Monetary policy and housing prices in an estimated DSGE model for the US and the euro area*

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Abstract

We estimate a two-country Dynamic Stochastic General Equilibrium model for the US and the euro area including relevant housing market features and examine the monetary policy implications of housing-related disturbances. In particular, we derive the optimal monetary policy cooperation consistent with the structural specification of the model. Our estimation results reinforce the existing evidence on the role of housing and mortgage markets for the US and provide new evidence on the importance of the collateral channel in the euro area. Moreover, we document the various implications of credit frictions for the propagation of macroeconomic disturbances and the conduct of monetary policy. We find that allowing for some degree of monetary policy response to fluctuations in the price of residential goods improves the empirical fit of the model and is consistent with the main features of optimal monetary policy coooperation in response to housing-related shocks.

Keywords: Housing, credit frictions, Optimal monetary policy, New open economy macroeconomics, Bayesian estimation.

JEL classification: E4, E5, F4.

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1 Introduction

This paper aims at analyzing the importance of housing markets and household credit frictions for the conduct of monetary policy within an open-economy framework. In so doing, our contribution intends to bridge a gap between the growing strand of literature focusing on credit frictions in closed economies characterized by the presence of nominal rigidities[1], and the existing estimated New Open Economy Macroeconomics models [2]. We estimate a two-country Dynamic Stochastic General Equilibrium model for the US and the euro area including relevant housing market features and examine the monetary policy implications of housing-related disturbances.

The macroeconomic literature has recently shown a particular interest in understanding the role played by credit market frictions faced by households in determining business cycle dynamics. More specifically, the conduct of monetary policy in the presence of such frictions has attracted a special attention. A common feature across the existing theoretical frameworks is the influence of housing collateral on households consumption decisions. The empirical evidence suggests the existence of a fraction of consumers in the economy who face binding collateral constraints when approaching loans and mortgage markets. As a result, institutional arrangements in such markets, as well as different housing market structures can potentially affect households' home-purchasing and consumption decisions in a significant way. Most of the existing literature has been focusing on a closed-economy setup, thus abstracting from international factors and cross-country spillovers[3].

In modeling the closed-economy setup, we follow a recent strand of literature which - like Kiyotaki and Moore (1997) - considers a dual structure on the household side, with agents belonging to two different groups according to their intertemporal discount factor. Households' heterogeneity generates equilibrium debt as the result of intertemporal borrowing between more and less impatient agents. Building on Iacoviello and Neri (2009)and Notarpietro (2007), we define a two-agent, two-sector economy for each country, where the impatient agents face collateral requirements when asking for mortgages or loans. Firms produce nondurable consumption goods (which can be traded internationally) and residential goods (which are considered non-tradable). 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.

[1]See Iacoviello (2005), Iacoviello and Neri (2009) and Monacelli (2009) among others.

[2]See Adjemian, Darracq Pariès, and Smets (2008), Adolfson, Laséen, Lindé, and Villani (2005),De Walque, Smets, and Wouters (2005), and Rabanal and Tuesta (2006)

[3]An exception is Christensen, Corrigan, Mendicino, and Nishiyama (2007), who estimate a small open economy model for Canada.

The role of collateral constraints in closed economies has been estimated in DSGE models by Iacoviello and Neri (2009) and Notarpietro (2007), who report the relevance of housing market shocks in shaping consumption dynamics in the US. We focus here on the role of housing market factors and credit frictions in explaining both closed and open-economy fluctuations. In particular, we estimate structural parameters such as the relative share of borrowers in the two economies, and we show how they affect the transmission mechanism of housing market and monetary policy shocks both domestically and internationally.

The use of an explicit two-country setup allows for estimating and testing for the existence of structural differences across the two economies. On the open-economy side, we introduce most of the common features of estimated open-economy DSGE models, following closely Adjemian, Darracq Pariès, and Smets (2008). In particular, we assume that financial markets are incomplete internationally. However, we do not allow for international trade of private debt, so that the borrowers can only access domestic credit markets; the savers can instead trade two nominal risk-less bonds denominated in the domestic and foreign currency respectively. The model is estimated on US and euro area quarterly data, over the period 1981 I: 2005 IV, using full-information Bayesian techniques.

Moreover, in order to put into perspective the monetary policy response to economic disturbances originating in the housing sector, we derive the optimal monetary policy cooperation consistent with the structural specification of the model. As in Adjemian, Darracq Pariès, and Smets (2008), the Ramsey approach to optimal monetary policy cooperation is computed by formulating an infinite-horizon Lagrangian problem of maximizing the conditional aggregate welfare of both countries subject to the full set of non-linear constraints forming the competitive equilibrium of the model. We solve the equilibrium conditions of the optimal allocation using second-order approximations to the policy function. In this paper, we restrict our analysis to the assessment of the optimal policy tolerance for relative house price fluctuations. We do not intend to explore systematically all the factors that shape optimal policy in our modeling framework. Such an exercise would go beyond the scope of the present contribution and is left for future research. We consider instead the optimal monetary policy response to housing-related shocks which, under standard Taylor rules, generate strong relative house price changes and ample asymmetries between the savers' and the borrowers' reactions.

The main contributions of the paper cover several dimensions. First, our results reinforce the existing evidence on the role of housing and mortgage markets for the US and provide new evidence on the importance of the collateral channel in the euro area. In particular, we estimate different versions of the model, considering high or low shares of borrowers in the economy. Our results suggest notably that the share of impatient households is higher in the US than in the euro area. We also find that the estimated shares of borrowers are quite sensitive to the specification of *a priori* distributions, which ultimately should be set based on appropriate economic considerations.

Second, in terms of economic propagation of non-housing related shocks, the presence of credit frictions alters significantly the relative responses of aggregate consumption and non-residential investment. Moreover, we find that structural housing-related shocks have significant spillovers on non-residential consumption through the collateral channel and the share of borrowers in the economy. Nonetheless, the residential sector is somewhat unaffected by shifts in the share of borrowers due to its dual nature of flexible-price, non-traded goods producing sector. In terms of international spillovers, the transmission of housing preference shocks on economic activity is found to be relatively limited and lower than in the case of demand shocks affecting the tradable sector. Finally, housing shocks play a key role in generating negative comovement across countries for both real housing prices and residential investment.

Third, we find that allowing for a monetary policy response to house prices improves the empirical fit of the model, and paves the way for a deeper analysis of optimal monetary policy cooperation in the proposed framework[4]. From a normative perspective, some degree of monetary policy reaction to fluctuations in the price of residential goods is consistent with the main features of optimal monetary policy response to housing-related shocks. Based on welfare computations when only housing shocks are allowed, the estimated Taylor rule augmented with real housing prices turns out to be welfare-improving compared with the benchmark case, in particular for the US economy. Beyond this, the optimal allocation suggests that the heterogenous responses across households and the associated welfare losses in terms of imperfect risk sharing should be counteracted, even at the cost of short term inflation volatility. Compared with the estimated rules, our results indicate that the optimal international transmission of positive housing-related shocks leads to a more pronounced monetary policy tightening in the foreign country and to a negative adjustment of housing prices and quantities as well as domestic demand for non-residential goods.

The rest of the paper is organized as follows. Section 2 describes the main decision problems of the structural model. Section 3 presents the results of the Bayesian estimation. Section 4 explores the international propagation of housing-related shocks in the estimated model. In section 5 we investigate the monetary policy response to housing shocks, both

[4] We use the expressions "house price" and "price of residential goods" as synonymous in the text.

from an historical perspective - by estimating Taylor rules augmented with real housing prices - and through an analysis of the optimal allocation.

2 Theoretical model

The world economy is represented by two symmetric countries, labelled Home (H) and Foreign (F). Each country is modeled as a two-agent, two-sector economy, producing residential and non residential goods[5]. Non-residential final goods are produced by a continuum of "single-good-firms" indexed on $[0, 1]$, mixing local production with imports. More precisely, in each country final producers for local sales and inputs operate in perfect competition and aggregate a continuum of differentiated products purchased from Home and Foreign intermediate-sector firms. The latter are monopolistic competitors and exert some market power through the setting of prices. The residential-goods sector has a similar structure, but final and intermediate goods are not traded.

We assume that in each country there exists a continuum of infinitely-lived households, the number of which is proportional to the number of firms. Following the seminal contribution of Kiyotaki and Moore (1997), we consider two types of households in each country, differing in their relative intertemporal discount factor. More precisely, a fraction $(1 - \omega)$ of households in country H (and, symmetrically, $(1 - \omega^*)$ in F) are relatively more patient, and the remaining ω (resp. ω^*) are impatient. Households receive utility from consuming both nonresidential and residential goods, and disutility from labor. Residential goods are treated here as *durable* goods, and serve two purposes: they can be either directly consumed or used as collateral in the credit market. Private debt is generated in equilibrium as the result of intertemporal trade among the patient agents (who act as lenders), and the impatient agents (who act as net borrowers). The existence of frictions in household credit markets is captured by imposing a perpetually binding collateral constraint on the entire group of impatient agents[6].

In the following, we present the structure of the model and some derivations for country H. Analogous derivations hold true for country F.

[5] We follow closely Iacoviello and Neri (2009) and Notarpietro (2007) in defining the closed-economy setup for each country.

[6] As a consequence, we will use the terms *impatient (patient)* and *borrower (saver)* as interchangeable throughout.

2.1 The borrower's program

Each impatient agent $b \in [0, \omega]$ receives utility from the following instantaneous utility function:

$$W_t^b = E_t \left\{ \sum_{j \geq 0} \beta^j \left[\begin{array}{c} \frac{1}{1-\sigma_X} \left(\widetilde{X}_{t+j}^b \right)^{1-\sigma_X} - \frac{\varepsilon_{t+j}^L \overline{L}_C}{1+\sigma_{LC}} \left(N_{C,t+j}^b \right)^{1+\sigma_{LC}} \\ - \frac{\varepsilon_{t+j}^L \overline{L}_D}{1+\sigma_{LD}} \left(N_{D,t+j}^b \right)^{1+\sigma_{LD}} \end{array} \right] \varepsilon_{t+j}^\beta \right\} \quad (1)$$

where $\widetilde{X}_t^b$ is an index of consumption services derived from non-residential final goods $\left(C^b\right)$ and residential stock $\left(D^b\right)$:

$$\widetilde{X}_t^b \equiv \left[\left(1 - \varepsilon_t^D \omega_D\right)^{\frac{1}{\eta_D}} \left(\widetilde{C}_t^b - h_B \widetilde{C}_{t-1}^b \right)^{\frac{\eta_D - 1}{\eta_D}} + \varepsilon_t^D \omega_D^{\frac{1}{\eta_D}} \left(\widetilde{D}_t^b \right)^{\frac{\eta_D - 1}{\eta_D}} \right]^{\frac{\eta_D}{\eta_D - 1}} \quad (2)$$

with the parameter h_B 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 negative utility from labor in each sector, $N_{C,t}^b$ and $N_{D,t}^b$. 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 impatient's labor supply equals one in steady state.

Impatient agents in each country can trade a nominal risk-less bond denominated in the domestic currency, but they cannot access the international financial markets to finance their expenditure plans. In addition, they do not save nor accumulate capital. Total savings and investment decisions in each country are implemented by the savers, as we show later.

Under these assumptions, each borrower maximizes utility function (1) subject to an infinite sequence of real budget constraints[7]:

$$\begin{aligned} \widetilde{C}_t^b + T_{D,t} \left(\widetilde{D}_t^b - (1-\delta) \widetilde{D}_{t-1}^b \right) + \frac{R_{t-1} \widetilde{B}_{H,t-1}^b}{\pi_t P_{t-1}} &= \frac{\widetilde{B}_{H,t}^b}{P_t} + \frac{\widetilde{A}_t^b + \widetilde{TT}_t^b}{P_t} \\ &+ \frac{W_{C,t}^b N_{C,t}^b + W_{D,t}^b N_{D,t}^b}{P_t} \end{aligned} \quad (3)$$

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

where $\delta \in (0,1)$ is the residential good depreciation rate, $T_{D,t} \equiv \frac{P_{D,t}}{P_t}$ is the relative price of residential goods in terms of non-residential goods, $\widetilde{B}^b_{H,t}$ is the stock of nominal debt issued by the borrower at time t, R_{t-1} is the nominal interest rate paid on the existing amount of debt $\widetilde{B}^b_{H,t-1}$ and π_t is the gross non-residential good inflation rate. $W^b_{C,t}$ and $W^b_{D,t}$ denote the borrower's nominal wages in the two sectors. $\widetilde{TT}^b_t$ are government transfers . Finally, $\widetilde{A}^b_t$ is the stream of income coming from state-contingent securities, allowing the borrowers to hedge against wage income risk. Given separability of preferences, trading such assets ensures that all borrowers have identical consumption plans. Therefore, we can drop the superscript b and simply use a $\tilde{}$ to denote variables related to the borrowers.

In each period t, all the borrowers have limited access to credit markets, as summarized by the following (nominal) collateral constraint:

$$\widetilde{B}_{H,t} \leq \varepsilon^{LTV}_t (1-\chi)\, \mathbb{E}_t \left\{ P_{D,t+1} \widetilde{D}_t \frac{1}{R_t} \right\}$$

where $\chi \in [0,1]$ is the fraction of the residential good that cannot be used as a collateral. Such a parameter is an indirect measure of the flexibility of the mortgage market. The term $(1-\chi)$ thus provides a proxy for the observed loan-to-value ratio, which is subject to a stationary stochastic shock ε^{LTV}_t. The collateral constraint can be conveniently rewritten in *real* terms as follows:

$$\widetilde{b}_{H,t} \leq \varepsilon^{LTV}_t (1-\chi)\, \mathbb{E}_t \left\{ T_{D,t+1} \widetilde{D}_t \frac{\pi_{t+1}}{R_t} \right\} \tag{4}$$

where $\widetilde{b}_{H,t} \equiv \frac{B_H}{P_t}$.

Summing up, the impatient agent maximizes (1) subject to the infinite sequence of (3) and (4) holding with equality[8]. We report the first order conditions for this problem in the Appendix.

2.2 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 in equilibrium. They own the productive capacities and make decisions on investment plans to build the capital stock which will be rented out to intermediate firms. The savers can trade two nominal risk-less bonds denominated in the domestic and foreign currency. Financial markets are assumed to be

[8]It is immediate to show that the collateral constraint always binds in the deterministic steady state, under general conditions. We assume here that it continues to bind in a sufficiently small neighborhood of the steady state, so that the model can be solved by taking a first order approximation.

incomplete internationally. We introduce a risk premium on the international financing of domestic consumption expenditures. Such risk premium is a function of real holdings of foreign assets in the entire economy. Each patient agent receives instantaneous utility from the same type function (1) adopted for the impatient[9]:

$$\mathcal{W}_t^s = \mathbb{E}_t \left\{ \sum_{j \geq 0} \gamma^j \left[\begin{array}{c} \frac{1}{1-\sigma_X} \left(X_{t+j}^s\right)^{1-\sigma_X} - \frac{\varepsilon_{t+j}^{L,s} \widetilde{L}_C}{1+\sigma_{LC}} \left(N_{Ct+j}^s\right)^{1+\sigma_{LC}} \\ - \frac{\varepsilon_{t+j}^{L,s} \widetilde{L}_D}{1+\sigma_{LD}} \left(N_{Dt+j}^s\right)^{1+\sigma_{LD}} \end{array} \right] \varepsilon_{t+j}^{\beta} \right\} \tag{5}$$

where X_t^s is given by

$$X_t^s \equiv \left[\left(1 - \varepsilon_t^D \omega_D\right)^{\frac{1}{\eta_D}} \left(C_t^s - h_S C_{t-1}^s\right)^{\frac{\eta_D - 1}{\eta_D}} + \varepsilon_t^D \omega_D^{\frac{1}{\eta_D}} \left(D_t^s\right)^{\frac{\eta_D - 1}{\eta_D}} \right]^{\frac{\eta_D}{\eta_D - 1}} \tag{6}$$

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

$$\begin{aligned} C_t^s + T_{D,t} \left(D_t^s - (1-\delta) D_{t-1}^s\right) + I_t^s + \frac{B_{H,t}^s}{P_t} + \frac{S_t B_{F,t}^s}{P_t \varepsilon_t^{\Delta S} \Psi \left(\frac{\mathbb{E}_t S_{t+1}}{S_{t-1}} - 1, \frac{S_t \left(B_{F,t} - \overline{\overline{B}}_F\right)}{P_t} \right)} \\ = \frac{R_{t-1} B_{H,t-1}^s}{\pi_t P_{t-1}} + \frac{S_t R_{t-1}^* B_{F,t-1}^s}{\pi_t P_{t-1}} + \sum_{j=C,D} \left[R_t^{k,j} u_t^j K_t^j - \Phi\left(u_t^j\right) K_t^j \right] \\ + \frac{\left(W_{C,t}^s N_{C,t}^s + W_{D,t}^s N_{D,t}^s\right) + A_t^s + \Pi_t^s + TT_t^s}{P_t} \end{aligned}$$

where S_t is the nominal exchange rate, TT_t^s are government transfers and Π_t^s are distributed profits. Capital is sector-specific and the savers decide in which sector to invest. The expression

$$R_t^{k,j} u_t^j K_t^j - \Phi\left(u_t^j\right) K_t^j$$

represents the sector-specific nominal return on the real capital stock minus the cost associated with variations in the degree of capital utilization[10]. $B_{H,t}^s$ and $B_{F,t}^s$ are the individual saver's holdings of domestic and foreign bonds denominated in local currency. The risk premium function $\Psi(\cdot, \cdot)$ is differentiable, decreasing in both arguments and verifies $\Psi(0,0) = 1$. The functional form used for the risk premium is $\Psi(X,Y) = \exp\left(-\chi_{\Delta S} X - 2\chi Y\right)$. The term $\varepsilon_t^{\Delta S}$ is a unitary-mean disturbance affecting the risk premium.

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

[10]Following Smets and Wouters (2007), we assume that the income obtained from renting out capital services depends on the level of capital augmented for its utilization rate. Moreover, the cost of capacity utilization is zero when capacity is fully used ($\Phi(1) = 0$). We assume the following functional form for the adjustment costs on capacity utilization: $\Phi(X) = \frac{\overline{\overline{R^k}}}{\varphi} \left(\exp\left[\varphi\left(X - 1\right)\right] - 1\right).$

As for the borrowers, we maintain the assumption that state-contingent assets are traded within the group of savers, in order to hedge against wage income risk. The corresponding stream of income is denoted A^s_t. As a result, all savers have identical consumption plans in equilibrium and we can therefore drop superscripts s.
The optimality conditions characterizing the solution of the saver's problem are reported in the Appendix.
In the following, we will refer to the saver's and borrower's *user costs* of residential investment (the exact definition of which can also be found in the Appendix). The user cost indicators drive the substitution effects between durable and non-durable goods for each household type. The aggregate user cost, denoted $R_D^{aggregate}$, is defined as the weighted average of the saver's and borrower's user costs.

2.3 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 household of the same type supply the same amount of hours worked in each sector, in equilibrium.
In each sector j ($j = C, D$), we assume the existence of perfectly competitive labor packers, who buy the individual agents' labor supplies N^i_{jt} ($i = B, S$) and aggregate them using a Cobb-Douglas function, to produce the aggregate labor indicators $L_{C,t}$ and $L_{D,t}$ that enter the firms' production functions (see later). We specify the details of the labor packers profit-maximization problem below.
We also assume that in each sector j ($j = C, D$) there exist monopolistically competitive labor unions indexed by i ($i = B, S$), representing the patient and impatient households, respectively. Unions differentiate the homogeneous labor provided by households, creating a continuum of measure one of labor services (indexed by $z \in [0, 1]$) which are sold to the above-mentioned labor packers in each sector. Each union thus faces the following labor demand (originating from sector-specific labor packers):

$$L_{j,i,t}(z) = \left(\frac{W_{j,i,t}(z)}{W_{j,i,t}} \right)^{-\frac{\mu_w}{\mu_w - 1}} L_{j,i,t}$$

where $z \in [0, 1]$, $\mu_w = \frac{\theta_w}{\theta_w - 1}$ and $\theta_w > 1$ is the elasticity of substitution between differentiated labor services, which we assume to be constant across types and sectors. $L_{j,i,t}$

measures demand for labor type i by firms in sector j,

$$L_{j,i,t} = \left[\int_0^1 L_{j,i,t}(z)^{\frac{1}{\mu_w}} \mathrm{d}z\right]^{\mu_w}$$

while $W_{j,i,t}$ denotes the nominal wage set by union i in market j at time t[11]:

$$W_{j,i,t} = \left[\int_0^1 W_{j,i,t}(z)^{\frac{1}{1-\mu_w}} \mathrm{d}z\right]^{1-\mu_w}$$

Clearly, our structure gives rise to four different wages in equilibrium, each corresponding to a specific worker type (patient, impatient) in a specific sector (C, D). 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 re-optimize, wages are indexed to past and steady-state inflation according to the following rule:

$$W_{j,i,t}(z) = [\Pi_{t-1}]^{\xi_w^{j,i}} \left[\overline{\Pi}\right]^{1-\xi_w^{j,i}} W_{j,i,t-1}(z)$$

where $\Pi_t = \frac{P_t}{P_{t-1}}$ and $\xi_w^{j,i}$ denotes the degree of indexation in each sector, for each type. Taking into account that unions might not be able to choose their nominal wage optimally in the future, the optimal nominal wage $\widetilde{W}_{j,i,t}(z)$ is chosen to maximize intertemporal utility under the budget constraint and the labor demand function. The Appendix reports the first order conditions for this program written in a recursive form, and an expression for the aggregate wage dynamics.

We can now define the labor packers' Cobb-Douglas production function as follows:

$$L_j \equiv \omega^{\omega}(1-\omega)^{(1-\omega)} \left(\frac{N_{j,t}^S}{\Delta_{j,S,t}^w}\right)^{(1-\omega)} \left(\frac{N_{j,t}^B}{\Delta_{j,B,t}^w}\right)^{\omega}$$

where

$$\frac{N_{j,t}^B}{\Delta_{j,B,t}^w} W_{j,B,t} = \frac{N_{j,t}^S}{\Delta_{j,S,t}^w} W_{j,S,t}$$

[11] The following definitions also hold:

$$N_{j,t}^B \equiv \int_0^1 L_{j,B,t}(z) dz$$

and

$$N_{j,t}^S \equiv \int_0^1 L_{j,S,t}(z) dz$$

and the term $\Delta^w_{j,i,t}$ denotes wage dispersion in sector j, related to agent i. Such term is a state variable that evolves as follows:

$$\Delta^w_{j,i,t} = (1-\alpha_{wji})\left(W_{j,i,t}\right)^{\frac{\mu_w}{\mu_w-1}}\left(\mu_w \frac{\mathcal{H}^{wji}_{1,t}}{\mathcal{H}^{wji}_{2,t}}\right)^{-\frac{\mu_w}{\mu_w-1}}$$
$$+\alpha_{wji}\Delta^w_{j,i,t-1}\left(\frac{W_{j,i,t}}{W_{j,i,t-1}}\right)^{\frac{\mu_w}{\mu_w-1}}\left(\frac{\Pi_t}{\Pi_{t-1}^{\xi_{wj,i}}\left[\overline{\Pi}\right]^{1-\xi_{wj,i}}}\right)^{\frac{\mu_w}{\mu_w-1}}$$

Notice that wage dispersion is inefficient, as all job varieties are ex-ante identical [12]. The solution to the labor packers' cost-minimization problem also determines the following wage indices:

$$W_{j,t} = \frac{\left(W_{j,S,t}\right)^{1-\omega}\left(W_{j,B,t}\right)^{\omega}}{\omega^{\omega}(1-\omega)^{1-\omega}}$$

2.4 Investment decisions

The patient agents own capital and rent it out to the intermediate goods-firms at the sector-specific rental rate $R^{k,j}_t$ $(j = C, D)$. Investment consists of the distributed non-residential good only. The savers choose the investment and capacity utilization in each sector to maximize their intertemporal utility, subject to the intertemporal budget constraint and the capital accumulation equation:

$$K^j_t = (1-\delta_K)K^j_{t-1} + \varepsilon^I_t\left[1 - S\left(\frac{I^j_t}{I^j_{t-1}}\right)\right]I^j_t \tag{7}$$

where $\delta_K \in [0,1]$ is the depreciation rate of capital, S is a non-negative adjustment cost function formulated in terms of the gross rate of change in investment, I^j_t/I^j_{t-1}, and ε^I_t is an efficiency shock to the technology of capital accumulation, common to both sectors. The functional forms adopted are $S\left(x\right) = \phi/2\ \ (x-1)^2$ for country H and $S\left(x\right) = \phi^*/2\ \ (x-1)^2$ for country F, with ϕ and ϕ^* constant. The resulting first order conditions read:

$$Q_t = \beta\mathbb{E}_t\left[\frac{\Lambda_{t+1}}{\Lambda_t}\left(Q_{t+1}(1-\delta) + R^k_{t+1}u_{t+1} - \Phi(u_{t+1})\right)\right]\varepsilon^Q_t$$

$$Q_t\left[1 - S\left(\frac{I_t}{I_{t-1}}\right) - \frac{I_t}{I_{t-1}}S'\left(\frac{I_t}{I_{t-1}}\right)\right]\varepsilon^I_t +$$
$$\beta\mathbb{E}_t\left[Q_{t+1}\frac{\Lambda_{t+1}}{\Lambda_t}\left(\frac{I_{t+1}}{I_t}\right)^2 S'\left(\frac{I_{t+1}}{I_t}\right)\right]$$
$$= 1$$

[12] see Schmitt-Grohe and Uribe (2006)

$$R_t^k = \Phi'(u_t)$$

where $\Lambda_t Q_t$ is the Lagrange multiplier associated with the capital accumulation equation. We follow Smets and Wouters (2003) in introducing an *ad hoc* shock ε_t^Q that accounts for fluctuations in the external finance risk premium.

2.5 Distribution sector for non-residential goods

Non-residential goods in each country are produced by a continuum of companies that, operating under perfect competition, mix local production with imports. There is a home bias in aggregation, n, which pins down the degree of openness in steady state. The $\iota - th$ distributor technology, $\forall \iota \in [0,1]$, is given by

$$Y_\iota = \left[n_t^{\frac{1}{\xi}} Y_{\iota,H}^{\frac{\xi-1}{\xi}} + (1-n_t)^{\frac{1}{\xi}} Y_{\iota,F}^{\frac{\xi-1}{\xi}} \right]^{\frac{\xi}{\xi-1}}$$

in the domestic country and

$$Y_\iota^* = \left[(1-n_t^*)^{\frac{1}{\xi}} Y_{\iota,H}^{*\frac{\xi-1}{\xi}} + n_t^{*\frac{1}{\xi}} Y_{\iota,F}^{*\frac{\xi-1}{\xi}} \right]^{\frac{\xi}{\xi-1}}$$

in the foreign country, with ξ denoting the elasticity of substitution between bundles Y_H and Y_F. The degrees of home bias are subject to shocks. Since only the difference of openness rates enters the linearized aggregate equations in the absence of adjustment costs on imports, home bias shocks are expressed as $n_t = n\sqrt{\varepsilon_t^{\Delta n}}$ and $n_t^* = \frac{n}{\sqrt{\varepsilon_t^{\Delta n}}}$. Cost minimization determines import demands:

$$\begin{aligned} Y_{H,t} &= n_t \left(T_{H,t}\right)^{-\xi} Y_t, \; Y_{F,t} = (1-n_t)\left(T_t \, T_{H,t}\right)^{-\xi} Y_t \\ Y_{F,t}^* &= n_t^* \left(T_{F,t}^*\right)^{-\xi} Y_t^*, \; Y_{H,t}^* = (1-n_t^*)\left(\frac{T_{F,t}^*}{T_t^*}\right)^{-\xi} Y_t^* \end{aligned} \tag{8}$$

Distribution prices are defined by:

$$\begin{aligned} P_t &= \left[n_t P_{H,t}^{1-\xi} + (1-n_t) P_{F,t}^{1-\xi} \right]^{\frac{1}{1-\xi}} \\ P_t^* &= \left[n_t^* P_{F,t}^{*1-\xi} + (1-n_t^*) P_{H,t}^{*1-\xi} \right]^{\frac{1}{1-\xi}} \end{aligned}$$

whereas $T_t = \frac{P_{F,t}}{P_{H,t}}$ and $T_t^* = \frac{P_{F,t}^*}{P_{H,t}^*}$ denote the interior terms of trade. We also make use of the relative prices $T_{H,t} = \frac{P_{H,t}}{P_t}$ and $T_{F,t}^* = \frac{P_{F,t}^*}{P_t^*}$.

2.6 Final non-residential goods sector

In country H, final producers for local sales and imports are in perfect competition and aggregate a continuum of differentiated intermediate products from home and foreign intermediate sector. Y_H and Y_F denote the continuum of differentiated goods produced respectively in country H and F. The elementary differentiated goods are imperfect substitutes with an elasticity of substitution denoted $\frac{\mu}{\mu-1}$. Final goods are produced with the following technology $Y_H = \left[\int_0^1 Y(h)^{\frac{1}{\mu}} \mathrm{d}h\right]^{\mu}$ and $Y_F = \left[\int_0^1 Y(f)^{\frac{1}{\mu}} \mathrm{d}f\right]^{\mu}$. In country F, the corresponding indices are given by $Y_F^* = \left[\int_0^1 Y^*(f)^{\frac{1}{\mu}} \mathrm{d}f\right]^{\mu}$ and $Y_H^* = \left[\int_0^1 Y^*(h)^{\frac{1}{\mu}} \mathrm{d}h\right]^{\mu}$. For a domestic product h, we denote $p(h)$ its price on local market and $p^*(h)$ its price on the foreign import market. The domestic-demand-based price indices associated with imports and local markets in both countries are defined as $P_H = \left[\int_0^1 p(h)^{\frac{1}{1-\mu}} \mathrm{d}h\right]^{1-\mu}$, $P_H^* = \left[\int_0^1 p^*(h)^{\frac{1}{1-\mu}} \mathrm{d}h\right]^{1-\mu}$, $P_F^* = \left[\int_0^1 p^*(f)^{\frac{1}{1-\mu}} \mathrm{d}f\right]^{1-\mu}$ and $P_F = \left[\int_0^1 p(f)^{\frac{1}{1-\mu}} \mathrm{d}f\right]^{1-\mu}$. Domestic demand is allocated across the differentiated goods as follows

$$\begin{cases} \forall h \in [0,1] \quad Y(h) = \left(\frac{p(h)}{P_H}\right)^{-\frac{\mu}{\mu-1}} Y_H, \quad Y^*(h) = \left(\frac{p^*(h)}{P_H^*}\right)^{-\frac{\mu}{\mu-1}} Y_H^* \\ \forall f \in [0,1] \quad Y(f) = \left(\frac{p(f)}{P_F}\right)^{-\frac{\mu}{\mu-1}} Y_F, \quad Y^*(f) = \left(\frac{p^*(f)}{P_F^*}\right)^{-\frac{\mu}{\mu-1}} Y_F^* \end{cases}$$

2.7 Intermediate non-residential firms

Intermediate goods producers are monopolistic competitors and produce differentiated products using a Cobb-Douglas mixing labour and capital services $\widetilde{K}_t(\cdot) = u_t(\cdot)K_t(\cdot)$:

$$\begin{cases} Y_t(h) = \varepsilon_t^A \left(u_t^C K_{t-1}^C(h)\right)^{\alpha_C} L_t^C(h)^{1-\alpha_C} - \Omega_C & \forall h \in [0,1] \\ Y_t^*(f) = \varepsilon_t^A \left(u_t^{C*} K_{t-1}^{C*}(f)\right)^{\alpha_C} L_t^{C*}(f)^{1-\alpha_C} - \Omega_C^* & \forall f \in [0,1] \end{cases}$$

where ε_t^A and ε_t^{A*} are exogenous technology shifters. Each firm sells its products both in the local and in the foreign market. We denote $Y_H(h)$ and $Y_H^*(h)$ (respectively $Y_F^*(f)$ and $Y_F(f)$) the local and foreign sales of domestic producer h (respectively foreign producer f) and define $L_H^C(h)$ and $L_H^{C*}(h)$ (respectively $L_F^{C*}(f)$ and $L_F^C(f)$) the corresponding labor demand.

Local firms set prices on a staggered basis *à la* Calvo (1983). In each period, a firm h (resp. f) faces a constant probability $1-\alpha_H$ (resp. $1-\alpha_F^*$) of being able to re-optimize its nominal price. The average duration of a rigidity period is then $\frac{1}{1-\alpha_H}$ (resp. $\frac{1}{1-\alpha_F^*}$). If a firm cannot re-optimize its price, the price evolves according to the following simple rule:

$$p_t(h) = \Pi_{H,t-1}^{\gamma_H} \overline{\Pi}^{1-\gamma_H} p_{t-1}(h)$$

with γ_H denoting price indexation.

Concerning exports, we assume that, in country H, a fraction η (respectively η^* in country F) of exporters exhibit producer-currency-pricing (PCP) while the remaining firms exhibit local-currency-pricing (LCP). Consequently, aggregate export prices denominated in foreign currency are given by

$$P_H^* = \left[\eta\left(\frac{P_{H,t}}{S_t}\right)^{\frac{1}{1-\mu}} + (1-\eta)\,\tilde{P}_H^{*\frac{1}{1-\mu}}\right]^{1-\mu}, \text{ and } P_F = \left[\eta^*\left(S_t P_{F,t}^*\right)^{\frac{1}{1-\mu}} + (1-\eta^*)\,\tilde{P}_F^{\frac{1}{1-\mu}}\right]^{1-\mu}.$$

The aggregate LCP export price indices are accordingly defined as

$$\tilde{P}_H^* = \left[\frac{1}{1-\eta}\int_\eta^1 p^*(h)^{\frac{1}{1-\mu}}dh\right]^{1-\mu}, \text{ and } \tilde{P}_F = \left[\frac{1}{1-\eta^*}\int_{\eta^*}^1 p(f)^{\frac{1}{1-\mu}}df\right]^{1-\mu}.$$

We define the following relative prices $R\tilde{E}R_H = \frac{S\tilde{P}_H^*}{P_H}$, $R\tilde{E}R_F = \frac{\tilde{P}_F}{SP_F^*}$ and $\tilde{T} = \frac{\tilde{P}_F}{P_H}$. Export margins relative to local sales are denoted $RER_H = \frac{SP_H^*}{P_H}$ and $RER_F = \frac{P_F}{SP_F^*}$. In the presence of international price discrimination, these ratios measure the relative profitability of foreign sales compared with the local ones. Finally, $RER_t = \frac{S_t P_t^*}{P_t}$ is the real exchange rate.

The optimality conditions for the price-setting problem are reported in the Appendix.

2.8 Residential goods sectors

Final producers of residential goods operate in perfect competition and aggregate a continuum of differentiated domestic intermediate products. Final and intermediate residential goods are non-traded. The elementary differentiated goods are imperfect substitutes with elasticity of substitution denoted $\frac{\mu_D}{\mu_D-1}$. Final goods are produced with the following technology $Z_D = \left[\int_0^1 Z_D(h)^{\frac{1}{\mu_D}}\mathrm{d}h\right]^{\mu_D}$. The price of a domestic product h is denoted by $p_D(h)$. The aggregate price index is defined as $P_D = \left[\int_0^1 p_D(h)^{\frac{1}{1-\mu_D}}\mathrm{d}h\right]^{1-\mu_D}$. Domestic demand is allocated across the differentiated goods as follows: $Z_D(h) = \left(\frac{p_D(h)}{P_D}\right)^{-\frac{\mu_D}{\mu_D-1}} Z_D$.

Residential goods are produced by combining capital, labor and land. We assume that in every period of time the savers are endowed with a given amount of land, which they sell to the firms in a fixed quantity. We assume that the supply of land is exogenously fixed and that each residential goods intermediate firm takes the price of land as given in its decision problem. Producers make use of a Cobb-Douglas technology as follows:

$$\begin{cases} Z_{D,t}(h) = \varepsilon_t^{A_D}\left(u_t^D K_{t-1}^D(h)\right)^{\alpha_D} L_t^D(h)^{1-\alpha_D-\alpha_{\mathcal{L}}}\mathcal{L}(h)_t^{\alpha_{\mathcal{L}}} - \Omega_D & \forall h\in[0,1] \\ Z_{D,t}^*(f) = \varepsilon_t^{A_D*}\left(u_t^{D*} K_{t-1}^{D*}(f)\right)^{\alpha_D} L_t^{D*}(h)^{1-\alpha_D*-\alpha_{\mathcal{L}}*}\mathcal{L}^*(f)_t^{\alpha_{\mathcal{L}}*} - \Omega_D^* & \forall f\in[0,1] \end{cases}$$

where $\varepsilon_t^{A_D}$ and $\varepsilon_t^{A_D*}$ are exogenous technology parameters and $\mathcal{L}_t(h)$ denotes the endowment of land used by producer h at time t.
As in the non-residential sector, firms are monopolistic competitors. However, we assume here that residential prices are perfectly flexible, so that in each period firms set their price as a constant markup mu_D over the marginal cost $MC_{D,t}$ defined as follows[13]:

$$MC_{D,t} = \frac{w_t^{(1-\alpha_D-\alpha_{\mathcal{L}})} \left[R_t^{k,D}\right]^{\alpha_D} [p_{lt}]^{\alpha_{\mathcal{L}}}}{\varepsilon_t^{A_D} \alpha_D^{\alpha_D} (1-\alpha_D-\alpha_{\mathcal{L}})^{(1-\alpha_D-\alpha_{LAND})} (\alpha_{\mathcal{L}})^{\alpha_{\mathcal{L}}} T_{D,t}} \tag{9}$$

where p_{lt} denotes the relative price of land deflated by non-residential goods price[14].

2.9 Government and monetary authority

In each country, 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 CPI inflation, output and their first difference. In the benchmark specification, we do not include housing prices in rule. Written in deviation from the steady state, the interest rate rule used has the following form:

$$r_t = \rho r_{t-1} + (1-\rho)\left(r_\pi \pi_{t-1} + r_y y_{t-1}\right) + r_{\Delta\pi}\left(\pi_t - \pi_{t-1}\right) + r_{\Delta y}\left(y_t - y_{t-1}\right) + \log\left(\varepsilon_t^R\right) \tag{12}$$

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

[13] The same assumption about residential prices is adopted in Iacoviello and Neri (2009). We have estimated a version of the model in which Calvo-type nominal price rigidities are allowed in the residential sector, and obtained evidence in favor of almost perfectly flexible prices. Hence, we have decided to maintain the assumption of flexible housing prices, in order to reduce the overall number of parameters to be estimated.

[14] Notice that cost minimization implies:

$$p_{lt} = \alpha_{\mathcal{L}} T_{D,t} \frac{Z_{D,t}}{\mathcal{L}_t} \tag{10}$$

and

$$\frac{w_t L_t^D}{R_t^{k,D} u_t^D K_{t-1}^D} = \frac{1-\alpha_D-\alpha_{\mathcal{L}}}{\alpha_D} \tag{11}$$

2.10 Market clearing conditions

Aggregate investment and capital stock are given by:

$$I_t^j = (1-\omega)\, I_t^{sj} \tag{13}$$
$$K_t^j = (1-\omega)\, K_t^{sj} \tag{14}$$

for $j = C, D$. Similar relations apply for country F.

Aggregate domestic demands for non-residential goods are given by:

$$Y_t = \omega \widetilde{C}_t + (1-\omega) C_t + I_t^C + I_t^D + \overline{\overline{G}}\varepsilon_t^G + \Phi\left(u_t^C\right) K_{t-1}^C + \Phi\left(u_t^D\right) K_{t-1}^D \tag{15}$$
$$Y_t^* = \omega^* \widetilde{C}_t^* + (1-\omega^*) C_t^* + I_t^{C*} + I_t^{D*} + \overline{\overline{G}}\varepsilon_t^{G*} + \Phi\left(u_t^{C*}\right) K_{t-1}^{C*} + \Phi\left(u_t^{D*}\right) K_{t-1}^{D*} \tag{16}$$

Aggregate non-residential productions satisfy:

$$Z_t = \varepsilon_t^A \left(u_t^C K_{t-1}^C\right)^{\alpha_C} \left(L_t^C\right)^{1-\alpha_C} - \Omega_C \tag{17}$$
$$Z_t^* = \varepsilon_t^{A*} \left(u_t^{C*} K_{t-1}^{C*}\right)^{\alpha_C} \left(L_t^{C*}\right)^{1-\alpha_C} - \Omega_C^* \tag{18}$$

Market clearing conditions in non-residential goods markets lead to the following relations:

$$Z_t = n_t \Delta_{H,t} \left(T_{H,t}\right)^{-\xi} Y_t + (1-n_t^*)\, \Delta_{H,t}^* \left(\frac{T_{F,t}^*}{T_t^*}\right)^{-\xi} Y_t^* \tag{19}$$
$$Z_t^* = n_t^* \Delta_{F,t}^* \left(T_{F,t}^*\right)^{-\xi} Y_t^* + (1-n_t)\, \Delta_{F,t} \left(T_t T_{H,t}\right)^{-\xi} \tag{20}$$

where $\Delta_{H,t} = \int_0^1 \left(\frac{p_t(h)}{P_{H,t}}\right)^{-\frac{\mu}{\mu-1}} \mathrm{d}h$, $\Delta_{H,t}^* = \int_0^1 \left(\frac{p_t^*(h)}{P_{H,t}^*}\right)^{-\frac{\mu}{\mu-1}} \mathrm{d}h$, $\Delta_{F,t}^* = \int_0^1 \left(\frac{p_t^*(f)}{P_{F,t}^*}\right)^{-\frac{\mu}{\mu-1}} \mathrm{d}f$ and $\Delta_{F,t} = \int_0^1 \left(\frac{p_t(f)}{P_{F,t}}\right)^{-\frac{\mu}{\mu-1}} \mathrm{d}f$ measure price dispersions among products of country H and F, either sold locally or exported.

Similarly, aggregate productions of residential goods read:

$$Z_{D,t} = \varepsilon_t^{A_D} \left(u_t^D K_{t-1}^D\right)^{\alpha_D} \left(L_t^D\right)_t^{1-\alpha_D-\alpha_{\mathcal{L}}} \mathcal{L}_t^{\alpha_{\mathcal{L}}} - \Omega_D \tag{21}$$
$$Z_{D,t}^* = \varepsilon_t^{A_D*} \left(u_t^{D*} K_{t-1}^{D*}\right)^{\alpha_D} \left(L_t^{D*}\right)_t^{1-\alpha_D-\alpha_{\mathcal{L}}} \mathcal{L}_t^{*\alpha_{\mathcal{L}}} - \Omega_D^* \tag{22}$$

Market clearing conditions for the residential markets are

$$Z_{D,t} = \Delta_{D,t} \left[\omega \left(\widetilde{D}_t - (1-\delta)\widetilde{D}_{t-1}\right) + (1-\omega)\left(D_t - (1-\delta) D_{t-1}\right)\right] \tag{23}$$
$$Z_{D,t}^* = \Delta_{D,t}^* \left[\omega^* \left(\widetilde{D}_t^* - (1-\delta)\widetilde{D}_{t-1}^*\right) + (1-\omega^*)\left(D_t^* - (1-\delta) D_{t-1}^*\right)\right] \tag{24}$$

where $\Delta_{D,t} = \int_0^1 \left(\frac{p_{D,t}(h)}{P_{D,t}}\right)^{-\frac{\mu_D}{\mu_D-1}} \mathrm{d}h$ and $\Delta_{D,t}^* = \int_0^1 \left(\frac{p_{D,t}^*(h)}{P_{D,t}^*}\right)^{-\frac{\mu_D}{\mu_D-1}} \mathrm{d}h$ measure price dispersions among non-residential intermediate goods of country H and F.

Equilibrium in the bond markets implies that $B^*_{H,t} + B^*_{F,t} = \widetilde{B}^*_{F,t}$ and $B_{H,t} + B_{F,t} = \widetilde{B}_{H,t}$. Moreover, demand for bonds denominated in currency F issued by agents in country H is given by

$$\frac{S_t B_{F,t}}{P_t R^*_t} - \frac{B^*_{H,t}}{P_t R_t} = \frac{S_t B_{F,t-1}}{P_t} - \frac{B^*_{H,t-1}}{\underline{P}_t} + T_{H,t} Y_{H,t} + RER_t \frac{T^*_{F,t}}{T^*_t} Y^*_{H,t} - Y_t \tag{25}$$

where RER_t is the real exchange rate measured with consumer prices net of consumption taxes.

The aggregate conditional welfare measures for each type of agent in each country are defined by $\mathcal{W}^B_{H,t} = \int_0^{\omega} \mathcal{W}^b_t \mathrm{d}b$ and $\mathcal{W}^S_{H,t} = \int_{1-\omega}^1 \mathcal{W}^s_t \mathrm{d}s$, and $\mathcal{W}^{B*}_{F,t} = \int_0^{\omega^*} \mathcal{W}^{b*}_t \mathrm{d}b$ and $\mathcal{W}^{S*}_{F,t} = \int_{1-\omega^*}^1 \mathcal{W}^{s*}_t \mathrm{d}s$, respectively.

3 Bayesian Estimation

The model is estimated on US and euro area data using Bayesian likelihood methods. For each country, we consider 11 key macroeconomic quarterly time series from 1981q1 to 2005q4 [15]: output, consumption, non-residential fixed investment, hours worked, real wages, GDP deflator inflation rate, CPI inflation rate, 3 month short-term interest rate, residential investment, real house prices and total household debt. We also use the exchange rate and the US current account[16]. All variables are linearly detrended prior to estimation.

In the following, country H represents the US and country F the euro area. Euro area parameters and shocks are therefore denoted with a *, in line with the notation adopted in the previous section. We summarize here the exogenous stochastic shocks that we introduce:

- Efficient shocks: technology (ε^A_t, ε^{A*}_t, $\varepsilon^{A_D}_t$, $\varepsilon^{A_D*}_t$), investment (ε^I_t, ε^{I*}_t), labor supply (ε^L_t, ε^{L*}_t), public expenditure (ε^G_t, ε^{G*}_t), consumption preferences (ε^B_t, ε^{B*}_t), housing preferences (ε^D_t, ε^{D*}_t), relative home bias ($\varepsilon^{\Delta n}_t$), loan-to-value ratio (ε^{LTV}_t, ε^{LTV*}_t).

- Inefficient shocks: PPI markups (ε^P_t, ε^{P*}_t), CPI markups (ε^{CPI}_t, ε^{CPI*}_t), external finance risk premium (ε^Q_t, ε^{Q*}_t), UIP ($\varepsilon^{\Delta S}_t$).

- Monetary policy shocks (ε^R_t, ε^{R*}_t).

[15] The choice of the estimation sample reflects the availability of housing sector data for the euro area.

[16] See Appendix for a detailed description of the dataset.

We also allow for the existence of common factors on some specific shocks. The motivation relies on the two-country nature of the model, which is supposed to capture cross-country dynamics only, while leaving the interactions between the two regions and the rest of the world unexplained. However, shocks originating from the rest of the world, or unspecified spillovers cannot be ruled out ex ante. Therefore, we modify the shocks structure to account for additional sources of economic fluctuations. As a first step, we include possible common factors on productivity shocks in the non-residential sector (f_t^A), CPI markup shocks (f_t^{CPI}) and monetary policy shocks (f_t^R) [17].

In addition, like Adjemian, Darracq Pariès, and Smets (2008), we introduce some correlations among structural shocks, to account for possible unmodeled spillovers. In particular, since we use US total net trade instead of bilateral net trade data in estimation, we introduce a correlation between the US home bias preference shock and the euro area public expenditure shock. Such correlation - denoted ρ_{n,G^*}- is meant to capture rest-of-the-world shocks that affect the US current account, with moderate immediate impact on euro area output. Moreover, considering the weak structural interpretation attributed to UIP shocks in a first-order approximation of the model, it seems justified to allow for links with other shocks. Hence, we include in the estimation some correlation terms between the UIP shock and other efficient shocks, in order to account for the impact of fundamental shocks on the time-varying risk premium. In particular, we consider correlations between the UIP shock and the US non-residential productivity shock ($\rho_{A,\Delta S}$) and between the UIP shock and government expenditure shocks in both areas ($\rho_{G,\Delta S}$) and ($\rho_{G^*,\Delta S}$). The presence of such terms helps the model generating the observed positive comovement between consumption and business investment.

3.1 Calibrated parameters

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 noninformative.

In particular, the discount factors are calibrated to 0.99 for the patient agents and 0.96 for the impatient agents[18]. The calibration is the same for the US and the Euro Area. The implied equilibrium real interest rate is 4% in annual terms[19]. The depreciation

[17] The three common factors were selected on the basis of their significance in explaining macroeconomic fluctuations and the implied marginal data density.

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

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

rate for housing, δ, is equal to 0.01, corresponding to an annual rate of 4%, whereas the depreciation rate of capital is set to 0.1. Markups are constant across countries and equal to 1.3 in the goods markets (for both nonresidential 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 in both countries. 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 relative shares of inputs in production are 0.3 for capital and 0.7 for labor in the nonresidential goods sector, while in the residential sector we assign a weight equal to 0.1 to land, and reduce the share of capital to 0.2, in order to maintain the level of labor intensity unchanged.

Finally, we calibrate the loan-to-value ratio (determined by the terms $(1-\chi)$ and $(1-\chi^*)$), to 0.8 in both areas. Although these two parameters could in principle be included in the estimation set, keeping them fixed - at the same level - helps focusing the attention on the estimation of the relative shares of borrowers (ω and ω^*). Moreover, existing empirical studies[20] document the presence of a substantial degree of heterogeneity within the euro area in terms of mortgage markets flexibility, with some countries as the Netherlands being close to the US, and others (e.g. Germany and Italy) displaying a much smaller degree of flexibility. The proposed calibration of χ^* thus provides an approximate average across European countries.

3.2 Prior distributions

Prior distributions of the structural parameters are assumed to be the same across countries, following a common practice in the literature[21]. The standard errors of the structural shocks are assumed to follow a Uniform distribution over the [0,6] interval[22], while the persistence parameters follow a Beta distribution with mean 0.5 and standard deviation 0.2. The UIP-correlations are normally distributed in the (0,1) interval, whereas the remaining correlation terms are uniformly distributed.

About the parameters of the monetary policy reaction function, we follow Smets and Wouters (2005)and Adjemian, Darracq Pariès, and Smets (2008) 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. Con-

[20]See Calza, Monacelli, and Stracca (2007).

[21]See, among others, Smets and Wouters (2005).

[22]Four shocks deviate from this assumption: ε_t^Q, which is uniformly distributed over $[0,20]$, ε_t^H and ε_t^{Q*}, which are $U[0,10]$, and ε_t^{I*}, which follows an Inverted Gamma $(0.5, Inf)$.

cerning the short-run response to inflation and output gap, the prior distributions are a Normal with mean 1.5 and standard deviation 0.25, and a Gamma with parameters 0.12 and 0.05, respectively. About preference parameters, the intertemporal elasticity of substitution, which is common to both household types, follows a Gamma distribution with mean 1 and standard deviation 0.375. The habit formation parameters are specific to savers and borrowers, following a Beta distribution with parameters 0.5 and 0.1. The elasticity of labor supply is the same for both household types and sectors, and has a Gamma(2, 0.75) prior distribution. On the production side, the adjustment cost parameter for investment and the capacity utilization elasticity, which are common to residential and non-residential sectors, follow respectively a Normal(4, 1.5) and a Beta(0.5, 0.15) prior distributions. 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[23]. The indexation parameters are instead centered around 0.5, with a standard deviation of 0.15. Finally, concerning the open economy parameters, we use fairly noninformative distributions for the elasticity of intratemporal substitution, the parameters related to the share of PCP producers, the degree of home bias in consumption and the elasticity of foreign exchange risk premium with respect to past exchange rate changes. The prior on the elasticity of the risk premium to net foreign assets is a Normal(1,0.25), the parameter being re-scaled by a factor 100.

The main estimated parameters driving the aggregate amount of credit frictions in both economies are the country-specific shares of impatient agents (ω and ω^*). In the benchmark estimation, the priors for those parameters are set as Beta distribution, with mean 0.35 and standard deviation 0.05. This choice is similar to the one of Iacoviello and Neri (2009). 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. Given the crucial role of ω and ω^* in the model, we also investigate the fit of the model with alternative prior distributions. We return to this in the next section.

3.3 Posterior distributions

Table 1 reports the mode, the mean and the 10th and 90th percentiles of the posterior distribution of the structural parameters, obtained using the Metropolis - Hastings algo-

[23]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.

rithm. Some of the results are similar to estimates found in the literature using similar models, without a housing sector for the US and the euro area (see for example Smets and Wouters (2005) or Adjemian, Darracq Pariès, and Smets (2008)). We concentrate here on those features that are more closely related to our expanded modeling framework with respect to the sectoral structure of the economy and the heterogeneity of households' types.

Among the stochastic exogenous disturbances, the government expenditure, UIP risk premium and housing preference shocks have the highest estimated persistence. In particular, the estimated means for the autoregressive parameter of the housing preference shocks are 0.97 for the US and 0.99 for the Euro Area. Such a high estimated degree of persistence suggests that the process will tend to explain a lot of the long horizon forecast error variance of the real variables. In general, the housing sector processes display a high persistence, as the estimated values for ρ_{AD}, ρ_{LTV} and ρ_H all lie above 0.93 in both countries.

About the behavioral parameters, the intertemporal elasticity of substitution, σ_C, is well below the prior mean: the estimated posterior means are in fact 0.64 for the U.S. and 1.06 for the Euro Area. The habit persistence parameters (h_B and h_S, respectively) indicate a much lower degree of persistence in the consumption plans of the borrowers, as opposed to the savers, in both areas. The estimated degrees of price stickiness in the non-residential goods sector are generally higher than the prior mean (0.75), and in particular the estimates are higher in the Euro Area than in the U.S., confirming a result reported in Smets and Wouters (2005) and Adjemian, Darracq Pariès, and Smets (2008). In the benchmark estimation, residential property prices are specified as flexible. This assumption is supported by estimations of Calvo parameters for the residential goods price setting very close to zero in both countries (results not reported here). Given such low levels of nominal rigidities, we preferred to keep the flexible price assumption. Wages are estimated to be slightly more flexible in the Euro Area, both in the non-residential and in the residential sector. All the indexation parameters, however, seem to be poorly identified, as indicated by the similarity of prior and posterior distributions.

Regarding open-economy parameters, our estimates are broadly similar to the ones of Adjemian, Darracq Pariès, and Smets (2008), with nonetheless a lower estimate for the trade elasticity. Finally, about the monetary policy reaction function, the baseline estimates tend to suggest that monetary policy reacted relatively more strongly to inflation in the U.S. than in the euro area over the estimation sample. Interest rate smoothing was also more pronounced in the euro area.

We turn now to the parameters capturing the share of borrowers in each economy (ω and ω^*). In the baseline specification, the estimated posterior modes are 0.24 and 0.19, respectively for the US and the euro area. Such values are below the prior mean, which is set at 0.25. The shape of the posterior distributions suggests that the data are not very informative on this direction. We therefore conduct some sensitivity analysis on the prior specification of ω and ω^* . Table 4 reports the estimates obtained when the prior distributions are shifted towards a mean of 0.5. In this case the estimated posterior modes are 0.46 and 0.42, respectively. Again, a look at prior and posterior distributions suggests a lack of information from the data. We also estimate the model using uniform priors, which leads to posterior values for the shares around 5% (estimation not reported here). Notably, however, even with uninformative priors, the estimation never sets the share of borrowers to 0, which would be possible in our parametric setting. In terms of marginal log-data density, the value reached in the benchmark specification is -2485.19 , compared to -2509.115 with high-share priors and -2478.3 with uniform priors.
Overall, our results suggests that ω and ω^* are not strongly identified given the dataset used. The presence of borrowers does not seem to be rejected, as all specifications lead to strictly positive values for such shares, but model comparison based on marginal data density would favor lower shares than in the benchmark estimation. A possible explanation for such a weak identification is related to the informational content of the observable variables, as opposed to the model-generated series. Although the model defines individual consumption plans for borrowers and savers, in practice only *aggregate* consumption data are observable in each sector, for a given country. Therefore, it is difficult to extract information on individual characteristics - such as habit persistence in consumption, or the relative weight of patient and impatient agents in the group of consumers - from aggregate data. Consequently, the prior distributions will have a substantial impact on the posterior estimates and should be carefully chosen based on economic information which may not be adequately reflected in the dataset. The prior specifications adopted in our exercise seem satisfying in terms of steady-state aggregate levels of households' debt compared to GDP and are in line with those adopted in similar studies (see Iacoviello and Neri (2009)).

3.4 Second order moments

Table 5 compares some selected second-order moments implied by the estimated model to the corresponding moments measured in the data. We use both linearly detrended and

HP-filtered data [24].

In terms of real variables comovement, we match the sign of almost all correlations. In particular, we replicate the negative comovement between the exchange rate and the current account, and the negative correlation between *relative* consumption and the real exchange rate, thus accounting for the *consumption-real exchange rate anomaly* (see Chari, Kehoe, and McGrattan (2002)). Our setup, including various types of shocks, thus appears to be more appropriate than standard stylized NOEM models in generating such an observed feature of the data. Given our set of common shocks across countries, the cross-country correlation of output is positive in the model, although lower than in the data. The measured comovement of consumption in the data is not robust to the filtering method nor to slight modifications in the sample length: still, the model generates too low correlation. The presence of common trends in the exogenous shocks to non-residential goods productivity, monetary policy and CPI helps the model generating enough cross-country spillovers, which are reflected into small but positive international correlations in real activity.

The volatilities of US residential and business investment are slightly underestimated in the model with respect to the data. In the euro area, the estimated standard deviation of residential investment is higher than the observed one, whereas the volatilities of house prices and business investment are lower. About the open economy variables, the estimates display and overweighted exchange rate volatility and an underweighted current account volatility. Overall, a better match between the data and the estimated model is obtained when we use HP-filtered series.

Turning now to the housing variables, the correlations of consumption and residential investment with real house prices are qualitatively reproduced by the model, albeit on the low side concerning consumption. However, the model-generated correlations of consumption and aggregate output with residential investment are substantially below the sample ones. This may suggest the introduction of some common shocks across sectors, such as government spending or productivity shocks. Regarding the cross-country correlations of housing prices and residential investment, some attention should be devoted to the measurement of international comovement in the housing sector. Over the full estimation sample, the cross-country comovement of residential investment is negative when we use detrended data, but positive with HP filtering. For real housing prices, the

[24] More precisely, the different sepcifications of the model are all estimated on linearly detrended data. When reporting second-order moments, we filter the model statistics using linear detrending and HP filter, respectively. Columns 2 to 4 and 5 to 8 in Table 5 thus compare model-generated moments with the data, using the same filtering procedure.

correlation is positive and lower with HP filtering than with detrending. Against this background, the model implies almost no correlation for both housing prices and residential investment. Given the uncertainty about the *true* evidence to match, it is important to identify the type of structural disturbances which can allow for either positive or negative cross-country correlations. We address such issue in the next section. Turning to prices, although the full-sample cross-country correlation of house prices is positive, the comovement becomes negative if we exclude the period 1998 q1: 2005 q4. During such period in fact, house prices in both countries show some clear evidence of a higher local trend, which a simple linear detrending procedure cannot completely offset[25]. Therefore, when focusing on the most stable part of our dataset, we can infer that a negative international comovement is actually observed in the data for both house prices and residential investment. All in all, it is very likely that the size of our sample is not large enough to capture the unconditional second order moments of housing data given the considerable length of cyclical fluctuations in the housing sector. The dataset may in fact only cover two medium-term housing cycles.

A final consideration regards the implications of stronger credit frictions in terms of simulated moments. Table 5 also presents the outcome from the estimated model with high priors on the shares of borrowers[26]. The High-Borrower specification seems to improve upon the benchmark model in several dimensions. In particular, the domestic correlations between consumption and housing variables are slightly higher. Moreover, the cross-country correlations of consumption, and to a lesser extent, housing variables increase marginally.

3.5 The contribution of housing shocks to economic fluctuations

Table 6 reports the unconditional variance decomposition of the macroeconomic variables, emphasizing the contribution of housing-related structural shocks. The aggregate role of housing shocks (both on the supply side, as in the case of technology and LTV-ratio shocks, and on the demand side, as for the housing preference shock) is particularly relevant in explaining the dynamics of housing production and house prices. Housing preference shocks are the main determinants of real house price fluctuations, while they contribute less than sector-specific productivity shocks in explaining residential investment. Concerning household debt in the two areas, housing preference and loan-to-value ratio (LTV) shocks explain more than 75% of the volatility. This reflects the model

[25] Over the same period, residential investment also shows signs of a trend, especially in the US.

[26] The corresponding posterior estimates are reported in Table 4

mechanics, with the borrowers adjusting very sharply and immediately to shocks that directly affect the collateral constraint[27]. Overall, the relative flexibility of house prices allows for significant adjustments in response to sectoral shocks.

The spillovers of housing-related shocks to the non-residential goods sector are modest. Housing preference shocks explain around 5% and 3% of consumption volatility in the euro area and the US respectively, while the contribution of LTV and productivity shocks is lower. Regarding other domestic variables, a relevant feature concerns the contribution of housing preference shocks to CPI inflation and nominal interest rate fluctuations, which range between 5 and 10% in the euro area. Such results are related to the higher persistence of the shock for the euro area as shown in the previous subsection.

Turning to the open-economy dimension, housing shocks are essentially affecting a non-tradable sector with flexible prices. Consequently, with interest rate rules targeting the non-residential inflation rate, both the direct trade channel and the scope of exchange-rate adjustment are relatively muted in response to housing shocks, compared with disturbances originating from the tradable sector. Regarding more specifically the international spillovers on real activity, the role of housing shocks is indeed quite limited. In addition, the estimated model implies a relatively low transmission of domestic shocks across countries[28].

In order to explore the sensitivity of the structural decomposition of business cycle fluctuations to the amount of credit frictions in the economy, Table 7 replicates the previous exercise moving the share of borrowers in the two countries to zero and to the estimates obtained in the High-Borrower case. We observe that the structural decomposition of house price and residential investment fluctuations are hardly affected by the size of credit-constrained consumers in the economy. Therefore, the main implications of varying the borrowers' shares can be analyzed through the aggregate substitution effect between residential and non-residential goods, which guides the macroeconomic transmission from prices and quantities in the residential sector to consumption and non-residential investment. Consumption is the most affected variable: the contribution of housing-related shocks reaches 23% in the US and 17% in the euro area with high shares of borrowers, against less than 1% when borrowers are absent. A similar pattern is observed for GDP.

[27] This is typically the case of LTV shocks and housing preference shocks, which have a sizeable influence on real housing prices and thus on the collateral value.

[28] A limited role for cross-country spillovers is a usual result in the literature (see Adjemian, Darracq Pariès, and Smets (2008) among others).

4 Housing shocks and the international business cycle

In this section we provide a positive analysis of the role played by the housing sector as both a part of the transmission mechanism and an independent source of economic fluctuations[29]. The impulse response functions analyzed here are based on the benchmark estimated model. We also illustrate the effects of varying the degree of credit frictions by comparing the outcomes of the benchmark model to the ones obtained by assuming either that the borrowers are absent, or that their share in the economy corresponds to the High-Borrower case.

4.1 Housing preference shock

A housing preference shock is defined here as an exogenous stochastic perturbation to the marginal rate of substitution between non-residential and residential consumption in the utility function of each agent. A positive housing preference shock thus generates a surge in housing demand and house prices (see Figures 5 and 6). Both effects are quite persistent over time, so that prices and quantities are still well above their steady state value after 20 quarters. The most interesting effect concerns the impact response of consumption, which is *positive* and increasing in the share of borrowers. The positive response of aggregate consumption is due to the *collateral channel*: by issuing more debt - made possible by the positive valuation effect of higher house prices on the existing collateral - the borrowers can finance extra consumption, thus consuming immediately more. Monetary policy responds to a generalized increase in domestic demand by raising the interest rate, which in turn causes an exchange rate appreciation. The current account deteriorates by a small amount on impact and the excess domestic demand in the source country leads to a positive effect on foreign output. The size of this spillover ranges between 0.05 and 0.1 which is, as expected, smaller than the one originating from demand shocks in the tradable sector. The exchange rate adjustment coupled with a monetary policy tightening induces in the foreign country a broad substitution effect away from nonresidential and domestically-produced residential goods. As a result, house prices and residential investment fall in the foreign country.

All the above-mentioned effects are amplified when the share of borrowers increases: the amplification mainly reflects the mechanical aggregation across the two different groups of consumers. Without borrowing instead, the response of domestic consumption to the

[29]See the working paper version for a complete analysis of the transmission mechanism of non-housing shocks.

housing preference shock is muted. Intuitively, without impatient households, there is no positive effect of higher house prices on consumption, because there is no collateral to be affected. The increase in house prices generates a higher user cost of housing for the savers (who now represent the entire group of households in the economy) and calls for a substitution from residential investment to consumption. However, the overall increase in domestic aggregate demand is lower than in the presence of borrowers. The required increase in the interest rate is therefore much smaller, and so is the exchange rate appreciation. The effect on the current account is consequently reduced, so that the spillover on foreign output falls by a half compared to the baseline case.

4.2 Housing technology shock

A positive productivity shock in the residential sector generates a sharp and persistent reduction in house prices, which are more flexible than nonresidential goods prices (see Figures 7 and 8). Intuitively, firms in the housing sector can almost fully exploit the technology improvement by adjusting prices and quantities in opposite directions. Residential investment indeed increases significantly on impact, with a persistent effect. The behavior of domestic demand follows from the individual responses to the shock. For the savers, an increase in housing supply, accompanied by a reduction in prices, generates a higher demand for residential investment. Moreover, the decrease in house prices lowers the savers' user cost of housing, generating a substitution effect from nonresidential to residential goods. Wage income also increases for the savers, who are accommodating the increase in labor demand in the residential-goods sector through the provision of more labor supply. The reverse holds true for the borrowers. A sustained decrease in house prices induces a negative *valuation effect* on the existing collateral, making borrowing more costly. As a result, the borrowers demand less of both goods compared with the savers, and debt decreases on impact in the source country. In addition, the borrowers have a stronger incentive to substitute residential investment for consumption goods in order to relax their collateral constraint. The resulting negative aggregate effect on consumption reduces CPI inflation, while aggregate output increases slightly.

Turning to the open-economy dimension, the transmission crucially depends on the response of monetary policy to aggregate demand. In the benchmark case, aggregate demand increases - reflecting the large increase in housing demand which offsets the fall in consumption - and inflation falls. The central bank responds by raising the interest rate. As a result, the exchange rate appreciates. The effect on the current account is very close to zero, and a very small positive spillover is generated on foreign output. Foreign

demand for domestically-produced goods falls, as well as house prices and debt.
Increasing the share of borrowers in the Home country reinforces the substitution effect in favor of residential goods (as testified by a lower aggregate user cost of housing), which dampens the initial response of aggregate consumption. Aggregate output also falls below its steady-state level in the first quarter after the shock. Given the downward pressures on consumer prices, monetary policy responds by *decreasing* the nominal interest rate, and the exchange rate appreciation is reduced by one half with respect to the baseline case. The current account now improves more, and a marginal negative spillover is generated on foreign output, with a small but positive substitution effect from the nonresidential to the residential goods sector. Conversely, setting the share of borrowers to zero increases Home output, and calls for an *increase* in the nominal interest rate. The exchange rate appreciation becomes larger than in the benchmark case, the current account now deteriorates, and the the positive spillover on Foreign output is stronger.

4.3 Loan-to-value ratio shock

A positive shock to the loan-to-value (LTV) ratio corresponds to an exogenous, temporary increase in the availability of funds to the borrowers in the domestic economy (see Figures 9 and 10). The borrowers thus demand more of both goods, driving house prices up. In particular, the relative flexibility of prices in the housing sector originates a sharp and sustained increase in house prices, whereas consumption-goods inflation moves slowly, due to nominal rigidities. Debt increases, fostered by the positive valuation effect of higher house prices on the existing collateral, and by the exogenous increase in the LTV ratio. The rise in house prices increases the user cost of housing for the savers and generates a substitution effect from residential investment to consumption. The increase in inflation calls for an interest rate rise. As a consequence, the exchange rate appreciates on impact and the current account deteriorates in the short term. However, the initial exchange rate appreciation is rapidly followed by a depreciation of a similar magnitude. The LTV shock generates a positive spillover on foreign output. The size of the spillover on economic activity is however smaller compared to the effects of a housing preference shock, notably reflecting a more moderate exchange rate adjustment. A broad substitution effect is observed in the Foreign economy, away from residential goods and domestically produced non-residential goods.
An increase in the share of borrowers reinforces the collateral channel in the Home country[30]. Demand and prices increase more in both sectors, thus requiring a stronger response

[30]Clearly, we do not consider here the case of no borrowers, which would imply the absence of a debt

of monetary policy to inflation. The exchange rate swings are more pronounced, and all the previously described spillover effects on the Foreign country are amplified.

4.4 Summing up

This section has provided a detailed description of the transmission of housing-related shocks, with a special focus on the role played by credit market imperfections. Overall, credit frictions alter the relative responses of aggregate consumption and non-residential investment to exogenous shocks. More precisely, moving the share of borrowers is implicitly equivalent to attributing more or less importance to credit constraints, thus influencing the propagation of standard demand and supply shocks. The housing sector plays a special role in the model, due to its dual nature of flexible-price, non-traded goods producing sector. On the one hand, prices and quantities are free to adjust almost instantaneously in response to external shocks, so that impact effects are typically large. On the other hand, as the residential investment good is non-traded, sectoral shocks typically generate *small and indirect* spillover effects on foreign country variables. The residential sector is therefore somewhat unaffected by shifts in the share of borrowers: the impact responses of prices and quantities are large enough that varying the size of the borrowers' group only marginally affects the overall adjustment. Nonetheless, structural housing-related shocks generate significant spillovers to non-residential consumption through the collateral channel and therefore the share of borrowers in the economy.

On the open-economy side, housing-related shocks expand the dynamic correlation properties of the model, which may help capturing important features of the dataset. In particular, there is evidence that the cross-country comovement of residential investment and house prices may have been negative over an extended period of time. The traditional "closed economy" set of non-housing related shocks generally induces a positive correlation in both house prices and residential investment across countries. Only open-economy shocks like foreign exchange risk premium or relative home bias disturbances generate strong asymmetric responses for most of the variables across countries. The introduction of housing shocks turns out to be helpful on this dimension. While housing technology shocks require the absence of borrowing to generate a negative correlation between home and foreign residential investment, the same result is obtained in the baseline estimation for housing preference, and to a lesser extent, loan-to-value ratio shocks. More specifically, the increase in domestic demand induced by larger borrowing leads to an interest rate raise and an exchange rate appreciation. Exports of non-residential goods increase.

channel, and prevent the existence of any LTV-ratio shocks.

In the Foreign country the increase in the interest rate reduces the demand for residential investment, which in turn drives house prices down. Housing preference shocks can thus reproduce sizeable negative international comovement in residential investment.

5 Monetary policy and housing prices

In this section we examine the relationship between monetary policy and housing prices along two dimensions. First, we evaluate whether the historical monetary policy conduct in the US and the euro area features a specific response to house prices. Second, we compare the macroeconomic transmission of housing shocks under the estimated Taylor rules to the one generated under the optimal monetary policy cooperation. A complete analysis of the normative prescriptions that could be derived in our framework is beyond the scope of this paper, and is left for future research.

5.1 The model with an augmented Taylor rule

We report here the results of an additional estimation exercise, in which we allow the central bank in each area to respond to fluctuations in house prices. In terms of modeling assumptions, this amounts to augmenting the specified Taylor rules by including relative house price changes as policy target variables.

The last three columns of 4 report the results obtained when we consider the following modified Taylor rule[31]:

$$r_t = \rho r_{t-1} + r_{\Delta\pi}\left(\pi_t - \pi_{t-1}\right) + (1-\rho)\left(r_\pi \pi_{t-1} + r_y y_{t-1}\right) + r_{\Delta y}\Delta y_t + r_{\Delta T_D}\Delta t_{D,t} + \log\left(\varepsilon_t^R\right) \tag{26}$$

We use a N(0,0.5) prior distribution for the parameter $r_{\Delta T_D}$ (and $r^*_{\Delta T_D}$), thus allowing, in principle, for both positive and negative systematic responses to house price inflation. The corresponding estimated posterior modes equal 0.10 in the US and 0.17 in the euro area, respectively. Both central banks thus feature a systematic mild increase in the interest rate in response to positive housing inflation rates. The estimates of the remaining parameters in the rule are quite robust to the modification, with the only exception of r^*_π - the response to the inflation rate in the euro area - which increases from 0.84 to 1.47[32].

Interestingly, the inclusion of these two additional coefficients in the estimation set largely improves the fit of the model: the log marginal density increases from -2485.19 in the

[31] An analogous expression is used for the euro area monetary policy rule.

[32] Several studies have documented the weak identification of the inflation level term in the policy rule, whose inference proves not to be robust to slight changes in priors or rule specification (see Adjemian, Darracq Pariès, and Moyen (2007) or Adjemian, Darracq Pariès, and Smets (2008) for example).

benchmark specification to -2450.12 in the augmented-rule case. We could therefore conclude - using a goodness-of-fit criterion - that a more accurate description of the historical conduct of monetary policy in the US and the euro area over the estimation sample should include a systematic small but positive response to house price inflation[33] . A similar exercise is performed in Finocchiaro and Queijo von Heideken (2007), who estimate a closed-economy model for the U.S. with a housing sector and credit frictions faced by households and entrepreneurs, as in Iacoviello (2005). Using different specifications for the monetary policy rule, they show that, over the sample 1983 Q1: 2006 Q4, the evidence does not support an active response of the Federal Reserve Bank to housing price fluctuations. Our results thus contrast with theirs. Possible explanations for the different findings may include: (i) the (augmented) Taylor rule specification, which in our case also includes *variations* in inflation and output, as opposed to only levels as in their exercise; (ii) the estimated degrees of nominal rigidities in the goods and labor market: in particular, our estimates for the wage stickiness parameter are relatively higher; and (iii) the open-economy dimension, which is absent in their framework, and may significantly influence the estimated monetary policy conduct over the sample period.

Some further observations concern the historical role of housing preference shocks in explaining business cycle fluctuations. Augmenting the monetary policy rule has two main consequences (results not reported here). First, housing preference shocks account for a larger fraction of the policy rate volatility. The interest rate in fact is now allowed to endogenously respond to fluctuations in house prices, which in turn are mainly driven by housing preference shocks in the model. Fluctuations in the policy rate will thus partly reflect the need to counteract the effect of inflationary demand shocks in the housing sector. Second, and related to the previous point, housing preference shocks explain much less of residential investment volatility, and to a lesser extent, of real house price fluctuations. The effect is robust across countries. In the benchmark specification, a positive demand shock in the housing sector - which moves residential investment and house prices in the same direction - has a large and significant effect on residential investment. When monetary policy is allowed to respond to housing inflation, the interest rate will move up in response to a positive demand shock. As a consequence, the cost of borrowing will

[33]Beyond marginal data density comparison, we also assess the model's ability to replicate the selected second moments reported in 5. Along this dimension, the augmented Taylor rule model does not provide a strong departure from the patterns obtained in the benchmark case. At the margin, the enriched model reduces the correlation between non-residential consumption and real house prices compared to the benchmark case, notably for the US, which may be less in line with data. At the same time, looking at the in-sample root mean square errors, the augmented Taylor rule model provides some improvements on most of the variables, in particular on real quantities (results are not reported here).

increase, dampening the initial increase in the demand for housing. Overall, residential investment will fluctuate less in response to movements in prices when the central bank is more reactive. Real house price fluctuations will be reduced as well by the counteracting effect of the monetary tightening.

Both effects are immediately recognized by looking at the impulse response functions associated to a housing preference shock, reported in Figure 11. When monetary policy responds to housing inflation, a larger increase in the policy rate is required in response to the shock. The tightening reduces the initial increase in house prices and partially counterbalances the surge in residential investment. Moreover, the overall effect on non-residential consumption becomes negative, for the amplified increase in the interest rate neutralizes the positive collateral effect on consumption.

Summing up, some degree of systematic response to house price inflation should characterize the historical conduct of monetary policy in the two areas over the estimation sample, at least according to model fit analysis. Importantly, under such behaviour, the two economies would *not* display a positive effect on nonresidential consumption after a housing demand shock, since the automatic increase in the interest rate would be sufficient to offset the positive valuation effect of higher house prices on the existing collateral. The next subsection discusses the transmission of the same shock under optimal monetary policy cooperation.

5.2 The optimal monetary policy response to housing shocks

In order to derive the international monetary policy coordination we proceed as Adjemian, Darracq Pariès, and Smets (2008) and follow the Ramsey approach by formulating an infinite-horizon problem of maximizing the conditional expected social welfare subject to the full set of non-linear constraints that define the competitive equilibrium of the model[34]. Since we are mainly interested in comparing the macroeconomic stabilization performances of different monetary policy regimes within a medium-scale open economy framework including a wide set of shocks and frictions, we assume a fiscal intervention, namely subsidies on labor and goods markets, to offset the first-order distortions caused by the presence of monopolistic competition. From an operational point of view, we have to face the issue that the zero lower bound on the nominal interest rate is an occasionally binding constraint. To avoid high probabilities of hitting the zero bound under the Ramsey allocation, we thus follow Woodford (2003) in introducing a quadratic term in the households welfare measure of each country, to penalize variations in the nominal interest

[34]The first order conditions to this problem are obtained using symbolic Matlab procedures.

rate:

$$\mathcal{W}_{H,t}^{R} = \omega \mathcal{W}_{H,t}^{B} + (1-\omega)\,\mathcal{W}_{H,t}^{S} + \lambda_R \mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \left(R_{t+j} - R^{\star}\right)^2$$

$$\mathcal{W}_{F,t}^{R} = \omega^* \mathcal{W}_{F,t}^{B*} + (1-\omega^*)\,\mathcal{W}_{F,t}^{S*} + \lambda_R^* \mathbb{E}_t \sum_{j=0}^{\infty} \beta^j \left(R_{t+j}^* - R^{\star}\right)^2$$

where λ_R and λ_R^* are the weights attached to the cost of nominal interest rate fluctuations. Instead of fixing this parameter to match a particular value of the probability to hit the zero bound, we pragmatically calibrate those parameters so that, under the operational optimal monetary policy coordination, the unconditional variance of the nominal interest rates are close to the ones obtained with the estimated rules. The penalty needed to achieve those standard deviations is substantially higher in the US than in the euro area. Under this assumption, the probability to hit the zero bound is reasonably low, even for zero steady-state inflation, which implies that the steady-state real rate is more than three times the standard deviation of the interest rate[35].

The introduction of a housing sector and household credit frictions brings several important dimensions to the analysis of optimal monetary policy cooperation. On the supply side, monetary policy has to face policy tradeoffs stemming from the sectoral structure of the economy, which are reinforced by nominal rigidities in price and wage setting (see for example Aoki (2001) on this point). Moreover, the presence of a durable good has relevant implications for the optimal allocation, as analyzed by Erceg and Levin (2005). Finally, households heterogeneity and collateral constraints may not only change the policy dilemma regarding price stability and the stabilization of real quantities, but also introduce an additional policy objective related to the dispersion of allocations across household types. The existence of imperfect risk sharing between borrowers and savers, in addition to international financial markets incompleteness, may in fact alter the traditional optimal policy prescriptions.

5.2.1 Housing preference shock

In this section we restrict our analysis to the assessment of the optimal policy tolerance for relative house price fluctuations. More specifically, we consider the optimal monetary policy cooperation in response to a housing demand shock, since this source of disturbance has been shown to generate, under standard Taylor rules, strong relative house price changes and ample asymmetries in the savers' and borrowers' reactions (see Section 3).

[35]Note that with the indexation schemes introduced in price and wage setting, the Ramsey steady state is consistent with any inflation rate.

Figures 11 and 12 compare the impulse response functions to a housing demand shock under three different monetary policy specifications: (i) the estimated interest rate rules of the benchmark model, (ii) the estimated interest rate rules augmented with house price inflation, and (iii) the optimal international cooperation[36] . Regarding domestic transmission, the optimal allocation generates a more muted response of real house prices and residential investment compared to the benchmark policy rules. The optimal spillover of a positive housing demand shock to non-residential consumption is now *negative*, and aggregate output contracts. These features are qualitatively unaltered under augmented interest rate rules, albeit with a more pronounced pattern. Regarding international spillovers, the exchange rate appreciates more on impact with the optimal and the augmented rules than in the benchmark case. In the foreign country, the optimal allocation implies a sharper adjustment of real variables while strongly stabilizing the inflation rate. Looking more specifically at the relationship between optimal policy and augmented interest rules in the two areas, the similarities seems to be tighter for the US, especially in terms of domestic transmission.

In order to provide some intuition on the role of credit frictions in the optimal response to house prices, the same exercise has been conducted setting the share of borrowers to zero. The corresponding impulse responses are reported in Figures 13 and 14. Some degree of control on house prices is still present in the optimal allocation. However, the "lean against the wind" features of the augmented policy rules now differ more from the optimal allocation.

The results illustrated above are consistent with those obtained using optimal (welfare-based) simple interest rate rules. In particular, we consider the problem of optimally choosing the two coefficients on house price inflation in the augmented policy rules, in order to maximize aggregate welfare under housing preference shocks, keeping the other parameters fixed. As expected, the optimal coefficients are both positive, even though lower than in the estimated version of the model with augmented policy rules. In particular, the optimal response to house prices is higher for the US (0.04) than for the euro area (0.02).

Summing up, this section has shown that, from a normative perspective, some degree of monetary policy reaction to fluctuations in the price of residential goods is consistent with the main features of optimal monetary policy cooperation, in response to a housing

[36] All the other structural parameters, not directly related to monetary policy, are fixed at the mode of their posterior distribution in the benchmark model estimation. When comparing these impulse response to those presented in Section 2, some differences can arise due to the fact that we assume here that public subsidies are offsetting steady-state distortions.

demand shock. Based on welfare computations when only housing shocks are allowed, the augmented Taylor rule estimation turns out to be welfare-improving compared with the benchmark case, in particular for the US economy. Beyond this, the optimal allocation suggests that the heterogenous responses across households and the associated welfare losses in terms of imperfect risk sharing should be counteracted, even at the cost of moderate short-term inflation volatility. The optimal international transmission of positive housing demand shocks leads to a monetary policy tightening in the foreign country and to a negative adjustment of housing prices and quantities, as well as domestic demand for non-residential goods.

6 Conclusions

In this paper we have provided an original framework to explore the importance of housing markets and credit frictions for the monetary policy conduct in open economy. We have reproduced some stylized facts for the US and the euro area, and provided a systematic analysis of cross-country business cycle dynamics. In particular, we have established that while the collateral channel entails significant effects of housing-related shocks on real activity domestically, the international spillovers are relatively smaller than in the case of shocks that affect the tradable sector. Regarding monetary policy, we have documented that, from a positive perspective, an accurate historical representation of monetary policy conduct in the two areas over the sample should allow for a systematic response to house price fluctuations. Moreover, from a normative standpoint, such a policy conduct is found to be welfare improving. Our results point to at least two directions. First, a better characterization of credit frictions may be required in order to understand the cross-country propagation of housing shocks, and the related borrowing dynamics. Second, a deeper analysis of the optimal monetary policy cooperation under housing-related credit frictions may reinforce the preliminary results obtained here. We plan to explore such dimensions in future work.

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A Supplementary model description

A.1 The borrower's program

The impatient agent maximizes (1) under (3) and (4) holding with equality[37]. We report the corresponding first order conditions in the next paragraph.
Let us denote

$$\widetilde{\mathcal{U}\prime}_{X,t} = \varepsilon_t^{\beta} \widetilde{X}_t^{-\sigma_C} \tag{27}$$

$$\begin{aligned} \widetilde{\mathcal{U}\prime}_{C,t} = &\left(1-\varepsilon_t^D \omega_D\right)^{\frac{1}{\eta_D}} \left(\widetilde{C}_t - h_B \widetilde{C}_{t-1}\right)^{-\frac{1}{\eta_D}} \widetilde{X}_t^{\frac{1}{\eta_D}} \widetilde{\mathcal{U}\prime}_{X,t} \\ &- \beta h_B \left(1-\varepsilon_t^D \omega_D\right)^{\frac{1}{\eta_D}} \left(\frac{\widetilde{C}_t}{\widetilde{X}_t}\right)^{-\frac{1}{\eta_D}} \mathbb{E}_t \left\{ \begin{array}{c} \left(1-\varepsilon_{t+1}^D \omega_D\right)^{\frac{1}{\eta_D}} \\ \left(\widetilde{C}_{t+1} - h_B \widetilde{C}_t\right)^{-\frac{1}{\eta_D}} \widetilde{X}_{t+1}^{\frac{1}{\eta_D}} \widetilde{\mathcal{U}\prime}_{X,t+1} \end{array} \right\} \end{aligned} \tag{28}$$

$$\widetilde{\mathcal{U}\prime}_{D,t} = \varepsilon_t^D \omega_D^{\frac{1}{\eta_D}} \left(\frac{\widetilde{D}_t}{\widetilde{X}_t}\right)^{-\frac{1}{\eta_D}} \widetilde{\mathcal{U}\prime}_{X,t} \tag{29}$$

The first order condition related to non-residential consumption and residential stock are respectively,

$$\widetilde{\Lambda}_t = \widetilde{\mathcal{U}\prime}_{C,t} \tag{30}$$

and

$$\begin{aligned} \widetilde{\Lambda}_t T_{D,t} = & \left(1-\chi\right) \varepsilon_t^{LTV} \Psi_t \widetilde{\Lambda}_t \mathbb{E}_t \left\{ T_{D,t+1} \frac{\pi_{t+1}}{R_t} \right\} \\ & + \widetilde{\mathcal{U}\prime}_{D,t} + \beta \left(1-\delta\right) \mathbb{E}_t \left\{ \widetilde{\Lambda}_{t+1} T_{D,t+1} \right\} \end{aligned} \tag{31}$$

where $\widetilde{\Lambda}_t$ and $\widetilde{\Lambda}_t \Psi_t$ are the multipliers associated to constraint (3) and (4), respectively. Finally, the marginal value of additional borrowing is defined by the following "modified" version of the standard Euler equation

$$\Psi_t = 1 - \beta \mathbb{E}_t \left\{ \frac{\widetilde{\Lambda}_{t+1}}{\widetilde{\Lambda}_t} \frac{R_t}{\pi_{t+1}} \right\} \tag{32}$$

The set of optimality conditions is completed by the intratemporal trade-off between consumption and leisure, which is analyzed in detail later. By rearranging equation (31) it is possible to define the borrower's *user cost* of residential investment as follows:

$$\widetilde{R}_D = T_{D,t} \left(1 - \varepsilon_t^{LTV} \left(1-\chi\right) \Psi_t E_t \left\{ \frac{T_{D,t+1}}{T_{D,t}} \frac{\pi_{t+1}}{R_t} \right\} - \beta \left(1-\delta\right) E_t \left\{ \frac{\widetilde{\Lambda}_{t+1}}{\widetilde{\Lambda}_t} \frac{T_{D,t+1}}{T_{D,t}} \right\} \right) \tag{33}$$

[37] It is possible to show that the collateral constraint always binds in the deterministic steady state, under general conditions. We assume here that continues to hold in a sufficiently small neighborhood of the steady state, so that the model can be solved by taking a first order approximation.

A.2 The saver's program

Let us denote

$$\mathcal{U}\prime_{X,t} = \varepsilon_t^{\beta} X_t{}^{-\sigma_C} \tag{34}$$

$$\mathcal{U}\prime_{C,t} = \left(1-\varepsilon_t^D\omega_D\right)^{\frac{1}{\eta_D}} \left(C_t - hC_{t-1}\right)^{-\frac{1}{\eta_D}} X_t^{\frac{1}{\eta_D}} \mathcal{U}\prime_{X,t} \tag{35}$$
$$- \gamma h \left(1-\varepsilon_t^D\omega_D\right)^{\frac{1}{\eta_D}} \left(\frac{C_t}{X_t}\right)^{-\frac{1}{\eta_D}} \mathbb{E}_t \left\{ \begin{array}{c} \left(1-\varepsilon_{t+1}^D\omega_D\right)^{\frac{1}{\eta_D}} \left(X_{t+1}\right)^{\frac{1}{\eta_D}} \\ \left(C_{t+1} - hC_t\right)^{-\frac{1}{\eta_D}} \mathcal{U}\prime_{X,t+1} \end{array} \right\}$$

$$\mathcal{U}\prime_{D,t} = \varepsilon_t^D \omega_D^{\frac{1}{\eta_D}} \left(\frac{D_t}{X_t}\right)^{-\frac{1}{\eta_D}} \mathcal{U}\prime_{X,t} \tag{36}$$

The first order condition related to non-residential consumption and residential stock are respectively,

$$\Lambda_t = \mathcal{U}\prime_{C,t} \tag{37}$$

and

$$\Lambda_t T_{D,t} = \mathcal{U}\prime_{D,t} + \gamma\left(1-\delta\right)\mathbb{E}_t\left\{\Lambda_{t+1}T_{D,t+1}\right\} \tag{38}$$

where Λ_t is the multiplier associated with the budget constraint.
Patient households in both countries are allowed to trade in two one-period nominal bonds, a domestic and a foreign one. First order conditions corresponding to the quantity of contingent bonds imply that

$$\Lambda_t = R_t \gamma \mathbb{E}_t \left[\Lambda_{t+1}\frac{P_t}{P_{t+1}}\right] \tag{39}$$

$$\Lambda_t = R_t^* \varepsilon_t^{\Delta S} \Psi \left(\frac{\mathbb{E}_t S_{t+1}}{S_{t-1}} - 1, \frac{S_t\left(B_{F,t} - \overline{\overline{B}}_F\right)}{P_t}\right) \beta \mathbb{E}_t \left[\Lambda_{t+1}\frac{S_{t+1}P_t}{S_t P_{t+1}}\right]$$

where R_t and R_t^* are one-period-ahead nominal interest rates for country H and F respectively.
The previous equations imply an arbitrage condition on bond prices which corresponds to a modified uncovered interest rate parity (UIP):

$$\frac{R_t}{R_t^* \varepsilon_t^{\Delta S} \Psi \left(\frac{\mathbb{E}_t S_{t+1}}{S_{t-1}} - 1, \frac{S_t\left(B_{F,t} - \overline{\overline{B}}_F\right)}{P_t}\right)} = \frac{\mathbb{E}_t\left[\Lambda_{t+1}\frac{S_{t+1}P_t}{S_t P_{t+1}}\right]}{\mathbb{E}_t\left[\Lambda_{t+1}\frac{P_t}{P_{t+1}}\right]} \tag{40}$$

Rearranging equation (38) yields the definition of the saver's *user cost* of residential investment:

$$R_D = T_{D,t}\left(1 - \gamma\left(1-\delta\right) E_t\left\{\frac{\Lambda_{t+1}}{\Lambda_t}\frac{T_{D,t+1}}{T_{D,t}}\right\}\right) \tag{41}$$

A.3 Labor supply and wage setting

The first-order condition for the wage setting program of agent i in sector j can be written recursively as follows:

$$\frac{\widetilde{W}_{j,i,t}}{P_t} = \left(\mu_w \frac{\mathcal{H}^{wji}_{1,t}}{\mathcal{H}^{wji}_{2,t}}\right)^{\frac{\mu_w - 1}{\mu_w - 1}}$$

The resulting aggregate wage dynamics for each type in each sector is:

$$\begin{aligned}(W_{j,i,t})^{\frac{1}{1-\mu_w}} &= (1-\alpha_{wji})\left(\mu_w \frac{\mathcal{H}^{wji}_{1,t}}{\mathcal{H}^{wji}_{2,t}}\right)^{-\frac{1}{\mu_w-1}} \\ &+ \alpha_{wji}\left(W_{j,i,t-1}\right)^{\frac{1}{1-\mu_w}}\left(\frac{\Pi_t}{\Pi_{t-1}^{\xi_{wji}}\overline{\Pi}^{1-\xi_{wji}}}\right)^{\frac{-1}{1-\mu_w}}\end{aligned} \tag{42}$$

where

$$\mathcal{H}^{wji}_{1,t} = \overline{L}_{j,i}\left(N^i_{j,t}\right)^{1+\sigma_{Lj,i}}\left(W_{j,i,t}\right)^{\frac{\mu_w}{\mu_w-1}} + \alpha_{wji}\beta_i\mathbb{E}_t\left[\left(\frac{\Pi_{t+1}}{\Pi_t^{\xi_{wj,i}}\left[\overline{\Pi}\right]^{1-\xi_{wj,i}}}\right)^{\frac{\mu_w}{\mu_w-1}}\mathcal{H}^{wji}_{1,t+1}\right] \tag{43}$$

and

$$\mathcal{H}^{wji}_{2,t} = \Lambda_{it}N^i_{j,t}\left(W_{j,i,t}\right)^{\frac{\mu_w}{\mu_w-1}} + \alpha_{wji}\beta_i\mathbb{E}_t\left(\frac{\Pi_{t+1}}{\Pi_t^{\xi_{wj,i}}\left[\overline{\Pi}\right]^{1-\xi_{wj,i}}}\right)^{\frac{1}{\mu_w-1}}\mathcal{H}^{wji}_{2,t+1} \tag{44}$$

with $\beta_i = \beta$ if $i = S$ and $\beta_i = \gamma$ if $i = B$. Also, $W_{j,i,t}$ denotes the real wage of type i in sector j and Λ_{it} is the marginal utility of consumption of type i.

A.4 Price setting

The intermediate, non-residential good producing firm h chooses the price $\hat{p}_t(h)$ to maximize its intertemporal profit:

$$\mathbb{E}_t\left[\sum_{j=0}^{\infty}\alpha_H^j\Xi_{t,t+j}\left(\begin{array}{c}(1-\tau_{t+j})\hat{p}_t(h)Y_{H,t+j}(h)\left(\frac{P_{H,t-1+j}}{P_{H,t-1}}\right)^{\gamma_H}\left(\overline{\Pi}^j\right)^{1-\gamma_H} \\ -MC_{t+j}P_{H,t+j}\left(Y_{H,t+j}(h)+\Omega\right)\end{array}\right)\right]$$

where $Y_{H,t+j}(h) = \left(\frac{\tilde{p}_t(h)}{P_{H,t}}\right)^{-\frac{\mu}{\mu-1}}\left(\frac{P_{H,t}}{P_{H,t+j}}\left(\frac{P_{H,t-1+j}}{P_{H,t-1}}\right)^{\gamma_H}\left(\overline{\Pi}^j\right)^{1-\gamma_H}\right)^{-\frac{\mu}{\mu-1}}Y_{H,t+j}$ and MC_{t+j} is the real marginal cost deflated by the interior-producer-price and. Due to our assumptions on labor and capital, the real marginal cost is identical across producers:

$$MC_t = \frac{w_t^{(1-\alpha_C)}\left[R_t^{k,C}\right]^{\alpha_C}}{\varepsilon_t^A\alpha_C^{\alpha_C}(1-\alpha_C)^{(1-\alpha_C)}T_{H,t}} \tag{45}$$

As a result, all the firms that can re-optimize at time t will choose the same price. The first order condition associated with the firm's choice of $\hat{p}_t(h)$ reads:

$$\mathbb{E}_t\left[\sum_{j=0}^{\infty}\alpha_H^j\Xi_{t,t+j}Y_{H,t+j}(h)P_{H,t+j}\left(\begin{array}{c}(1-\tau_{t+j})\frac{\tilde{p}_t(h)}{P_{H,t}}\frac{P_{H,t}}{P_{H,t+j}}\left(\frac{P_{H,t-1+j}}{P_{H,t-1}}\right)^{\gamma_H}\left(\overline{\Pi}^j\right)^{1-\gamma_H}\\-\mu MC_{t+j}\end{array}\right)\right]=0$$

This price setting scheme can be written in the following recursive form: $\frac{\hat{p}_t(h)}{P_{H,t}}=\mu\frac{Z_{H1,t}}{Z_{H2,t}}$ where

$$\mathcal{Z}_{H1,t}=\widetilde{\Lambda}_tMC_tY_{H,t}T_{H,t}+\alpha_H\gamma\mathbb{E}_t\left[\left(\frac{\Pi_{H,t+1}}{\Pi_{H,t}^{\gamma_H}\overline{\Pi}^{1-\gamma_H}}\right)^{\frac{\mu}{\mu-1}}\mathcal{Z}_{H1,t+1}\right]\tag{46}$$

and

$$\mathcal{Z}_{H2,t}=\varepsilon_t^P\widetilde{\Lambda}_tY_{H,t}T_{H,t}+\alpha_H\gamma\mathbb{E}_t\left[\left(\frac{\Pi_{H,t+1}}{\Pi_{H,t}^{\gamma_H}\overline{\Pi}^{1-\gamma_H}}\right)^{\frac{1}{\mu-1}}\mathcal{Z}_{H2,t+1}\right]\tag{47}$$

where ε_t^P represents a stationary cost-push shock. Accordingly, the aggregate price dynamics leads to the following relation:

$$1=\alpha_H\left(\frac{\Pi_{H,t}}{\Pi_{H,t-1}^{\gamma_H}\overline{\Pi}^{1-\gamma_H}}\right)^{\frac{1}{\mu-1}}+(1-\alpha_H)\left(\mu\frac{\mathcal{Z}_{H1,t}}{\mathcal{Z}_{H2,t}}\right)^{\frac{1}{1-\mu}}\tag{48}$$

Analogous equations hold for foreign producers:

$$\mathcal{Z}_{F1,t}^*=\widetilde{\Lambda}_t^*MC_t^*Y_{F,t}^*T_{F,t}^*+\alpha_F^*\gamma\mathbb{E}_t\left[\left(\frac{\Pi_{F,t+1}^*}{\Pi_{F,t}^{*\gamma_F^*}\overline{\Pi}^{*1-\gamma_F^*}}\right)^{\frac{\mu}{\mu-1}}\mathcal{Z}_{F1,t+1}^*\right]\tag{49}$$

$$\mathcal{Z}_{F2,t}^*=\varepsilon_t^{P^*}\widetilde{\Lambda}_t^*Y_{F,t}^*T_{F,t}^*+\alpha_F^*\gamma\mathbb{E}_t\left[\left(\frac{\Pi_{F,t+1}^*}{\Pi_{F,t}^{*\gamma_F^*}\overline{\Pi}^{*1-\gamma_F^*}}\right)^{\frac{1}{\mu-1}}\mathcal{Z}_{F2,t+1}^*\right]\tag{50}$$

and

$$1=\alpha_F^*\left(\frac{\Pi_{F,t}^*}{\Pi_{F,t-1}^{*\gamma_F^*}\overline{\Pi}^{*1-\gamma_F^*}}\right)^{\frac{1}{\mu-1}}+(1-\alpha_F^*)\left(\mu\frac{\mathcal{Z}_{F1,t}^*}{\mathcal{Z}_{F2,t}^*}\right)^{\frac{1}{1-\mu}}\tag{51}$$

where the real marginal cost for country F is given by:

$$MC_t^*=\frac{W_t^{*(1-\alpha_C)}\left[R_t^{k*}\right]^{\alpha_C}}{\varepsilon_t^{A*}\alpha_C^{\alpha_C}(1-\alpha_C)^{(1-\alpha_C)}T_F^*}\tag{52}$$

Concerning exports, LCP exporters also set their prices on a staggered basis and face the same type of nominal rigidities that affect local producers. Consequently, the inflation dynamics of LCP export prices for the country H, $\tilde{\Pi}^*_{H,t}$, is described by the following three equations:

$$\tilde{\mathcal{Z}}^*_{H1,t} = \widetilde{\Lambda}_t MC_t Y^*_{H,t} T_{H,t} + \alpha^*_F \gamma \mathbb{E}_t \left[\left(\frac{\tilde{\Pi}^*_{H,t+1}}{\tilde{\Pi}^{*\gamma^*_F}_{H,t} \overline{\Pi}^{1-\gamma^*_F}} \right)^{\frac{\mu}{\mu-1}} \tilde{\mathcal{Z}}^*_{H1,t+1} \right] \tag{53}$$

$$\tilde{\mathcal{Z}}^*_{H2,t} = \widetilde{\Lambda}_t Y^*_{H,t} T_{H,t} R\tilde{E}R_{H,t} + \alpha^*_F \gamma \mathbb{E}_t \left[\left(\frac{\tilde{\Pi}^*_{H,t+1}}{\tilde{\Pi}^{*\gamma^*_F}_{H,t} \overline{\Pi}^{1-\gamma^*_F}} \right)^{\frac{1}{\mu-1}} \tilde{\mathcal{Z}}^*_{H2,t+1} \right] \tag{54}$$

$$1 = \alpha^*_F \left(\frac{\tilde{\Pi}^*_{H,t}}{\tilde{\Pi}^{*\gamma^*_F}_{H,t-1} \overline{\Pi}^{1-\gamma^*_F}} \right)^{\frac{1}{\mu-1}} + (1-\alpha^*_F) \left(\mu \frac{\tilde{\mathcal{Z}}^*_{H1,t}}{\tilde{\mathcal{Z}}^*_{H2,t}} \right)^{\frac{1}{1-\mu}} \tag{55}$$

Analogous equations hold for country-F LCP export price inflation:

$$\tilde{\mathcal{Z}}_{F1,t} = \widetilde{\Lambda}^*_t MC^*_t Y_{F,t} T^*_{F,t} + \alpha_H \beta \mathbb{E}_t \left[\left(\frac{\tilde{\Pi}_{F,t+1}}{\tilde{\Pi}^{\gamma_H}_{F,t} \overline{\Pi}^{*1-\gamma_H}} \right)^{\frac{\mu}{\mu-1}} \tilde{Z}_{F1,t+1} \right] \tag{56}$$

$$\tilde{\mathcal{Z}}_{F2,t} = \widetilde{\Lambda}^*_t Y_{F,t} T^*_{F,t} R\tilde{E}R_{F,t} + \alpha_H \beta \mathbb{E}_t \left[\left(\frac{\tilde{\Pi}_{F,t+1}}{\tilde{\Pi}^{\gamma_H}_{F,t} \overline{\Pi}^{*1-\gamma_H}} \right)^{\frac{1}{\mu-1}} \tilde{Z}_{F2,t+1} \right] \tag{57}$$

$$1 = \alpha_H \left(\frac{\tilde{\Pi}_{F,t}}{\tilde{\Pi}^{\gamma_H}_{F,t-1} \overline{\Pi}^{*1-\gamma_H}} \right)^{\frac{1}{\mu-1}} + (1-\alpha_H) \left(\mu \frac{\tilde{\mathcal{Z}}_{F1,t}}{\tilde{\mathcal{Z}}_{F2,t}} \right)^{\frac{1}{1-\mu}} \tag{58}$$

Finally, aggregate export price inflation rates and CPI inflation rates are given by

$$\Pi^*_{H,t} = \frac{RER_{H,t}}{RER_{H,t-1}} \Pi_{H,t} \tag{59}$$

$$\Pi_{F,t} = \frac{RER_{F,t}}{RER_{F,t-1}} \Pi^*_{F,t} \tag{60}$$

$$\Pi_t = \frac{T_{H,t}}{T_{H,t-1}} \Pi_{H,t} \varepsilon^{CPI}_t \tag{61}$$

$$\Pi^*_t = \frac{T^*_{F,t}}{T^*_{F,t-1}} \Pi^*_{F,t} \varepsilon^{CPI*}_t \tag{62}$$

where the two additional shocks ε^{CPI}_t and $\varepsilon^{CPI^*}_t$ have been introduced.

B Data

US series come from the BEA, the BLS, the Census Bureau and the Federal Reserve Board. In particular, real house prices in the US are computed using the Census Bureau index (house price index for new one-family houses sold including value of lot). US household debt is obtained by the Federal Reserve Board Flow of Funds as a measure of total debt outstanding, held by domestic nonfinancial sectors. Euro area data are taken from Fagan et al (2001) and Eurostat. Concerning the euro area, 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:

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

House prices for the euro area are based on national sources and taken from the ECB website[38]. Residential investment is taken from Eurostat national accounts and is backcasted using national sources. Households' debt for the euro area also comes from the ECB and Eurostat[39]. The exchange rate is the euro/dollar exchange rate. Due to statistical problems in computing long series of bilateral current account and current account for the euro area, we use the US current account as a share of US GDP. Aggregate real variables are expressed in per capita terms by dividing through with working age population. All the data are detrended before the estimation. Our structural description of the US and euro area interactions assumes no rest-of-the-world and therefore remains, from a global point of view, a reduced-form representation. As already mentioned, in order to take into account sources of economic fluctuations emanating from other countries, we allow first for common structural shocks. But we also introduce a correlation between the home bias preference shock and the euro area public expenditure shock. Since we use the US total net trade instead of bilateral net trade, we intend to capture, through this variable, rest-of-the-world shocks that affect the US current account with moderate immediate impact on euro area output. The correlation between the home bias shock and the Euro Area public expenditures shock ($\rho_{\Delta n,G}$), which acts as a GDP residual shock, is meant to control for this drawback. Notice however that using total US trade instead of bilateral trade broadens the data information on the rest of the world. Finally, given that, in the first order approximation of the model, the UIP shock has a weak structural interpretation, examining the links with other shocks seems justified. Consequently, correlations between the UIP shock and other efficient shocks are incorporated in the estimation and

[38]we applied some statistical interpolation methods to generate quarterly series

[39]See ECB Monthly Bulletin, October 2007, for the description of the data used

may account for the impact of fundamental shocks on time-varying risk premium. In practice, the benchmark model features a correlation between the UIP shocks and the US productivity shocks ($\rho_{A,\Delta S}$) as well as the government expenditure shocks ($\rho_{G,\Delta S}$, $\rho_{G^*,\Delta S}$) from both countries. Those correlations were also selected according to their significance and the improvement brought to the marginal data density[40].

[40]The correlation between the home bias shock and EA government expenditures is introduced by adding a term $\rho_{\Delta n,G}\epsilon_t^{\Delta n}$ in the AR(1) of the EA government spending exogenous. The correlations with the UIP shock are introduced by adding terms like $(\varepsilon_t^A)^{\rho_{A,\Delta S}}$ in the risk premium exogenous $\varepsilon_t^{\Delta S}$

Tab. 1: PARAMETER ESTIMATES 1

Shock names	*A priori* beliefs			*A posteriori* beliefs			
	Distribution	Mean	Std.	Mode	Mean	$\mathcal{I}_1$	$\mathcal{I}_2$
σ_t^A	Uniform	3	1.73	0.35	0.35	0.29	0.41
σ_t^B	Uniform	3	1.73	1.04	1.08	0.81	1.34
σ_t^G	Uniform	3	1.73	3.02	3.08	2.68	3.46
σ_t^L	Uniform	3	1.73	0.90	1.09	0.49	1.67
σ_t^I	Uniform	3	1.73	0.78	2.06	0.41	4.26
σ_t^Q	Uniform	10	5.77	5.71	5.79	2.99	8.56
σ_t^R	Uniform	3	1.73	0.15	0.15	0.13	0.18
σ_t^P	Uniform	3	1.73	0.23	0.24	0.20	0.27
$\sigma_t^{A_D}$	Uniform	3	1.73	1.21	1.22	1.05	1.39
σ_t^{LTV}	Uniform	3	1.73	1.11	1.13	0.99	1.26
σ_t^D	Uniform	5	2.89	3.56	3.94	2.31	5.49
σ_t^{A*}	Uniform	3	1.73	0.50	0.52	0.41	0.63
σ_t^{B*}	Uniform	3	1.73	2.20	2.27	1.20	3.18
σ_t^{G*}	Uniform	3	1.73	2.15	2.21	1.85	2.57
σ_t^{L*}	Uniform	3	1.73	0.25	0.29	0.15	0.42
σ_t^{I*}	Uniform	3	1.73	0.24	0.35	0.12	0.59
σ_t^{Q*}	Uniform	5	2.89	3.28	3.53	1.92	5.03
σ_t^{R*}	Uniform	3	1.73	0.10	0.11	0.09	0.12
σ_t^{P*}	Uniform	3	1.73	0.27	0.27	0.23	0.31
$\sigma_t^{A_D*}$	Uniform	3	1.73	0.85	0.85	0.74	0.96
σ_t^{LTV*}	Uniform	3	1.73	0.77	0.78	0.68	0.89
σ_t^{D*}	Uniform	3	1.73	1.41	1.44	1.12	1.76
$\sigma_t^{\Delta S}$	Uniform	3	1.73	0.26	0.31	0.15	0.47
$\sigma_t^{\Delta n}$	Uniform	3	1.73	0.41	0.43	0.35	0.50
$\sigma_t^{P_F}$	Uniform	3	1.73	0.13	0.13	0.09	0.16
$\sigma_t^{P_H*}$	Uniform	3	1.73	0.21	0.22	0.18	0.25
F_t^A	Uniform	3	1.73	0.02	0.12	0.00	0.22
F_t^I	Uniform	3	1.73	0.01	0.03	0.00	0.08
F_t^{CPI}	Uniform	3	1.73	0.13	0.13	0.10	0.17

Tab. 2: Parameter Estimates 2

Parameter names	*A priori* beliefs			*A posteriori* beliefs			
	Distribution	Mean	Std.	Mode	Mean	$\mathcal{I}_1$	$\mathcal{I}_2$
ρ_{AA}	Beta	0.5	0.2	0.82	0.62	0.28	0.92
ρ_{RR}	Beta	0.5	0.2	0.23	0.37	0.06	0.72
ρ_{CCPI}	Beta	0.5	0.2	0.21	0.26	0.07	0.44
ρ_{A}	Beta	0.5	0.2	0.90	0.90	0.86	0.93
ρ_{B}	Beta	0.5	0.2	0.71	0.71	0.63	0.79
ρ_{G}	Beta	0.5	0.2	0.83	0.82	0.75	0.90
ρ_{L}	Beta	0.5	0.2	0.11	0.13	0.03	0.23
ρ_{I}	Beta	0.5	0.2	0.89	0.76	0.56	0.96
ρ_{A_D}	Beta	0.5	0.2	0.98	0.96	0.93	0.99
ρ_{LTV}	Beta	0.5	0.2	0.93	0.93	0.89	0.97
ρ_{H}	Beta	0.5	0.2	0.97	0.97	0.94	0.99
ρ_{A^*}	Beta	0.5	0.2	0.92	0.92	0.89	0.95
ρ_{B^*}	Beta	0.5	0.2	0.46	0.46	0.29	0.62
ρ_{G^*}	Beta	0.5	0.2	0.89	0.89	0.85	0.93
ρ_{L^*}	Beta	0.5	0.2	0.09	0.12	0.02	0.22
ρ_{I^*}	Beta	0.5	0.2	0.47	0.50	0.16	0.83
$\rho_{A_D^*}$	Beta	0.5	0.2	0.97	0.94	0.90	0.99
ρ_{LTV^*}	Beta	0.5	0.2	0.96	0.96	0.94	0.98
ρ_{H^*}	Beta	0.5	0.2	1.00	0.99	0.99	1.00
$\rho_{\Delta S}$	Beta	0.5	0.2	0.92	0.91	0.85	0.97
$\rho_{\Delta n}$	Beta	0.5	0.2	0.99	0.97	0.94	1.00
$\rho_{I,C}$	Uniform	5	2.89	0.63	0.75	0.32	1.15
$\rho_{I*,C*}$	Uniform	5	2.89	0.26	0.29	0.09	0.48
$\rho_{G^*,\Delta n}$	Uniform	7.5	4.33	4.47	4.30	2.87	5.72
$\rho_{A,\Delta S}$	Normal	0	1	0.02	0.02	-0.22	0.24
$\rho_{G,\Delta S}$	Normal	0	1	0.03	0.04	0.00	0.09
$\rho_{G^*,\Delta S}$	Normal	0	1	-0.09	-0.09	-0.13	-0.05

Tab. 3: PARAMETER ESTIMATES 3

Parameter names	*A priori* beliefs			*A posteriori* beliefs			
	Distribution	Mean	Std.	Mode	Mean	$\mathcal{I}_1$	$\mathcal{I}_2$
ϕ	Normal	4	1.5	5.55	5.31	3.31	7.32
φ	Beta	0.5	0.15	0.78	0.77	0.65	0.90
σ_C	Gamma	1.5	0.375	0.64	0.63	0.50	0.76
h	Beta	0.5	0.1	0.58	0.56	0.45	0.68
h_B	Beta	0.5	0.1	0.31	0.32	0.19	0.45
σ_{L_C}	Gamma	2	0.75	2.55	2.77	1.49	4.10
α_{w_C}	Beta	0.75	0.05	0.83	0.82	0.79	0.86
α_{w_D}	Beta	0.75	0.05	0.84	0.84	0.80	0.88
ξ_{w_C}	Beta	0.5	0.15	0.42	0.44	0.22	0.66
ξ_{w_D}	Beta	0.5	0.15	0.59	0.56	0.32	0.81
α_H	Beta	0.75	0.05	0.89	0.89	0.86	0.92
γ_H	Beta	0.5	0.15	0.55	0.54	0.38	0.70
ϕ^*	Normal	4	1.5	2.47	2.60	1.44	3.71
φ^*	Beta	0.5	0.15	0.89	0.87	0.78	0.95
σ_C^*	Gamma	1.5	0.375	1.06	1.10	0.94	1.24
h^*	Beta	0.5	0.1	0.83	0.77	0.63	0.90
h_B^*	Beta	0.5	0.1	0.28	0.30	0.19	0.41
$\sigma_{L_C}^*$	Gamma	2	0.75	1.53	1.69	0.92	2.40
$\alpha_{w_C}^*$	Beta	0.75	0.05	0.81	0.81	0.78	0.84
$\alpha_{w_D}^*$	Beta	0.75	0.05	0.81	0.81	0.77	0.86
$\xi_{w_C^*}$	Beta	0.5	0.15	0.26	0.28	0.12	0.44
$\xi_{w_D^*}$	Beta	0.5	0.15	0.44	0.47	0.22	0.70
α_F^*	Beta	0.75	0.05	0.92	0.92	0.91	0.94
γ_F^*	Beta	0.5	0.15	0.51	0.51	0.38	0.64
λ_e	Beta	0.75	0.05	0.79	0.78	0.75	0.82
ρ	Beta	0.75	0.1	0.79	0.79	0.74	0.83
r_π	Normal	1.5	0.25	1.78	1.79	1.49	2.07
$r_{\Delta\pi}$	Gamma	0.3	0.1	0.26	0.26	0.18	0.34
r_Y	Gamma	0.12	0.05	0.11	0.11	0.06	0.15
$r_{\Delta Y}$	Gamma	0.12	0.05	0.17	0.18	0.13	0.24
ρ^*	Beta	0.75	0.1	0.84	0.83	0.78	0.88
r_π^*	Normal	1.5	0.25	0.84	0.90	0.69	1.12
$r_{\Delta\pi}^*$	Gamma	0.3	0.1	0.16	0.17	0.11	0.22
r_Y^*	Gamma	0.12	0.05	0.17	0.17	0.12	0.23
$r_{\Delta Y}^*$	Gamma	0.12	0.05	0.14	0.15	0.10	0.20
ξ	Uniform	3	1.7321	1.27	1.55	0.92	2.18
n	Uniform	0.5	0.2887	0.98	0.98	0.97	0.98
η	Beta	0.5	0.28	0.98	0.90	0.80	1.00
η^*	Beta	0.5	0.28	0.86	0.80	0.62	1.00
χ	Normal	1	0.25	0.83	0.89	0.49	1.28
$\chi_{\Delta S}$	Uniform	0.5	0.2887	0.21	0.21	0.13	0.29
ω	Beta	0.35	0.05	0.24	0.23	0.18	0.29
ω^*	Beta	0.35	0.05	0.19	0.20	0.15	0.24

Tab. 4: Parameter Estimates Comparison

Parameters	High borrowers' share			Augmented Taylor Rule		
	Mode	$\mathcal{I}_1$	$\mathcal{I}_2$	Mode	$\mathcal{I}_1$	$\mathcal{I}_2$
ϕ	4.70	2.50	6.46	5.11	3.38	7.08
φ	0.77	0.66	0.88	0.83	0.73	0.92
σ_C	0.67	0.54	0.83	0.75	0.67	0.86
h	0.49	0.36	0.63	0.59	0.46	0.69
h_B	0.38	0.25	0.51	0.36	0.23	0.53
σ_{L_C}	2.09	1.12	3.49	1.68	0.92	2.95
α_{w_C}	0.82	0.78	0.85	0.80	0.76	0.84
α_{w_D}	0.84	0.79	0.88	0.84	0.78	0.87
ξ_{w_C}	0.46	0.25	0.72	0.42	0.22	0.70
ξ_{w_D}	0.60	0.37	0.83	0.63	0.35	0.82
ξ_p	0.89	0.85	0.91	0.89	0.86	0.91
γ_p	0.51	0.35	0.68	0.49	0.34	0.66
ϕ^*	1.69	0.78	3.22	4.34	3.15	6.33
φ^*	0.84	0.74	0.93	0.93	0.85	0.97
σ_C^*	0.99	0.57	1.20	0.79	0.68	0.96
h^*	0.37	0.21	0.68	0.82	0.73	0.89
h_B^*	0.31	0.19	0.44	0.35	0.21	0.49
$\sigma_{L_C}^*$	1.54	0.88	2.80	1.52	0.93	2.58
$\alpha_{w_C}^*$	0.81	0.78	0.85	0.81	0.78	0.84
$\alpha_{w_D}^*$	0.82	0.77	0.86	0.82	0.77	0.86
$\xi_{w_C}^*$	0.36	0.18	0.55	0.27	0.12	0.43
$\xi_{w_D}^*$	0.48	0.23	0.72	0.40	0.21	0.68
ξ_p^*	0.94	0.92	0.95	0.91	0.88	0.93
γ_p^*	0.49	0.35	0.60	0.59	0.46	0.73
λ_e	0.79	0.75	0.82	0.80	0.77	0.83
ρ	0.78	0.74	0.83	0.79	0.73	0.83
r_π	1.90	1.62	2.20	1.86	1.54	2.20
$r_{\Delta\pi}$	0.29	0.20	0.38	0.28	0.19	0.37
r_Y	0.12	0.08	0.18	0.10	0.05	0.14
$r_{\Delta Y}$	0.20	0.15	0.26	0.14	0.10	0.19
ρ^*	0.86	0.81	0.91	0.88	0.83	0.91
r_π^*	1.39	0.84	1.84	1.47	1.15	1.85
$r_{\Delta\pi}^*$	0.19	0.13	0.28	0.20	0.13	0.27
r_Y^*	0.18	0.12	0.27	0.06	0.03	0.11
$r_{\Delta Y}^*$	0.25	0.18	0.33	0.16	0.12	0.20
$r_{\Delta T_D}$				0.10	0.07	0.14
$r_{\Delta T_D}^*$				0.17	0.13	0.23
ξ	1.47	0.96	2.20	1.08	0.85	1.62
n	0.98	0.97	0.98	0.98	0.97	0.98
η	0.98	0.82	1.00	0.97	0.78	1.00
η^*	0.78	0.63	1.00	0.76	0.58	0.98
χ	0.96	0.48	1.33	0.85	0.42	1.25
$\chi_{\Delta S}$	0.19	0.12	0.26	0.19	0.12	0.29
ω	0.46	0.40	0.51	0.22	0.18	0.28
ω^*	0.42	0.37	0.48	0.19	0.15	0.24

Tab. 5: Comparison of Second-Order Moments

	DETRENDED				HP FILTERED			
	data	Baseline	High Borr.	Aug. Taylor	data	Baseline	High Borr.	Aug. Taylor
Standard deviation								
US								
Z_t	2.14	1.91	1.99	2.03	1.25	1.18	1.27	1.30
C_t	1.90	1.76	1.93	1.76	0.84	1.07	1.28	1.11
I_t	6.11	5.03	5.45	5.52	3.78	2.62	2.89	3.01
Z_{Dt}	11.21	9.17	9.18	8.43	6.51	5.22	5.27	4.99
T_{Dt}	4.87	4.32	4.12	3.48	1.34	2.19	2.13	1.92
Π_t	0.27	0.30	0.31	0.29	0.18	0.26	0.26	0.25
R_t	0.46	0.30	0.35	0.30	0.30	0.22	0.25	0.22
Euro Area								
Z_t^*	1.67	1.15	1.48	2.17	0.88	0.84	0.93	1.19
C_t^*	1.76	1.16	1.66	1.82	0.83	0.74	1.05	0.96
I_t^*	5.47	3.16	3.86	5.56	2.75	2.13	2.31	2.93
Z_{Dt}^*	3.34	6.12	6.47	5.60	1.90	3.28	3.30	3.20
T_{Dt}^*	6.24	3.17	3.17	2.78	1.88	1.55	1.51	1.33
Π_t^*	0.37	0.36	0.35	0.40	0.21	0.29	0.28	0.32
R_t^*	0.37	0.27	0.30		0.19	0.17	0.19	0.16
ΔS_t	4.80	5.75	5.02	5.24	4.39	5.41	4.74	4.98
CA_t	1.28	0.66	0.70	0.78	0.46	0.39	0.42	0.44
Correlations								
Z_t, Z_t^*	0.22	0.09	0.14	0.14	0.27	0.13	0.17	0.16
C_t, C_t^*	-0.03	-0.17	-0.03	-0.06	0.09	-0.04	0.05	0.08
Z_{Dt}, Z_{Dt}^*	-0.47	0.00	0.01	0.00	0.23	0.00	0.02	0.03
T_{Dt}, T_{Dt}^*	0.15	-0.03	0.00	-0.01	0.06	-0.01	0.04	0.07
ΔS_t, CA_t	-0.23	-0.34	-0.24	-0.28	-0.15	-0.34	-0.22	-0.22
C_t^{rel}, RER_t	-0.24	-0.21	-0.34	-0.25	-0.22	-0.26	-0.33	-0.16
Z_t, C_t	0.80	0.68	0.70	0.70	0.84	0.69	0.72	0.73
Z_t, I_t	0.64	0.72	0.67	0.74	0.65	0.65	0.60	0.72
Z_t, Z_{Dt}	0.52	0.17	0.15	0.12	0.62	0.08	0.08	-0.01
T_{Dt}, C_t	0.12	0.30	0.31	0.10	0.47	0.32	0.43	0.02
Z_{Dt}, T_{Dt}	0.25	0.40	0.41	0.38	0.35	0.49	0.50	0.45
Z_{Dt}, C_t	0.74	0.12	0.12	0.05	0.68	0.08	0.13	-0.05
Z_t^*, C_t^*	0.93	0.65	0.77	0.84	0.83	0.74	0.78	0.84
Z_t^*, I_t^*	0.92	0.65	0.72	0.87	0.90	0.71	0.68	0.85
Z_t^*, Z_{Dt}^*	0.24	0.04	0.04	0.05	0.14	0.00	0.04	0.04
T_{Dt}^*, C_t^*	0.52	0.11	0.16	0.16	0.57	0.15	0.31	0.08
Z_{Dt}^*, T_{Dt}^*	0.41	0.42	0.39	0.34	0.25	0.42	0.42	0.37
Z_{Dt}^*, C_t^*	0.34	-0.07	-0.06	-0.07	0.20	-0.02	0.05	0.01

Tab. 6: SHOCKS DECOMPOSITION OF UNCONDITIONAL VARIANCES

	Domestic Housing			Other Domestic	Non Domestic
	$\epsilon_t^{A_D}$	ϵ_t^{LTV}	ϵ_t^{D}		
US					
Z_t	0.34	0.39	2.45	87.61	9.21
C_t	1.32	1.30	2.99	74.60	19.79
Z_{Dt}	57.65	0.04	31.93	9.98	0.40
T_{Dt}	7.87	0.08	80.11	9.37	2.57
Π_t	0.15	0.01	0.02	66.21	33.61
R_t	0.09	0.48	2.11	87.53	9.79
B_t	2.94	36.16	49.26	10.55	1.09
Euro Area					
Z_t^*	0.09	0.25	4.79	84.97	9.90
C_t^*	0.68	0.92	4.54	71.47	22.39
Z_{Dt}^*	59.51	0.04	34.36	5.62	0.47
T_{Dt}^*	5.62	0.08	85.36	5.37	3.57
Π_t^*	0.03	0.01	3.42	56.89	39.65
R_t^*	0.05	0.14	8.97	75.13	15.71
B_t^*	1.97	31.16	42.92	23.18	0.77
ΔS_t	0.01	0.00	0.57	17.60	81.82
CA_t	0.00	0.01	0.84	11.24	87.91

Tab. 7: SHOCKS DECOMPOSITION OF UNCONDITIONAL VARIANCES: VARYING THE SHARE OF BORROWERS.

	No Borrowers			High Borrowers' share		
	Domestic housing	Other Domestic	Non Domestic	Domestic housing	Other Domestic	Non Domestic
US						
Z_t	1.35	89.85	8.80	9.76	80.90	9.34
C_t	0.94	78.62	20.44	22.65	61.25	16.10
Z_{Dt}	89.74	9.83	0.43	89.47	10.13	0.40
T_{Dt}	87.42	9.68	2.90	88.70	9.07	2.23
Π_t	0.20	65.22	34.58	0.26	67.38	32.36
R_t	0.59	89.16	10.25	10.21	80.92	8.87
B_t	-	-	-	89.10	9.92	0.98
Euro Area						
Z_t^*	4.37	84.61	11.02	9.44	82.41	8.15
C_t^*	0.63	73.95	25.42	16.91	69.90	13.19
Z_{Dt}^*	94.04	5.54	0.42	93.54	5.95	0.51
T_{Dt}^*	91.01	5.50	3.49	91.16	5.31	3.53
Π_t^*	5.40	54.02	40.58	2.52	60.61	36.87
R_t^*	13.77	68.58	17.65	8.38	79.64	11.98
B_t^*	-	-	-	76.95	22.25	0.80
ΔS_t	0.72	17.35	81.93	0.65	18.33	81.02
CA_t	1.23	10.23	88.54	0.80	13.19	86.01

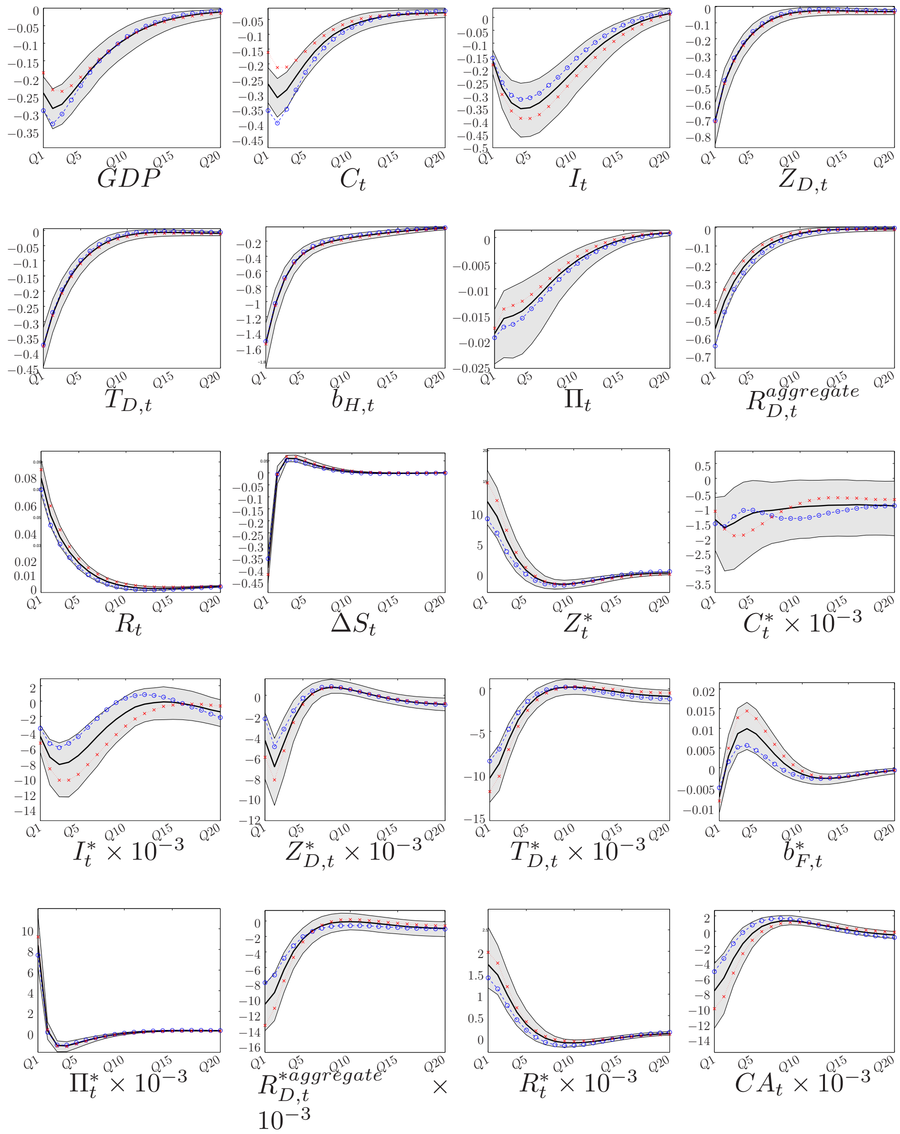

Fig. 1: Impulse Response Functions associated to a monetary policy shock in the US. *Benchmark model (plain lines and shaded areas), model with high borrowers (dotted lines with circle), model with no borrowers (dashed lines with cross).*

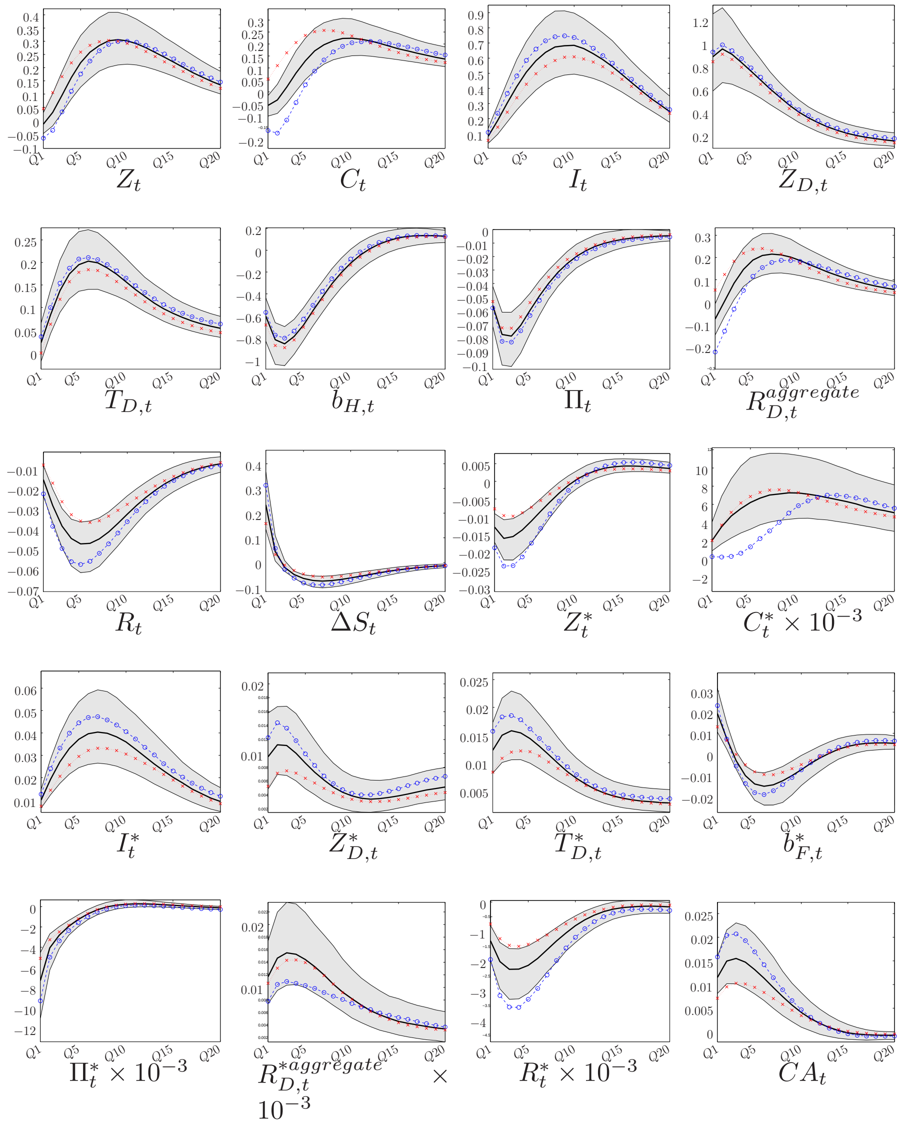

Fig. 2: Impulse Response Functions associated to a labor supply shock in the US. *Benchmark model (plain lines and shaded areas), model with high borrowers (dotted lines with circle), model with no borrowers (dashed lines with cross).*

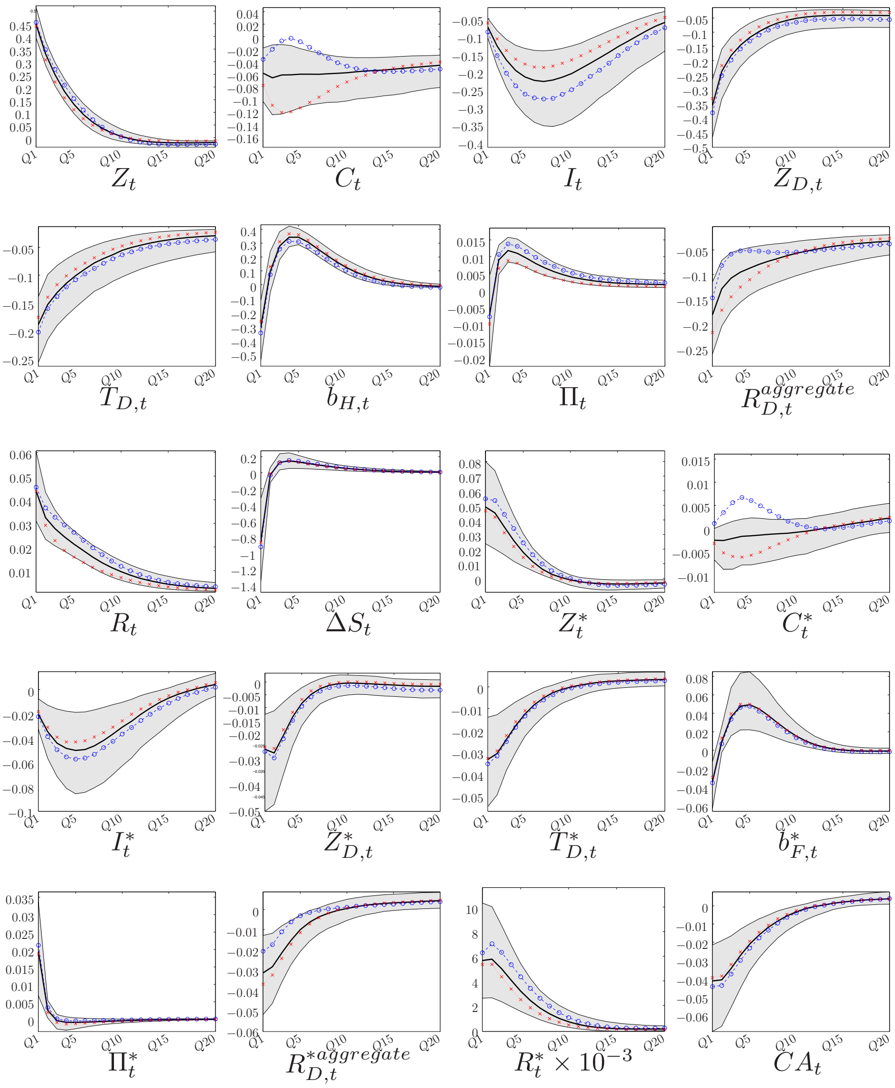

Fig. 3: Impulse Response Functions associated to a government spending shock in the US. *Benchmark model (plain lines and shaded areas), model with high borrowers (dotted lines with circle), model with no borrowers (dashed lines with cross).*

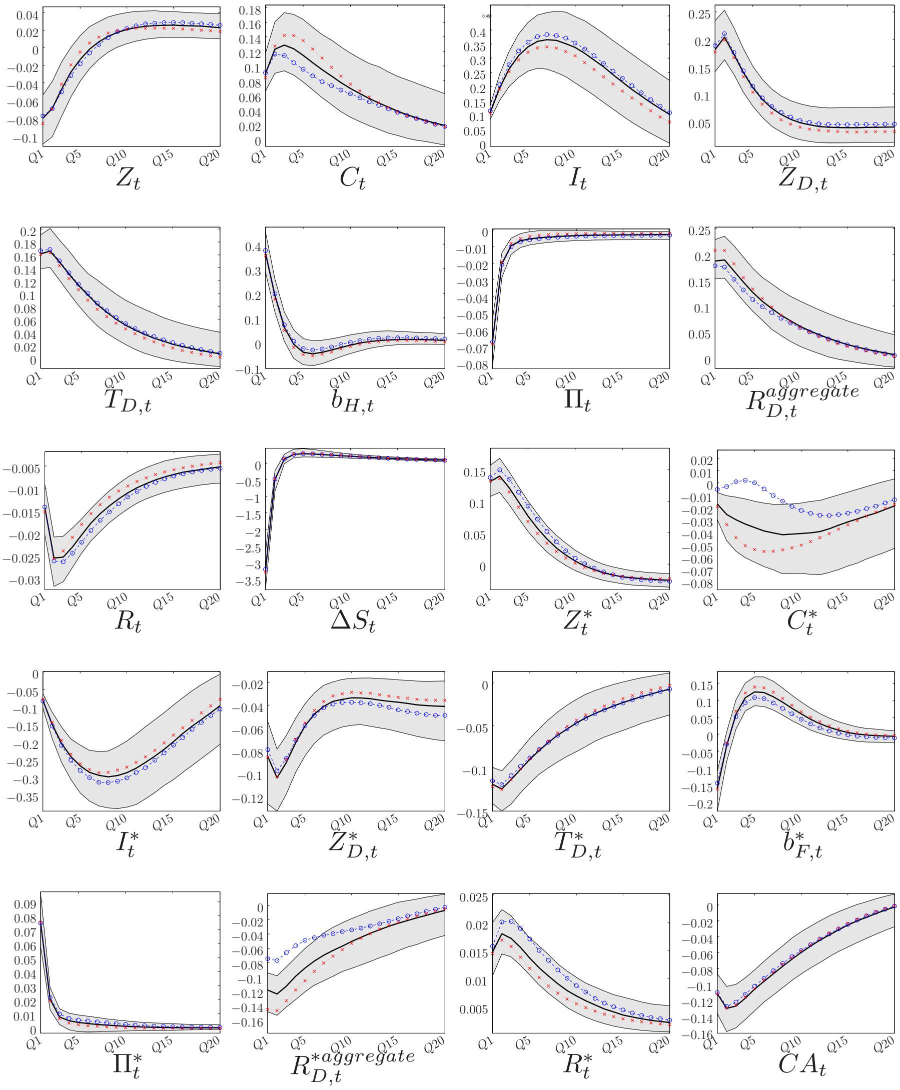

Fig. 4: Impulse Response Functions associated to a risk-premium shock. *Benchmark model (plain lines and shaded areas), model with high borrowers (dotted lines with circle), model with no borrowers (dashed lines with cross).*

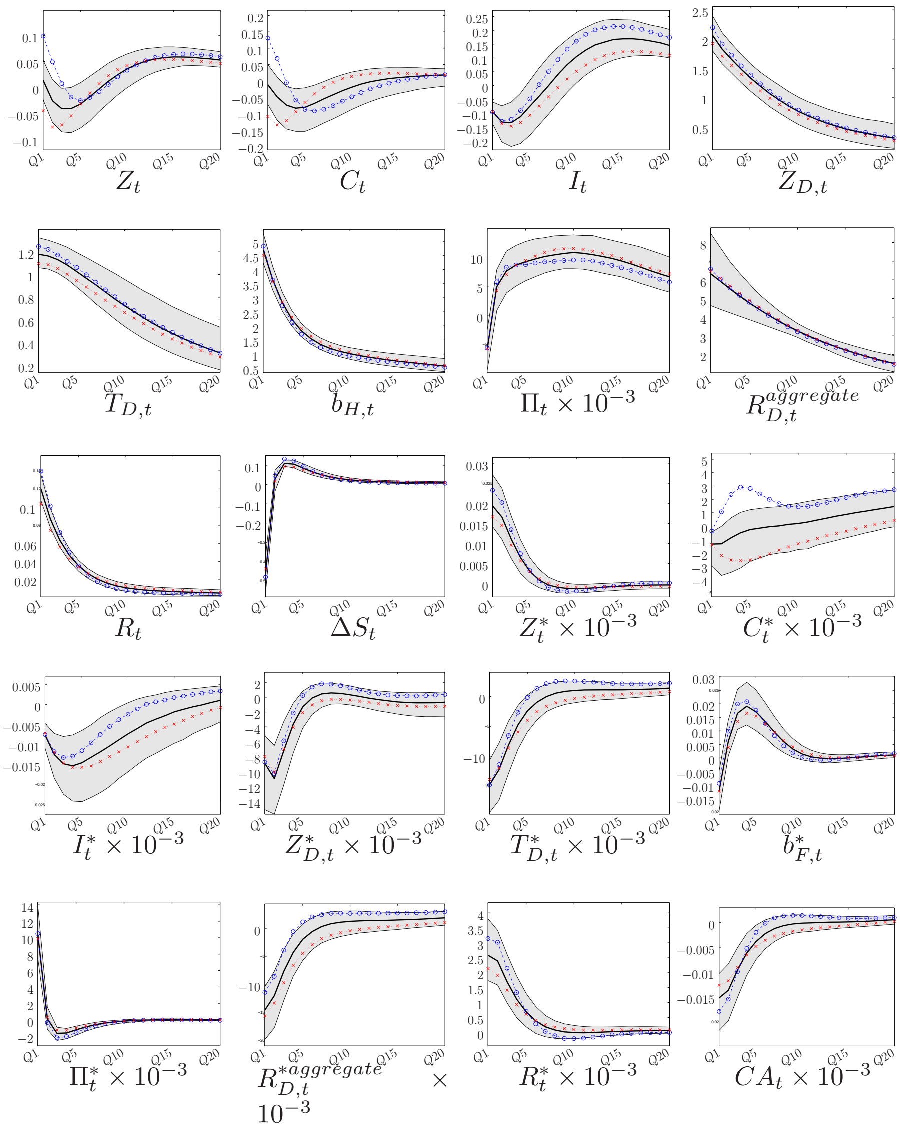

Fig. 5: Impulse Response Functions associated to a housing preference shock in the US. *Benchmark model (plain lines and shaded areas), model with high borrowers (dotted lines with circle), model with no borrowers (dashed lines with cross).*

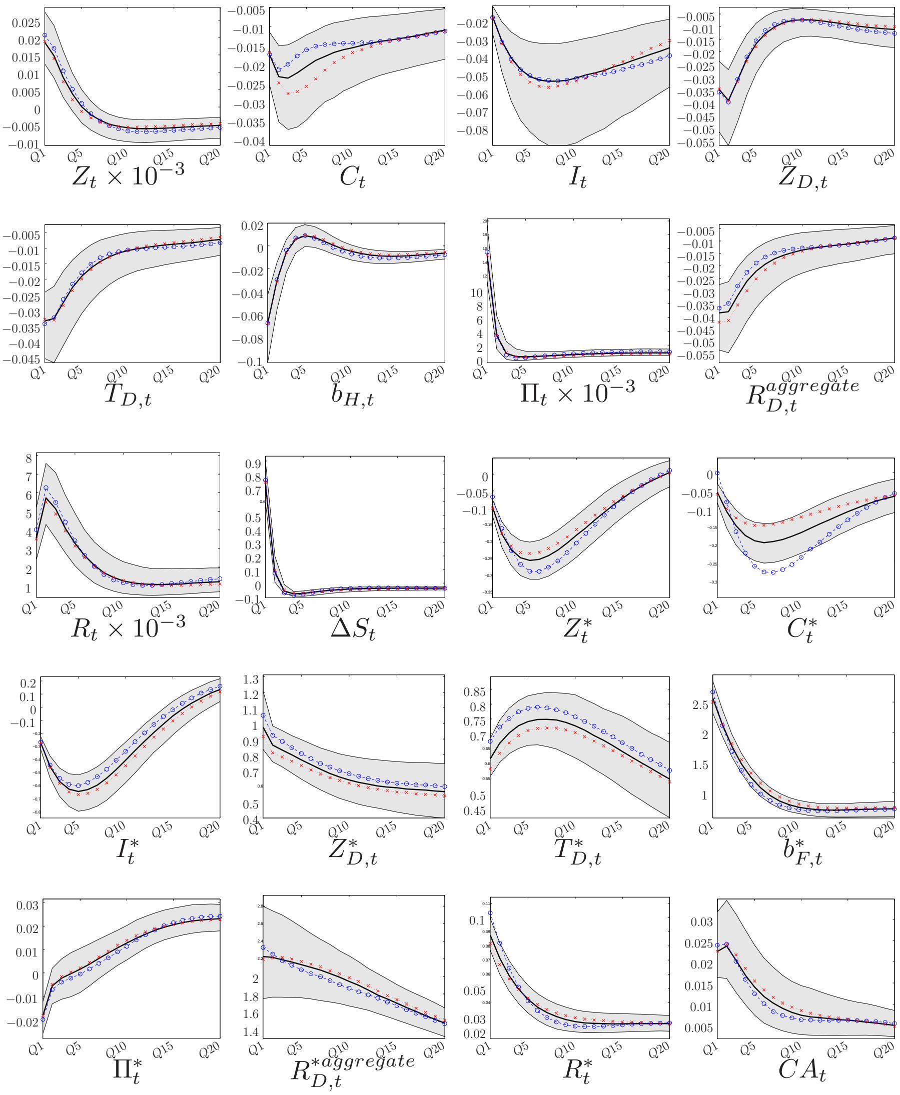

Fig. 6: Impulse Response Functions associated to a housing preference shock in the euro area. *Benchmark model (plain lines and shaded areas), model with high borrowers (dotted lines with circle), model with no borrowers (dashed lines with cross).*

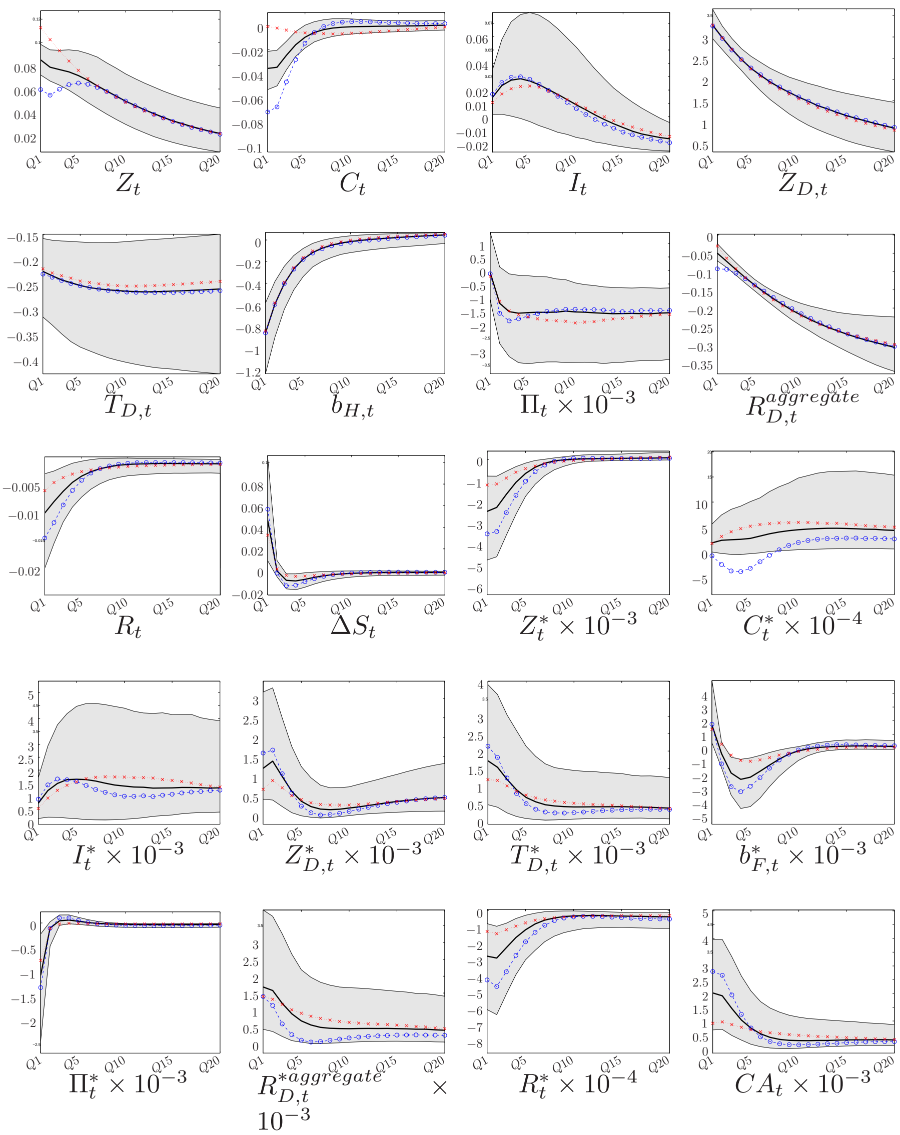

Fig. 7: Impulse Response Functions associated to a housing technology shock in the US. *Benchmark model (plain lines and shaded areas), model with high borrowers (dotted lines with circle), model with no borrowers (dashed lines with cross).*

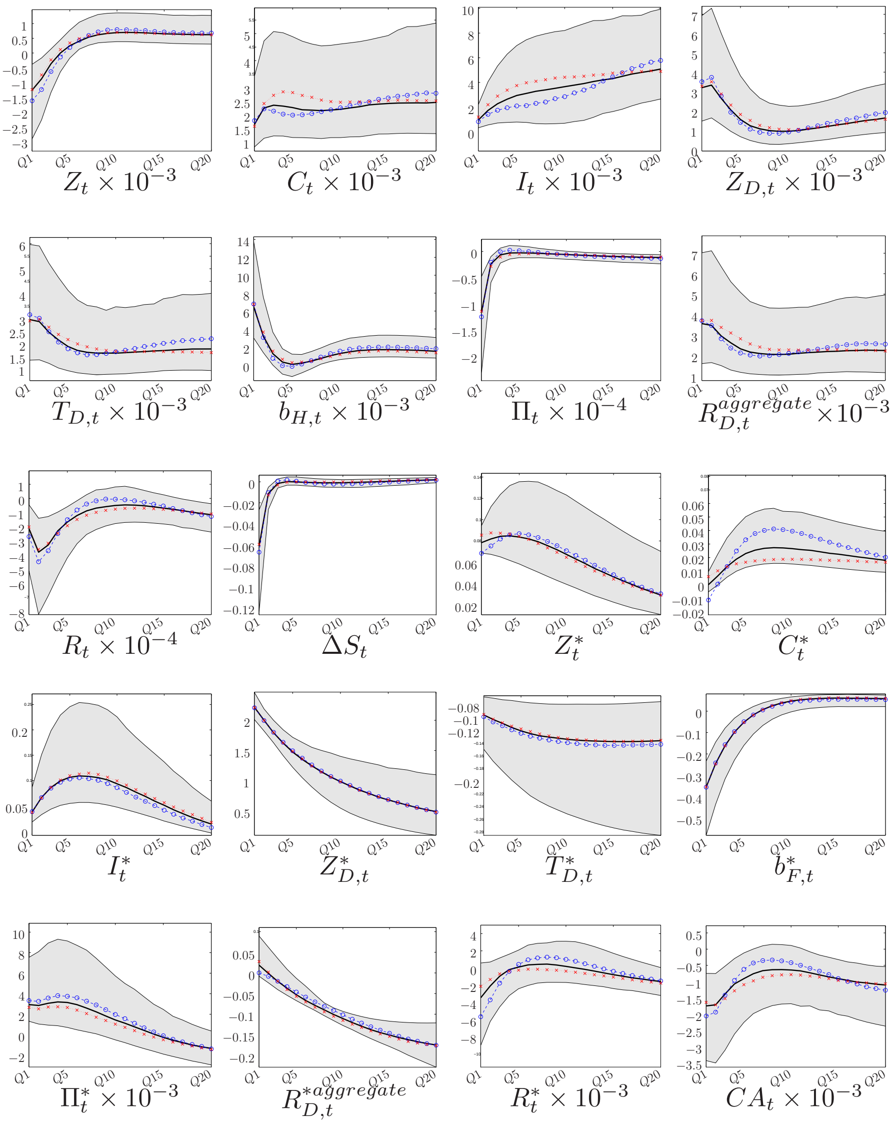

Fig. 8: Impulse Response Functions associated to a housing technology shock in the euro area. *Benchmark model (plain lines and shaded areas), model with high borrowers (dotted lines with circle), model with no borrowers (dashed lines with cross).*

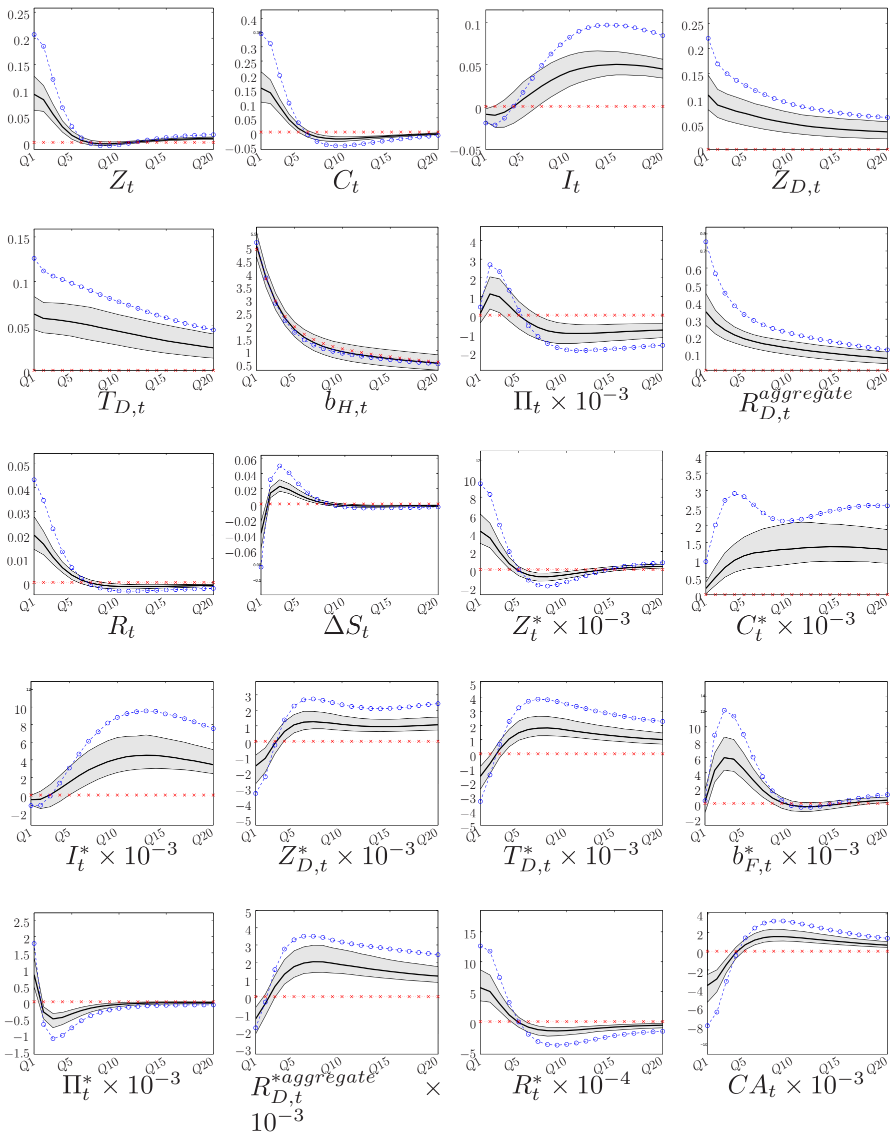

Fig. 9: Impulse Response Functions associated to a loan-to-value ratio shock in the US. *Benchmark model (plain lines and shaded areas), model with high borrowers (dotted lines with circle), model with no borrowers (dashed lines with cross).*

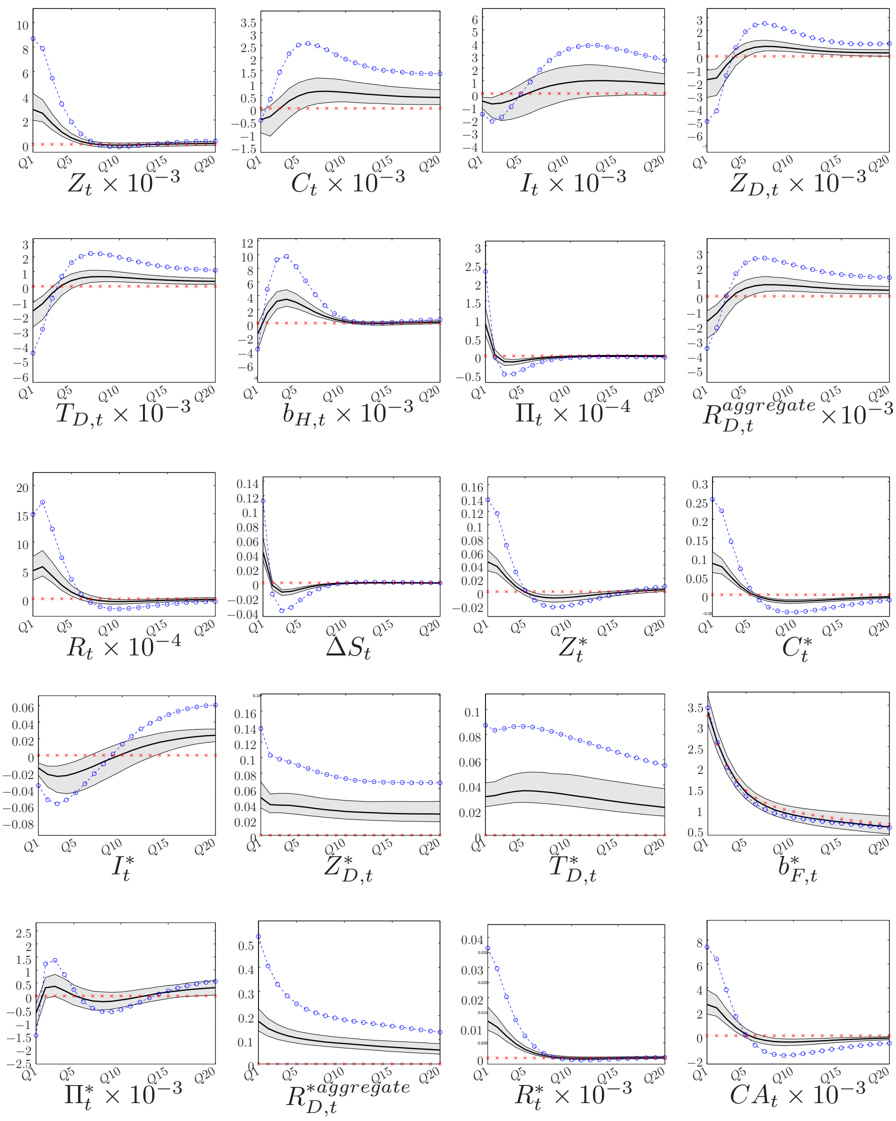

Fig. 10: Impulse Response Functions associated to a loan-to- value ratio shock in the euro area. *Benchmark model (plain lines and shaded areas), model with high borrowers (dotted lines with circle), model with no borrowers (dashed lines with cross).*

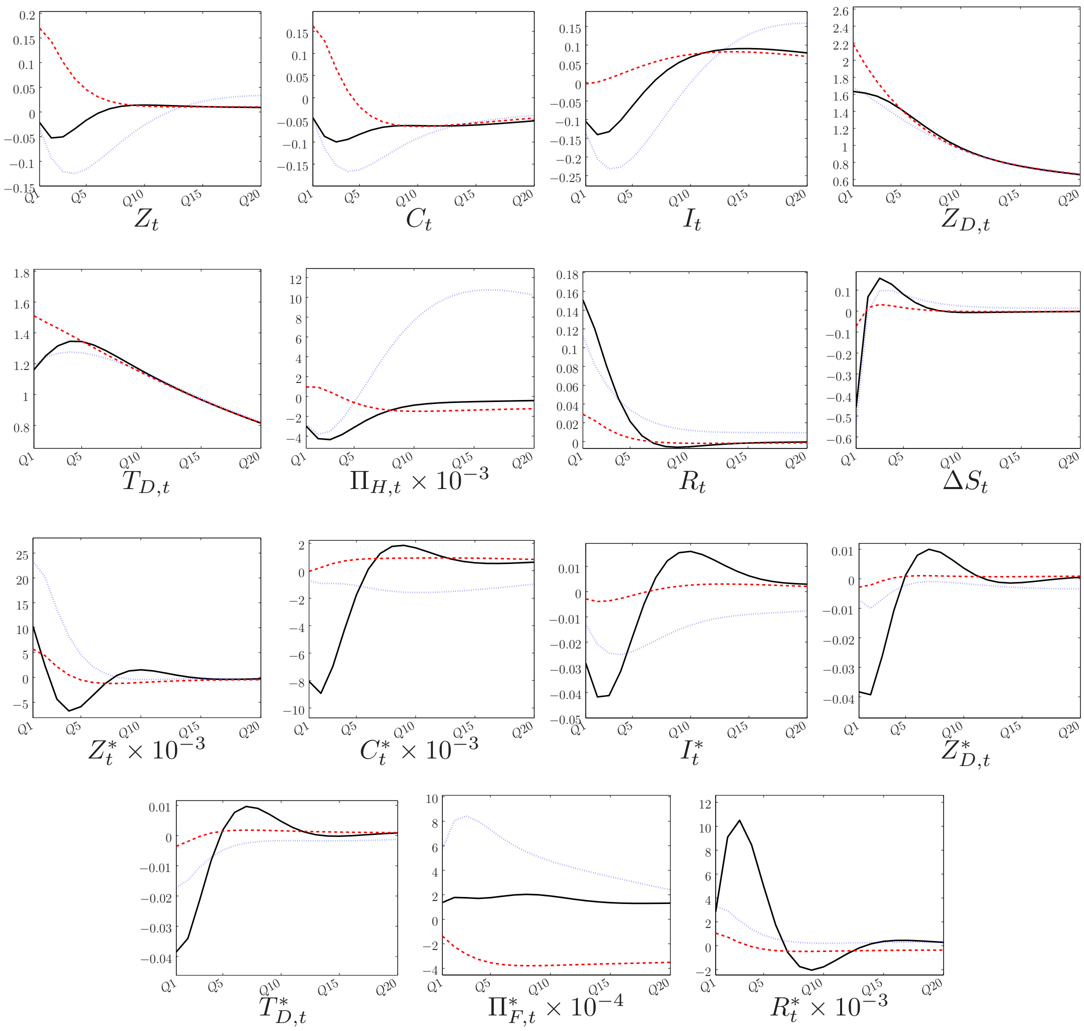

Fig. 11: Impulse Response Functions associated to a housing preference shock (US). *Optimal cooperation (plain lines), Benchmark Estimated Rules (dotted and circle lines), Augmented Estimated Rules (dashed and cross lines).*

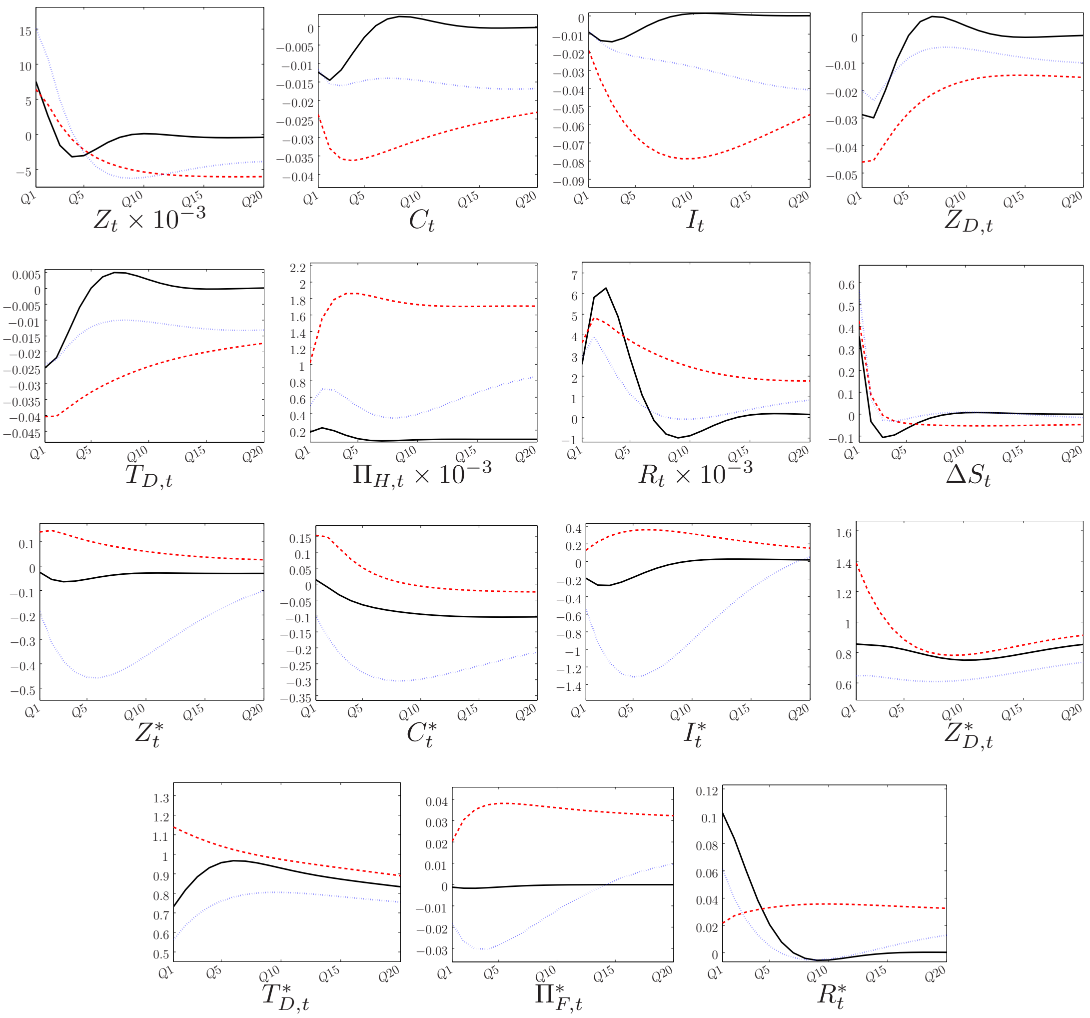

Fig. 12: Impulse Response Functions associated to a housing preference shock (euro area). *Optimal cooperation (plain lines), Benchmark Estimated Rules (dotted and circle lines), Augmented Estimated Rules (dashed and cross lines).*

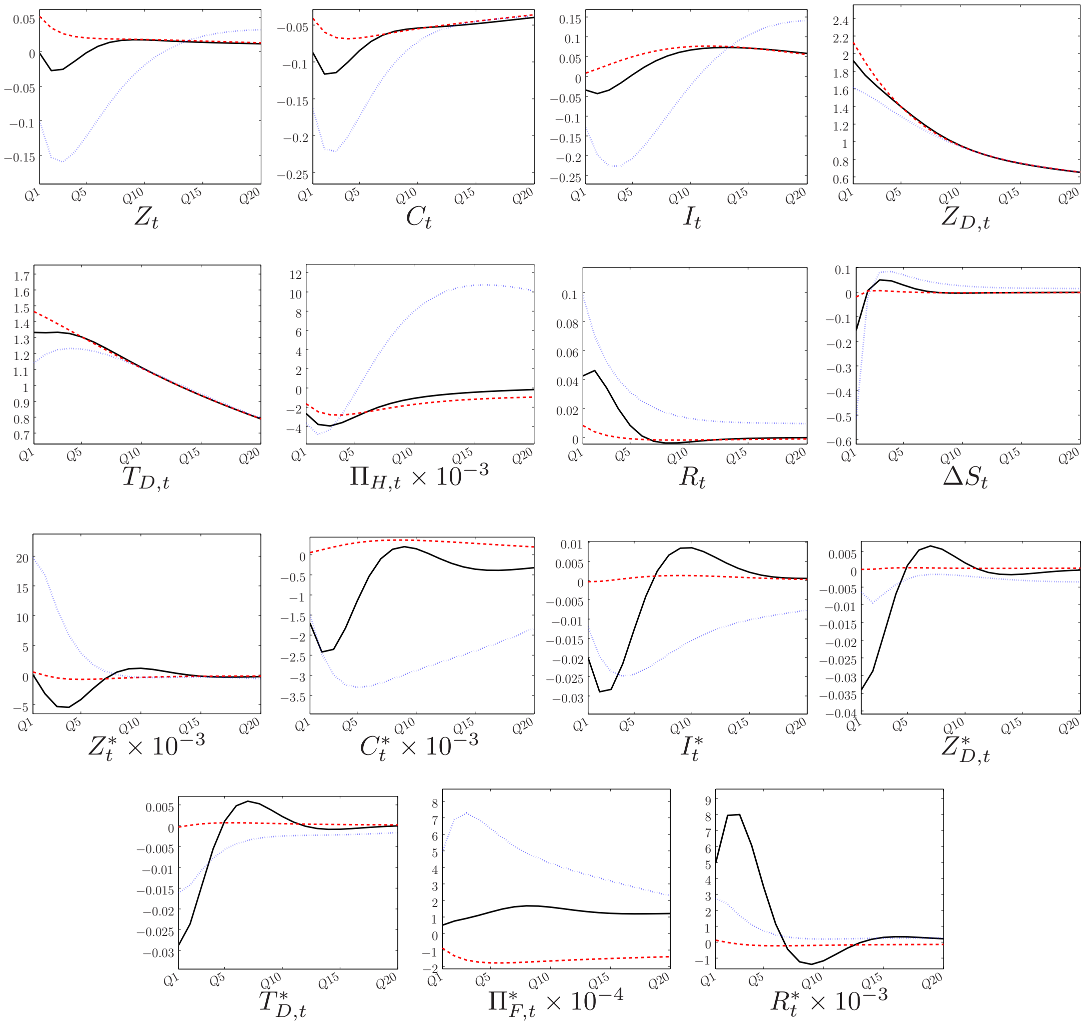

Fig. 13: Impulse Response Functions associated to a housing preference shock (US). **No borrower case**. *Optimal cooperation (plain lines), Benchmark Estimated Rules (dotted and circle lines), Augmented Estimated Rules (dashed and cross lines).*

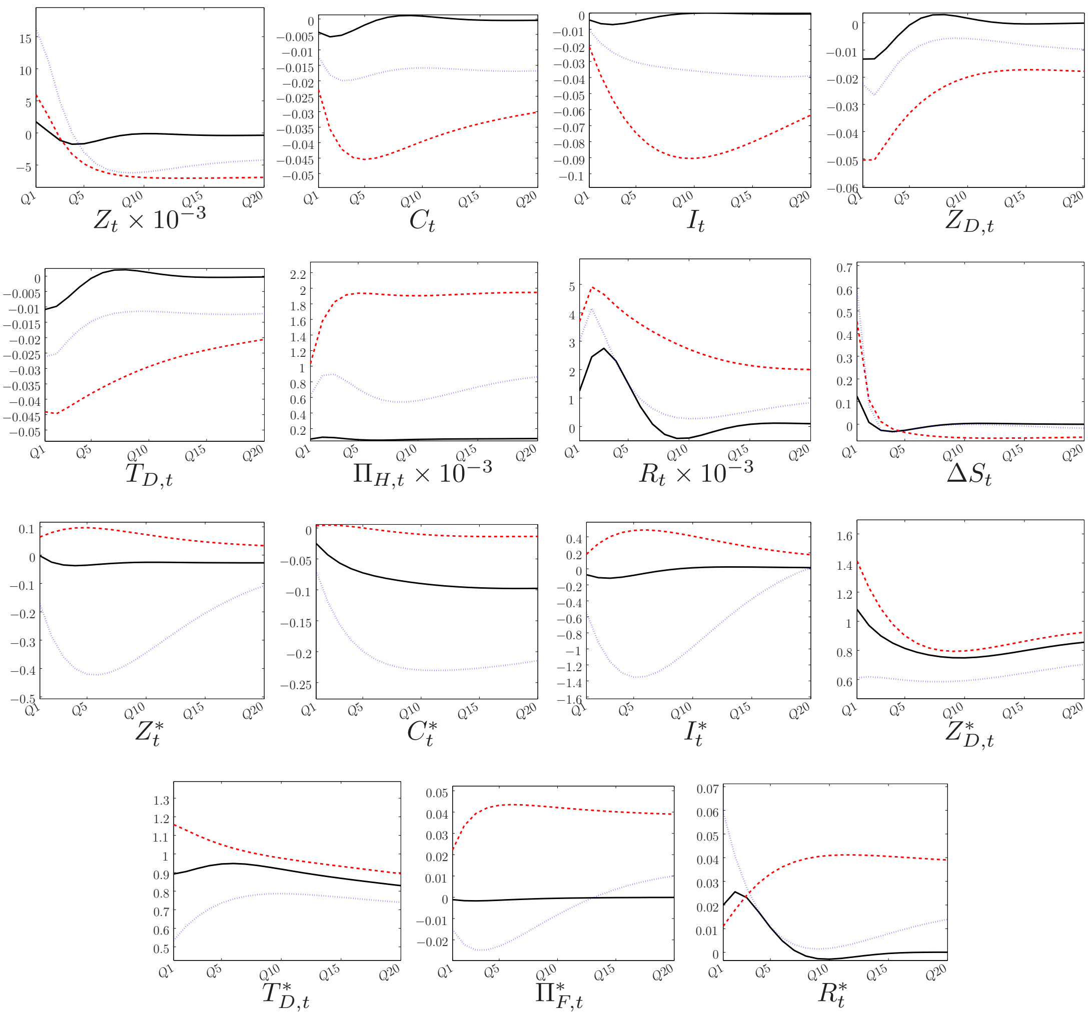

Fig. 14: Impulse Response Functions associated to a housing preference shock (euro area). **No borrower case**. *Optimal cooperation (plain lines), Benchmark Estimated Rules (dotted and circle lines), Augmented Estimated Rules (dashed and cross lines).*

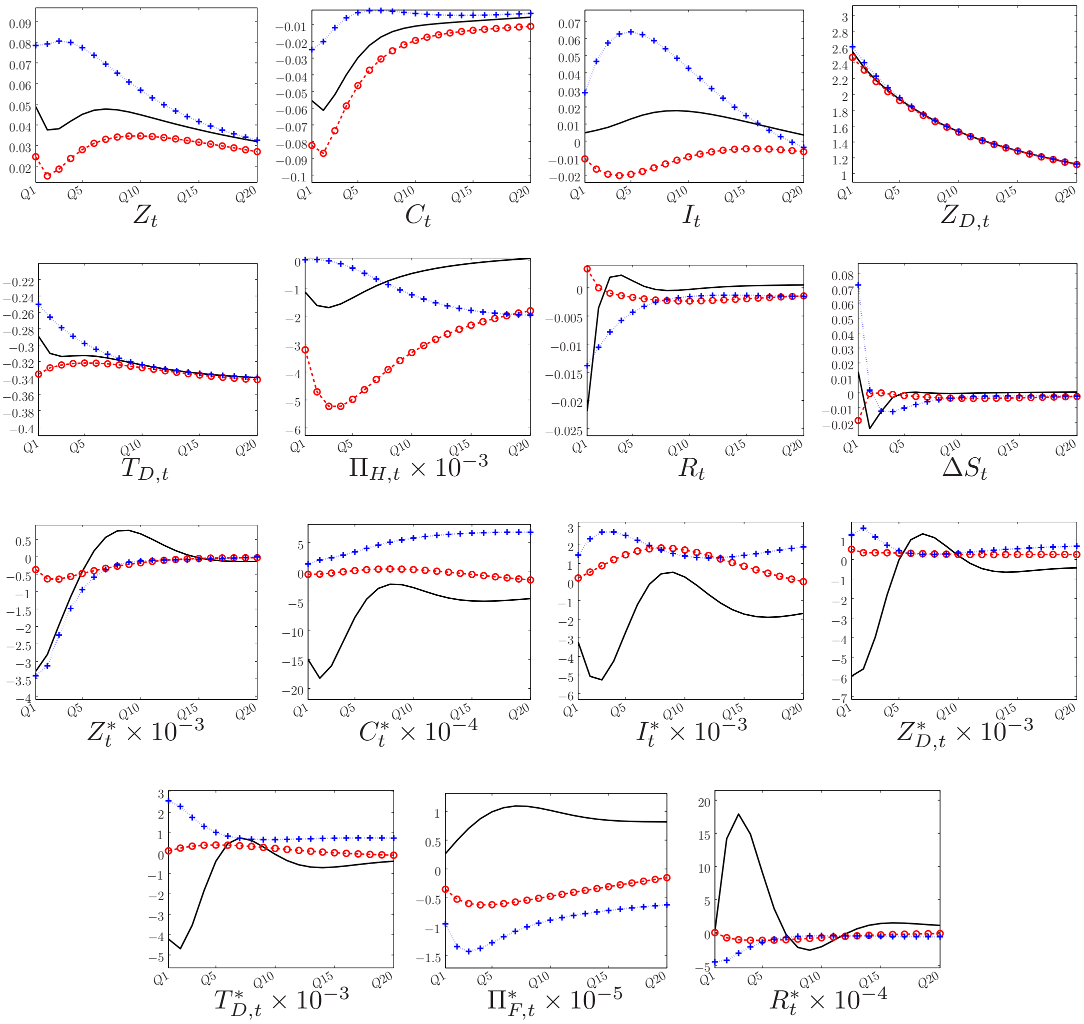

Fig. 15: Impulse Response Functions associated to a housing technology shock (US). *Optimal cooperation (plain lines), Benchmark Estimated Rules (dotted and circle lines), Augmented Estimated Rules (dashed and cross lines).*

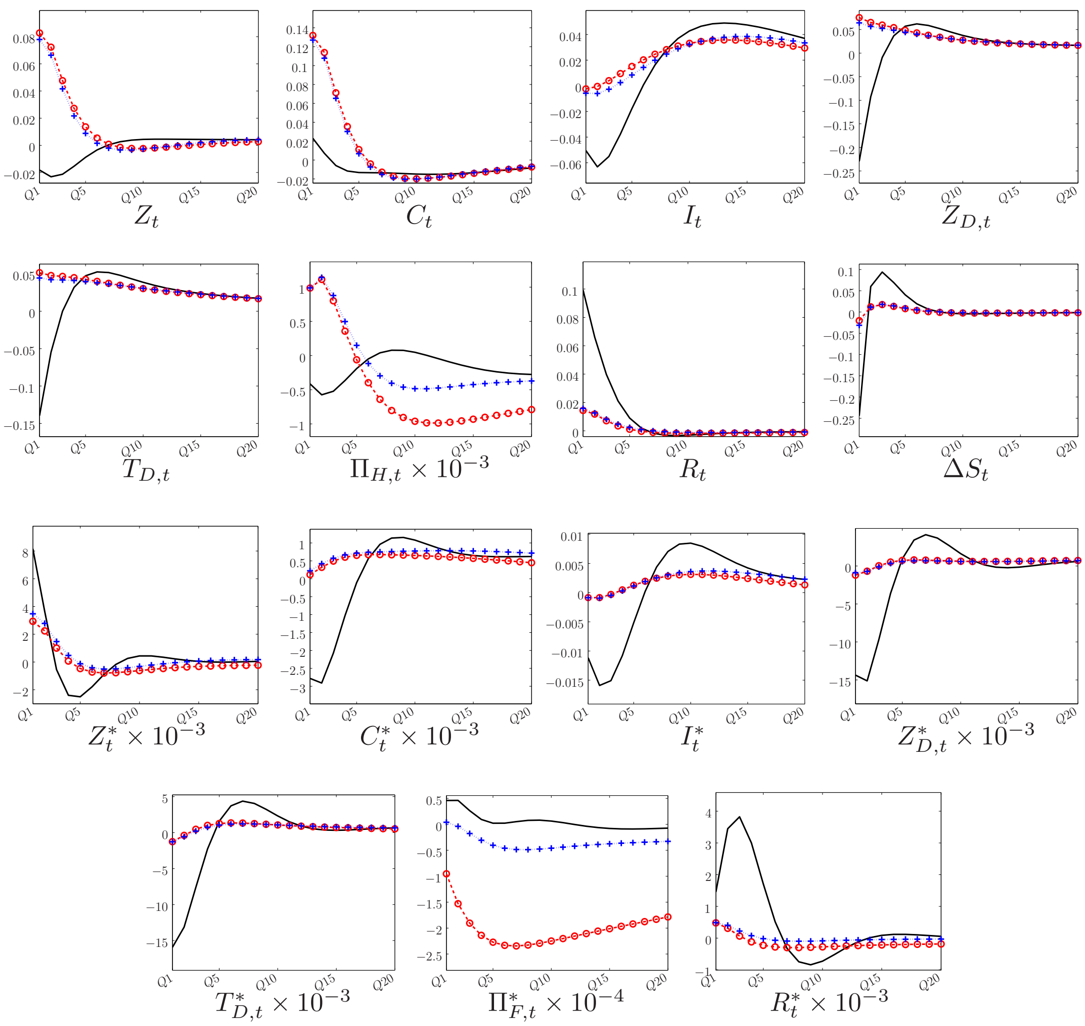

Fig. 16: Impulse Response Functions associated to a loan-to-value ratio shock (US). *Optimal cooperation (plain lines), Benchmark Estimated Rules (dotted and circle lines), Augmented Estimated Rules (dashed and cross lines).*