresses its potential amplifying effect on economic fluctuations. Sharp deteriorations in the creditworthiness of households and firms—as, for example, observed during the 2007–09 financial crisis[28]—are therefore likely to produce reverberating feedback effects on real economic activity.

This notwithstanding, it is notable that under risk-sensitive capital requirements, banks are found to more actively reshuffle their loan portfolio in response to credit-risk shocks—as, for example, illustrated by the stronger reaction of the volumes of corporate loans and mortgage loans to a shock to household and corporate creditworthiness, respectively. This might hence exert a mitigating impact on the procyclical nature of the risk-sensitive capital requirements, although in our specification it is not enough to completely eliminate the cyclical propagation mechanism of the Basel II framework.

[28] For example, expected default frequencies of euro-area non-financial corporations (which is a measure of corporate default risk produced by Moody's KMV) increased sixfold between June 2007 and December 2009. Likewise, according to the ECB Bank Lending Survey, the net percentage of banks reporting that risk perceptions contributed to a tightening of credit standards increased from 9 percent in 2007:Q2 to 46 percent in 2008:Q4 with respect to mortgage loans and from −4 percent in 2007:Q2 to 64 percent in 2008:Q4 with respect to loans to enterprises.

4.4 Accounting for Countercyclical Macroprudential Policies

A final application of the model is devoted to the interactions between monetary policy and macroprudential policy. In particular, we want to assess whether a countercyclical regulatory regime would support macroeconomic stabilization. Recent papers like Angeloni and Faia (2009) or Kannan, Rabanal, and Scott (2009) have investigated this issue with different formulations of the strategic interactions between monetary policy and macroprudential policy. Here we focus on the joint determination of the two policy rules so as to maximize an ad hoc loss function under credible commitment.

The intertemporal quadratic loss function penalizes deviations from steady state for consumer price inflation, output growth, and policy rate. Monetary policy conduct is described as an interest rate rule, while macroprudential policy is assumed to follow a capital requirement rule. Both rules feature policy inertia and respond to level and first difference of consumer inflation, detrended output, and first difference of loans to households, loans to entrepreneurs, real housing prices, and real equity prices.[29] We chose to limit the analysis to a stylized loss function instead of a welfare-based objective, as the "reduced-form" nature of the bank capital friction considered in this paper would weakly portray the welfare trade-offs faced by macroprudential policy in particular. Consequently, we preferred to abstract from welfare calculations and gear the policy discussion towards general macroeconomic stabilization without investigating how the microfoundations of the model influence the policy objectives.

The loss function considered can be written as follows:

$$\mathcal{L}_t = \lambda_\pi \pi_t^2 + \lambda_z[\Delta z_t]^2 + \lambda_r r_t^2 + \lambda_{lev}[Leverage_t]^2 + \beta \mathbb{E}_t \mathcal{L}_{t+1},$$

where λ_π, λ_z, and λ_r are the coefficients weighting the respective costs of volatility in CPI inflation, changes in output, and nominal interest rate. Later on, we would consider introducing a penalty for bank leverage volatility.

The weights in the loss function are selected in the following way. The monetary policy rule has the same form as the estimated one.

[29] Real equity prices are defined as the average real price of fixed capital in the economy.

The exogenous processes for the structural shocks are taken from the benchmark estimation. Then we search for the weighting scheme which delivers, at the optimal rule, the same volatility for inflation and policy rate as under the estimated rule. The optimal weights we obtain are $\lambda_\pi = 1$, $\lambda_z = 4$, and $\lambda_r = 0.75$. Such a loss function constitutes an intuitive benchmark. Another possibility would have been to consider the full efficiency curve in the inflation, output growth space. But, for the sake of clarity, we kept only one specific loss function. The essence of the results presented thereafter holds for any point of this efficiency curve.

A first exercise consists of optimizing the parameters of the monetary policy rule augmented with asset prices and credit variables, keeping capital requirements constant. We concentrate on the following formulation of the monetary policy rule:

$$r_t = \rho r_{t-1} + (1-\rho)(r_\pi \pi_{t-1} + r_y y_{t-1}) + r_{\Delta\pi}\Delta\pi_t + r_{\Delta y}\Delta y_t \\ + r_{T_D}\Delta t_{D,t} + r_Q \Delta q_t + r_h \Delta b_{HH,t} + r_e \Delta b_{E,t}.$$

We only consider financial shocks, as provided by the benchmark estimation: those disturbances relate to interest rate markups, borrowers' risk, bank capital, and housing preference, which also introduced its contribution to housing prices. Focusing on economic disturbances at the core of credit intermediation enables us to present more striking results on the role of credit and asset prices for monetary policy conduct in interaction with a countercyclical regulatory framework. As sensitivity analysis (not presented here), we verified that the findings exposed thereafter were still holding when all shocks were introduced.

Table 4 presents the macroeconomic volatilities associated with various optimized rules in the presence of financial shocks (except for the first column). In the first two columns, the monetary policy rule is specified as in the estimation and optimized under constant capital requirements. For the sake of completeness, the exercise is conducted either with financial shocks or with the overall set of economic disturbances. In both cases, the optimized monetary policy rule features a high level of interest rate inertia, a strong long-term response to inflation, stronger reaction to changes in output than in its level, and a specific role for housing prices. The restriction to financial shocks seems to increase the coefficient on housing prices

Table 4. Optimized Monetary and Macroprudential Policy Rules

Loss Function						
λ_π				1		1
λ_z				4		4
λ_r				0.75		0.75
λ_{lev}				0		0.0001
Regulatory Regime	*Basel I All Shocks*	Basel I *Bench.*	Basel I	Basel II	Countercyclical	Countercyclical
Optimized Policy Parameters						
ρ	*0.98*	0.95	0.96	0.93	0.997	0.96
r_π	*43.90*	43.90	52.06	52.07	43.91	43.91
$r_{\Delta\pi}$	*0.53*	0.75	1.12	1.13	−0.43	0.43
r_y	*0.57*	0.75	0.04	0.07	0.92	0.93
$r_{\Delta y}$	*0.56*	1.74	2.30	2.24	1.61	1.99
r_{T_D}	*0.20*	0.68	0.41	0.63	0.00	0.26
$r_{\Delta h}$	—	—	0.45	0.63	0.00	0.36
r_Q	—	—	0.01	0.07	0.00	0.00
$r_{\Delta e}$	—	—	−0.08	−0.12	0.00	0.02
ρ^{bc}	—	—	—	—	0.78	0.77
r^{bc}_y	—	—	—	—	113.00	0.00
$r^{bc}_{\Delta y}$	—	—	—	—	0.40	0.00
$r^{bc}_{T_D}$	—	—	—	—	0.03	0.13
$r^{bc}_{\Delta h}$	—	—	—	—	−0.05	0.01
r^{bc}_Q	—	—	—	—	−1.91	−0.38
$r^{bc}_{\Delta e}$	—	—	—	—	−0.43	−0.11

(continued)

Table 4. (Continued)

Loss Function						
λ_π				1		1
λ_z				4		4
λ_r				0.75		0.75
λ_{lev}				0		0.0001
Regulatory Regime	*Basel I All Shocks*	Basel I *Bench.*	Basel I	Basel II	Countercyclical	Countercyclical
Relative STD to Bench. (in %)						
ΔZ_t	—	100.0	80.3	102.3	16.5	78.6
Π_t	—	100.0	139.8	116.7	71.6	138.2
R_t	—	100.0	72.0	91.9	29.7	65.1
$T_{D,t}$	—	100.0	100.0	96.1	104.6	100.6
$B_{HH,t}$	—	100.0	97.0	84.7	227.8	103.2
$B_{E,t}$	—	100.0	99.9	80.4	136.8	94.4
$Leverage_t$	—	100.0	99.0	230.1	482.4	94.6
$\mathcal{L}$	—	0.34	0.23	0.40	0.03	0.32

and output growth but does not change qualitatively the main properties on the monetary policy rule. The macroeconomic variances generated by this monetary policy rule are taken as benchmark to normalize the moments obtained with the other policy regimes in table 4.

In the third column, we allow for monetary policy reaction to credit and equity prices. The augmented optimal rule improves upon the previous one, reducing the loss function from 0.34 to 0.23. However, the lower volatility obtained for output growth and the interest rate is counterbalanced by a higher standard deviation for inflation. This optimal rule still displays a high degree of interest rate inertia, a strong reaction to inflation, and some specific role for housing prices. But in addition, the rule includes some positive response to household loans, whereas the coefficients on loans to entrepreneurs and real equity prices are close to zero. Even without introducing asset prices or credit in the objective function, it turns out that the financial frictions on the household side vindicate some specific monetary policy focus on credit and asset prices.

With the augmented monetary policy rule specification, we also investigated the implications of risk-sensitive capital requirements. In this case, the optimized coefficients remain very close to the ones obtained with constant capital requirements (see column 4 in table 4). At the margin, the monetary policy response to housing prices and household loans turns out to be stronger.

In the last two columns of table 4, we allow for time-varying capital requirements. We assume that the target bank capital ratio follows a log-linear rule of the form

$$cap_t = \rho^{bc} cap_{t-1} + r_y^{bc} y_t + r_{\Delta y}^{bc} \Delta y_t \\ + r_{\Delta h}^{bc} \Delta b_{HH,t} + r_{\Delta e}^{bc} \Delta b_{E,t} + r_{T_D}^{bc} \Delta t_{D,t} + r_Q^{bc} \Delta q_t.$$

Keeping the same loss function as in the previous experiments, the joint optimal determination of policy rules suggests that countercyclical regulation could provide a strong support to macroeconomic stabilization. The optimized capital requirement rule features some inertia and a very high positive response to output, while the role for credit variables and asset prices seems negligible. The optimized monetary policy rule is very much affected by the introduction of countercyclical regulation: in particular, all coefficients on credit and asset prices become insignificant. Acting at the core of the financial system, regulatory policy seems to be relatively more effective than monetary policy in addressing destabilizing fluctuations in credit markets and intratemporal wedges between financial costs, therefore alleviating somehow the need for monetary policy to "lean against the wind." The jointly determined policy rules deliver a superior macroeconomic outcome. The loss function gets close to zero, with output growth volatility at 16.5 percent of the benchmark, inflation volatility at 70 percent, and interest rate at 30 percent. However, in the model, the main transmission channel of regulatory policy on the economy works through the adjustment of bank balance sheets and its impact on bank lending rates. Consequently, the macroeconomic stabilization support from the optimized capital requirement rule implies an almost fivefold increase in bank leverage volatility. Such a degree of countercyclical capital requirements would therefore be difficult to implement and lead to excessive volatility in bank balance sheets. As shown in the last column of table 4, if we constrain the regulatory framework by introducing a relatively small penalty for leverage volatility in the loss function, then the optimized capital requirement rule becomes only moderately time varying and the monetary policy rule is very similar to the one obtained under constant capital requirements.

Overall, while some countercyclical regulation seems suitable as far as macroeconomic stabilization is concerned, its design and magnitude should be carefully considered. The analysis presented here remains illustrative and subject to clear limitations. Notably, a structural interpretation of systemic risk (and in particular its cross-sectional dimension) is absent from the model. Such a concept is essential to define a meaningful objective for macroprudential policy.

5. Conclusions

The recent years' dramatic events which brought financial markets into turmoil highlighted the crucial role of credit market frictions in the propagation of economic and financial shocks. However, the nature of banking and the role of banks in amplifying macroeconomic fluctuations are elements that hitherto have been largely neglected in the macroeconomic literature and, in particular, in the design of general equilibrium models. To reflect this, a number of recent papers try to correct this void by incorporating banking sectors and other financial frictions into DSGE modeling frameworks. The model presented in this paper contributes to this research by incorporating a number of demand and supply credit frictions into an estimated DSGE model of the euro area.

Apart from documenting the potential amplifying effects of credit frictions, this setup allows us to analyze changes in the regulatory regimes facing the financial sector, such as the introduction of risk-sensitive capital requirements or the transition towards more stringent regulatory regimes. Moreover, reflecting the renewed focus on the nexus between monetary policy and macroprudential (or financial-stability-oriented) policies, our results point to important complementarities.

Finally, a few caveats and directions for further research should be mentioned. First of all, the banking sector in our setup is of a reduced-form nature and can be further improved. For example, a more complete description of the balance sheet composition of the banks taking into account issues such as liquidity, wholesale funding, and trading book valuations would enhance the specification and also allow for analyzing the macroeconomic impact of money market disruptions, bank liquidity positions, and unconventional monetary policies. Likewise, a more microfounded optimization of the policy rule to study the interactions between macroprudential and monetary policies could be pursued.

Appendix 1. Data

Data for GDP, consumption, investment, employment, wages, and consumption deflator are taken from Fagan, Henry, and Mestre (2001) and Eurostat. Employment numbers replace hours. Consequently, as in Smets and Wouters (2005), hours are linked to the number of people employed, e_t^*, with the following dynamics:

$$e_t^* = \beta \mathbb{E}_t e_{t+1}^* + \frac{(1-\beta\lambda_e)(1-\lambda_e)}{\lambda_e}\left(l_t^* - e_t^*\right).$$

House prices for the euro area are based on national sources and taken from the ECB web site.[30] Residential investment is taken from Eurostat national accounts and is backdated using national sources. Households' debt for the euro area also comes from the ECB and Eurostat.[31] The three-month money market rate is the three-month Euribor taken from the ECB web site, and we use backdated series for the period prior to 1999 based on national data sources. Household deposits are proxied using a backdated series of M2 which is available from the ECB web site and which represents the main part of deposits held with monetary financial institutions (MFIs) by euro-area non-financial private-sector residents (households primarily). Data on MFI loans to households and non-financial corporations are likewise taken from the ECB web site. Data prior to September 1997 have been backdated based on national sources. Meanwhile, data on retail bank loan and deposit rates are based on official ECB statistics from January 2003 onwards and on ECB internal estimates based on national sources in the period before. The lending rates refer to new business rates on loans to households for house purchase and new business rates on loans to non-financial corporations, excluding bank overdrafts. For the period prior to January 2003, the euro-area aggregate series have been weighted using corresponding loan volumes (outstanding amounts) by country. Deposit rates refer to MFI interest rates on time deposits with agreed maturity taken from households. Similar to the derivation of the loan rates, from January 2003 deposit rates are based on official ECB statistics; prior to that period, they are based on a volume-weighted average of country-based rates.

Appendix 2. Calibrated Parameters and Steady State

Some parameters are excluded from the estimation and have to be calibrated. These are typically parameters driving the steady-state values of the state variables, for which the econometric model based on detrended data is almost non-informative.

[30] We applied some statistical interpolation methods to generate quarterly series.

[31] See the ECB's *Monthly Bulletin*, October 2007, for the description of the data used.

The discount factors are calibrated to 0.995 for the patient agents and 0.96 for the impatient agents and entrepreneurs.[32] The implied equilibrium real deposit interest rate is 2 percent in annual terms.[33] The depreciation rate for housing, δ, is equal to 0.01, corresponding to an annual rate of 4 percent, whereas the depreciation rate of capital, δ_X, is set to 0.1. Markups are equal to 1.3 in the goods markets (for both non-residential and residential goods) and 1.5 in the labor market (in each sector). The relative share of residential goods in the utility function, ω_D, is set to 0.1 for both household types. The value is chosen to pin down the steady-state ratio of residential investment to GDP. The intratemporal elasticity of substitution, η_D, is equal to 1. The intertemporal elasticity of substitution of entrepreneurs is set to 1 (σ_{CE}). The relative shares of inputs in production are 0.3 for capital (α) and 0.7 for labor in the non-residential goods sector, while in the residential sector we assign a weight equal to 0.1 to land ($\alpha_{\mathcal{L}}$) and reduce the share of capital to 0.2 (α_D), in order to maintain the level of labor intensity unchanged.

The markups on loan and deposit rates are calibrated so that the margin between the loan rate and the deposit rate is 100 basis points in annual terms, while the annual spreads on lending rates to households and entrepreneurs are 200 basis points and 120 basis points, respectively. Those numbers are very close to the historical averages from 1999:Q1 to 2008:Q2.[34] Given the discount factors and the markups on retail interest rates, the steady-state values for the default cut-off points $\overline{\varpi}_E, \overline{\varpi}_{HH}$ are numerically determined by the modified Euler equations of borrowers and entrepreneurs. Once those cut-off points are computed—and assuming monitoring costs of 0.2 for non-financial corporations, μ_E, and 0.15 for households, μ_{HH}—the standard deviations of the idiosyncratic shocks are adjusted to

[32] See, e.g., Iacoviello (2005), Monacelli (2009), and Iacoviello and Neri (2010) for a thorough discussion of the calibration of the discount factors in a similar setup.

[33] The steady-state level of the interest rate is pinned down by the savers' intertemporal discount factor.

[34] We confine the calibration of the loan-deposit margin and the lending spreads to the period starting in 1999:Q1, as due to the convergence of interest rates prior to the introduction of the euro there was a gradual downward level shift in loan and deposit rates in the years preceding 1999. Because of this structural shift in the level of rates, for the steady-state calibration we apply the pattern of loan and deposit rates for the euro period only.

reproduce default frequencies for impatient households and firms of 0.3 percent and 0.7 percent, respectively.[35]

Finally, we set in the benchmark estimation the share of borrowers ω at 0.25. The loan-to-value ratios (determined by the terms $(1-\chi_E)$ for non-financial corporations and $(1-\chi_{HH})$ for impatient households) are then determined to ensure plausible debt-to-GDP ratio in the steady state. With $(1-\chi_E)$ at 0.6 and $(1-\chi_{HH})$ at 0.2, the share of corporate loans to annual GDP is around 33 percent, while the share of household housing loans to annual GDP is around 25 percent. This calibration is close to the levels recorded in the euro area around the year 2000 as well as to their historical average levels since 1980. Besides, the loan-to-value (LTV) ratios are consistent with the available range of estimates.[36]

Appendix 3. Prior Distributions

The standard errors of the structural shocks are assumed to follow a uniform distribution, while the persistence parameters follow a beta distribution with mean 0.5 and standard deviation 0.2.

Regarding the parameters of the monetary policy reaction function, we follow Smets and Wouters (2005) quite closely. The interest rate smoothing parameter follows a beta distribution with parameters 0.75 and 0.1. The parameters capturing the response to changes in inflation and output gap follow a gamma distribution with parameters 0.3 and 0.1, and 0.12 and 0.05, respectively. Concerning the response to inflation and output gap, the prior distributions

[35]This is consistent with corporate default statistics from Moody's, the rating agency, which show an average default rate on (non-U.S.) non-financial corporate bonds of 0.75 percent for the period 1989–2009. Household default rates can be approximately derived using the loan write-off data in the ECB's MFI balance sheet statistics. Computing the ratio of average write-offs on mortgage loans to corporate loans for the period of available data (2001–09), it is found that the share of defaulting mortgage loans to corporate loans is c. 45 percent. Hence, using the non-financial corporate default rate derived from Moody's implies an approximate mortgage default rate of 0.34 percent, i.e., close to our steady-state calibrated value.

[36]LTV ratios for euro-area housing loans differ across countries but tend on average to lie in the range of 0.7–0.8 percent; see European Central Bank (2009). LTV ratios can be approximated by the debt-to-financial-asset ratio of the non-financial corporate sector, which on average between 1999 and 2009 was around 0.45 (sources: ECB and Eurostat and ECB calculations).

are a normal with mean 2.5 and standard deviation 0.25, and a gamma with parameters 0.12 and 0.05, respectively. The prior on the level inflation terms has been increased compared with the empirical DSGE literature, as the determinacy region in the two-sector economy considered in this paper requires stronger reaction to price pressures.

Regarding preference parameters, the intertemporal elasticity of substitution, which is common to both household types, follows a gamma distribution with mean 1.2 and standard deviation 0.2. The habit formation parameter is also the same for savers, borrowers, and entrepreneurs, following a beta distribution with parameters 0.75 and 0.1. The elasticity of labor supply is the same for both household types and sectors, and has a gamma(1.5, 0.1) prior distribution. On the production side, the adjustment cost parameters for fixed investment and the capacity utilization elasticity, which are common to both sectors, follow respectively a normal(4, 1.5) and a beta(0.5, 0.15) prior distribution. The prior distribution regarding the adjustment cost parameter for residential investments of savers and borrowers is a gamma(1,0.5). About nominal rigidities, the Calvo parameters for price setting in the non-residential sector and wage settings in each sector are distributed according to a beta distribution with mean 0.75 and standard deviation 0.05.[37] The indexation parameters are instead centered around 0.5, with a standard deviation of 0.15. In the residential sector, we set lower priors for the nominal price rigidities, with a beta(0.2,0.1) given assumptions made in the literature on the flexibility of housing prices (see Iacoviello and Neri 2010, for example). We do not introduce indexation on past inflation in the residential sector price setting.

Turning to the Calvo parameters driving the imperfect pass-through of policy rate on lending rates, we choose fairly uninformative priors with beta(0.5,0.2). The sensitivity of bank spreads on bank capital ratio inadequacy has relative tight priors, with a gamma(20,2.5), as in Gerali et al. (2010). Finally, in the benchmark model, the share of borrowers is not estimated, but in alternative

[37]In the estimation exercise we impose that the same level of nominal rigidity applies to the saver's and borrower's wages in a given sector. Such restriction is motivated by the availability of sector-specific, as opposed to individual-specific, data on wages.

specifications we introduce priors following beta distribution, with mean 0.35 and standard deviation 0.05. This choice is similar to the one of Iacoviello and Neri (2010). The model is still well defined when the share of borrowers goes to zero so that the estimation of the parameters is not affected by a singular point in zero.

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