Open access • Journal Article • DOI:10.1007/S11079-013-9276-6

What Drives Ireland's Housing Market? A Bayesian DSGE Approach

— Source link

Eric Mayer, Johannes Gareis

Institutions: University of Würzburg

Published on: 28 Apr 2013 - Open Economies Review (Springer US)

Topics: Dynamic stochastic general equilibrium and Investment (macroeconomics)

Gareis, Johannes; Mayer, Eric

Working Paper

What drives Ireland's housing market? A Bayesian DSGE approach

W.E.P. - Würzburg Economic Papers, No. 88

Provided in Cooperation with:
University of Würzburg, Chair for Monetary Policy and International Economics

W. E. P.

Würzburg Economic Papers

No. 88

What drives Ireland's Housing Market? A Bayesian DSGE Approach

Johannes Gareis[(a)] and Eric Mayer[(a)]

[(a)]University of Würzburg
March 2012

University of Würzburg
Department of Economics
Chair VWL 1
Sanderring 2, D-97070 Würzburg
johannes.gareis@uni-wuerzburg.de

Postal Address

Johannes Gareis
University of Würzburg, Department of Economics, Sanderring 2,
97070 Würzburg, Germany
Email: johannes.gareis@uni-wuerzburg.de

What Drives Ireland's Housing Market? A Bayesian DSGE Approach

Johannes Gareis and Eric Mayer*

March 14, 2012

Abstract

In this paper we study the drivers of fluctuations in the Irish housing market by developing a dynamic stochastic general equilibrium (DSGE) model of Ireland as a member of the European Monetary Union (EMU). We estimate the model with Bayesian methods using time series for both Ireland and the rest of the EMU for the period from 1997:Q1 to 2008:Q2. We find that housing preference (demand) and technology shocks are the main drivers of fluctuations in house prices and residential investment. Moreover, we find that adding housing collateral does not improve the fit of our model to the data. A standard regression analysis shows that a good part of the variation of housing preference shocks is explained by unmodeled demand factors that have been considered in the empirical literature as important determinants of Irish house prices.

Keywords Housing, monetary policy, Bayesian estimation

JEL codes E44, E52, F41

*University of Wuerzburg, Department of Economics, Sanderring 2, 97070 Wuerzburg, Germany
Corresponding author: Johannes Gareis; E-mail: johannes.gareis@uni-wuerzburg.de, Tel.: +49-(0)931-3183730.

1 Introduction

Given the key role played by the US mortgage market in the run-up and origin of the recent financial and economic crisis, the sources and consequences of fluctuations in the housing market have become a central issue in quantitative macroeconomics in the last few years. Iacoviello (2005) is among the first to study the economic effects associated to the housing sector in a New Keynesian stochastic general equilibrium (DSGE) model. By using structural estimation, he provides evidence that binding collateral constraints tied to housing values are crucial to explain US consumption dynamics. In a related paper, Iacoviello and Neri (2010) estimate a DSGE model with Bayesian likelihood methods for the US and find that housing preference (demand) and technology shocks contribute the most to fluctuations in the housing sector. Pariès and Notarpietro (2008) reinforce the evidence on the role of housing for the US and provide new evidence for the euro area by building and estimating a two country model. Recently, Aspachs-Bracons and Rabanal (2010) study the drivers of housing cycles in Spain during the European Monetary Union (EMU) period. They conclude that the bulk of the variation in house prices is due to housing preference shocks. Moreover, they find that monetary policy shocks play a minor role in explaining the Spanish house price boom, despite the view that the sustained low levels of real interest rates was behind it.

In this paper, we develop and estimate a Bayesian DSGE model with Irish and EMU data to gain insights into the sources of the recent Irish housing market dynamics. Ireland stands out because of its extraordinary surge in house prices and housing demand over the last decade. As illustrated in figure 1, from 1997 to their peak at the end of 2006 Irish house prices rose by an average of 14% per year (10% in real terms). At the same time, real residential investment increased by a yearly average of 12%. In comparison, house prices in the rest of the EMU grew on average by about 5% per year (3.5% in real terms), while the average annual growth rate of real residential investment was roughly 3%. Besides the fact that the housing market in Ireland has been particularly dynamic, the figure also highlights that the fluctuations in the Irish housing market have been much more volatile compared to those in the rest of the EMU. This is especially relevant for house prices: While annual growth rates of house prices in the rest of the EMU moved smoothly between 2% and 7%, Irish house prices varied substantially, with annual growth rates ranging from 25% in 1998:Q4 to -9% in 2008:Q2.

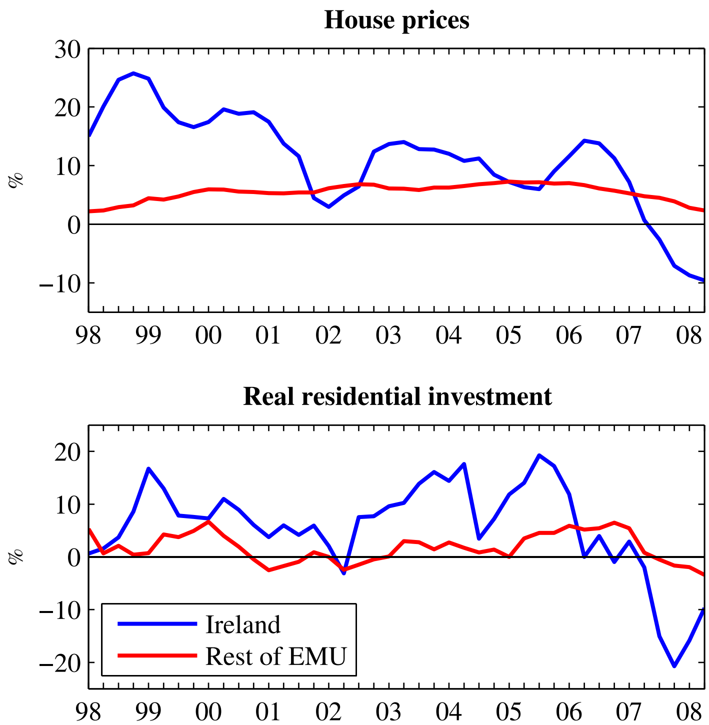

Figure 1: Housing market dynamics in Ireland and the rest of the EMU (y-o-y growth rates)

Much of the debate on the developments in the Irish housing market attempted to investigate the factors behind the housing boom and involved questions as to whether a housing price bubble existed (see, for instance, Malzubris, 2008; Rae and van den Noord, 2006; McQuinn and O'Reilly, 2006; IMF, 2004). By applying an econometric model for house prices, most studies provide evidence that a large part of the recent developments of house prices was due to a strong housing demand fueled by strong population growth, especially among the household formation cohort, strong growth of real disposable income, low short-term real interest rates, lax access to mortgage finance and tax advantages. However, these studies also report that house prices have been deviating from fundamental prices over time, with the degree of under- or overshooting varying considerably. For instance, McQuinn and O'Reilly (2006) estimate the degree of overvaluation of new house prices to be 15% at the end of 2005.

Here, we address the recent developments in the Irish housing market using a Bayesian DSGE model. We borrow from Aspachs-Bracons and Rabanal (2010) as well as Pariès and Notarpietro (2008) and build a two country model of a monetary union including housing. In spite of the fact that Ireland forms only a small part of the EMU, we employ a two country setup because it provides a realistic framework to study the implications of a common monetary policy in the EMU for Ireland and allows us to investigate the transmission of all structural shocks in the rest of the EMU to the Irish housing market. The stochastic dynamics of our model are driven by a rich set of structural shocks such that the model is successful in explaining key features of the data. In particular, the model includes two housing-related shocks. On the supply side, we implement a standard technology shock to the production function of firms, and, on the demand side, we introduce a housing preference shock that tries to capture all unmodeled shifts in the demand for housing. As in Aspachs-Bracons and Rabanal (2010) our baseline model does not include housing collateral, which is otherwise the case in the models used by Iacoviello and Neri (2010) and Pariès and Notarpietro (2008). We do so because, in line with Aspachs-Bracons and Rabanal (2010), we provide evidence that the model without housing collateral fits the data better.

We estimate our model on Irish and EMU quarterly data for the period from 1997:Q1 to 2008:Q2 with standard Bayesian likelihood methods. After showing that our model fits the volatility of the observable variables quite good, we use it to examine the drivers of fluctuations in the Irish housing market by applying variance as well as historical decompositions and standard impulse response analysis. Turning to our main results, the posterior estimates of the structural parameters are broadly similar to the ones obtained in the housing DSGE literature with euro area data. Most importantly, we find clear evidence on the existence of asymmetric price rigidities across sectors. With an estimated Calvo lottery parameter of 0.22, house prices are much more flexible than consumer prices, which corresponding Calvo parameter is estimated to be 0.84. Moreover, we find a relatively high posterior mean of the costly labor reallocation parameter. This reinforces the evidence reported in Aspachs-Bracons and Rabanal (2010) that labor market reallocation is more costly in Europe than in the US. Focusing on the drivers of Irish housing cycles, we find that housing preference and technology shocks are the main contributors to housing market dynamics. In particular, housing technology shocks explain about 70% of the variance of residential investment and housing preference shocks account for about 67% of the variation of house prices as well as for about 25% of the variation of residential investment. Similar to what Aspachs-Bracons and Rabanal (2010) reports for Spain, we find that monetary factors have played a negligible role in the recent Irish housing market fluctuations. Quite surprisingly, risk premium and monetary policy shocks explain less than 3% of the overall variation of Irish house prices. Given the important role of housing preference shocks in explaining Irish house prices, we follow the approach of Iacoviello and Neri (2010) and investigate if the estimated housing preference shocks can be furhter traced back to unmodeled shifts in the demand for housing that have been considered in the empirical literature as important determinants of house prices. Indeed, our results suggest that a large part of the estimated innovations to housing preferences are explained by demographic factors, shifts in real disposable income and mortgage finance growth. Moreover, we find that consumer price inflation has an impact on housing preference innovations although it has already been included in the model. This indicates that consumer price inflation has a stronger impact on housing demand than the effects that our model captures, which may be due to inflation illusion when people decide to invest in housing.

2 The model

The model economy consists of two countries in a closed single currency union, i.e., a home country (Ireland) and a foreign country (the rest of the EMU). The countries are of size n and $1 - n$, and each of them is modeled as a two sector economy producing nondurable consumption/nonresidential investment goods and housing. In each sector there exists a continuum of intermediate goods producers that operate under monopolistic competition and final goods producers that are perfect competitors. Firms in the nondurable goods sector produce consumption and nonresidential investment goods with labor and capital, while firms in the housing sector produce housing using labor, capital and land. In each country there is a continuum of households that derive utility from consumption of nondurable goods and housing and disutility from labor supply. In addition, households own the economy's capital stock and land which they rent out to intermediate goods producers. Nondurable consumption and nonresidential investment goods are traded across countries.

The stochastic dynamics of the model are driven by four preference shocks, seven technology/efficiency shocks, one risk premium and one monetary policy shock. We also allow for a number of real and nominal frictions following a large strand of the literature. In particular, we assume habit formation in consumption, investment adjustments costs, variable capital utilization, labor immobility and sticky nominal prices.

As the problem set of the foreign country is equivalent to that of the home country, in the following we present only equations characterizing the latter, unless stated otherwise.

Variables labeled with a * refer to the foreign country.

2.1 Households

Each household in the home country, indicated by $h \in [0, n]$, maximizes an intertemporal utility function

$$E_t \sum_{k=0}^{\infty} \beta^k U_{t+k}(h), \quad \beta \in [0, 1], \tag{1}$$

where E_t is the expectation operator, β is the discount factor, and $U_t(h)$ is the period utility function that is separable in consumption and labor and reads

$$U_t(h) = \alpha log(C_t(h) - \varepsilon C_{t-1}) + \zeta_t^H (1-\alpha) log(H_t(h)) - \frac{L_t(h)^{1+\eta}}{1+\eta}, \tag{2}$$

where C_t is an index of nondurable consumption goods that is composed of home and foreign goods, H_t is the housing stock and L_t describes a labor supply index. The parameter ε captures external habit formation in consumption of nondurable goods, α is the relative size of nondurable goods in total private consumption and η is the inverse elasticity of labor supply. ζ_t^H is a housing preference shock that is meant to capture all exogenous shifts in the demand for housing. The shock follows $log(\zeta_t^H) = \rho_H log(\zeta_{t-1}^H) + u_t^H$. The index of nondurable consumption goods is defined as

$$C_t(h) = \left[(\zeta_t^D \tau)^{\frac{1}{\iota}} (C_t^h(h))^{\frac{\iota-1}{\iota}} + (1-\tau)^{\frac{1}{\iota}} (C_t^f(h))^{\frac{\iota-1}{\iota}} \right]^{\frac{\iota}{\iota-1}}, \tag{3}$$

where C_t^h and C_t^f stand for the consumption of goods produced in the home and the foreign country respectively, ι is the constant elasticity of substitution between home and foreign goods and τ governs the share of home produced goods in the consumption basket. ζ_t^D is a domestic goods preference shock that follows $log(\zeta_t^D) = \rho_D log(\zeta_{t-1}^D) + u_t^D$. The housing stock evolves as

$$H_t(h) = (1-\delta) H_{t-1}(h) + HI_t(h), \tag{4}$$

where $HI_t(h)$ stands for residential investment and δ is the housing depreciation rate. Following Aspachs-Bracons and Rabanal (2010), we define the labor supply index as

$$L_t(h) = \left[(1-\Delta_H)^{-\iota_L} (L_{C,t}(h))^{1+\iota_L} + \Delta_H^{-\iota_L} (L_{H,t}(h))^{1+\iota_L} \right]^{\frac{1}{1+\iota_L}}, \quad \iota_L \geq 0, \tag{5}$$

where $L_{C,t}(h)$ and $L_{H,t}(h)$ stands for sector-specific labor supply, Δ_H measures the relative size of labor supply in the housing sector and ι_L measures the cost of reallocating labor across sectors (see also Iacoviello and Neri, 2010; Horvath, 2000). Note that when labor reallocation costs equal zero, $L_{C,t}(h)$ and $L_{H,t}(h)$ are perfect substitutes.

The period budget constraint of a household in the home country is given in nominal terms as

$$\begin{aligned} & P_t^{CPI} C_t(h) + P_t^H HI_t(h) + P_t^{CPI} \sum_j^{C,H} I_{j,t}(h) + B_t(h) \leq \\ & \sum_j^{C,H} W_{j,t} L_{j,t}(h) + \sum_j^{C,H} \left[R_{j,t} z_{j,t}(h) - P_t^{CPI} A(z_{j,t}(h)) \right] K_{j,t-1}(h) + R_{l,t} \bar{l}(h) \\ & + R_{t-1} B_{t-1}(h) + \sum_j^{C,H} Div_{j,t}(h), \end{aligned} \tag{6}$$

where P_t^{CPI} and P_t^H are the price indices of nondurable consumption goods and housing respectively. $B_t(h)$ are holdings of internationally traded assets that pay/cost a gross nominal interest rate of R_t. $I_{j,t}(h)$ denotes nonresidential investment in sector-specific capital that is $K_{j,t}(h)$. $\bar{l}(h)$ is an exogenously fixed amount of land which the household rent out to firms in the housing sector at a rental rate of $R_{l,t}$. $W_{j,t}$ stands for the nominal wage rate in sector j and $\sum_j^{C,H} Div_{j,t}(h)$ are profits from intermediate goods producers as households are the owner of firms. The term $[R_{j,t} z_{j,t}(h) - P_t^{CPI} A_j(z_{j,t}(h))] K_{j,t-1}(h)$ is the sector-specific nominal return on the existing capital stock adjusted with the capital utilization rate minus the nominal cost associated with variations in the degree of capital utilization as in Smets and Wouters (2003) and Christiano et al. (2005).[1] The accumulation equation for capital in sector j reads

$$K_{j,t}(h) = (1 - \delta_j) K_{j,t-1}(h) + \zeta_t^I \left[1 - S\left(\frac{I_{j,t}(h)}{I_{j,t-1}(h)} \right) \right] I_{j,t}(h), \quad j = C, H, \tag{7}$$

where δ_j is the depreciation rate of capital, $S(\cdot)$ is a convex function that captures adjustment costs in investment and ζ_t^I is an efficiency shock to the technology of capital accumulation which is assumed to be equal across sectors like in Pariès and Notarpietro (2008). For $S(\cdot)$ it holds that $S(1) = S'(1) = 0$ and $S''(1) = \varphi > 0$. The efficiency

[1] The functional form for the cost function follows Pariès and Notarpietro (2008) and is $A_j(X) = \frac{\bar{R}_j}{\upsilon}(exp[\upsilon(X-1)] - 1)$, where $\bar{R}_j$ is the steady state rental rate of capital ($j = C, H$). Given a full capital utilization in the steady state ($\bar{z}_j = 1$), the associated cost of capital utilization is zero.

shock is given by $log(\zeta_t^I) = \rho_j log(\zeta_{t-1}^I) + u_t^I$. Similar to the consumption of nondurable goods, sector-specific investment is defined as an index over home and foreign goods. In particular, it holds that

$$I_{j,t}(h) = \left[(\zeta_t^D \tau)^{\frac{1}{\iota}} (I_{j,t}^h(h))^{\frac{\iota-1}{\iota}} + (1-\tau)^{\frac{1}{\iota}} (I_{j,t}^f(h))^{\frac{\iota-1}{\iota}} \right]^{\frac{\iota}{\iota-1}}, \quad j = C, H, \tag{8}$$

where $I_{j,t}^h$ and $I_{j,t}^f$ stands for sector-specific investment goods produced in the home, respectively, the foreign country.[2]

As in Aspachs-Bracons and Rabanal (2010), we assume that home country households have to pay a premium above the riskless union-wide nominal interest rate, when the country's net foreign assets as percent of GDP fall below its steady state value (see also Schmitt-Grohe and Uribe, 2003). In particular, the interest rate for the home country households follows

$$R_t = \zeta_t^{Risk} R_t^* exp \left[-\kappa \left(\tilde{B}_t - \bar{\tilde{B}} \right) \right], \quad \kappa \geq 0, \tag{9}$$

where R_t^* is the union-wide riskless gross nominal interest rate, $\tilde{B}_t \equiv \frac{nB_t}{P_t Y_t}$ is the home country's aggregate net foreign asset position as percent of total GDP and $\bar{\tilde{B}}$ is the corresponding steady state value. The parameter κ governs the risk premium elasticity. ζ_t^{Risk} is a risk premium shock that affects the home country's interest rate only and follows $log(\zeta_t^{Risk}) = \rho_{Risk} log(\zeta_{t-1}^{Risk}) + u_t^{Risk}$.

The maximization of the objective function (1) subject to the budget constraint (6) with respect to consumption of nondurable goods and asset holdings yield the following first-order conditions to the household's program

$$MU_t^C = P_t^{CPI} \lambda_t^{BC} \tag{10}$$

$$\text{and} \quad \lambda_t^{BC} = \beta E_t \left(\lambda_{t+1}^{BC} R_t \right), \tag{11}$$

where $MU_t^C(h) = \frac{\partial U_t(h)}{\partial C_t(h)}$ is the marginal utility of an additional unit of nondurable goods consumption and λ_t^{BC} is the multiplier on the budget constraint. The demand functions

[2] For the sake of simplicity, we assume that the weights of home and foreign goods in the nonresidential investment indices are the same as in the index of nondurable consumption goods. As a consequence, the price indices for both investment goods equal the price index of the consumption goods basket.

for home and foreign nondurable consumption goods are given by

$$C_t^h = \zeta_t^D \tau \left(\frac{P_t^C}{P_t^{CPI}} \right)^{-\iota} C_t \tag{12}$$

$$\text{and} \quad C_t^f = (1-\tau) \left(\frac{P_t^{C^*}}{P_t^{CPI}} \right)^{-\iota} C_t, \tag{13}$$

where P_t^C and $P_t^{C^*}$ stand for the domestic and the foreign price level in the nondurable goods sector respectively. The utility based price index for nondurable consumption goods (consumer price index) is given as

$$P_t^{CPI} = \left[\zeta_t^D \tau \left(P_t^C \right)^{1-\iota} + (1-\tau) \left(P_t^{C^*} \right)^{1-\iota} \right]^{\frac{1}{1-\iota}}. \tag{14}$$

The first-order condition to the household's choice of housing is

$$MU_t^C q_t = MU_t^H + \beta(1-\delta) E_t \left(MU_{t+1}^C q_{t+1} \right), \tag{15}$$

where $q_t = \frac{P_t^H}{P_t^{CPI}}$ is the real house price and $MU_t^H(h) = \frac{\partial U_t(h)}{\partial H_t(h)}$ is the marginal utility of an additional unit of housing. The labor supply conditions are given by

$$\frac{W_t^C}{P_t^{CPI}} = \frac{L_t^{(\eta-\iota_L)} (1-\Delta_H)^{-\iota_L} (L_{C,t})^{\iota_L}}{MU_t^C} \tag{16}$$

$$\text{and} \quad \frac{W_t^H}{P_t^{CPI}} = \frac{L_t^{(\eta-\iota_L)} \Delta_H^{-\iota_L} (L_{H,t})^{\iota_L}}{MU_t^C}. \tag{17}$$

Turning to the household's choice of capital, investment and capital utilization, the first-order conditions are the following

$$Q_{j,t} = \beta E_t \left[\frac{MU_{t+1}^C}{MU_t^C} \left(Q_{j,t+1}(1-\delta_j) + \left(\frac{R_{j,t+1}}{P_{t+1}^{CPI}} z_{j,t+1} - A(z_{j,t+1}) \right) \right) \right], \tag{18}$$

$$Q_{j,t}\zeta_t^I \left[1 - S\left(\frac{I_{j,t}}{I_{j,t-1}} \right) - S'\left(\frac{I_{j,t}}{I_{j,t-1}} \right) \left(\frac{I_{j,t}}{I_{j,t-1}} \right) \right] =$$

$$1 - \beta \zeta_{t+1}^I E_t \left[Q_{j,t+1} \frac{MU_{t+1}^C}{MU_t^C} S'\left(\frac{I_{j,t+1}}{I_{j,t}} \right) \left(\frac{I_{j,t+1}}{I_{j,t}} \right)^2 \right] \tag{19}$$

$$\text{and} \quad \frac{R_{j,t}}{P_t^{CPI}} = A_j{}'(z_{j,t}), \quad j = C, H, \tag{20}$$

where the term $Q_{j,t}$ represents Tobin's Q defined as the ratio between the multiplier on (7) and $\lambda_t^{BC} P_t^{CPI}$. The demand functions for home and foreign produced investment goods are

$$I_{j,t}^{h} = \zeta_t^D \tau \left(\frac{P_t^C}{P_t^{CPI}} \right)^{-\iota} I_{j,t} \tag{21}$$

$$\text{and} \quad I_{j,t}^{f} = (1-\tau) \left(\frac{P_t^{C*}}{P_t^{CPI}} \right)^{-\iota} I_{j,t}, \quad j = C, H. \tag{22}$$

2.2 Final goods producer

In each sector a perfectly competitive final goods producer purchases units of intermediate goods i and bundles them according to the following technology

$$Y_{j,t} = \left(\left(\frac{1}{n} \right)^{\frac{\lambda}{1+\lambda}} \int_0^n Y_{j,t}(i)^{\frac{1}{1+\lambda}} di \right)^{1+\lambda}, \quad j = C, H, \tag{23}$$

where $Y_{j,t}$ is the quantity of the final good in sector j and $Y_{j,t}(i)$ is the quantity of intermediate goods, indexed by $i \in [0, n]$. The parameter λ governs the price markup in each sector. Profit maximization of the final goods producer leads to the demand for the intermediate good i according to

$$Y_{j,t}(i) = \left(\frac{1}{n} \right) \left(\frac{P_t^j(i)}{P_t^j} \right)^{-\frac{1+\lambda}{\lambda}} Y_{j,t}, \quad j = C, H, \tag{24}$$

where $P_t^j(i)$ is the price of the intermediate good i and P_t^j is the price of the final good. Given zero profits in equilibrium, the price of the final good is

$$P_t^j = \left(\left(\frac{1}{n} \right) \int_0^n P_t^j(i)^{-\frac{1}{\lambda}} di \right)^{-\lambda}, \quad j = C, H. \tag{25}$$

2.3 Intermediate goods producers

Intermediate goods in each sector are produced by monopolistically competitive producers. Following Iacoviello and Neri (2010), we introduce sectoral heterogeneity such that the model is able to generate endogenous dynamics in both sectors. Nondurable consumption/nonresidential investment goods are produced with labor and capital and housing is produced with labor, capital and land. The technologies of producer i in the nondurable goods sector, respectively, the housing sector are given by Cobb-Douglas functions according to

$$Y_{C,t}(i) = u_t^A \zeta_t^{AC} (\tilde{K}_{C,t}(i))^{\mu_C} (L_{C,t}(i))^{1-\mu_C} \quad \text{and} \tag{26}$$

$$Y_{H,t}(i) = u_t^A \zeta_t^{AH} (\bar{l}(i))^{\mu_l} (\tilde{K}_{H,t}(i))^{\mu_H} (L_{H,t}(i))^{1-\mu_l-\mu_H}, \tag{27}$$

where $\tilde{K}_{j,t}$ is the effective utilization of the sector-specific capital stock that follows $\tilde{K}_{j,t} = z_{j,t} K_{j,t-1}$. u_t^A is an union-wide technology shock that is serially uncorrelated. ζ_t^{AC} and ζ_t^{AH} are country and sector-specific technology shocks that follow $log(\zeta_t^{AC}) = \rho_{AC} log(\zeta_{t-1}^{AC}) + u_t^{AC}$ and $log(\zeta_t^{AH}) = \rho_{AH} log(\zeta_{t-1}^{AH}) + u_t^{AH}$. The parameter μ_C denotes the capital share in the nondurable goods sector, μ_l and μ_H are the land share and the capital share in the housing sector respectively. The producers' marginal costs in the nondurable goods sector are given by

$$MC_{C,t}(i) = \frac{1}{u_t^A \zeta_t^C} \frac{(R_{C,t})^{\mu_C} (W_{C,t})^{1-\mu_C}}{\mu_C^{\mu_C} (1-\mu_C)^{1-\mu_C}} \tag{28}$$

and the producers' marginal costs in the housing sector are

$$MC_{H,t}(i) = \frac{1}{u_t^A \zeta_t^H} \frac{(R_{l,t})^{\mu_l} (R_{H,t})^{\mu_H} (W_{H,t})^{1-\mu_l-\mu_H}}{\mu_l^{\mu_l} \mu_H^{\mu_H} (1-\mu_l-\mu_H)^{1-\mu_l-\mu_H}}, \tag{29}$$

where the optimal rental rate of land is

$$R_{l,t} = \frac{\mu_l}{1-\mu_H-\mu_l} \frac{W_{H,t} L_{H,t}(i)}{\bar{l}}. \tag{30}$$

Then, nominal profits of intermediate goods producer i operating in sector $j = C, H$ are given by

$$Div_{j,t}(i) = \left(P_t^j(i) - MC_{j,t}(i)\right) \left(\frac{1}{n}\right) \left(\frac{P_t^j(i)}{P_t^j}\right)^{-\frac{1+\lambda}{\lambda}} Y_{j,t}. \tag{31}$$

Each monopolistically competitive firm i in sector j maximizes expected profits using a discount rate $\Lambda_{t,t+k} = \beta^k \frac{\lambda_{t+k}^{BC}}{\lambda_t^{BC}}$. Following Calvo (1983), intermediate goods producers are only allowed to change prices optimally with probability $1 - \theta_j$. In addition, producers that do not optimize prices index prices to last period's sectoral inflation rate (see Smets and Wouters, 2007, 2003). The first-order condition of the maximization problem of firms in sector $j = C, H$ is given by

$$E_t \sum_{k=0}^{\infty} \theta_j \Lambda_{t,t+k} Y_{j,t+k}(i) \left(\frac{\dot{P}_t^j(i)}{P_t^j} \frac{(P_{t-1+k}^j / P_{t-1}^j)^{\gamma_j}}{P_{t+k}^j / P_t^j} - (1+\lambda) mc_{j,t+k}(i) \right) = 0, \tag{32}$$

where $\dot{P}_t^j(i)$ is the optimal price for intermediate good i, $mc_{j,t} = \frac{MC_{j,t}}{P_t^j}$ are the real marginal cost of production and the parameter γ_j measures the degree of price indexation. The sectoral aggregate price level implied by (25) can be written as

$$\left(P_t^j\right)^{-\frac{1}{\lambda}} = \theta_j \left(P_{t-1}^j \left(\frac{P_{t-1}^j}{P_{t-2}^j}\right)^{\gamma_j}\right)^{-\frac{1}{\lambda}} + (1-\theta_j)\left(\dot{P}_t^j(i)\right)^{-\frac{1}{\lambda}}, \quad j = C, H. \tag{33}$$

2.4 Market clearing

The home country's equilibrium condition in the nondurable goods sector is given by[3]

$$Y_{C,t} = nC_t^h + (1-n)C_t^{h^*} + I_t + n\frac{\sum_j^{C,H} P_t^{CPI} A(z_{j,t})K_{j,t-1}}{P_t^C}, \tag{34}$$

where $C_t^{h^*}$ is foreign consumption of home produced goods, $I_t = n(I_{C,t}^h + I_{H,t}^h) + (1-n)(I_{C,t}^{h^*} + I_{H,t}^{h^*})$ is total demand for home produced nonresidential investment goods and the last term of the expression are the real costs associated with variations in the degree of capital utilization expressed in units of home produced goods. The equilibrium condition in the housing sector is

$$Y_{H,t} = nHI_t, \tag{35}$$

such that the home country's total housing production satisfies domestic housing demand. The home country's real GDP is defined as

$$Y_t = Y_{C,t} + Y_{H,t}. \tag{36}$$

For the foreign country the equilibrium conditions are

$$Y_{C,t}^* = (1-n)C_t^{f^*} + nC_t^f + I_t^* + (1-n)\frac{\sum_j^{C^*,H^*} P_t^{CPI^*} A(z_{j,t}^*)K_{j,t-1}^*}{P_t^{C^*}}, \tag{37}$$

$$\text{where} \quad I_t^* = (1-n)(I_{C,t}^{f^*} + I_{H,t}^{f^*}) + n(I_{C,t}^f + I_{H,t}^f), \tag{38}$$

$$Y_{H,t}^* = (1-n)HI_t^*, \tag{39}$$

and real GDP is $Y_t^* = Y_{C,t}^* + Y_{H,t}^*$.

[3] Throughout we write the market clearing conditions in aggregate quantities which implies that per-capita quantities are multiplied by population size of each country (see Aspachs-Bracons and Rabanal, 2010).

The equilibrium condition in each labor market is

$$\int_0^n L_{j,t}(h)dh = \int_0^n L_{j,t}(i)di \tag{40}$$

$$\text{and} \quad \int_n^1 L^*_{j,t}(f)df = \int_n^1 L^*_{j,t}(i)di, \quad j = C, H. \tag{41}$$

Market clearing in the international assets market is defined as

$$nB_t = -(1-n)B^*_t. \tag{42}$$

The law of motion for the aggregate net foreign assets of the home country is given by

$$nB_t = nR_{t-1}B_{t-1} + (1-n)\left(P^C_t C^{h^*}_t + P^C_t \sum_j^{C,H} I^{h^*}_{j,t}\right) - n\left(P^{C^*}_t C^f_t + P^{C^*}_t \sum_j^{C,H} I^f_{j,t}\right). \tag{43}$$

2.5 Monetary policy

Finally, the model is closed by assuming that the central bank sets the union-wide riskless interest rate according to a Taylor-type rule

$$R^*_t = R^{*\mu_R}_{t-1}\left(\bar{R}^*\left(\frac{\Pi_t}{\bar{\Pi}}\right)^{\mu_\pi}\right)^{(1-\mu_R)} exp\left(u^{R^*}_t\right), \tag{44}$$

where $\bar{R}^*$ stands for the steady state union-wide gross nominal interest rate, Π_t is the union-wide consumer price inflation rate with steady state value of $\bar{\Pi}$ and $u^{R^*}_t$ is a serially uncorrelated monetary policy shock. The union-wide consumer price inflation is defined as the weighted average of home and foreign consumer price inflation. It holds that $\Pi_t = n\Pi^{CPI}_t + (1-n)\Pi^{CPI^*}_t$, where $\Pi^{CPI}_t = \frac{P^{CPI}_t}{P^{CPI}_{t-1}}$ and $\Pi^{CPI^*}_t = \frac{P^{CPI^*}_t}{P^{CPI^*}_{t-1}}$.

3 Bayesian estimation

In this section, we estimate the log-linear approximation of the model described in the previous section using standard Bayesian likelihood methods.[4,5] We begin by describing the dataset we use and some measurement issues that arise. Then, we outline the calibration of model parameters that are kept fixed in the estimation and continue by explaining the

[4]See appendix A for the model's steady state and log-linear equations.

[5]For a detailed description of the Bayesian estimation methodology see An and Schorfheide (2007) and Fernández-Villaverde (2010), among others.

prior distributions and the posterior estimates. Finally, we assess the empirical relevance of our model by comparing the second moments implied by the estimated model with that measured in the data.

3.1 Data and measurement issues

To estimate the model we use the following six quarterly time series for both Ireland and the EMU: real private consumption, real nonresidential investment, real residential investment, consumer prices, house prices and short-term interest rates. We obtain the quantity series and consumer prices from Eurostat. House prices come from the ECB's Statistical Data Warehouse and compile the prices of new and existing dwellings. The interest rate series are from the OECD and measure 3-month interbank rates.

The sample period we consider is from 1997:Q1 to 2008:Q2. We decide to extend our sample period to pre-EMU data as the Irish housing boom already started in the mid-1990s. Moreover, by extending the sample period to pre-EMU data, we are able to capture the effect of the contraction of the interest rate spread between Ireland and the EMU average.[6] The choice of the starting date finally reflects the availability of Eurostat's harmonized national accounts data for Ireland, which is only provided from 1997 onwards. We decided to end our sample period in 2008:Q2 when the fall of Lehmann took place in order to prevent that our estimation results are biased by the nonlinear dynamics of the financial crisis implied by the zero lower bound of interest rates.

We estimate our model using quarterly growth rates of all quantity and price series expressed in percent. We seasonally adjust these series and take first-differences in logs multiplied by 100. We divide interest rates by four to formulate them on a quarterly basis and demean all series prior to estimation. As in the model foreign country aggregates (except interest rates) stand for the rest of the EMU, we adjust the EMU time series such that they correspond to the model equivalents. We do so by subtracting from the EMU growth rate series the Irish counterpart series weighted with Ireland's weight in the EMU harmonized index of consumer prices.[7] Moreover, we follow Adolfson et al. (2007) by introducing observed consumption and nonresidential investment as new variables into the model. Thereby, we take into account that observed consumption and investment are

[6] In general, the inclusion of pre-EMU data can be justified by the assumption that market participants anticipated the formation of the EMU with Ireland as one of its Member States. See Rabanal (2009) and Aspachs-Bracons and Rabanal (2010) for a similar argument in the case of Spain.

[7] See appendix B for a visual representation of the data used in the estimation.

given each as a sum of domestic and foreign produced goods and not as an index over these goods (see equations (3) and (8)). Thus, when we estimate our model we match real private consumption growth to $\Delta\hat{C}_t^{obs} = \tau\Delta\hat{C}_t^h + (1-\tau)\Delta\hat{C}_t^f$ for Ireland and to $\Delta\hat{C}_t^{obs*} = \tau^*\Delta\hat{C}_t^{f^*} + (1-\tau^*)\Delta\hat{C}_t^{h^*}$ for the rest of the EMU. Accordingly, we match real investment growth to $\Delta\hat{I}_t^{obs} = \tau\left(s\Delta\hat{I}_{C,t}^h + (1-s)\Delta\hat{I}_{H,t}^h\right) + (1-\tau)\left(s\Delta\hat{I}_{C,t}^f + (1-s)\Delta\hat{I}_{H,t}^f\right)$ and to $\Delta\hat{I}_t^{obs*} = \tau^*\left(s^*\Delta\hat{I}_{C,t}^{f^*} + (1-s^*)\Delta\hat{I}_{H,t}^{f^*}\right) + (1-\tau^*)\left(s^*\Delta\hat{I}_{C,t}^{h^*} + (1-s^*)\Delta\hat{I}_{H,t}^{h^*}\right)$ respectively, where $s = \frac{\bar{I}_C}{\bar{I}_C+\bar{I}_H}$ and $s^* = \frac{\bar{I}_C^*}{\bar{I}_C^*+\bar{I}_H^*}$.

3.2 Calibrated parameters

A number of parameters are kept fixed. Most of these parameters are related to steady state values of state variables for which the data is noninformative. We apply the same values of parameters for Ireland and the rest of the EMU, if not otherwise specified. Table 1 displays our choice.

Table 1: Calibration of model parameters

Parameter		Value
n	Size of Ireland	0.012
$1-\tau$	Fraction of imported goods from EMU	0.22
$1-\tau^*$	Fraction of imported goods from Ireland	0.007
Δ_H	Size of housing sector	0.1
β	Discount factor	0.99
δ	Housing depreciation rate	0.01
δ_C	Capital depreciation rate in nondurable goods sector	0.025
δ_H	Capital depreciation rate in housing sector	0.025
μ_C	Capital share in nondurable goods sector	0.3
μ_H	Capital share in housing sector	0.2
μ_l	Land share in housing sector	0.1

In particular, we set the size of Ireland, n, to 1.2% which is approximately the country's average weight in the EMU harmonized index of consumer prices. We calibrate the weight of foreign goods in Ireland's consumption and investment index equal to the weight of total imports from EMU Member States in total spending. Based on Eurostat's national account data this implies $1-\tau = 0.22$. Analogous calibration for the weight of home goods in the rest of EMU's respective indices yields $1-\tau^* = 0.007$.[8] The discount factor, β, is set to 0.99 which implies an annual steady state union-wide real interest rate of 4%. We assume the annual depreciation rate of housing to be 4%, this means $\delta = 0.01$. The depreciation

[8]Note that Eurostat provides trade data for the Irish economy only from 2002 onwards.

rate of capital, δ_C respectively δ_H, is equal to 0.025 which is 10% per year. The share of capital in the nondurable goods production function, μ_C, is set to 0.3 which correponds to a labor share of $1-\mu_C = 0.7$. To maintain the same labor share in the housing production function, we assume that $\mu_H = 0.2$, and that the share of land, μ_l, equals 0.1 (see Pariès and Notarpietro, 2008). This assumption guarantess that in the steady state the relative size of the housing sector, $\frac{\bar{Y}_H}{\bar{Y}}$, equals Δ_H. As Aspachs-Bracons and Rabanal (2010) points out, the weight of nondurable goods in total private consumption, α, and Δ_H cannot be determined independently. We numerically solve for α such that Δ_H is 10%, which is roughly the average share of residential investment in total spending from 1997 to 2008 for both Ireland and the EMU.

3.3 Prior distributions and posterior estimates

In table 2 and 3, we report the prior distributions of all structural parameters as well as all AR(1) coefficients and standard deviations of the structural shocks. Following Aspachs-Bracons and Rabanal (2010), we restrict the number of parameters to be estimated by assuming that the parameter values of structural parameters and AR(1) coefficients are the same for Ireland and the rest of the EMU. We only allow the standard deviations of the structural shocks to deviate across countries.[9]

Our choice of prior distributions is as follows. For the standard deviations of the innovations to structural shocks we assume an inverse-gamma distribution, where we have chosen the respective means by trial and error. We set the standard errors to 2 such that a large domain of parameter values is encompassed. AR(1) coefficients are assumed to follow a beta distribution with mean of 0.7 and standard error of 0.1. The habit formation parameter follows a beta distribution with prior mean of 0.66 and the parameters governing the labor supply, ι_L and η, have both a gamma distribution with parameters 1 and 0.5. The elasticity of substitution between home and foreign goods is assumed to follow a normal distribution with prior mean of 1 and standard deviation of 0.5 such that a wide range of feasible parameter values are accommodated.[10] Similar to Smets and Wouters (2003), the elasticity of the cost of adjusting investment follows a normal

[9]We also estimated the model by allowing parameter values of structural parameters and AR(1) coefficients to differ across countries. For most of the parameters we found little difference among the estimated values for Ireland and that for the rest of the EMU. The log marginal likelihood declines to -776.45 compared to -748.54 for the benchmark specification. The results are available upon request.

[10]In general, the evidence on the elasticity of substitution between home and foreign produced goods is mixed with values ranging from 0.1 to 10 and above. See Adjemian et al. (2008) for a brief discussion.

Table 2: Prior and posterior distribution of shock processes*

Parameter		Prior			Posterior		
		Distr.	Mean	St. dev.	Mode	Mean	95% CI
Home and foreign country							
ρ_D	Preference	Beta	0.7	0.1	0.90	0.89	[0.85,0.93]
ρ_H	Preference	Beta	0.7	0.1	0.98	0.97	[0.96,0.99]
ρ_I	Technology	Beta	0.7	0.1	0.33	0.34	[0.22,0.46]
ρ_{AC}	Technology	Beta	0.7	0.1	0.97	0.97	[0.96,0.99]
ρ_{AH}	Technology	Beta	0.7	0.1	0.86	0.84	[0.76,0.92]
ρ_{Risk}	Risk	Beta	0.7	0.1	0.73	0.73	[0.61,0.84]
σ_A	Technology	Invgamma	0.5	2	0.22	0.29	[0.13,0.46]
Home country							
σ_D	Preference	Invgamma	0.5	2	0.57	0.61	[0.49,0.73]
σ_H	Preference	Invgamma	1	2	6.00	7.20	[4.56,9.73]
σ_I	Technology	Invgamma	1	2	4.53	4.61	[3.71,5.47]
σ_{AC}	Technology	Invgamma	1	2	2.55	2.64	[2.00,3.53]
σ_{AH}	Technology	Invgamma	1	2	2.71	2.77	[2.27,3.44]
σ_{Risk}	Risk	Invgamma	0.5	2	0.09	0.09	[0.08,0.11]
Foreign country							
σ_{D^*}	Preference	Invgamma	0.5	2	0.23	0.24	[0.19,0.23]
σ_{H^*}	Preference	Invgamma	1	2	1.03	1.23	[0.80,1.64]
σ_{I^*}	Technology	Invgamma	1	2	0.24	0.24	[0.19,0.30]
σ_{AC^*}	Technology	Invgamma	1	2	0.54	0.56	[0.41,0.71]
σ_{AH^*}	Technology	Invgamma	1	2	0.86	0.89	[0.70,1.11]
σ_{R^*}	Monetary	Invgamma	0.5	2	0.13	0.14	[0.11,0.17]

* Note that the estimated standard deviations of the domestic goods preference and investment shocks do not correspond to the standard deviations of the corresponding shocks in the model described in section 2. This is due to a rescaling of these shocks in the estimation procedure to reduce the degree of nonlinearity (see appendix A).

distribution with prior mean of 4 and standard deviation of 1.5. When we estimate the elasticity of the capital utilization cost function, we follow Smets and Wouters (2007) and estimate a transformation of that parameter. In particular, we define $\upsilon = \frac{\psi}{1-\psi}$, where ψ is normalized to be between 0 and 1. The prior distribution of ψ follows a beta distribution with parameters 0.5 and 0.15. The parameters describing the price setting behavior of firms are assumed to have the same prior distributions across sectors. Thereby, we take no stand on the relative degree of price stickiness between nondurable goods and house prices a priori. For the Calvo parameters we specify a beta distribution loosely centered around a prior mean of 0.66 and for the indexation parameters we assume a beta distribution with a prior mean of 0.5. As in Aspachs-Bracons and Rabanal (2010) the risk premium elasticity has a gamma distribution. The prior mean is 0.01 implying a risk premium of 50 basis points given a reduction of net foreign assets of 50 percentage points. The assumptions for the prior distribution of the Taylor rule coefficients are standard. The interest rate smoothing coefficient has a beta distribution with prior mean of 0.75 and standard deviation of 0.15 and the coefficient on consumer price inflation follows a normal distribution with parameters 1.5 and 0.15.

Table 3: Prior and posterior distribution of structural parameters

Parameter		Prior			Posterior		
		Distr.	Mean	St. dev.	Mode	Mean	95% CI
ϵ	Habits	Beta	0.66	0.15	0.11	0.12	[0.05,0.18]
ι_L	Labor adj. cost	Gamma	1	0.5	1.61	1.86	[1.11,2.63]
η	Labor disutility	Gamma	1	0.5	1.31	1.49	[0.43,2.43]
ι	Elasticity of subst.	Normal	1	0.5	2.25	2.30	[1.82,2.75]
φ	Investment adj. cost	Normal	4	1.5	3.49	3.67	[2.23,4.97]
ψ	Capital utilization	Beta	0.5	0.15	0.65	0.66	[0.48,0.84]
θ_C	Calvo lottery	Beta	0.66	0.15	0.85	0.84	[0.76,0.90]
θ_H	Calvo lottery	Beta	0.66	0.15	0.25	0.26	[0.15,0.39]
γ_C	Price indexation	Beta	0.5	0.15	0.35	0.37	[0.15,0.58]
γ_H	Price indexation	Beta	0.5	0.15	0.42	0.44	[0.20,0.68]
κ	Risk premium	Gamma	0.01	0.0075	0.007	0.012	[0.003,0.022]
μ_R	Taylor rule	Beta	0.75	0.15	0.72	0.70	[0.63,0.77]
μ_π	Taylor rule	Normal	1.5	0.15	1.45	1.48	[1.24,1.69]

In the last three columns of table 2 and 3, we summarize our estimation results by reporting the posterior mode of parameters and standard deviations together with their mean and 95% confidence intervall obtained through draws from the posterior distribution of the model.[11] Focusing on the shock processes, we find that all standard deviations are estimated to be significantly different from zero. We also find that the persistence of all shocks are estimated to be very high, with the exception of the investment shock, which estimated AR(1) coefficient is around 0.34. Among the shocks with the highest persistence is the technology shock in the nondurable goods sector and the housing preference shock. The estimated means of the AR(1) coefficients are both 0.97. These findings are similar to the ones in Pariès and Notarpietro (2008), who find posterior means of ρ_I, ρ_{AC} and ρ_H to be 0.5, 0.92 and 0.99, respectively. Turning to the structural parameters, we estimate the importance of past consumption in utility to be 0.12, which is much smaller compared to the estimates typically reported for the EMU. A robustness check indicates that the estimate is due to the relatively low persitstence in the Irish consumption time series. When we estimate the model by allowing the habit parameter to be different across countries, we find a posterior mean of 0.21 for the rest of the EMU. The posterior mean of the labor reallocation cost parameter is estimated to be 1.86 and is somewhat higher than the estimate reported in Aspachs-Bracons and Rabanal (2010). Iacoviello and Neri (2010) estimate the posterior mean of ι_L to be below one. Hence, our relative high posterior estimate of ι_L reinforces the result of Aspachs-Bracons and Rabanal (2010) that labor market reallocation is more costly in Europe than in the US. For the labor disutility parameter we find a posterior mean of 1.49. However, as the overlapping prior and posterior distribution indicates, there is no information on this parameter in the dataset.[12] Our estimate of the elasticity of substitution between home and foreign goods is around 2.30. This value implies that goods produced in Ireland and the rest of the EMU are perceived as substitutes. We find that the posterior mean of the elasticity of the investment adjustment cost is 3.67, wich is below the assumed prior mean of 4. For the parameter governing the capital utilization cost function the posterior mean is estimated to be 0.66, which yields an elasticity of capital utilization with respect to the rental rate of capital of about 0.5. Regarding the parameters governing the stickiness of prices, we find clear evidence on the existence of asymmetric price rigidities across sectors similar to Aspachs-Bracons and Rabanal (2010) and Pariès and Notarpietro (2008). In particular, we estimated the posterior mean of the

[11] All estimations in our paper are done with Dynare (http://www.dynare.org). The mode of the posterior distribution was calculated with Chris Sim's csminwel. The Metropolis-Hastings algorithm was run with 250000 draws (neglecting the first 50000 draws). A step size of 0.35 yields an average acceptance ratio of 31%.

[12] We display the figures of prior and posterior distributions of all parameters and standard deviations in appendix C.

degree of price stickiness in the nondurable goods sector to be 0.84, corresponding to an average frequency of price adjustment of roughly 6 quarters. In contrast, prices in the housing sector are found to be much more flexible. The posterior mean for θ_H is 0.26, which is equivalent to an average frequency of price adjustment of about 1 quarter. The estimated posterior means for the degrees of price indexation are 0.37 for the nondurable goods sector and 0.44 for the housing sector. The risk premium elasticity is estimated to be almost zero, which is consistent with the interest rate series we use. Finally, we comment on the parameter estimates related to the conduct of monetary policy. For the coefficient on the lagged interest rate we find a posterior mean of 0.70, which is somewhat below the prior belief. The posterior estimate of the coefficient on consumer price inflation is found to be identical to the prior assumptions. The posterior mean of μ_π is 1.48 and the corresponding 95% confidence intervall is ranging from 1.24 to 1.69.

3.4 Second moments

In table 4, we assess the empirical relevance of our model by comparing the volatility of the 12 observables with the model's counterparts. For the latter, we report the posterior mean and the corresponding 95% confidence interval.

Table 4: Comparison of second order moments

St. dev. (%)	Data	Model	
		Mean	95% CI
Home country			
ΔC^{obs}	1.79	1.88	[1.50,2.17]
ΔY_I^{obs}	10.73	10.17	[8.59,11.64]
ΔY_H	4.26	4.46	[3.58,5.24]
π^{CPI}	0.41	0.59	[0.54,0.64]
π^H	2.52	2.88	[2.30,3.32]
$\hat{R}$	0.32	0.30	[0.27,0.33]
Foreign country			
ΔC^{obs*}	0.32	0.49	[0.44,0.56]
ΔY_I^{obs*}	0.91	1.01	[0.88,1.12]
ΔY_H^*	1.37	1.52	[1.28,1.76]
π^{CPI*}	0.24	0.24	[0.22,0.26]
π^{H*}	0.46	0.80	[0.68,0.91]
$\hat{R}^*$	0.23	0.22	[0.19,0.24]

Focusing on Ireland, the model hits the volatilities of the housing-related variables such as residential investment and house prices. Moreover, the estimated model replicates the volatility of consumption of nondurable goods, nonresidential investment and interest rates. For consumer prices, however, the model estimates imply a slightly higher standard deviation than measured in the data. Turning to the rest of the EMU, the model replicates the standard deviations of nonresidential investment, residential investment, consumer prices and interest rates, but overestimates the standard deviations of nondurable goods consumption and house prices. Overall, the estimated model explains the variation observed in the data quite reasonable. For both countries the model replicates the relative volatility differentials between real aggregates as well as prices, and, most importantly, for most of the observables the actual standard deviation lies well within the corresponding 95% confidence interval implied by model. In addition, the model accounts for the higher volatility of all Irish observables compared with that of the rest of the EMU.

4 Irish housing market dynamics

In this section, we use our estimated model to gain insights into the dynamics of the Irish housing market. We begin by decomposing the variances of the Irish observables to examine the sources of housing market fluctuations. Next, we present the historical decomposition of residential investment and house prices which allows us to assess the relative importance of each of the structural shocks for the variation of the observables over the sample period. Finally, we apply some standard impulse response analysis to discuss the propagation mechanisms implied by our model.

4.1 Variance decomposition

Table 5 displays the results from the variance decomposition of the Irish observables. Similar to what Aspachs-Bracons and Rabanal (2010) reports for Spain, we find that domestic housing preference and technology shocks are the main determinants of the overall fluctuations in the Irish housing market. In particular, housing technology shocks explain about 70% of the variance of residential investment and housing preference shocks account for 25%. For house prices the opposite picture emerges. The bulk of the variation of house prices is explained by housing preference shocks, which is 67%. Somewhat surprisingly, but in line with what Aspachs-Bracons and Rabanal (2010) show for Spain, we find that monetary policy and risk premia shocks have a negligible effect on the fluctuations in the Irish housing market. Togehter, they account for only around 1% of the variation of residential investment and generate roughly 3% of the variance of house prices.

Table 5: Unconditional variance decomposition (%)

	ΔC^{obs}	ΔY_I^{obs}	ΔY_H	π^{CPI}	π^H	$\hat{R}$
Home and foreign country						
u^A	0.02	0.00	1.23	0.11	0.00	0.16
Home country						
u^{AC}	91.32	4.90	3.29	24.93	29.11	24.58
u^{AH}	0.00	0.00	69.25	0.00	0.17	0.00
u^I	1.41	94.80	0.30	6.17	0.22	10.80
u^D	0.07	0.21	0.02	62.23	0.03	0.10
u^H	0.01	0.02	24.98	0.00	66.48	0.02
u^{Risk}	1.59	0.02	0.20	0.13	0.83	16.63
Foreign country						
u^{AC^*}	1.60	0.03	0.24	3.17	1.33	13.32
u^{AH^*}	0.00	0.00	0.00	0.00	0.00	0.00
u^{I^*}	0.01	0.01	0.00	0.35	0.02	1.06
u^{D^*}	0.28	0.01	0.04	0.89	0.20	16.32
u^{H^*}	0.00	0.00	0.00	0.00	0.00	0.01
u^{R^*}	2.94	0.02	0.45	2.02	1.62	17.01

4.2 Historical decomposition

In figure 2 and 3, we present the historical contribution of the various structural shocks to the movements of residential investment and house prices over the sample period. Since we have 12 structural shocks in the model, we group monetary policy and risk premium shocks into one category and do the same for the shocks coming from the rest of the EMU (excluding monetary policy shocks), the EMU-wide technology shock and initial conditions.

In line with the results from the variance decomposition, domestic housing technology and preference shocks are the main contributors to the movements of residential investment. Over the sample period technology shocks play the dominant role, with housing preference shocks having sometimes an offsetting effect. Towards the end of the sample period, however, when residential investment dramatically drops, large negative housing technology and preference shocks are observed. The historical decomposition of house prices shows that housing preference shocks are the main drivers during the whole sample period. In particular, the severe downturn in house prices starting in the second quarter of 2006 is mostly accounted for by large negative housing preference shocks. Likewise,

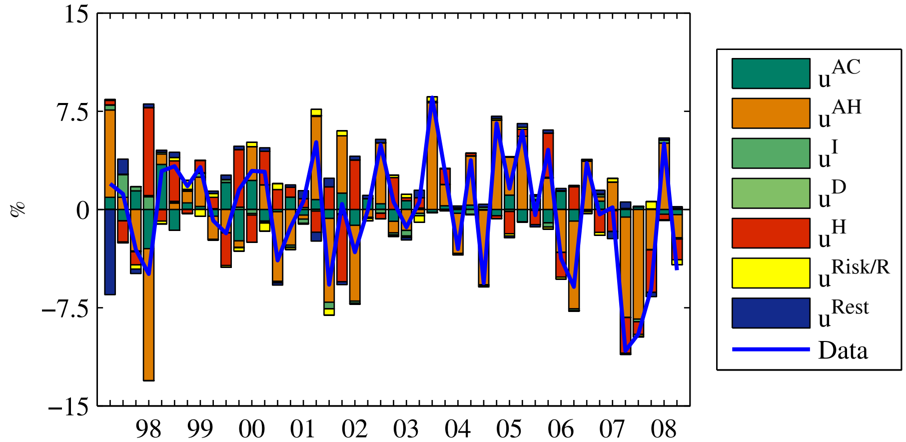

Figure 2: Historical decomposition of real residential investment in Ireland (q-o-q growth rate)

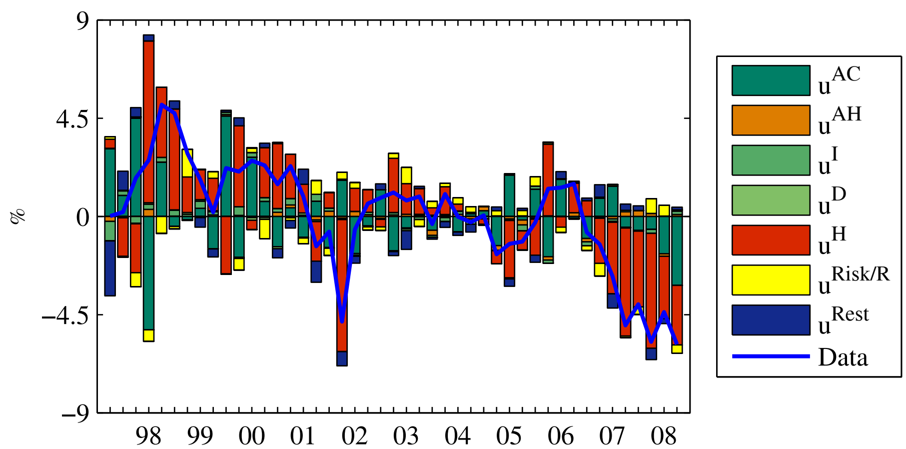

Figure 3: Historical decomposition of house prices in Ireland (q-o-q growth rate)

technology shocks emerging in the nondurable goods sector have their impact on house price fluctuations, but they are not dominant. As it is already clear from the previous section, monetary shocks do not contribute much to the overall variability of Irish house prices. Interestingly, monetary shocks are neither very supportive between 2004 to 2006, when monetary conditions were pretty loose, nor play a more important role around the slump of house prices towards the end of the sample period, when monetary conditions tightened. Also, we do not find that monetary shocks contributed much to house price variations at the beginning of the sample, when the risk premium essentially vanished.

4.3 Impulse responses

In figures 4-6 we focus on the propagation of housing-related and monetary shocks by standard impulse response analysis to sharpen the results from the variance and historical decomposition. For each of the shocks considered, we plot the posterior mean response together with the 95% confidence interval of key variables.

In figure 4, we display the responses to a positive housing technology shock. By standard mechanisms, a positive technology shock in the housing sector leads to an increase in residential investment and to a decline in house prices. Also, consumer prices slightly drop and consumption of nondurable goods and nonresidential investment increase. However, these effects are small and not significant at the 95% confidence intervall. During the quarters following the shock, residential investment gradually reverts back to the baseline. By contrast, the fall in house price inflation is rather short-lived. Finally, the figure also indicates that domestic interest rates do not move in response to the shock.

In figure 5, we look at a positive housing preference shock. In response to the shock, residential investment and house prices significantly rise. While house price inflation quickly reverts back to zero, the effect on residential investment is quite persistent such that it is well above its steady state value after 15 quarters. Nonresidential investment significantly increases in a humped-shape fashion, but the quantitative effect is relatively small. Like in the case of the housing technology shock, the spillover effects on nondurable consumption and consumer price inflation are not significant and the domestic interest rate remains unchanged.

In figure 6 we provide responses to a positive monetary policy shock.[13] In response to the monetary policy tightening domestic interest rates significantly rise and all aggregate

[13]The responses of the selected variables to a risk premium shock are qualitatively the same.

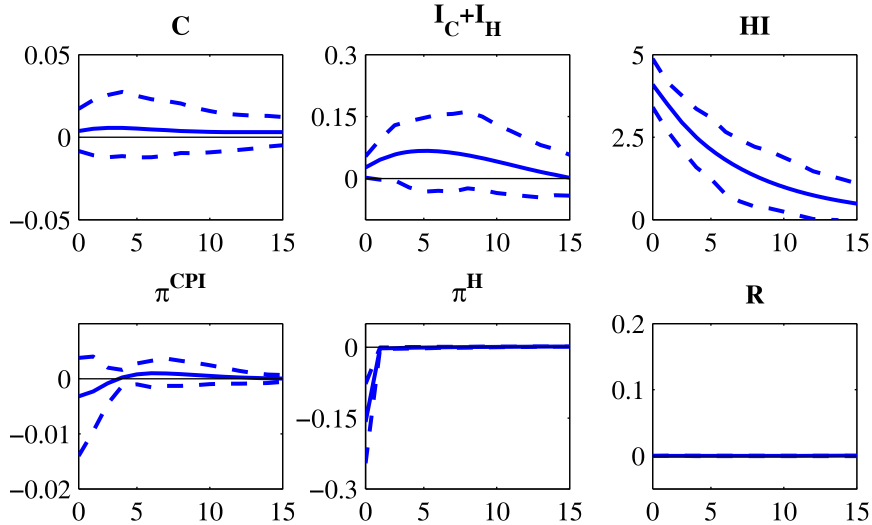

Figure 4: Posterior impulse responses to a technology shock in the housing sector

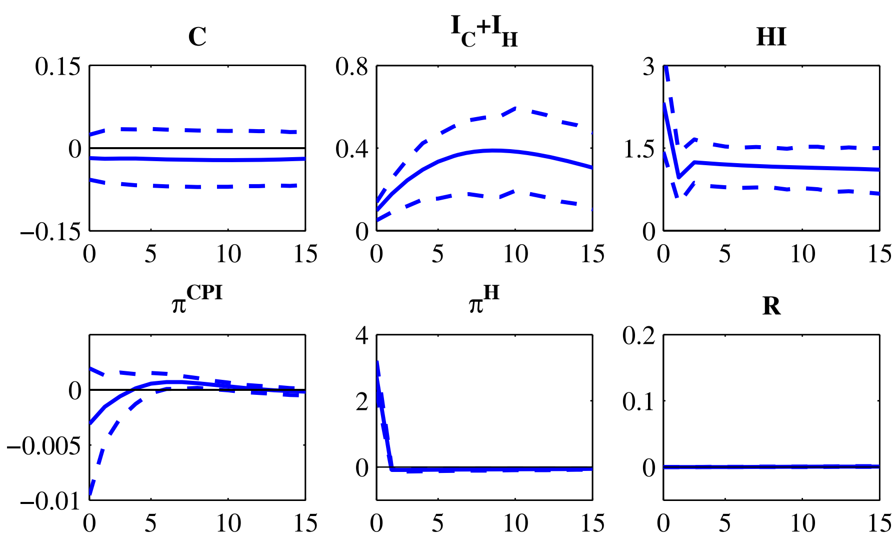

Figure 5: Posterior impulse responses to a housing preference shock

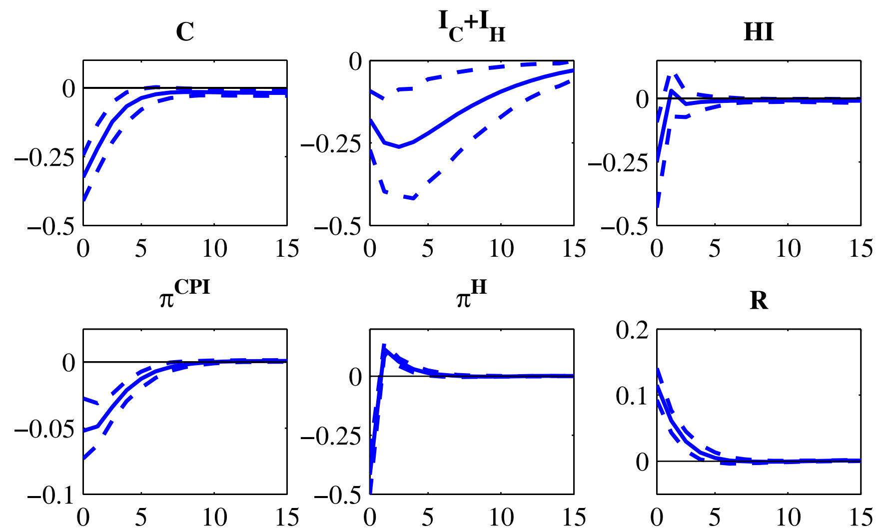

Figure 6: Posterior impulse responses to a monetary policy shock

quantities as well as inflation rates significantly drop. Ultimately all variables revert back to the baseline. The immediate drop of residential investment and consumption of nondurable goods reconciles the positive co-movement of these quantities in response to a monetary policy shock that is generally found using VAR models (see, for instance, Calza et al., 2011; Aspachs-Bracons and Rabanal, 2011; Monacelli, 2009). Yet, as argued by Barsky et al. (2007) a standard NK model is at odds with these facts. If durable goods prices are fully flexible and consumption goods prices are sticky, a monetary tightening will imply that nondurable goods consumption decreases, while durable goods consumption increases due to the fall of the relative price. Two features of our model solve the co-movement problem. First and foremost, the introduction of costly labor reallocation limits the mobility of labor supply across sectors and consequently helps in restricting housing production in response to the monetary tightening (see Aspachs-Bracons and Rabanal, 2011). Second, our estimate of the Calvo parameter in the housing sector implies that house prices are less than fully flexible. Thus, the fall in real house prices in response to the monetary contraction is dampened relative to the case of fully flexibel house prices.

5 Robustness analysis

5.1 The role of housing collateral

Several authors have stressed the role of housing collateral in determining economic fluctuations (see, for instance, Iacoviello, 2005; Iacoviello and Neri, 2010; Monacelli, 2009; Pariès and Notarpietro, 2008; Calza et al., 2011). In these models it is assumed that some households face credit constraints in the sense that they can borrow money only to the extent they can post housing collateral. As a consequence, rising house prices increases the funding they can get and hence stimulates their consumption.

In this subsection, we test whether adding this feature improves the fit of our model to the data. First, we briefly explain how we incorporate housing collateral into the model.[14] We assume that a fraction of households $(1-\omega)$ in each country behaves like the households we have already presented. Henceforth, we label these households as *savers*. The reaming fraction of households (ω) in each country is labeled as *borrowers*. These households derive utility from consumption of nondurable goods and housing and disutility from labor as savers do, but neither accumulate capital nor own firms and land. Moreover, borrowers are less patient than savers, which means that they have a lower intertemporal discount factor than savers.[15] In addition, borrowers have no access to international asset markets. The only way they can obtain credit is by borrowing from the savers of the same country at the country-specific interest rate (see Pariès and Notarpietro, 2008; Aspachs-Bracons and Rabanal, 2010). The credit constraint borrowers face is described in nominal terms as follows

$$S_t^B \leq (1-\chi)(1-\delta)E_t\left(\frac{P_{t+1}^H H_t^B}{R_t}\right), \tag{45}$$

where S_t^B stands for credit received from savers and $1-\chi$ is the loan-to-value ratio.

Next, we estimate the extended model with the same methods described in section 3. Therefore, we calibrate the loan-to-value ratio. We assume that χ is 0.25. This implies a loan-to-value ratio of 75%, which is a reasonable value for both Irleand and the rest of the EMU (see Calza et al., 2011). For simplicity, we follow Aspachs-Bracons and Rabanal (2010) and assume that the parameters describing the behavior of borrowers are the same as for savers such that the only new parameter that we have to estimate is the fraction of borrowers ω. In the baseline specification of the extended model, we assume that ω has

[14] An appendix with the full set of equations is available upon request.

[15] For the discount factor of borrowers we assume a value of 0.97.

a beta distribution with parameters 0.35 and 0.05 as in Pariès and Notarpietro (2008). However, to check the sensitivity of the results to these parameters values, we reestimate the model by choosing a prior mean of 0.5, and, by increasing the standard deviation threefold. Table 6 summarizes the estimation results.

Table 6: Estimation statistics

Model	Parameter		Prior			Posterior		log L.
			Distr.	Mean	St. dev.	Mean	95% CI	
No collat.								-748.54
Collat.	ω	Borrowers	Beta	0.35	0.05	0.24	[0.18,0.29]	-766.20
	ω	Borrowers	Beta	0.50	0.05	0.42	[0.33,0.50]	-776.38
	ω	Borrowers	Beta	0.35	0.15	0.09	[0.02,0.15]	-760.41

In the last column of table 7, we report the log marginal likelihood of each model based on Geweke (1999)'s modified harmonic mean estimator. First of all, we find that the log marginal likelihood difference between the model without housing collateral and the models with housing collateral ranges from 12 to 28, which implies that the data provides at least "substantial" evidence in favor of the model without housing collateral.[16] Moreover, we find that the fraction of borrowers is not well identified in the data. By setting the prior mean of ω at 0.35, we find a posterior mean of 0.24 and when we increase the prior mean to 0.5, the posterior mean moves to 0.34. Finally, by increasing the standard deviation of the prior distribution of ω, we estimate the posterior mean to be 0.09. Again, a look at the log marginal likelihood of these models reveals that the data favors a low fraction of borrowers. The log marginal likelihood of the model with the highest share of borrowers with respect to the model with the lowest is -776.38 versus -760.41.

All in all, our results are in line with Aspachs-Bracons and Rabanal (2010). However, while they report only little evidence in favor of the model without housing collateral, we can find more substantial evidence that housing collateral does not lead to an improvement of the model fit to the data. This reinforces our choice not to include this feature in the baseline specification of our model.

5.2 Tracing back housing preference shocks

From the variance and historical decomposition we know that housing preference shocks play the dominant role in explaining the recent house price dynamics in Ireland. As housing

[16] See Kass and Raftery (1995) for a classification.

preference shocks capture all exogenous shifts in the demand for housing, it is natural to ask whether they can be further traced back to unmodeled demand factors that typically have been considered in the empirical literature as relevant determinants of house prices (see Malzubris, 2008, for a survey). In particular, we follow the approach of Iacoviello and Neri (2010) and test whether the estimated innovations to housing preferences (u_t^H) can survive simple exogeneity tests by estimating the following equation[17]

$$u_t^H = \alpha u_{t-1}^H + \beta x_{t-1} + v_t, \tag{46}$$

where v_t is an IID-normal process with zero mean and x_t is a vector containing explanatory variables for housing demand.

Our choice for the set of explanatory variables is the following: To capture the hypothesis that demographic factors account for shifts in the demand for housing, we consider young population (between ages 25 and 44) and total population (other). We also add real disposable income to check whether it feeds back into housing demand. To capture the hypothesis that a lax access to mortgage finance contributed to the house price boom, we also add house mortgage finance. In addition, we include real interest rates and consumer price inflation into the set of explanatory variables even though they have already been included into our model. Given our result that monetary factors do not account for the fluctuations in the Irish housing market, the introduction of the real interest rate is meant to assess the robustness of this results. In the same vein, we consider consumer price inflation to test whether inflation illusion matters for housing demand. If inflation illusion matters, one should expect that consumer price inflation has a stronger impact on housing demand than the mechanisms of our model allow for (Iacoviello and Neri, 2010). Finally, we follow Rae and van den Noord (2006) and consider a dummy variable to take account of a confidence crisis in 2001, which was due to an announced tax program to discourage investors from buying rental property.

We construct total population (other) as total population minus young population. We obtain the population numbers from the Central Statistics Office. These series are at an annual frequency such that we convert them by linear interpolation into quarterly series. We get nominal disposable income from Eurostat and deflate it with the consumer price index.[18] The source of the time series for private mortgage finance is the Central Bank

[17]The same approach has been used in Neri (2010).

[18]Note that nominal disposable income is only available be from 1998 onwards.

of Ireland. The real interest rate is constructed as $\hat{R}_t - \pi_t^{CPI}$. In the regression, we enter all variables, except real interest rates and consumer price inflation, in first-differences in logs multiplied by 100. Table 7 displays our results.

Table 7: The predictability of housing preference innovations

Variable	Coefficient	Std. error	T-stat.	Prob.
Innovation	0.076	0.123	0.620	0.5393
Population growth (25-44)	16.622	7.718	2.154	0.038
Population growth (other)	-39.761	13.713	-2.899	0.007
Real disposable income growth	0.518	0.261	1.986	0.056
Mortgage finance growth	0.576	0.298	1.934	0.062
Consumer price inflation	3.490	1.444	2.416	0.022
Real interest rate	-1.695	1.813	-0.935	0.357
Dummy	-15.995	0.761	-21.013	0.000
Sample	1998:Q3-2008:Q2			
R^2	0.621			
Durbin-Watson stat.	2.245			
Q(4), Q(8), Q(12)	5.609, 10.511, 13.191			

We find that all variables have the expected sign. The only exception to this is total population growth (other) that has a negative impact on the estimated innovations to housing preferences. The coefficient on the real interest rate is negative but not significant. All other explanatory variables are significant at the 10% level. In particular, we find that housing preference innovations depend positively on young population, real dispsoable income and mortgage finance. We also find that consumer price inflation has a positive impact on the shifts in the demand for housing. This finding supports the hypothesis that inflation illusion matters for housing demand as consumer price inflation is found to have a stronger effect on housing demand than the mechanisms of our model imply.

Overall, the combined explanatory power of the exogenous regressors is around 62%. Note that a significant part of the fit of the regression is explained by the dummy variable. When we omit the dummy variable from the regression, R^2 falls to 43%.[19] In figure 7, we provide a visual representation of actual versus fitted innovations from the regression reported in table 7.

[19] This has no effect on the significance levels of the remaining regressors.

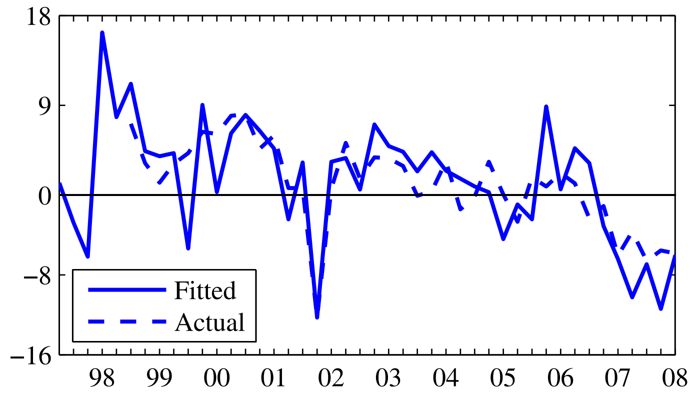

Figure 7: Actual innovations to housing preferences and fitted values.

6 Conclusion

In this paper we study the drivers of the fluctuations in the Irish housing market by developing and estimating a dynamic stochastic general equilibrium (DSGE) model of Ireland as a member of the European Monetary Union (EMU). We estimate the model with Bayesian methods using six quarterly time series for both Ireland and the rest of the EMU for the period from 1997:Q2 to 2008:Q2. Our posterior estimates are well in line with the ones obtained in the housing DSGE literature with euro area data such as Pariès and Notarpietro (2008) and Aspachs-Bracons and Rabanal (2010). Most importantly, we find clear evidence on the existence of asymmetric price rigidities across sectors and reinforce the finding of Aspachs-Bracons and Rabanal (2010) that labor market reallocation is more costly in Europe than in the US. Regarding the drivers of fluctuations in the Irish housing market, we find that housing preference and technology shocks are the main contributors to movements in house prices and residential investment. In particular, housing technology shocks explain about 70% of the variance of residential investment and housing preference shocks account for about 67% of the variation of house prices as well as for about 25% of the variation of residential investment. Similar to what Aspachs-Bracons and Rabanal (2010) reports for Spain, we find that monetary factors played a negligible role in the recent Irish housing market cycle. In a robustness analysis, we ask whether adding housing collateral improves the model fit to the data. In line with Aspachs-Bracons and Rabanal (2010), we find that the share of borrowers is weakly identified and that a model comparison based on the log marginal likelihood favors the model without housing collateral. Following the approach of Iacoviello and Neri (2010), we investigate if the estimated innovations to housing preferences can be further traced back to unmodeled shifts in the demand for housing that have been considered in the empirical literature as important determinants of Irish house prices. Our results suggest that a good part of the estimated housing preference shocks can be explained by demographic factors, real disposable income and mortgage finance. Also consumer price inflation is found to be positively related to housing demand shocks. As it has already been included in our model, this may be explained by inflation illusion when people decide to invest in housing.

It becomes obvious from our analysis of the recent housing market dynamics in Ireland that housing preference shocks generate the bulk of the variation of house prices. This result is generally obtained in the housing DSGE literature: It is similar to what Aspachs-Bracons and Rabanal (2010) find for Spain, Pariès and Notarpietro (2008) for the EMU, and Iacoviello and Neri (2010) for the US. As we show by using a standard regression analysis, the estimated innovations to housing preferences can be further traced back to unmodeled shifts in the demand for housing typically considered as important determinants of housing demand. Hence, it remains a task for future research to encompass those unmodeled demand factors and give more explicit structural interpretation to them inside the model, all in all strengthening the empirical veracity of the recent generation of housing DSGE models.

A The log-linear model

Here, we present the model's steady state and log-linear equations. Variables with a bar stand for steady state levels, variables with a hat describe log-deviations. A * indicates foreign country variables.

A.1 Steady state

In the steady state we assume inflation rates, the trade balance and the net international positions of both countries to be zero. As a consequence, we only solve for the per capita values of the home country and use the same values for the foreign country (see Aspachs-Bracons and Rabanal, 2010).

Prices are constant markups ($\lambda = 0.1$) over nominal marginal costs which gives $\bar{P}^j = (1+\lambda)\bar{MC}_j$ (for $j = C, H$). It holds that

$$\bar{MC}_C = \frac{(\bar{R}_C)^{\mu_C}(\bar{W}_C)^{1-\mu_C}}{\mu_C^{\mu_C}(1-\mu_C)^{1-\mu_C}} \tag{47}$$

$$\text{and} \quad \bar{MC}_H = \frac{(\bar{R}_l)^{\mu_l}(\bar{R}_H)^{\mu_H}(\bar{W}_H)^{1-\mu_l-\mu_H}}{\mu_l^{\mu_l}\mu_H^{\mu_H}(1-\mu_l-\mu_H)^{1-\mu_l-\mu_H}}, \tag{48}$$

where $\bar{R}_j = \frac{1-\beta(1-\delta_j)}{\beta}$ (for $j = C, H$) and $\bar{R}_l = \frac{\mu_l}{1-\mu_l-\mu_H}\frac{\bar{W}_H \bar{L}_H}{\bar{l}}$. Assuming that $\bar{P}^j = 1$ (for $j = C, H$) and that wages are equal across sectors ($\bar{W} = \bar{W}_C = \bar{W}_H$), it follows that

$$\bar{l} = \left((\bar{W})^{1-\mu_H} \frac{(1-\lambda)\left(\bar{L}_H \frac{\mu_l}{1-\mu_l-\mu_H}\right)^{\mu_l}(\bar{R}_H)^{\mu_H}}{\mu_l^{\mu_l}\mu_H^{\mu_H}(1-\mu_l-\mu_H)^{1-\mu_l-\mu_H}} \right)^{\frac{1}{\mu_l}}. \tag{49}$$

Sector-specific capital stocks are given by

$$\bar{K}_C = \frac{\mu_C}{1-\mu_C}\frac{\bar{W}\bar{L}_C}{\bar{R}_C} \tag{50}$$

$$\text{and} \quad \bar{K}_H = \frac{\mu_H}{1-\mu_l-\mu_H}\frac{\bar{W}\bar{L}_H}{\bar{R}_H}. \tag{51}$$

The household's consumption of nondurable goods is

$$\bar{C} = \left(\frac{\alpha}{1-\epsilon}\right)\bar{W}\bar{L}^{-\eta}. \tag{52}$$

The allocation of nondurable goods consumption between home and foreign goods is given by $\bar{C}^h = \tau\bar{C}$ and $\bar{C}^f = (1-\tau)\bar{C}$. The household's relative consumption of nondurable goods is defined as

$$\bar{\Omega} \equiv \frac{\bar{C}}{\bar{H}} = \frac{\alpha}{1-\alpha}\frac{1}{1-\epsilon}\left(1-\beta(1-\delta)\right). \tag{53}$$

The housing stock is $\bar{H} = \bar{C}\bar{\Omega}^{-1}$ and the household's residential investment is given by $\bar{HI} = \delta\bar{H}$. Investment in additional capital is $\bar{I}_j = \delta_j\bar{K}_j$ and the demand for home and foreign investment goods are respectively $\bar{I}_j^h = \tau\bar{I}_j$ and $\bar{I}_j^f = (1-\tau)\bar{I}_j$ (for $j = C, H$). Sector-specific labor supply is $\bar{L}_C = (1-\Delta_H)\bar{L}$ and $\bar{L}_H = \Delta_H\bar{L}$ respectively. The household's total supply of labor is[20]

$$\frac{\alpha}{1-\epsilon}\bar{W}\left(1+\delta\bar{\Omega}^{-1}\right) - \bar{W}\bar{L}^{1+\eta} - \bar{\Sigma}\bar{L}^{\eta} = 0, \tag{54}$$

$$\text{where} \quad \bar{\Sigma} = \sum_j^{C,H}(\bar{R}_j - \delta_j)\bar{K}_j + \bar{R}_l\bar{l} + \sum_j^{C,H}\bar{Div}_j. \tag{55}$$

Technologies are given by $\bar{Y}_C(i) = (\bar{K}_C)^{\mu_C}\left(\bar{L}_C\right)^{1-\mu_C}$ and $\bar{Y}_H(i) = (\bar{l})^{\mu_l}(\bar{K}_H)^{\mu_H}(\bar{L}_H)^{1-\mu_l-\mu_H}$ (for $i \in [0,n]$). Market clearing in the nondurable goods sector is given as $\bar{Y}_C = n\bar{Y}_C(i) = n\bar{C} + n\bar{I}$, where $n\bar{I} = n(\bar{I}_C + \bar{I}_H)$, and in the housing sector market clearing implies $\bar{Y}_H = n\bar{Y}_H(i) = n\bar{IH}$. GDP equals $\bar{Y} = \bar{Y}_C + \bar{q}\bar{Y}_H$, where $\bar{q} = 1$. Dividends received by the household are defined as $\sum_j^{C,H}\bar{Div}_j = \frac{\lambda}{1+\lambda}\bar{Y}$.

A.2 Log-linear approximation

A.2.1 Home country

Households: The *consumption of nondurable goods* is

$$\hat{C}_t = \frac{1}{1+\epsilon}E_t\hat{C}_{t+1} + \frac{\epsilon}{1+\epsilon}\hat{C}_{t-1} - \frac{1-\epsilon}{1+\epsilon}\left(\hat{R}_t - E_t\pi_{t+1}^{CPI}\right). \tag{56}$$

Home and *foreign nondurable goods consumption* are given by[21]

$$\hat{C}_t^h = (1-\iota(1-\tau))\hat{\zeta}_t^D + \iota(1-\tau)\widehat{tot}_t + \hat{C}_t \tag{57}$$

$$\text{and} \quad \hat{C}_t^f = \iota\tau\hat{\zeta}_t^D - \iota\tau\widehat{tot}_t + \hat{C}_t. \tag{58}$$

[20]This expression is numerically solved for $\bar{L}$.
[21]Note that the domestic goods preference shock is rescaled by $1-\iota$.

The *terms of trade* for the home country evolve as $\widehat{tot}_t = \hat{P}_t^{C*} - \hat{P}_t^C$. For *housing* it holds that

$$\hat{\zeta}_t^H - \hat{H}_t + \frac{1}{1-\epsilon}\hat{C}_t - \frac{\epsilon}{1-\epsilon}\hat{C}_{t-1} = (1-\beta(1-\delta))^{-1}\left[\hat{q}_t + \beta(1-\delta)(\hat{R}_t - E_t\pi_{t+1}^{CPI} - E_t\hat{q}_{t+1})\right] \tag{59}$$

The *accumulation equation of the housing stock* is $\hat{H}_t = \delta\hat{H}I_t + (1-\delta)\hat{H}_{t-1}$. The *real house price* is defined as $\hat{q}_t = \hat{P}_t^H - \hat{P}_t^{CPI}$. The *consumer price level* is $\hat{P}_t^{CPI} = \pi_t^{CPI} + \hat{P}_{t-1}^{CPI}$, where the *consumer price inflation* is given as

$$\pi_t^{CPI} = \tau\pi_t^C + (1-\tau)\pi_t^{C*} + \tau\left(\hat{\zeta}_t^D - \hat{\zeta}_{t-1}^D\right). \tag{60}$$

The *labor supply equations* are

$$\frac{1}{1-\epsilon}\hat{C}_t - \frac{\epsilon}{1-\epsilon}\hat{C}_{t-1} + [\iota_L + (\eta-\iota_L)(1-\Delta_H)]\,\hat{L}_{C,t} + (\eta-\iota_L)\Delta_H\hat{L}_{H,t} = \hat{w}_{C,t}, \tag{61}$$

$$\frac{1}{1-\epsilon}\hat{C}_t - \frac{\epsilon}{1-\epsilon}\hat{C}_{t-1} + [\iota_L + (\eta-\iota_L)\Delta_H]\hat{L}_{H,t} + (\eta-\iota_L)(1-\Delta_H)\hat{L}_{C,t} = \hat{w}_{H,t}, \tag{62}$$

where $\hat{w}_{j,t} = \hat{W}_{j,t} - \hat{P}_t^{CPI}$ is the *real wage* in sector $j = C, H$. The *investment equations* for capital in the nondurable goods and housing sector are[22]

$$\hat{I}_{C,t} = \frac{1}{1+\beta}\hat{I}_{C,t-1} + \frac{\beta}{1+\beta}E_t\hat{I}_{C,t+1} + \frac{1}{\varphi(1+\beta)}\hat{Q}_{C,t} + \hat{\zeta}_t^I, \tag{63}$$

$$\hat{I}_{H,t} = \frac{1}{1+\beta}\hat{I}_{H,t-1} + \frac{\beta}{1+\beta}E_t\hat{I}_{H,t+1} + \frac{1}{\varphi(1+\beta)}\hat{Q}_{H,t} + \hat{\zeta}_t^I. \tag{64}$$

The corresponding *Q equations* are defined as

$$\hat{Q}_{C,t} = -(\hat{R}_t - E_t\pi_{t+1}^{CPI}) + \frac{\bar{R}_C}{1-\delta_C+\bar{R}_C}E_t\hat{r}_{C,t+1} + \frac{1-\delta_C}{1-\delta_C+\bar{R}_C}E_t\hat{Q}_{C,t+1}, \tag{65}$$

$$\hat{Q}_{H,t} = -(\hat{R}_t - E_t\pi_{t+1}^{CPI}) + \frac{\bar{R}_H}{1-\delta_H+\bar{R}_H}E_t\hat{r}_{H,t+1} + \frac{1-\delta_H}{1-\delta_H+\bar{R}_H}E_t\hat{Q}_{H,t+1}, \tag{66}$$

where $\hat{r}_{C,t} = \hat{R}_{C,t} - \hat{P}_t^{CPI}$ and $\hat{r}_{H,t} = \hat{R}_{H,t} - \hat{P}_t^{CPI}$. Demand for *home* and *foreign investment goods* is

$$\hat{I}_{j,t}^h = (1-\iota(1-\tau))\hat{\zeta}_t^D + \iota(1-\tau)\widehat{tot}_t + \hat{I}_{j,t} \tag{67}$$

$$\text{and} \quad \hat{I}_{j,t}^f = \iota\tau\hat{\zeta}_t^D - \iota\tau\widehat{tot}_t + \hat{I}_{j,t}, \quad \text{for} \quad j = C, H. \tag{68}$$

[22]Note that the efficiency shock is rescaled by $\varphi(1+\beta)$.

The *capital accumulation equations* are given by

$$\hat{K}_{C,t} = \delta_C \varphi(1+\beta)\hat{\zeta}_t^I + \delta_C \hat{I}_{C,t} + (1-\delta_C)\hat{K}_{C,t-1} \tag{69}$$

$$\text{and} \quad \hat{K}_{H,t} = \delta_H \varphi(1+\beta)\hat{\zeta}_t^I + \delta_H \hat{I}_{H,t} + (1-\delta_H)\hat{K}_{H,t-1}. \tag{70}$$

Capital utilization rates are $\hat{z}_{C,t} = \frac{1}{\upsilon}\hat{r}_{C,t}$ and $\hat{z}_{H,t} = \frac{1}{\upsilon}\hat{r}_{H,t}$.

Firms: The *production functions* in the nondurable goods sector and the housing sector are

$$\hat{Y}_{C,t} = u_t^A + \hat{\zeta}_t^{AC} + \mu_C \hat{\tilde{K}}_{C,t} + (1-\mu_C)\hat{L}_{C,t}, \tag{71}$$

$$\hat{Y}_{H,t} = u_t^A + \hat{\zeta}_t^{AH} + \mu_H \hat{\tilde{K}}_{H,t} + (1-\mu_l-\mu_H)\hat{L}_{H,t}. \tag{72}$$

Effective capital stocks are defined as $\hat{\tilde{K}}_{j,t} = \hat{z}_{j,t} + \hat{K}_{j,t-1}$ for $j = C, H$. *Nominal marginal costs* are

$$\widehat{MC}_{C,t} = -u_t^A - \hat{\zeta}_t^{AC} + \mu_C \hat{R}_{C,t} + (1-\mu_C)\hat{W}_{C,t} \tag{73}$$

$$\widehat{MC}_{H,t} = -u_t^A - \hat{\zeta}_t^{AH} + \mu_l \hat{R}_{l,t} + \mu_H \hat{R}_{H,t} + (1-\mu_l-\mu_H)\hat{W}_{H,t}. \tag{74}$$

The *optimal nominal rental rates of capital* and *land* are

$$\hat{R}_{C,t} = \hat{W}_{C,t} + \hat{L}_{C,t} - \hat{\tilde{K}}_{C,t}, \tag{75}$$

$$\hat{R}_{H,t} = \hat{W}_{H,t} + \hat{L}_{H,t} - \hat{\tilde{K}}_{H,t}, \tag{76}$$

$$\hat{R}_{l,t} = \hat{W}_{H,t} + \hat{L}_{H,t}. \tag{77}$$

The *evolution of inflation* in both sectors is

$$\pi_t^j = \phi_f E_t \pi_{t+1}^j + \phi_b \pi_{t-1}^j + \kappa_j \widehat{mc}_{j,t}, \quad \text{for} \quad j = C, H, \tag{78}$$

where $\phi_f = \frac{\beta}{1+\beta\gamma_j}$, $\phi_b = \frac{\gamma_j}{1+\beta\gamma_j}$ and $\kappa_j = \frac{(1-\theta_j)(1-\beta\theta_j)}{\theta_j}\frac{1}{1+\beta\gamma_j}$. For the *real marginal costs* it holds that $\widehat{mc}_{C,t} = \widehat{MC}_{C,t} - \hat{P}_t^C$ and $\widehat{mc}_{H,t} = \widehat{MC}_{H,t} - \hat{P}_t^H$. *Sectoral prices* are defined as $\hat{P}_t^j = \pi_t^j + \hat{P}_{t-1}^j$, for $j = C, H$.

A.2.2 Foreign country

Households: The *consumption of nondurable goods* is

$$\hat{C}_t^* = \frac{1}{1+\epsilon} E_t \hat{C}_{t+1}^* + \frac{\epsilon}{1+\epsilon} \hat{C}_{t-1}^* - \frac{1-\epsilon}{1+\epsilon} \left(\hat{R}_t^* - E_t \pi_{t+1}^{CPI^*} \right). \tag{79}$$

Home and *foreign nondurable goods consumption* are given by

$$\hat{C}_t^{f^*} = (1 - \iota(1-\tau^*)) \hat{\zeta}_t^{D^*} - \iota(1-\tau^*) \widehat{tot}_t + \hat{C}_t^*, \tag{80}$$

$$\text{and} \quad \hat{C}_t^{h^*} = \iota\tau^* \hat{\zeta}_t^{D^*} + \iota\tau^* \widehat{tot}_t + \hat{C}_t^*. \tag{81}$$

For *housing* it holds that

$$\hat{\zeta}_t^{H^*} - \hat{H}_t^* + \frac{1}{1-\epsilon} \hat{C}_t^* - \frac{\epsilon}{1-\epsilon} \hat{C}_{t-1}^* = (1-\beta(1-\delta))^{-1} \left[\hat{q}_t^* + \beta(1-\delta)(\hat{R}_t^* - E_t \pi_{t+1}^{CPI^*} - E_t \hat{q}_{t+1}^*) \right] \tag{82}$$

The *accumulation equation of the housing stock* is $\hat{H}_t^* = \delta \hat{H} \hat{I}_t^* + (1-\delta) \hat{H}_{t-1}^*$. The *real house price* is defined as $\hat{q}_t^* = \hat{P}_t^{H^*} - \hat{P}_t^{CPI^*}$. The *consumer price level* is $\hat{P}_t^{CPI^*} = \pi_t^{CPI^*} + \hat{P}_{t-1}^{CPI^*}$ and $\pi_t^{CPI^*}$ is given as

$$\pi_t^{CPI^*} = \tau^* \pi_t^{C^*} + (1-\tau^*) \pi_t^C + \tau^* \left(\hat{\zeta}_t^{D^*} - \hat{\zeta}_{t-1}^{D^*} \right). \tag{83}$$

The *labor supply equations* are

$$\frac{1}{1-\epsilon} \hat{C}_t^* - \frac{\epsilon}{1-\epsilon} \hat{C}_{t-1}^* + [\iota_L + (\eta - \iota_L)(1-\Delta_H)] \hat{L}_{C,t}^* + (\eta - \iota_L)\Delta_H \hat{L}_{H,t}^* = \hat{w}_{C,t}^* \tag{84}$$

$$\frac{1}{1-\epsilon} \hat{C}_t^* - \frac{\epsilon}{1-\epsilon} \hat{C}_{t-1}^* + [\iota_L + (\eta - \iota_L)\Delta_H] \hat{L}_{H,t}^* + (\eta - \iota_L)(1-\Delta_H) \hat{L}_{C,t}^* = \hat{w}_{H,t}^*, \tag{85}$$

where $\hat{w}_{j,t}^* = W_{j,t}^* - P_t^{CPI^*}$ is the *real wage* in sector $j = C, H$. The *investment equations* for capital in the nondurable goods and the housing sector are

$$\hat{I}_{C,t}^* = \frac{1}{1+\beta} \hat{I}_{C,t-1}^* + \frac{\beta}{1+\beta} E_t \hat{I}_{C,t+1}^* + \frac{1}{\varphi(1+\beta)} \hat{Q}_{C,t}^* + \hat{\zeta}_t^{I^*}, \tag{86}$$

$$\hat{I}_{H,t}^* = \frac{1}{1+\beta} \hat{I}_{H,t-1}^* + \frac{\beta}{1+\beta} E_t \hat{I}_{H,t+1}^* + \frac{1}{\varphi(1+\beta)} \hat{Q}_{H,t}^* + \hat{\zeta}_t^{I^*}. \tag{87}$$

The corresponding Q *equations* are defined as

$$\hat{Q}^*_{C,t} = -(\hat{R}^*_t - E_t\pi^{CPI^*}_{t+1}) + \frac{\bar{R}_C}{1-\delta_C+\bar{R}_C}E_t\hat{r}^*_{C,t+1} + \frac{1-\delta_C}{1-\delta_C+\bar{R}_C}E_t\hat{Q}^*_{C,t+1}, \tag{88}$$

$$\hat{Q}^*_{H,t} = -(\hat{R}^*_t - E_t\pi^{CPI^*}_{t+1}) + \frac{\bar{R}_H}{1-\delta_H+\bar{R}_H}E_t\hat{r}^*_{H,t+1} + \frac{1-\delta_H}{1-\delta_H+\bar{R}_H}E_t\hat{Q}^*_{H,t+1}, \tag{89}$$

where $\hat{r}^*_{C,t} = \hat{R}^*_{C,t} - \hat{P}^{CPI^*}_t$ and $\hat{r}^*_{H,t} = \hat{R}^*_{H,t} - \hat{P}^{CPI^*}_t$. Demand for *foreign* and *home investment goods* is

$$\hat{I}^{f^*}_{j,t} = (1-\iota(1-\tau^*))\,\hat{\zeta}^{D^*}_t - \iota(1-\tau^*)\widehat{tot}_t + \hat{I}^*_{j,t}, \tag{90}$$

$$\text{and} \quad \hat{I}^{h^*}_{j,t} = \iota\tau^*\hat{\zeta}^{D^*}_t + \iota\tau^*\widehat{tot}_t + \hat{I}^*_{j,t}, \quad \text{for} \quad j = C, H. \tag{91}$$

The *capital accumulation equations* are given by

$$\hat{K}^*_{C,t} = \delta_C\varphi(1+\beta)\hat{\zeta}^{I^*}_t + \delta_C\hat{I}^*_{C,t} + (1-\delta_C)\hat{K}^*_{C,t-1} \tag{92}$$

$$\hat{K}^*_{H,t} = \delta_H\varphi(1+\beta)\hat{\zeta}^{I^*}_t + \delta_H\hat{I}^*_{H,t} + (1-\delta_H)\hat{K}^*_{H,t-1}. \tag{93}$$

Capital utilization rates are $\hat{z}^*_{C,t} = \frac{1}{v}\hat{r}^*_{C,t}$ and $\hat{z}^*_{H,t} = \frac{1}{v}\hat{r}^*_{H,t}$.

Firms: The *production functions* in the nondurable goods sector and the housing sector are

$$\hat{Y}^*_{C,t} = u^A_t + \hat{\zeta}^{AC^*}_t + \mu_C\hat{\tilde{K}}^*_{C,t} + (1-\mu_C)\hat{L}^*_{C,t}, \tag{94}$$

$$\hat{Y}^*_{H,t} = u^A_t + \hat{\zeta}^{AH^*}_t + \mu_H\hat{\tilde{K}}^*_{H,t} + (1-\mu_l-\mu_H)\hat{L}^*_{H,t}. \tag{95}$$

Effective capital stocks are defined as $\hat{\tilde{K}}^*_{j,t} = \hat{z}^*_{j,t} + \hat{\tilde{K}}^*_{j,t-1}$ for $j = C, H$.

Nominal marginal costs are

$$\widehat{MC}^*_{C,t} = -u^A_t - \hat{\zeta}^{AC^*}_t + \mu_C\hat{R}^*_{C,t} + (1-\mu_C)\hat{W}^*_{C,t} \tag{96}$$

$$\widehat{MC}^*_{H,t} = -u^A_t - \hat{\zeta}^{AH^*}_t + \mu_l\hat{R}^*_{l,t} + \mu_H\hat{R}^*_{H,t} + (1-\mu_l-\mu_H)\hat{W}^*_{H,t}. \tag{97}$$

The *optimal nominal rental rates of capital* and *land* are

$$\hat{R}^*_{C,t} = \hat{W}^*_{C,t} + \hat{L}^*_{C,t} - \hat{K}^{eff^*}_{C,t}, \tag{98}$$

$$\hat{R}^*_{H,t} = \hat{W}^*_{H,t} + \hat{L}^*_{H,t} - \hat{K}^{eff^*}_{H,t}, \tag{99}$$

$$\hat{R}^*_{l,t} = \hat{W}^*_{H,t} + \hat{L}^*_{H,t}. \tag{100}$$

The *evolution of inflation* in both sectors is

$$\pi^{j^*}_t = \phi_{j,f} E_t \pi^{j^*}_{t+1} + \phi_{j,b} \pi^{j^*}_{t-1} + \kappa_j \widehat{mc}^*_{j,t}, \quad \text{for} \quad j = C, H, \tag{101}$$

where $\phi_{j,f} = \frac{\beta}{1+\beta\gamma_j}$, $\phi_{j,b} = \frac{\gamma_j}{1+\beta\gamma_j}$ and $\kappa_j = \frac{(1-\theta_j)(1-\beta\theta_j)}{\theta_j} \frac{1}{1+\beta\gamma_j}$. For the *real marginal costs* it holds that $\widehat{mc}^*_{C,t} = \widehat{MC}^*_{C,t} - \hat{P}^{C^*}_t$ and $\widehat{mc}^*_{H,t} = \widehat{MC}^*_{H,t} - \hat{P}^{H^*}_t$. *Sectoral prices* are defined as $\hat{P}^{j^*}_t = \pi^{j^*}_t + \hat{P}^{j^*}_{t-1}$, for $j = C, H$.

A.2.3 Market clearing and monetary policy

In each country the *equilibrium in the nondurable goods sector* is

$$\bar{Y}_C \hat{Y}_{C,t} = n\bar{C}^h \hat{C}^h_t + (1-n)\bar{C}^{h^*} \hat{C}^{h^*}_t + \bar{I}\hat{I}_t \tag{102}$$

$$\bar{Y}^*_C \hat{Y}^*_{C,t} = (1-n)\bar{C}^{f^*} \hat{C}^{f^*}_t + n\bar{C}^f \hat{C}^f_t + \bar{I}^* \hat{I}^*_t. \tag{103}$$

Total demand for *nonresidential investment* is defined as

$$\bar{I}\hat{I}_t = n(\bar{I}^h_C \hat{I}^h_{C,t} + \bar{I}^h_H \hat{I}^h_{H,t}) + (1-n)(\bar{I}^{h^*}_C \hat{I}^{h^*}_{C,t} + \bar{I}^{h^*}_H \hat{I}^{h^*}_{H,t}) \tag{104}$$

$$\text{and} \quad \bar{I}^* \hat{I}^*_t = (1-n)(\bar{I}^{f^*}_C \hat{I}^{f^*}_{C,t} + \bar{I}^{f^*}_H \hat{I}^{f^*}_{H,t}) + n(\bar{I}^f_C \hat{I}^f_{C,t} + \bar{I}^f_H \hat{I}^f_{H,t}). \tag{105}$$

The *equilibrium in each housing market* is given by $\hat{Y}_{H,t} = \hat{H}I_t$ and $\hat{Y}^*_{H,t} = \hat{H}I^*_t$.

Real GDP of the home and foreign country evolves as

$$\hat{Y}_t = (1-\Delta_H)\hat{Y}_{C,t} + \Delta_H \hat{Y}_{H,t} \tag{106}$$

$$\text{and} \quad \hat{Y}^*_t = (1-\Delta_H)\hat{Y}^*_{C,t} + \Delta_H \hat{Y}^*_{H,t}. \tag{107}$$

The *debt market* is in equilibrium if $\hat{B}_t = \hat{B}^*_t$. The law of motion for the *net foreign assets* of the home country is defined as

$$\tilde{B}_t = \frac{1}{\beta}\tilde{B}_{t-1} - \frac{(1-n)(\bar{C}^{h^*} + \bar{I}_C^{h^*} + \bar{I}_H^{h^*})}{\bar{Y}}\widehat{tot}_t \tag{108}$$

$$+ \frac{(1-n)\bar{C}^{h^*}}{\bar{Y}}\hat{C}_t^{h^*} + \frac{(1-n)\bar{I}_C^{h^*}}{\bar{Y}}\hat{I}_{C,t}^{h^*} + \frac{(1-n)\bar{I}_H^{h^*}}{\bar{Y}}\hat{I}_{H,t}^{h^*} \tag{109}$$

$$- \frac{n\bar{C}^f}{\bar{Y}}\hat{C}_t^f - \frac{n\bar{I}_C^f}{\bar{Y}}\hat{I}_{C,t}^f - \frac{\bar{I}_H^f}{\bar{Y}}\hat{I}_{H,t}^f, \tag{110}$$

where $\tilde{B}_t$ are aggregate net foreign assets as percent of GDP. The home country interest rate evolves as $\hat{R}_t = \hat{R}_t^* - \kappa\tilde{B}_t + \hat{\zeta}_t^{Risk}$.

The *central bank* sets the union-wide nominal interest rates according to the following Taylor rule

$$\hat{R}_t^* = \mu_R\hat{R}_{t-1}^* + (1-\mu_R)\mu_\pi\pi_t + u_t^{R^*}, \tag{111}$$

where $\pi_t = n\pi_t^{CPI} + (1-n)\pi_t^{CPI^*}$.

B Data

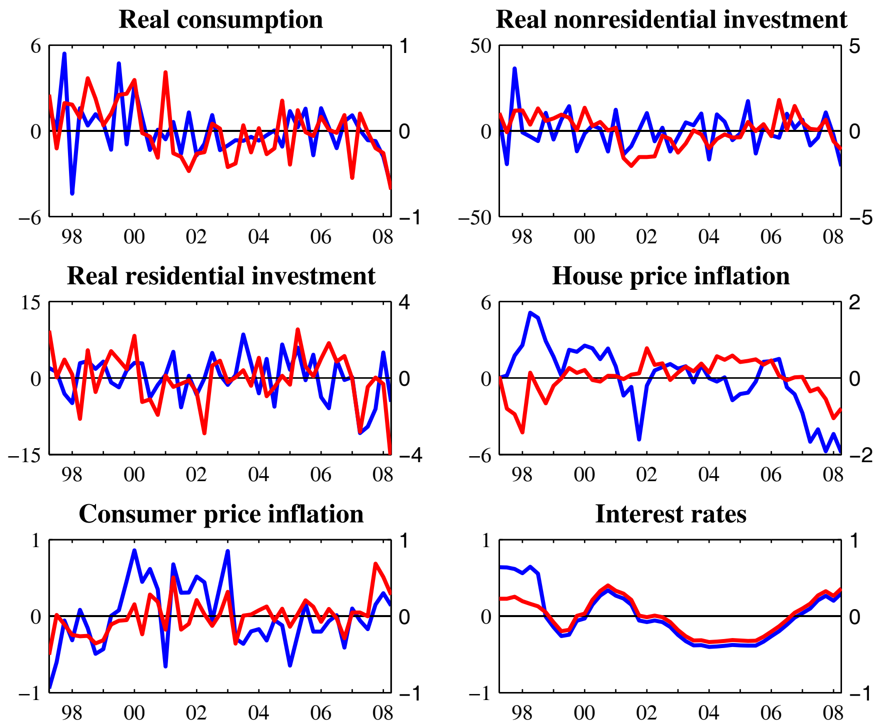

Figure 8: Data

Note: The y-axis measures percent. The *blue line* stands for Ireland (lhs) and the *red line* is the rest of the EMU (rhs) .

C Prior and posterior distributions

The following figures report the prior and posterior distributions of structural parameters and shock processes. The *dashed line* is the prior density and the *solid line* is the posterior density.

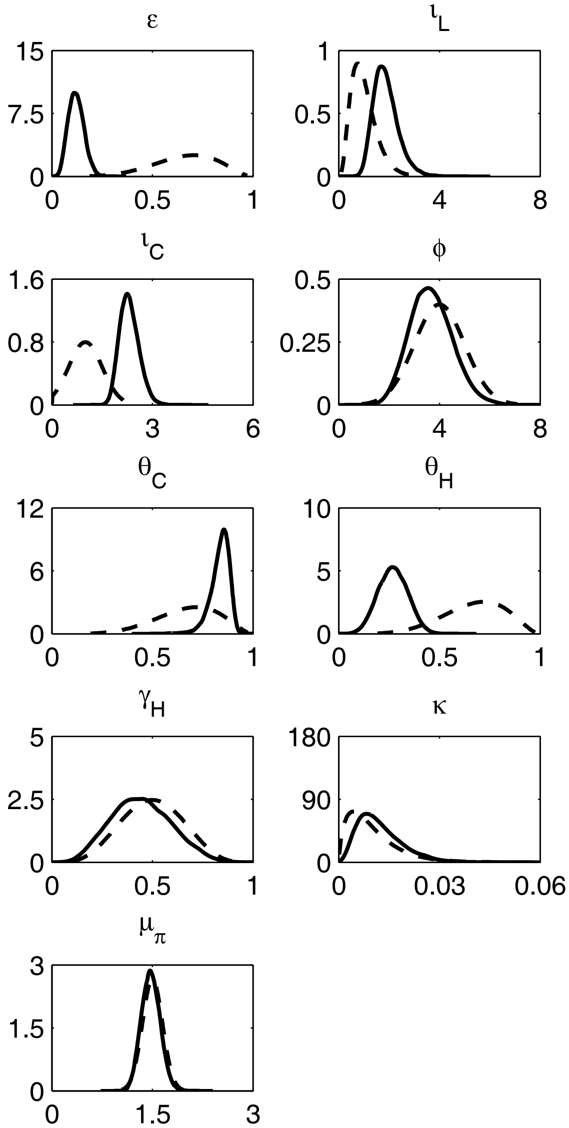

Figure 9: Estimated distribution of structural parameters

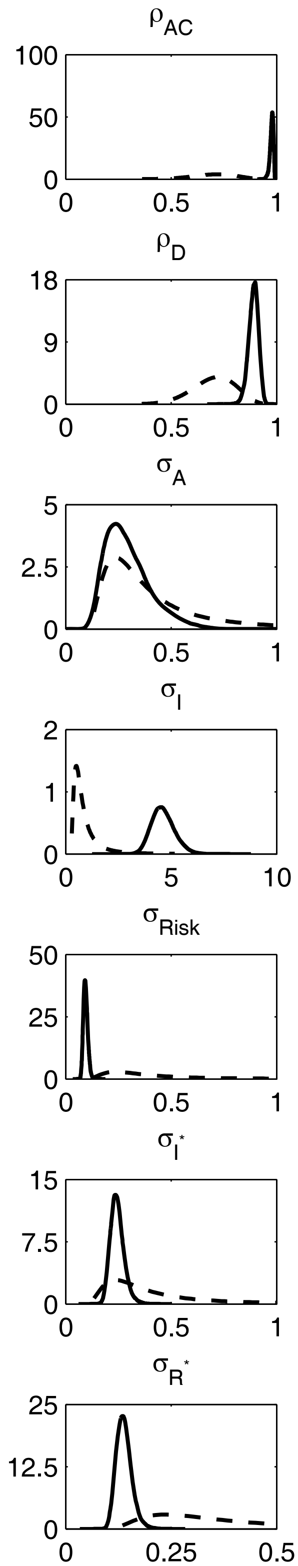

Figure 10: Estimated distribution of shock processes.

References

Adjemian, S., Pariès, M. D., Smets, F., 2008. A quantitative perspective on optimal monetary policy cooperation between the US and the euro area. Working Paper Series 884, European Central Bank.

Adolfson, M., Laseen, S., Linde, J., Villani, M., 2007. Bayesian estimation of an open economy DSGE model with incomplete pass-through. Journal of International Economics 72 (2), 481–511.

An, S., Schorfheide, F., 2007. Bayesian analysis of DSGE models. Econometric Reviews 26 (2-4), 113–172.

Aspachs-Bracons, O., Rabanal, P., 2010. The drivers of housing cycles in Spain. SERIEs 1 (1), 101–130.

Aspachs-Bracons, O., Rabanal, P., 2011. The effects of housing prices and monetary policy in a currency union. International Journal of Central Banking 7 (1), 225–274.

Barsky, R. B., House, C. L., Kimball, M. S., 2007. Sticky-price models and durable goods. American Economic Review 97 (3), 984–998.

Calvo, G. A., 1983. Staggered prices in a utility-maximizing framework. Journal of Monetary Economics 12 (3), 383–398.

Calza, A., Monacelli, T., Stracca, L., 2011. Housing finance and monetary policy. Journal of the European Economic Association, forthcoming.

Christiano, L. J., Eichenbaum, M., Evans, C. L., 2005. Nominal rigidities and the dynamic effects of a shock to monetary policy. Journal of Political Economy 113 (1), 1–45.

Fernández-Villaverde, J., 2010. The econometrics of DSGE models. SERIEs 1 (1), 3–49.

Geweke, J., 1999. Using simulation methods for Bayesian econometric models: inference, development,and communication. Econometric Reviews 18 (1), 1–73.

Horvath, M., 2000. Sectoral shocks and aggregate fluctuations. Journal of Monetary Economics 45 (1), 69–106.

Iacoviello, M., 2005. House prices, borrowing constraints, and monetary policy in the business cycle. American Economic Review 95 (3), 739–764.

Iacoviello, M., Neri, S., 2010. Housing market spillovers: Evidence from an estimated DSGE model. American Economic Journal: Macroeconomics 2 (2), 125–64.

IMF, 2004. Ireland: Selected issues. IMF country report (04/349).

Kass, R. E., Raftery, A. E., 1995. Bayes factors. Journal of the American Statistical Association 90 (430), 773–795.

Malzubris, J., 2008. Ireland's housing market: Bubble trouble? ECFIN Country Focus 5 (9).

McQuinn, K., O'Reilly, G., 2006. Assessing the role of income and interest rates in determining house prices. Research Technical Papers 15/RT/06, Central Bank of Ireland.

Monacelli, T., 2009. New Keynesian models, durable goods, and collateral constraints. Journal of Monetary Economics 56 (2), 242–254.

Neri, S., 2010. Comments on "The drivers of housing cycles in Spain" by Oriol Aspachs-Bracons and Pau Rabanal. SERIEs 1 (1), 131–134.

Pariès, M. D., Notarpietro, A., 2008. Monetary policy and housing prices in an estimated DSGE model for the US and the euro area. Working Paper Series 972, European Central Bank.

Rabanal, P., 2009. Inflation differentials between Spain and the EMU: A DSGE perspective. Journal of Money, Credit and Banking 41 (6), 1141–1166.

Rae, D., van den Noord, P., 2006. Ireland's housing boom: What has driven it and have prices overshot? OECD Economics Department Working Papers (492).

Schmitt-Grohe, S., Uribe, M., 2003. Closing small open economy models. Journal of International Economics 61 (1), 163–185.

Smets, F., Wouters, R., 2003. An estimated dynamic stochastic general equilibrium model of the euro area. Journal of the European Economic Association 1 (5), 1123–1175.

Smets, F., Wouters, R., 2007. Shocks and frictions in US business cycles: A Bayesian DSGE approach. American Economic Review 97 (3), 586–606.