Housing, Consumption Dynamics, and Monetary Policy

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Zusammenfassung

Die vorliegende Dissertation beschäftigt sich sowohl empirisch als auch theoretisch mit der Rolle von Immobilieninvestitionen und -finanzierung in der Makroökonomie im Rahmen von Neu-Keynesianischen dynamischen stochastischen allgemeinen Gleichgewichtsmodellen (DSGE). Das erste Kapitel untersucht die Ursachen des Immobilienbooms in Irland für die Zeit der Mitgliedschaft in der Europäischen Wirtschafts- und Währungsunion (EWWU). Dazu wird ein Zwei-Länder-Modell für Irland als Mitglied der EWWU entwickelt und mittels eines bayesianischen Verfahrens ökonometrisch geschätzt. Varianzzerlegungen und Impulsantwortfunktionen beleuchten die Triebkräfte der Dynamik auf dem irischen Immobilienmarkt und verdeutlichen wichtige Modelleigenschaften. Hauptergebnis der Untersuchung ist, dass Immobiliennachfrageschocks den zentralen Treiber des irischen Immobilienbooms darstellen - ein Resultat, das für die empirische Neu-Keynesianische DSGE-Literatur typisch ist. Eine Robustheitsanalyse zeigt schließlich, dass ein Teil der Variation der durch die Schätzung bestimmten Immobiliennachfrageschocks auf exogene Erklärungsvariablen zurückgeführt werden kann.

Das zweite Kapitel baut auf dem im ersten Kapitel entwickelten Modellrahmen auf und beschäftigt sich mit der Auswirkung einer asymmetrischen Deregulierung von Hypothekenmärkten einzelner Mitgliedsländer der Europäischen Währungsunion. Es wird gezeigt, dass eine unmittelbare regulatorische Anhebung der Beleihungsgrenze von 65% auf 75% in einem Mitgliedsland der Größe Spaniens einen massiven Nachfrageboom in diesem Land auslöst, während der Rest der Währungsunion unter einer Rezession leidet. Die asymmetrische Entwicklung der nationalen Konjunkturzyklen spiegelt das Dilemma der Europäischen Zentralbank wider, die ihren Leitzinsentscheid an der durchschnittlichen Inflationsrate der Union ausrichtet. Neben der Betrachtung der Transitionsdynamik und der Betrachtung der langen Frist analysiert das Kapitel 2 die Wohlfahrtswirkung der Regulierungsreform und kommt zu dem Ergebnis, dass das Heimatland, in dem die Reform

beschlossen wird, Wohlfahrtsgewinne realisiert, während der Rest der Währungsunion Wohlfahrtsverluste erleidet, wobei sich die Höhe der Verluste nach der Größe des Heimatlandes richtet.

In einem Ein-Länder-Modell wird im dritten Kapitel die Frage gestellt, ob die Geldpolitik durch temporäre Abweichungen von der Taylor-Regel persistente Boom-Bust-Zyklen auf dem Immobilienmarkt und konjunkturelle Zyklen auslösen kann. Zur Beantwortung dieser Fragestellung werden in einen ansonsten standardisierten Modellrahmen verhaltenstheoretische Erwartungsbildungsmechanismen (Heuristiken) eingebaut. Insbesondere wird unterstellt, dass die Akteure des Modells zwischen einer optimistischen und einer pessimistischen Prognoseregel für zukünftige Immobilienpreise wählen und ihre Entscheidung auf die relative Prognoseperformance der Regeln stützen. Mittels Modellsimulationen und Impulsantwortfunktionen werden die sich daraus ergebenden Implikationen für den geldpolitischen Transmissionsprozess untersucht und mit dem Standardmodell, das auf dem Paradigma der rationalen Erwartungen fußt, kontrastiert. Es wird gezeigt, dass im verhaltenstheoretischen Modell eine expansive Geldpolitik eine selbsterfüllende Welle von Optimismus bezüglich zukünftiger Immobilienpreise verursachen kann, welche wiederum durch eine steigende Verschuldung der Akteure und die damit verbundene Ausgabensteigerung die realwirtschaftliche Aktivität einer Volkswirtschaft bestimmt. Aufgrund dieser destabilisierenden Mechanismen kommt Kapitel 3 zu dem Schluss, dass die Immobilienpreisentwicklung bei der Leitzinsentscheidung einer Zentralbank Berücksichtigung finden sollte. Indem die Zentralbank das Zinsniveau einer Ökonomie gemäß makroökonomischen als auch finanziellen Bedingungen steuert, wird verhindert, dass Fehlbewertungen auf dem Immobilienmarkt die konjunkturelle Stabilität einer Volkswirtschaft gefährden.

Im abschließenden Kapitel befasst sich die vorliegende Dissertation mit der empirischen Plausibilität der Konsum-Euler-Gleichung und nähert sich der Rolle von Immobilieninvestitionen und -finanzierung in der Makroökonomie im Rahmen von Neu-Keynesianischen DSGE-Modellen aus einer weitergefassten Perspektive. Im Besonderen beschäftigt sich das Kapitel mit dem Zusammenhang von monetären Bedingungen und dem Befund der negativen Korrelation zwischen der Federal Funds Rate und dem impliziten Zins von Konsum-Euler-Gleichungen (vgl. Canzonerie et al., 2007). Mittels einer auf dem Modell von Smets und Wouters (2007) basierenden Monte-Carlo-Simulation wird gezeigt, dass Risikoprämienschocks - im Gegensatz zu geldpolitischen Schocks - einen Keil zwischen die

Federal Funds Rate und den impliziten Zins der Konsum-Euler-Gleichung treiben können, so dass beide Zinszeitreihen eine negative Korrelation aufweisen. Auf Grundlage dieses Befundes wird in Kapitel 4 abschließend argumentiert, dass die strukturelle Untermauerung der Konsum-Euler-Gleichung durch die Implementierung von finanziellen Friktionen auf dem Immobilienmarkt gemäß Iacoviello (2005) einen potentiellen Beitrag leisten kann, um die Federal Funds Rate und den impliziten Zins der Konsum-Euler-Gleichung in Einklang zu bringen.

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Introduction

Following the financial market turmoil in the US in 2007 to 2008, most major economies entered into the most severe financial and economic crisis since the Great Depression of the 1930s. While the roots of the crisis are diverse and do not allow for a simplistic explanation, housing and housing finance unquestionably played a decisive role in causing the crisis, and the complex interplay between developments on the housing market with financial and real economic activity significantly contributed to the rapid unfolding and devastating consequences of the crisis (see, for instance, Bernanke, 2008).

This dissertation studies the role of housing and housing finance in the macroeconomy. It intends to continue the ongoing empirical and theoretical research in monetary economics within the class of New Keynesian (NK) dynamic stochastic general equilibrium (DSGE) models. In the last decade, the NK approach has become the main reference among monetary economists for the analysis of the sources of business fluctuations and the implications of monetary policy. Besides its growing popularity in academics, the NK approach exerts influence on practical policies as it constitutes the framework for macroeconomic models built for the aim of policy analysis and forecasting at several central banks and international institutions.[1]

Since the basic NK DSGE model was established in the late 1990s, typified by the contributions of Goodfriend and King (1997), Clarida et al. (1999), and Woodford (2003), there has been a substantial progress in its theoretical foundation and empirical use (see Tovar, 2009). Prominent extensions of the basic framework, e.g., Christiano et al. (2005) and Smets and Wouters (2003, 2007), allow for many types of real and nominal frictions and are able to compete with unrestricted multivariate models in terms of explaining main

[1]See Gali and Gertler (2007) and Gali (2008) for a detailed introduction to the NK DSGE framework. Woodford (2009) makes a comparison between the NK and the "New Classical" approach and gives a historical context. Tovar (2009) reviews the use of DSGE models at central banks and discusses modeling challenges and estimation issues. Smets et al. (2010) give an overview of euro area DSGE models used at the European Central Bank.

features of macroeconomic time series and forecasting. With the experience of the recent US housing market fluctuations and following crisis, a new strand of literature has emerged that adds financial frictions in the housing market to the NK DSGE framework. Based on Iacoviello (2005), which again is a NK DSGE extension of the seminal Kiyotaki and Moore (1997) framework, this literature features the presence of collateral constraints tied to housing values. Via the asset-price channel of the collateral constraint, fluctuations in real house prices are an important propagation mechanism for monetary policy. Models that apply this type of financial friction to a NK DSGE framework include Darracq Pariès and Notarpietro (2008), Monacelli (2009), Gerali et al. (2010), Iacoviello and Neri (2010), Aspachs-Bracons and Rabanal (2010, 2011), Calza et al. (2011), and Forlati and Lambertini (2011), among others.[2]

Comprising four chapters, this dissertation builds on this recent strand of literature and provides both empirically and theoretically new insights into the economic effects of housing and housing finance.[3] Chapter 1 studies the drivers of the recent housing cycle in Ireland by developing and estimating a two-country NK DSGE model of the European Economic and Monetary Union (EMU). Ireland's housing market has been exceptionally dynamic over the last decade with annual growth rates of house prices of above 10% on average. Econometric models for house prices suggest that Ireland's house price boom was largely driven by demand factors, e.g., population and income growth, low short-term real interest rates, lax access to mortgage finance, and tax advantages (see, for instance, Rae and van den Noord, 2006; Malzubris, 2008). The first chapter addresses Ireland's housing market developments from a Bayesian NK DSGE perspective. It develops a model of Ireland as a member of the EMU that includes several real and nominal frictions, a collateral constraint, and a large number of structural shocks and estimates the model with Irish and EMU data for the period from 1997:Q1 to 2008:Q2. Using variance and historical decomposition and impulse response analysis, the chapter gains insights into Ireland's housing market dynamics. Concerning the drivers of Ireland's housing market fluctuations, chapter 1 finds that housing preference (demand) and technology shocks are the most important drivers of real house prices and real residential investment. In particular,

[2] See also Iacoviello (2010) who provides a brief introduction to the modeling of housing features in the NK framework. Brázdik et al. (2012) provide a literature survey on different approaches to build financial frictions into DSGE models.

[3] Note that, as each chapter is self-contained and can be read independently of the other, some repetition of explanations and arguments is necessary throughout.

housing preference shocks account for about 87% of the variation in real house prices and explain about 60% of the variation in real residential investment. A robustness analysis finally shows that a good part of the variation of the estimated housing preference shocks can be explained by unmodeled demand factors that have been considered in the empirical literature as important determinants of Irish house prices. Remarkably, the analysis also shows that real interest rates have an impact on housing preference innovations, although they have been included in the model.

Building on a similar model, chapter 2 deals with the implications of cross-country mortgage market heterogeneity for the EMU. Related studies, i.e., Rubio (2009) and Hristov et al. (2010), highlight the role of existing cross-country differences in mortgage market characteristics within the EMU for the transmission of common and asymmetric shocks, but they neglect to analyze the effects of a mortgage market reform itself in terms of transition dynamics and welfare implications. In fact, the chapter shows that a change in cross-country institutional characteristics of mortgage markets, such as the loan-to-value (LTV) ratio, is likely to be an important driver of an asymmetric development in the housing market and real economic activity of member states. According to the calculations in chapter 2, an asymmetric mortgage market deregulation that increases the LTV ratio in a member country of the size of Spain from 65% to 75% leads to a demand-driven boom in the country that implements the deregulation, while the rest of the EMU faces a recession. This finding reflects the dilemma faced by the European Central Bank that sets interest rates according to EMU-wide aggregates. Alongside the adjustment path, monetary conditions are too loose for the home country that enforces the deregulation of its mortgage market, while they are too tight for the rest of the EMU, which suffers from a drop in GDP. In conclusion, the chapter evaluates the welfare implication of the home country's mortgage market reform. The analysis suggests that the mortgage market deregulation increases the welfare of the home country substantially. In contrast, the rest of the EMU's welfare falls with magnitude depending on the size of the home country.

Chapter 3 asks whether monetary policy shocks can trigger boom-bust periods in house prices and create persistent business cycles. The chapter addresses this question by implementing behavioral expectations into an otherwise standard NK DSGE model with housing and a collateral constraint. Applying the notion of behavioral expectations is substantial, because standard models that deal with the role of housing in the macroeconomy exclusively rely on the rational representative agent approach. In these models housing booms and busts merely reflect macroeconomic fundamentals and/or are the outcome of structural shocks (see also the model derived in chapter 1). Key to the approach in chapter 3 is that agents form heterogeneous and biased expectations on future real house prices. In particular, it is assumed that agents choose between simple forecasting rules ("heuristics") and base their choice on the relative forecasting performance of the rules following Brock and Hommes (1997). Model simulations and impulse response functions suggest that these assumptions have strong implications for the transmission of monetary policy shocks. Most notably, it is shown that monetary policy shocks might trigger pronounced waves of optimism, respectively, pessimism that drive house prices and the broader economy, all in a self-reinforcing fashion. Given these destabilizing dynamics, chapter 3 explores to what extend a modification of the Taylor rule can be beneficial in terms of maintaining macroeconomic stability. The chapter shows that in an environment in which behavioral mechanisms play a role an augmented Taylor rule that incorporates house prices is superior, because it limits the scope of self-fulfilling waves of optimism and pessimism to arise.

Studying the performance of the consumption Euler equation of standard NK models, the final chapter approaches the role of housing and housing finance in the macroeconomy from a different angle. In particular, chapter 4 challenges the view that the observed negative correlation between the Federal Funds rate and the interest rate implied by consumption Euler equations is systematically linked to monetary policy as discussed in Canzoneri et al. (2007). Using a Monte Carlo experiment based on the estimated model in Smets and Wouters (2007), this chapter shows that risk premium shocks have the capability to drive a wedge between the interest rate targeted by the central bank and the implied Euler equation interest rate, so that the correlation between actual and implied rates is negative. While the message of the chapter is good news for the analysis of monetary policy within the NK DSGE framework, the finding that actual consumption dynamics are driven to a large extend by risk premium disturbances is bad news for the structural underpinning of the Smets and Wouters' consumption Euler equation. Chapter 4 concludes by arguing that the implementation of collateral constraints along the lines of Iacoviello (2005) is a promising way to strengthen the empirical performance of consumption Euler equations. Given the quantitatively large effects of housing collateral on US consumption dynamics, this friction might limit the dependence of consumption dynamics on risk premium disturbances as implied by the model of Smets and Wouters and thus might resolve the failure of consumption Euler equations following the analysis in Canzoneri et al. (2007).

Chapter 1

What Drives Ireland's Housing Market? A Bayesian DSGE Approach[1]

1.1 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 with the housing sector in a New Keynesian dynamic stochastic general equilibrium (DSGE) model. Using structural estimation, he provides evidence that collateral constraints tied to housing values are crucial to explain US consumption dynamics. 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. Building and estimating a two-country model, Darracq Pariès and Notarpietro (2008) confirm the evidence on the role of housing collateral for the US and provide new evidence for the euro area. Aspachs-Bracons and Rabanal (2010) study the drivers of housing cycles in Spain during the period of the European Economic and Monetary Union (EMU). 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

[1]This chapter is based on joint work with Eric Mayer that appeared as Gareis and Mayer (2012c).

negligible role in explaining the Spanish house price boom, against the general view that the low levels of real interest rates accounted for it. Recently, Quint and Rabanal (2011) employ an estimated two-country model of the euro area with collateral constraints to study the role of macroprudential policies.

In this chapter, we develop and estimate a Bayesian DSGE model with Irish and EMU data to gain insights into the sources of recent Irish housing market dynamics. Ireland is prominent because of its exceptional surge in housing prices and housing investment over the last decade. As illustrated in figure 1.1, real house prices rose by an average of 10% per year (14% in nominal terms) from 1997 to their peak at the end of 2006. At the same time, real residential investment increased by a yearly average of 12%. In comparison, real house prices in the rest of the EMU grew on average by about 3.5% per year (5% in nominal terms), while the average annual growth rate of real residential investment was roughly 3%. Besides that the housing market in Ireland has been exceptionally dynamic, the figure highlights that the fluctuations in the Irish housing market have been much more volatile compared to those in the rest of the EMU. This has been especially relevant for house prices. While annual growth rates of real house prices in the rest of the EMU moved smoothly between 0% and 5%, Irish real house prices varied substantially with annual growth rates ranging from 23% in 1998:Q4 to -13% in 2008:Q2.

Much of the debate on the developments in the Irish housing market centers on the factors behind the housing boom and includes questions as to whether a housing price bubble existed (see, for instance, IMF, 2004; McQuinn and O'Reilly, 2006; Rae and van den Noord, 2006; Malzubris, 2008). Applying an econometric model for house prices, most studies provide evidence that a large part of the recent developments of Irish 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. Moreover, studies report that Irish house prices have been deviating from fundamental prices over time with the degree of under- or overshooting varying substantially. For instance, McQuinn and O'Reilly (2006) estimate the degree of overvaluation of new house prices to be 15% at the end of 2005. In this chapter, we address the recent developments in the Irish housing market by using a Bayesian DSGE model. We borrow from the recent strand of housing DSGE literature and build a two-country model of a monetary union including housing.

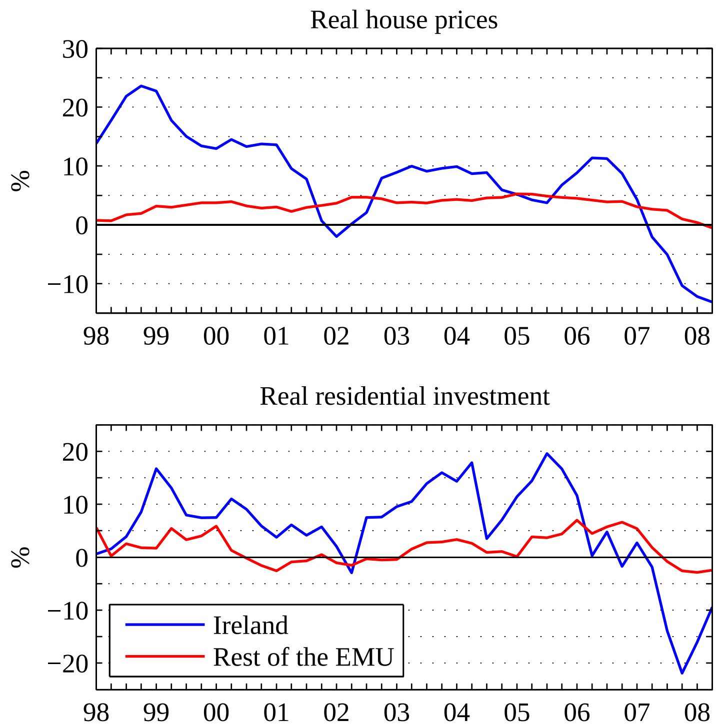

Figure 1.1: Housing market dynamics in Ireland and the rest of the EMU (y-o-y growth rate)

We use a two-country model, even though Ireland constitutes only a small part of the EMU, because it provides a realistic framework to study the implications of a common monetary policy in the EMU for the Irish economy and allows to analyze the transmission of all shocks emanating from the rest of the EMU to the Irish housing market.[2] The stochastic dynamics of our model are driven by a rich set of structural shocks, so 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 into the production function of firms. On the household side we introduce a housing preference shock that captures all unmodeled shifts in the demand for housing. In addition, we consider a number of real and nominal frictions that have proven to be successful in explaining macroeconomic data (see, for instance, Smets and Wouters, 2003, 2007; Iacoviello and Neri, 2010). As the Irish mortgage market is particularly less regulated (see, for instance, Rae and van den Noord, 2006), we choose to include collateral constraints in the baseline specification of the model following Darracq Pariès and Notarpietro (2008)

[2]See Aspachs-Bracons and Rabanal (2010) who make a similar point for the case of Spain.

and Iacoviello and Neri (2010).

We estimate the model on Irish and EMU quarterly data for the period from 1997:Q1 to 2008:Q2 with standard Bayesian likelihood methods. After showing that the model fits second-order moments of selected observables quite well, we examine the drivers of fluctuations in the Irish housing market by applying variance and historical decompositions as well as standard impulse response analysis. Turning to the main results, we find that posterior estimates of structural parameters are broadly similar to the ones obtained in the housing DSGE literature with focus on the euro area. Most importantly, we find clear evidence on the existence of asymmetric price rigidities across sectors. Moreover, we obtain a relatively high posterior mean of the costly labor reallocation parameter. This confirms the finding 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 preference shocks account for about 87% of the variation of house prices as well as for about 60% of the variation of real residential investment. Housing technology shocks explain about 30% of the variation of real residential investment. Similar to what Aspachs-Bracons and Rabanal (2010) report for Spain, we find that monetary shocks have played a negligible role in shaping Irish housing market dynamics. Risk premium and monetary policy shocks explain only about 3% of the overall variation of house prices. In a robustness analysis we investigate if the estimated housing preference shocks can be traced back to unmodeled shifts in the demand for housing that have been considered in the empirical literature as relevant determinants of Irish house prices. Besides demographic factors, we find that real interest rates have an impact on housing preference innovations, although they have been included in the model.

The remainder of the chapter is as follows. In the next section, we present the model. In section 1.3, we estimate the model with standard Bayesian likelihood methods. In section 1.4, we use the estimated model to gain insights into the dynamics of Ireland's housing market. In section 1.5, we use a simple regression analysis to trace back housing preference shocks. The last section concludes.

1.2 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 country is modeled as a two-agent, two-sector economy. 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. Along the lines of Kiyotaki and Moore (1997), households are divided into two groups, namely, savers and borrowers. The latter have a relatively low discount factor, so that they are less patient than the former. As a consequence, savers and borrowers shift resources and debt is generated in equilibrium. Following Iacoviello (2005), borrowers face a collateral constraint that ties their maximum borrowing to the value of their housing stock. We assume that savers accumulate capital and own land. In addition, only savers have access to international bond trading (see Darracq Pariès and Notarpietro, 2008; Aspachs-Bracons and Rabanal, 2010).

The stochastic dynamics of the model are driven by four preference shocks, seven technology/efficiency shocks, one risk premium shock, and one monetary policy shock. Also, we allow for a number of real and nominal frictions following the recent strand of empirical DSGE literature (see, for instance, Smets and Wouters, 2003, 2007; Iacoviello and Neri, 2010). In particular, we consider external habit formation in consumption of nondurable goods, investment adjustment costs, variable capital utilization, imperfect labor mobility between sectors, and sticky nominal prices and wages.

As the problem set of the foreign country is equivalent to that of the home country, we proceed to present only equations characterizing the latter, unless stated otherwise. Variables indicated with a $\tilde{}$ refer to borrowers. Variables labeled with a * refer to the foreign country and those without a time subscript denote steady state values.[3]

[3] See appendix A for the full set of model equations.

1.2.1 Borrower's program

Each borrower, indicated by $b \in [0, \omega]$, maximizes an intertemporal utility function given by

$$E_t \sum_{k=0}^{\infty} \tilde{\beta}^k \tilde{U}_{t+k}(b), \quad \tilde{\beta} \in [0,1], \tag{1.1}$$

where E_t is the expectation operator, $\tilde{\beta}$ is the discount factor, and $\tilde{U}_t(b)$ is the period utility function, which reads

$$\tilde{U}_t(b) = \zeta_{\beta,t} \left((1 - \zeta_{D,t}\alpha) \log(\tilde{C}_t(b) - \varepsilon \tilde{C}_{t-1}) + (\zeta_{D,t}\alpha) \log(\tilde{D}_t(b)) - \frac{\tilde{L}_t(b)^{1+\eta}}{1+\eta} \right), \tag{1.2}$$

where $\tilde{C}_t(b)$ is an index of nondurable consumption goods that is composed of home and foreign goods, $\tilde{D}_t(b)$ is the end-of-period housing stock, and $\tilde{L}_t(b)$ describes an index of labor supply. The parameter ε captures external habit formation in consumption of nondurable goods, η is the inverse elasticity of labor supply, $\zeta_{D,t}$ is a housing preference shock that captures exogenous shifts in the demand for housing, and $\zeta_{\beta,t}$ is a discount factor shock. Both shocks follow a stationary AR(1) process in logs: $\log(\zeta_{D,t}) = \rho_D \log(\zeta_{D,t-1}) + u_{D,t}$ and $\log(\zeta_{\beta,t}) = \rho_\beta \log(\zeta_{\beta,t-1}) + u_{\beta,t}$.

The index of nondurable consumption goods is defined as

$$\tilde{C}_t(b) = \left[(\tau)^{\frac{1}{\iota}} (\tilde{C}_{H,t}(b))^{\frac{\iota-1}{\iota}} + (1-\tau)^{\frac{1}{\iota}} (\tilde{C}_{F,t}(b))^{\frac{\iota-1}{\iota}} \right]^{\frac{\iota}{\iota-1}}, \tag{1.3}$$

where $\tilde{C}_{H,t}(b)$ and $\tilde{C}_{F,t}(b)$ stand for the consumption of nondurable goods produced in the home, respectively, the foreign country. The parameter ι is the elasticity of substitution between home and foreign goods, and τ governs the share of domestically produced goods in the nondurable goods consumption index. The housing stock evolves as

$$\tilde{D}_t(b) = (1-\delta)\tilde{D}_{t-1}(b) + \tilde{X}_t(b), \tag{1.4}$$

where $\tilde{X}_t(b)$ stands for real residential investment, and δ is the depreciation rate. Following Aspachs-Bracons and Rabanal (2010), we define the labor supply index as

$$\tilde{L}_t(b) = \left[(1-\Delta_D)^{-\iota_L} \tilde{L}_{C,t}(b)^{1+\iota_L} + \Delta_D^{-\iota_L} \tilde{L}_{D,t}(b)^{1+\iota_L} \right]^{\frac{1}{1+\iota_L}}, \tag{1.5}$$

where $\tilde{L}_{C,t}(b)$ and $\tilde{L}_{D,t}(b)$ stand for sector-specific labor supply, Δ_D measures the economic size of the housing sector, and ι_L is the cost of reallocating labor between sectors (see also Horvath, 2000; Iacoviello and Neri, 2010).

The period budget constraint of a borrower b is given in nominal terms as

$$P_{C,t}\tilde{C}_t(b)+P_{D,t}\tilde{X}_t(b)+R_{t-1}\tilde{S}_{t-1}(b)=\frac{W_{C,t}}{M_{C,t}}\tilde{L}_{C,t}(b)+\frac{W_{D,t}}{M_{D,t}}\tilde{L}_{D,t}(b)+\tilde{S}_t(b)+Div'_t(b), \quad (1.6)$$

where $P_{C,t}$ and $P_{D,t}$ are the price indices of nondurable consumption goods and housing, $\tilde{S}_t(b)$ is the stock of nominal debt that costs a gross nominal interest rate of R_t, $W_{j,t}$ stands for the nominal wage rate in sector $j = C, D$, $M_{C,t}$ and $M_{D,t}$ denote the sectoral markup between the wage paid by intermediate goods producers and the wage paid to borrowers, and $Div'_t(b)$ are lump-sum profits from labor unions (see section 1.2.3).

As in Iacoviello (2005), borrowers face a collateral constraint that ties their maximum level of debt to the expected present value of their future housing stock times a loan-to-value (LTV) ratio. The collateral constraint is described in nominal terms as follows

$$R_t\tilde{S}_t(b) \leq (1-\chi)(1-\delta)E_t\left(P_{D,t+1}\tilde{D}_t(b)\right), \quad (1.7)$$

where $1-\chi$ is the LTV ratio.[4]

Note that the home country interest rate depends on the country's net foreign asset position.[5] In particular, we follow Aspachs-Bracons and Rabanal (2010) and assume that home country households have to pay a premium above the union-wide nominal interest rate if the country's net foreign asset position falls below its steady state value. Accordingly, the interest rate for home country households follows

$$R_t = R^*_t exp\left[-\kappa\left(b'_t - b'\right) + \zeta_{Risk,t}\right], \quad \kappa \geq 0, \quad (1.8)$$

where R^*_t is the union-wide gross nominal interest rate, and b'_t stands for the home country's aggregate net foreign assets as percent of nominal GDP. The parameter κ governs the risk premium elasticity. $\zeta_{Risk,t}$ is a shock to the risk premium that follows: $\zeta_{Risk,t} = \rho_{Risk}\zeta_{Risk,t-1} + u_{Risk,t}$.

The maximization of the objective function (1.1) subject to the budget constraint (1.6) with respect to consumption of nondurable goods and debt yields the following first-order

[4] As is customary in the literature, we assume that the collateral constraints always binds.

[5] This assumption is needed to guarantee a well-defined steady state in the model (see Schmitt-Grohé and Uribe, 2003).

conditions to the borrower's program

$$\tilde{U}_{C,t} = P_{C,t}\tilde{\lambda}_t \tag{1.9}$$

$$\text{and} \quad 1 = \tilde{\beta} E_t \left(\frac{R_t}{\Pi_{C,t+1}} \frac{\tilde{U}_{C,t+1}}{\tilde{U}_{C,t}} \right) + R_t \tilde{\psi}_t, \tag{1.10}$$

where $\tilde{U}_{C,t} = \frac{\partial \tilde{U}_t}{\partial \tilde{C}_t}$ is the marginal utility of an additional unit of nondurable goods, $\tilde{\lambda}_t$ is the multiplier on the budget constraint, $\tilde{\lambda}_t \tilde{\psi}_t$ is the multiplier on the collateral constraint, and $\Pi_{C,t} = \frac{P_{C,t}}{P_{C,t-1}}$ is the gross inflation rate of nondurable consumption goods prices.

The first-order condition to a typical borrower's choice of housing is

$$\frac{\tilde{U}_{D,t}}{\tilde{U}_{C,t}} = q_t \Big(1 - (1-\chi)(1-\delta)\tilde{\psi}_t E_t \left(\Pi_{D,t+1} \right) \Big) - \tilde{\beta}(1-\delta) E_t \left(\frac{\tilde{U}_{C,t+1}}{\tilde{U}_{C,t}} q_{t+1} \right), \tag{1.11}$$

where $\tilde{U}_{D,t} = \frac{\partial \tilde{U}_t}{\partial \tilde{D}_t}$ is the marginal utility of an additional unit of housing, $q_t = \frac{P_{D,t}}{P_{C,t}}$ is the real house price, and $\Pi_{D,t} = \frac{P_{D,t}}{P_{D,t-1}}$ is the gross inflation rate of house prices.

The demand equations for home and foreign nondurable consumption goods are given by

$$\tilde{C}_{H,t} = \tau \left(\frac{P_{H,t}}{P_{C,t}} \right)^{-\iota} \tilde{C}_t \tag{1.12}$$

$$\text{and} \quad \tilde{C}_{F,t} = (1-\tau) \left(\frac{P_{F,t}}{P_{C,t}} \right)^{-\iota} \tilde{C}_t, \tag{1.13}$$

where $P_{H,t}$ and $P_{F,t}$ stand for the home and the foreign price level in the nondurable goods sector respectively. The terms of trade are given as

$$T_t = \frac{P_{F,t}}{P_{H,t}}, \tag{1.14}$$

and the utility based price index for nondurable consumption goods (consumer price index) is

$$P_{C,t} = \Big[\tau \left(P_{H,t} \right)^{1-\iota} + (1-\tau)(P_{F,t})^{1-\iota} \Big]^{\frac{1}{1-\iota}}. \tag{1.15}$$

1.2.2 Saver's program

Each saver, indicated by $s \in [\omega, 1]$, maximizes an intertemporal utility function given by

$$E_t \sum_{k=0}^{\infty} \beta^k U_{t+k}(s), \quad \text{where} \quad \tilde{\beta} < \beta. \tag{1.16}$$

The saver's period utility function is given as

$$U_t(s) = \zeta_{\beta,t} \left((1 - \zeta_{D,t}\alpha) \log(C_t(s) - \varepsilon C_{t-1}) + (\zeta_{D,t}\alpha) \log(D_t(s)) - \frac{L_t(s)^{1+\eta}}{1+\eta} \right). \tag{1.17}$$

The saver's index of nondurable consumption goods is

$$C_t(s) = \left[(\tau)^{\frac{1}{\iota}} (C_{H,t}(s))^{\frac{\iota-1}{\iota}} + (1-\tau)^{\frac{1}{\iota}} (C_{F,t}(s))^{\frac{\iota-1}{\iota}} \right]^{\frac{\iota}{\iota-1}}, \tag{1.18}$$

housing evolves as

$$D_t(s) = (1-\delta) D_{t-1}(s) + X_t(s), \tag{1.19}$$

and the labor supply index is defined as

$$L_t(s) = \left[(1-\Delta_D)^{-\iota_L} (L_{C,t}(s))^{1+\iota_L} + \Delta_D^{-\iota_L} (L_{D,t}(s))^{1+\iota_L} \right]^{\frac{1}{1+\iota_L}}. \tag{1.20}$$

The period budget constraint of a saver s is given in nominal terms as

$$\begin{aligned} &P_{C,t} C_t(s) + P_{D,t} X_t(s) + P_{C,t} \sum_{j}^{C,D} I_t^j(s) + S_t(s) + B_t(s) = \frac{W_{C,t}}{M_{C,t}} L_{C,t}(s) + \frac{W_{D,t}}{M_{D,t}} L_{D,t}(s) \\ &+ \sum_{j}^{C,D} \left[R_{j,t} z_{j,t}(s) - P_{C,t} a(z_{j,t}(s)) \right] K_{j,t-1}(s) + R_{l,t} l(s) + R_{t-1} S_{t-1}(s) + R_{t-1} B_{t-1}(s) \\ &+ Div_t(s) + Div_t''(s), \end{aligned} \tag{1.21}$$

where $B_t(s)$ are holdings of internationally traded bonds, $I_t^j(s)$ denotes nonresidential investment in sector-specific capital, which is $K_{j,t}(s)$, and $l(s)$ is an exogenously fixed amount of land that a saver rent out to firms in the housing sector at a rental rate of $R_{l,t}$. $Div_t(s)$ are lump-sum profits from intermediate goods producers, and $Div_t''(s)$ are profits from labor unions. Following Smets and Wouters (2003) and Christiano et al. (2005), the term $[R_{j,t} z_{j,t}(s) - P_{C,t} a(z_{j,t}(s))] K_{j,t-1}(s)$ is the sector-specific nominal return on the capital stock, which is adjusted with the capital utilization rate, minus the nominal costs associated with variations in the degree of capital utilization.[6] The accumulation equation for capital in sector $j = C, D$ reads

$$K_{j,t}(s) = (1-\delta_j)K_{j,t-1}(s) + \zeta_{I,t}\left[1 - S\left(\frac{I_t^j(s)}{I_{t-1}^j(s)}\right)\right] I_t^j(s), \tag{1.22}$$

where δ_j is the depreciation rate of capital, $S(\cdot)$ is a convex function that captures adjustment costs in investment, and $\zeta_{I,t}$ is an efficiency shock to the technology of capital accumulation, which is assumed to be equal across sectors as in Darracq Pariès and Notarpietro (2008).[7] The shock follows: $\log(\zeta_{I,t}) = \rho_I \log(\zeta_{I,t-1}) + u_{I,t}$. Similar to the definition of consumption of nondurable goods, sector-specific investment is defined as an index over home and foreign produced goods. It holds that

$$I_t^j(s) = \left[(\tau)^{\frac{1}{\iota}}(I_{H,t}^j(s))^{\frac{\iota-1}{\iota}} + (1-\tau)^{\frac{1}{\iota}}(I_{F,t}^j(s))^{\frac{\iota-1}{\iota}}\right]^{\frac{\iota}{\iota-1}}, \quad j = C, D, \tag{1.23}$$

where $I_{H,t}^j(s)$ and $I_{F,t}^j(s)$ stand for sector-specific investment goods produced in the home and the foreign country respectively.[8]

The maximization of the objective function (1.16) subject to the budget constraint (1.21) with respect to consumption of nondurable goods and bond holdings yields the following first-order conditions to the saver's program

$$U_{C,t} = P_{C,t}\lambda_t \tag{1.24}$$

$$\text{and} \quad 1 = \beta E_t\left(\frac{R_t}{\Pi_{C,t+1}}\frac{U_{C,t+1}}{U_{C,t}}\right). \tag{1.25}$$

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

$$\frac{U_{D,t}}{U_{C,t}} = q_t - \beta(1-\delta)E_t\left(\frac{U_{C,t+1}}{U_{C,t}}q_{t+1}\right). \tag{1.26}$$

[6] The functional form for the cost function follows Darracq Pariès and Notarpietro (2008) and is given by $a(z_j) = \frac{R_j}{\upsilon}(exp[\upsilon(z_j-1)]-1)$, where R_j is the steady state rental rate of capital in sector $j = C, D$. Given a full capital utilization in the steady state ($z_j = 1$), the associated cost of capital utilization is zero.

[7] It holds that $S(1) = S'(1) = 0$ and $S''(1) = \rho > 0$.

[8] For the sake of simplicity, we assume that the relative weights of home and foreign goods are the same as in the index of nondurable consumption goods. As a consequence, the price index for investment goods is $P_{C,t}$.

The demand equations for home and foreign nondurable consumption goods are given by

$$C_{H,t} = \tau \left(\frac{P_{H,t}}{P_{C,t}} \right)^{-\iota} C_t \tag{1.27}$$

$$\text{and} \quad C_{F,t} = (1-\tau) \left(\frac{P_{F,t}}{P_{C,t}} \right)^{-\iota} C_t. \tag{1.28}$$

Turning to the typical saver's choice of capital, investment, and capital utilization, we obtain the following first-order conditions

$$Q_{j,t} = \beta E_t \left[\frac{U_{C,t+1}}{U_{C,t}} \left(Q_{j,t+1}(1-\delta_j) + \left(\frac{R_{j,t+1}}{P_{C,t+1}} z_{j,t+1} - a(z_{j,t+1}) \right) \right) \right], \tag{1.29}$$

$$Q_{j,t}\zeta_t^I \left[1 - S\left(\frac{I_t^j}{I_{t-1}^j} \right) - S'\left(\frac{I_t^j}{I_{t-1}^j} \right) \left(\frac{I_t^j}{I_{t-1}^j} \right) \right] = 1 - \beta E_t \left[\zeta_{t+1}^I Q_{j,t+1} \frac{U_{C,t+1}}{U_{C,t}} S'\left(\frac{I_{t+1}^j}{I_t^j} \right) \left(\frac{I_{t+1}^j}{I_t^j} \right)^2 \right], \tag{1.30}$$

$$\text{and} \quad \frac{R_{j,t}}{P_{C,t}} = a'(z_{j,t}), \quad j = C, D, \tag{1.31}$$

where $Q_{j,t}$ represents Tobin's Q defined as the ratio between the multiplier on (1.22) and $P_{C,t}\lambda_t$. The demand for home and foreign produced investment goods is

$$I_{H,t}^j = \tau \left(\frac{P_{H,t}}{P_{C,t}} \right)^{-\iota} I_t^j \tag{1.32}$$

$$\text{and} \quad I_{F,t}^j = (1-\tau) \left(\frac{P_{F,t}}{P_{C,t}} \right)^{-\iota} I_t^j, \quad j = C, D. \tag{1.33}$$

1.2.3 Labor supply and wage setting

As in Smets and Wouters (2007) and Iacoviello and Neri (2010), households' labor services are differentiated by a union, so that there is a monopoly power over wages. In particular, we assume that each country features two unions, one for each sector. In each sector households supply their homogeneous labor services to a union. The union differentiates labor services and sells them to labor packers. Labor packers, in turn, transform the differentiated labor services into aggregate labor input and offer it to intermediate goods producers. Similar to the price setting of intermediate goods producers (see section 1.2.5), unions reset wages subject to a Calvo (1983) scheme with partial indexation to past consumer price inflation. The unions' pricing rules then imply the following sectoral wage

Phillips curves

$$\log\left(\frac{\omega_{C,t}}{(\Pi_{C,t-1})^{\gamma_{WC}}}\right) = \beta E_t \log\left(\frac{\omega_{C,t+1}}{(\Pi_{C,t})^{\gamma_{WC}}}\right) - \frac{(1-\theta_{WC})(1-\beta\theta_{WC})}{\theta_{WC}} \log\left(\frac{M_{C,t}}{M_C}\right) \tag{1.34}$$

$$\log\left(\frac{\omega_{D,t}}{(\Pi_{C,t-1})^{\gamma_{WD}}}\right) = \beta E_t \log\left(\frac{\omega_{D,t+1}}{(\Pi_{C,t})^{\gamma_{WD}}}\right) - \frac{(1-\theta_{WD})(1-\beta\theta_{WD})}{\theta_{WD}} \log\left(\frac{M_{D,t}}{M_D}\right), \tag{1.35}$$

where $\omega_{C,t} = \frac{W_{C,t}}{W_{C,t-1}}$ and $\omega_{D,t} = \frac{W_{D,t}}{W_{D,t-1}}$ stand, respectively, for nominal wage inflation in the nondurable goods sector and the housing sector. The sectoral probabilities to re-adjust wages are given by θ_{WC} and θ_{WD}, and the corresponding indexation parameters are γ_{WC} and γ_{WD}. Assuming that unions are governed by savers and that borrowers are simply members, we define the wage markup in each sector as the ratio between the saver's marginal rate of substitution and the real wage according to[9]

$$\frac{L_t^{(\eta-\iota_L)}(1-\Delta_D)^{-\iota_L}(L_{C,t})^{\iota_L}}{U_{C,t}} = \frac{1}{M_{C,t}}\frac{W_{C,t}}{P_{C,t}} \tag{1.36}$$

$$\text{and} \quad \frac{L_t^{(\eta-\iota_L)}\Delta_D^{-\iota_L}(\tilde{L}_{D,t})^{\iota_L}}{U_{C,t}} = \frac{1}{M_{D,t}}\frac{W_{D,t}}{P_{C,t}}. \tag{1.37}$$

In comparison, borrowers take the sectoral wage rates as given when they optimize their sectoral labor supply. Thus it holds that

$$\frac{\tilde{L}_t^{(\eta-\iota_L)}(1-\Delta_D)^{-\iota_L}(\tilde{L}_{C,t})^{\iota_L}}{\tilde{U}_{C,t}} = \frac{1}{M_{C,t}}\frac{W_{C,t}}{P_{C,t}} \tag{1.38}$$

$$\text{and} \quad \frac{\tilde{L}_t^{(\eta-\iota_L)}\Delta_D^{-\iota_L}(\tilde{L}_{D,t})^{\iota_L}}{\tilde{U}_{C,t}} = \frac{1}{M_{D,t}}\frac{W_{D,t}}{P_{C,t}}. \tag{1.39}$$

[9]The assumption that unions are governed by savers simplifies the model setup and allows for a closed-form derivation of the wage Phillips curves. Note that this follows the approach in Quint and Rabanal (2011). Alternatively, one could assume that there exists a labor union for each sector/household pair as in Iacoviello and Neri (2010). A different approach can be found in Darracq Pariès and Notarpietro (2008). These authors assume that households supply differentiated labor services and that the fraction of borrowers and savers is uniformly distributed over the range of labor types.

1.2.4 Final goods producers

In each sector perfectly competitive final goods producers purchase units of intermediate goods i and bundle them according to the following technology

$$Y_{j,t} = \left(\left(\frac{1}{n} \right)^{\frac{\lambda}{1+\lambda}} \int_0^n Y_{j,t}(i)^{\frac{1}{1+\lambda}} di \right)^{1+\lambda}, \quad j = C, D, \tag{1.40}$$

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 final goods producers leads to the demand for intermediate goods i according to

$$Y_{C,t}(i) = \left(\frac{1}{n} \right) \left(\frac{P_{H,t}(i)}{P_{H,t}} \right)^{-\frac{1+\lambda}{\lambda}} Y_{C,t} \tag{1.41}$$

$$\text{and} \quad Y_{D,t}(i) = \left(\frac{1}{n} \right) \left(\frac{P_{D,t}(i)}{P_{D,t}} \right)^{-\frac{1+\lambda}{\lambda}} Y_{D,t}, \tag{1.42}$$

where $P_{H,t}(i)$ and $P_{D,t}(i)$ stand for intermediate goods prices, and $P_{H,t}$ and $P_{D,t}$ stand for final goods prices. Given zero profits in equilibrium, the latter are defined by

$$P_{H,t} = \left(\left(\frac{1}{n} \right) \int_0^n P_{H,t}(i)^{-\frac{1}{\lambda}} di \right)^{-\lambda} \tag{1.43}$$

$$\text{and} \quad P_{D,t} = \left(\left(\frac{1}{n} \right) \int_0^n P_{D,t}(i)^{-\frac{1}{\lambda}} di \right)^{-\lambda}. \tag{1.44}$$

1.2.5 Intermediate goods producers

In each sector intermediate goods are produced by monopolistically competitive producers. Following Iacoviello and Neri (2010), we introduce sectoral heterogeneity, so that the model is able to generate endogenous dynamics in both sectors. Nondurable consumption and nonresidential investment goods are produced with labor and capital, while 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

$$Y_{C,t}(i) = \exp(u_{A,t}) \zeta_{AC,t} (K'_{C,t}(i))^{\mu_C} (L_{C,t}(i))^{1-\mu_C} \tag{1.45}$$

$$\text{and} \quad Y_{D,t}(i) = \exp(u_{A,t}) \zeta_{AD,t} (l(i))^{\mu_l} (K'_{D,t}(i))^{\mu_D} (L_{D,t}(i))^{1-\mu_l-\mu_D}, \tag{1.46}$$

where $K'_{j,t}(i) = z_{j,t} K_{j,t-1}(i)$ is the effective utilization of the capital stock and $u_{A,t}$ is an union-wide technology shock that is serially uncorrelated. $\zeta_{AC,t}$ and $\zeta_{AD,t}$ are domestic, sector-specific technology shocks that follow: $\log(\zeta_{AC,t}) = \rho_{AC} \log(\zeta_{AC,t-1}) + u_{AC,t}$ and $\log(\zeta_{AD,t}) = \rho_{AD} \log(\zeta_{AD,t-1}) + u_{AD,t}$. The parameter μ_C denotes the capital share in the nondurable goods sector, and μ_l and μ_D are, respectively, the land share and the capital share in the housing sector.

Cost minimization yields the following nominal marginal costs for intermediate goods producers in the nondurable goods sector

$$MC_{C,t} = \frac{1}{\exp(u_{A,t})\zeta_{AC,t}} \frac{(R_{C,t})^{\mu_C} (W_{C,t})^{1-\mu_C}}{\mu_C^{\mu_C} (1-\mu_C)^{1-\mu_C}}, \tag{1.47}$$

and the nominal marginal costs for intermediate goods producers in the housing sector are

$$MC_{D,t} = \frac{1}{\exp(u_{A,t})\zeta_{AD,t}} \frac{(R_{l,t})^{\mu_l} (R_{D,t})^{\mu_D} (W_{D,t})^{1-\mu_l-\mu_D}}{\mu_l^{\mu_l} \mu_D^{\mu_D} (1-\mu_l-\mu_D)^{1-\mu_l-\mu_D}}, \tag{1.48}$$

where the optimal rental rate of land is[10]

$$R_{l,t} = \frac{\mu_l}{1-\mu_l-\mu_D} \frac{W_{D,t} L_{D,t}(i)}{l}. \tag{1.49}$$

Nominal profits of intermediate goods producer i, operating in sector $j = C, D$, are given by

$$Div_{C,t}(i) = (P_{H,t}(i) - MC_{C,t}) \left(\frac{1}{n}\right) \left(\frac{P_{H,t}(i)}{P_{H,t}}\right)^{-\frac{1+\lambda}{\lambda}} Y_{C,t} \tag{1.50}$$

$$\text{and} \quad Div_{D,t}(i) = (P_{D,t}(i) - MC_{D,t}) \left(\frac{1}{n}\right) \left(\frac{P_{D,t}(i)}{P_{D,t}}\right)^{-\frac{1+\lambda}{\lambda}} Y_{D,t}. \tag{1.51}$$

Each monopolistically competitive firm i in sector j maximizes expected profits using a discount rate, which is given by $\Lambda_{t,t+k} = \beta^k \frac{\lambda_{t+k}}{\lambda_t}$. 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, 2003, 2007).

The first-order condition to the maximization problem of firms in the nondurable goods

[10] As in Aspachs-Bracons and Rabanal (2011), we calibrate l in manner such that steady state wages are equal across sectors.

sector is given by

$$E_t \sum_{k=0}^{\infty} \theta_C \Lambda_{t,t+k} Y_{C,t+k}(i) \left(\frac{\dot{P}_{H,t}(i)}{P_{H,t}} \frac{(P_{H,t-1+k}/P_{H,t-1})^{\gamma_C}}{P_{H,t+k}/P_{H,t}} - (1+\lambda) mc_{C,t+k} \right) = 0, \quad (1.52)$$

where $\dot{P}_{H,t}(i)$ is the optimal price for intermediate good i, $mc_{C,t} = \frac{MC_{C,t}}{P_{H,t}}$ are real marginal costs of production, and γ_C measures the degree of price indexation. Firms in the housing sector face the similar optimization problem as firms in the nondurable goods sector. The optimal choice of firms in the housing sector is then

$$E_t \sum_{k=0}^{\infty} \theta_D \Lambda_{t,t+k} Y_{D,t+k}(i) \left(\frac{\dot{P}_{D,t}(i)}{P_{D,t}} \frac{(P_{D,t-1+k}/P_{D,t-1})^{\gamma_D}}{P_{D,t+k}/P_{D,t}} - (1+\lambda) mc_{D,t+k} \right) = 0, \quad (1.53)$$

where $mc_{D,t} = \frac{MC_{D,t}}{P_{D,t}}$ are real marginal costs of production in the housing sector.

Finally, the sectoral aggregate price levels implied by equations (1.43) and (1.44) are given by

$$(P_{H,t})^{-\frac{1}{\lambda}} = \theta_C \left(P_{H,t-1} \left(\frac{P_{H,t-1}}{P_{H,t-2}} \right)^{\gamma_C} \right)^{-\frac{1}{\lambda}} + (1-\theta_C) \left(\dot{P}_{H,t}(i) \right)^{-\frac{1}{\lambda}} \quad (1.54)$$

$$\text{and} \quad (P_{D,t})^{-\frac{1}{\lambda}} = \theta_D \left(P_{D,t-1} \left(\frac{P_{D,t-1}}{P_{D,t-2}} \right)^{\gamma_D} \right)^{-\frac{1}{\lambda}} + (1-\theta_D) \left(\dot{P}_{D,t}(i) \right)^{-\frac{1}{\lambda}}. \quad (1.55)$$

1.2.6 Market clearing

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

$$\begin{aligned} Y_{C,t} = n &\left(\omega \tilde{C}_{H,t} + (1-\omega) C_{H,t} + (1-\omega)\left(I_{H,t}^C + I_{H,t}^D \right) \right) \\ &+ (1-n) \left(\omega^* \tilde{C}_{H,t}^* + (1-\omega^*) C_{H,t}^* + (1-\omega^*) \left(I_{H,t}^{C*} + I_{H,t}^{D*} \right) \right) + \Omega_t, \end{aligned} \quad (1.56)$$

where Ω_t are the real costs associated with variations in the degree of capital utilization that are expressed in units of home produced goods. It holds that

$$\Omega_t = n(1-\omega) \frac{P_{C,t}}{P_{H,t}} \sum_{j}^{C,D} a(z_{j,t}) K_{j,t-1}. \quad (1.57)$$

The equilibrium condition in the housing sector is

$$Y_{D,t} = n \left(\omega \tilde{X}_t + (1-\omega) X_t \right). \quad (1.58)$$

The home country's real GDP is defined as

$$Y_t = Y_{C,t} + Y_{D,t}. \tag{1.59}$$

The equilibrium condition in each labor market is

$$\omega \tilde{L}_{j,t} + (1-\omega)L_{j,t} = \int_0^n L_{j,t}(i)di, \quad j = C, D. \tag{1.60}$$

Market clearing in the domestic debt market is given by

$$\omega \tilde{S}_t = (1-\omega)S_t, \tag{1.61}$$

and market clearing in the international bond market is defined as

$$n(1-\omega)B_t + (1-n)(1-\omega^*)B_t^* = 0. \tag{1.62}$$

The law of motion of the home country's aggregate net foreign asset position is given by

$$\begin{aligned} n(1-\omega)B_t = & \; n(1-\omega)R_{t-1}B_{t-1} \\ & + (1-n)P_{H,t}\left(\omega^*\tilde{C}^*_{H,t} + (1-\omega^*)C^*_{H,t} + (1-\omega^*)\left(I^{C*}_{H,t} + I^{D*}_{H,t}\right)\right) \\ & - nP_{F,t}\left(\omega\tilde{C}_{F,t} + (1-\omega)C_{F,t} + (1-\omega)\left(I^{C}_{F,t} + I^{D}_{F,t}\right)\right). \end{aligned} \tag{1.63}$$

1.2.7 Monetary policy

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

$$R_t^* = \left(R^*_{t-1}\right)^{\mu_R}\left(R^*\left(\frac{\Pi_t}{\Pi}\right)^{\mu_\pi}\right)^{1-\mu_R} exp\left(u^*_{R,t}\right), \tag{1.64}$$

where Π_t is the union-wide consumer price inflation rate, 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

$$\Pi_t = \left(\Pi_{C,t}\right)^n\left(\Pi^*_{C,t}\right)^{1-n}. \tag{1.65}$$

1.3 Bayesian estimation

In this section, we estimate the model using standard Bayesian likelihood methods.[11] We begin to describe the dataset and some measurement issues that arise. Then we outline the calibration of model parameters that are kept fixed in the estimation and continue to explain prior distributions and posterior estimates. Finally, we assess the empirical relevance of our model by comparing second-order moments implied by the model with those measured in the data.

1.3.1 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 is from 1997:Q1 to 2008:Q2. We decide to extend the 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.[12] The choice of the starting date reflects the availability of Eurostat's harmonized national accounts data for Ireland. We decide to end the sample period in 2008:Q2, before the fall of Lehman took place, to prevent that estimation results are biased by the nonlinear dynamics of the financial crisis. 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. Prior to estimation all series are demeaned. 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

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

[12] 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 for the case of Spain. Further, note that we use the 3-month Euro Interbank Offered Rate for both countries from 1999:Q1 onwards.

growth rate series the Irish counterpart series weighted with Ireland's weight in the EMU harmonized index of consumer prices.[13] Following Adolfson et al. (2007), we introduce observed demand for nondurable consumption and investment goods as new variables in the model. Thereby, we take into account that observed aggregates are given as a sum of domestic and foreign produced goods and not as an index over these goods (see equations (1.3), (1.18), and (1.23)).

1.3.2 Calibrated parameters

A number of parameters are kept fixed. Most of these parameters are related to steady state values of variables for which the data is noninformative. If not otherwise specified, we apply the same values of parameters for Ireland and the rest of the EMU. Table 1.1 displays our choice.

Table 1.1: Calibration of model parameters

Parameter		Value
n	Size of Ireland	0.01
$1-\tau$	Fraction of imported goods from EMU	0.2
$1-\tau^*$	Fraction of imported goods from Ireland	0.003
Δ_D	Size of housing sector	0.1
β	Discount factor of savers	0.99
$\tilde{\beta}$	Discount factor of borrowers	0.97
$1-\chi$	LTV ratio	0.8
δ	Housing depreciation rate	0.01
δ_C, δ_D	Capital depreciation rate	0.025
μ_C	Capital share	0.3
μ_D	Capital share	0.2
μ_l	Land share	0.1
θ_{WC}, θ_{WD}	Calvo lottery, wages	0.75
γ_{WC}, γ_{WD}	Indexation, wages	0.5
M_C, M_D	Steady state wage markup	1.5
$1+\lambda$	Steady state price markup	1.2

In particular, we set the size of Ireland, n, to 0.01, which is approximately the country's weight in the EMU harmonized index of consumer prices. We calibrate the weight of foreign goods in Ireland's nonresidential consumption and investment goods index equal to the weight of total imports from EMU member states in total GDP. Based on Eurostat's national accounts data, this implies $1-\tau = 0.2$. Following Quint and Rabanal (2011), we

[13]See appendix B for a visual representation of the data.

choose the corresponding parameter for the rest of the EMU to guarantee that the trade balance is zero in the steady state. This yields $1 - \tau^* = 0.003$. The discount factor of savers, β, is set to 0.99, which implies an annual steady state interest rate of 4%. For the discount factor of borrowers, $\tilde{\beta}$, we follow Iacoviello and Neri (2010) and pick a value of 0.97. The LTV ratio, $1-\chi$, is fixed at 0.8, which is the typical LTV ratio for both Ireland and the EMU (see Drudi et al., 2009). As in Iacoviello and Neri (2010) and Darracq Pariès and Notarpietro (2008), we assume that the annual depreciation rate of housing is 4%, which gives $\delta = 0.01$. The depreciation rate of capital in sector $j = C, D$, δ_j, 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 corresponds to a labor share of $1 - \mu_C = 0.7$. To maintain the same labor share in the housing production function, we assume that $\mu_D = 0.2$ and that $\mu_l = 0.1$.[14] As Aspachs-Bracons and Rabanal (2010) point out, the weight of nondurable goods in total private consumption, $1-\alpha$, and the relative size of the housing sector, Δ_D, cannot be determined independently. We numerically solve for $1-\alpha$, so that Δ_D is fixed to be 10%, which is roughly the share of residential investment in total GDP from 1997 to 2008 for Ireland.[15] Following Quint and Rabanal (2011), we choose to calibrate the parameters governing the wage Phillips curves. We calibrate the Calvo lottery parameters, θ_{WC} and θ_{WD}, to 0.75. This implies an average frequency of wage adjustment of four quarters in both sectors. For the indexation parameters we assume $\gamma_{WC} = \gamma_{WD} = 0.5$. Finally, the steady state markup in the goods markets is fixed at 1.2 and the steady state markup in the labor markets is set to 1.5.

1.3.3 Prior distributions and posterior estimates

In tables 1.2 and 1.3 we report the prior distributions of structural parameters as well as the prior distributions of AR(1) coefficients and standard deviations of shocks. As the data sample is relatively short, we restrict the number of parameters to be estimated. In particular, we assume that the parameter values of structural parameters and AR(1) coefficients are the same for Ireland and the rest of the EMU, so that only the standard deviations of shocks deviate across countries (see also Aspachs-Bracons and Rabanal,

[14] This ensures that the relative size of the housing sector equals Δ_D in the steady state.

[15] Note that three parameters that we estimate, namely, ω, h, and η, affect steady state ratios and thus have an impact on $1 - \alpha$. An evaluation of the model at the prior mean of parameters to be estimated yields $1 - \alpha = 0.55$.

2010).[16]

Table 1.2: Prior and posterior distribution of shock processes

Parameter		Prior			Posterior		
		Distr.	Mean	St. dev.	Mode	Mean	95% CI
Home and foreign country							
ρ_β	Preference	Beta	0.7	0.1	0.77	0.73	[0.61,0.85]
ρ_D	Preference	Beta	0.7	0.1	0.98	0.97	[0.95,0.99]
ρ_I	Technology	Beta	0.7	0.1	0.40	0.39	[0.28,0.50]
ρ_{AC}	Technology	Beta	0.7	0.1	0.94	0.90	[0.83,0.98]
ρ_{AD}	Technology	Beta	0.7	0.1	0.92	0.92	[0.88,0.96]
ρ_{Risk}	Risk	Beta	0.7	0.1	0.75	0.75	[0.63,0.88]
σ_A	Technology	Invg.	0.01	2	0.002	0.003	[0.002,0.003]
Home country							
σ_β	Preference	Invg.	0.01	2	0.033	0.037	[0.025,0.048]
σ_D	Preference	Invg.	0.01	2	0.038	0.044	[0.028,0.061]
σ_I	Technology	Invg.	0.01	2	0.449	0.500	[0.258,0.721]
σ_{AC}	Technology	Invg.	0.01	2	0.018	0.023	[0.013,0.033]
σ_{AD}	Technology	Invg.	0.01	2	0.015	0.016	[0.013,0.019]
σ_{Risk}	Risk	Invg.	0.001	2	0.0007	0.0007	[0.0006,0.0008]
Foreign country							
σ^*_β	Preference	Invg.	0.001	2	0.005	0.006	[0.005,0.008]
σ^*_D	Preference	Invg.	0.01	2	0.008	0.009	[0.006,0.013]
σ^*_I	Technology	Invg.	0.01	2	0.031	0.037	[0.019,0.053]
σ^*_{AC}	Technology	Invg.	0.01	2	0.007	0.009	[0.004,0.014]
σ^*_{AD}	Technology	Invg.	0.01	2	0.005	0.005	[0.004,0.007]
σ^*_R	Monetary	Invg.	0.001	2	0.0011	0.0012	[0.0009,0.0014]

Our choice of prior distributions is standard and corresponds to a large extend to that in Aspachs-Bracons and Rabanal (2010) and Darracq Pariès and Notarpietro (2008). For the standard deviations of the innovations to shocks we assume an inverse-gamma distribution. We set the standard errors to 2, so that a large domain of parameter values is encompassed. The AR(1) coefficients of shocks are assumed to follow a beta distribution with mean of 0.7 and standard error of 0.1. Turning to the structural parameters of the model, we assume that the share of borrowers, ω, follows a beta distribution with mean of 0.35 and standard deviation of 0.05. The habit formation parameter follows a beta distribution with prior mean of 0.66 and standard deviation of 0.15. The parameter governing the inverse elasticity of labor supply, η, has a gamma distribution with parameters 2 and 0.75. The

[16]We have also estimated the model by allowing the share of borrowers, price setting parameters, and AR(1) coefficients of shocks to differ across countries. For most of the parameters we found little difference between the estimated values for Ireland and those for the rest of the EMU. The log marginal likelihood declines to -769.76 compared to -758.02 for the benchmark specification.

labor reallocation parameter, ι_L, has a normal distribution as in Iacoviello and Neri (2010). We choose to set the parameters to 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.[17] As in Smets and Wouters (2003), the elasticity of the cost of adjusting investment follows a normal distribution with prior mean of 4 and standard deviation of 1.5. The elasticity of the capital utilization cost function, υ, follows a beta distribution with parameters 0.5 and 0.15. The parameters describing the price setting behavior of firms have the same prior distributions across sectors. Thus we take no stand on the relative degree of price stickiness between nondurable goods prices and house prices a priori. For the Calvo parameters we specify a beta distribution loosely centered around a prior mean of 0.75, and for the indexation parameters we assume a beta distribution with prior mean of 0.5. The risk premium elasticity has a gamma distribution. The prior mean is 0.01, which implies a risk premium of 50 basis points given a reduction of net foreign assets of 50 percentage points. Turning to the assumptions for the prior distribution of the Taylor rule coefficients, we assume that the interest rate smoothing coefficient has a beta distribution with prior mean of 0.75 and standard deviation of 0.15 and that the coefficient on consumer price inflation follows a normal distribution with parameters 1.5 and 0.15.

In the last three columns of tables 1.2 and 1.3 we summarize the estimation results by reporting the posterior modes together with posterior means and 95% confidence intervals, which are obtained through draws from the posterior distribution of the model.[18] Focusing on the shock processes, we find that all standard deviations are estimated to be significantly different from zero. Moreover, we find a high persistence of all shocks with the exception of the investment shock, which features an AR(1) coefficient of 0.39. As in Darracq Pariès and Notarpietro (2008), we find that among the shocks with the highest persistence is the housing preference shock and the technology shock in the housing sector. Turning to the structural parameters, we estimate the share of borrowers to be 0.32, which is below the prior mean of 0.35.[19] We estimate the importance of past consumption of

[17]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.

[18]The estimation was executed 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 dropping the first 50000. A step size of 0.3 yielded an average acceptance ratio of about 31%. Figures of prior and posterior distributions of all estimated parameters are shown in appendix C.

[19]Similar to Darracq Pariès and Notarpietro (2008) and Aspachs-Bracons and Rabanal (2010), we find that the data is not very informative on this parameter. When we choose to set the prior mean of ω equal

Table 1.3: Prior and posterior distribution of structural parameters

Parameter		Prior			Posterior		
		Distr.	Mean	St. dev.	Mode	Mean	95% CI
ω	Share of borrowers	Beta	0.35	0.05	0.32	0.32	[0.25,0.39]
ϵ	Habits	Beta	0.66	0.15	0.38	0.42	[0.27,0.57]
ι_L	Labor adj. cost	Normal	1	0.5	2.06	2.11	[1.46,2.75]
η	Labor disutility	Gamma	2	0.75	1.59	2.01	[1.12,2.93]
ι	Elasticity of subst.	Normal	1	0.5	2.27	2.23	[1.71,2.74]
ρ	Investment adj. cost	Normal	4	1.5	4.64	5.04	[2.83,7.26]
υ	Capital utilization	Beta	0.5	0.15	0.79	0.78	[0.65,0.91]
θ_C	Calvo lottery, prices	Beta	0.75	0.15	0.69	0.72	[0.60,0.85]
θ_D	Calvo lottery, prices	Beta	0.75	0.15	0.07	0.08	[0.03,0.13]
γ_C	Indexation, prices	Beta	0.5	0.15	0.11	0.14	[0.04,0.24]
γ_D	Indexation, prices	Beta	0.5	0.15	0.42	0.43	[0.18,0.66]
κ	Risk premium	Gamma	0.01	0.0075	0.02	0.02	[0.01,0.02]
μ_R	Taylor rule	Beta	0.75	0.15	0.70	0.71	[0.65,0.78]
μ_π	Taylor rule	Normal	1.5	0.15	1.14	1.25	[1.06,1.42]

nondurable goods in the utility function of households to be 0.42, which is quite similar to the finding in Aspachs-Bracons and Rabanal (2010). The posterior mean of the labor reallocation cost parameter is estimated to be 2.11. This estimate confirms the result in Aspachs-Bracons and Rabanal (2010) that labor market reallocation is more costly in Europe than in the US. However, it stands in contrast to Quint and Rabanal (2011) who find a posterior mean on that parameter well below 0.5. For the labor disutility parameter we find a posterior mean of 2.01. Our estimate of the elasticity of substitution between home and foreign goods is around 2.23, implying 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 function is around 5, which is above the prior mean of 4. For the parameter governing the capital utilization cost function the posterior mean is estimated to be 0.78. Regarding the parameters governing the stickiness of prices, we find clear evidence on the existence of asymmetric price rigidities across sectors similar to Darracq Pariès and Notarpietro (2008) and Aspachs-Bracons and Rabanal (2010). In particular, we estimate the posterior mean of the degree of price stickiness in the nondurable goods sector to be 0.72, which corresponds to an average

to 0.5, we estimate a posterior mean of 0.43. The log marginal likelihood of the model with the high share of borrowers declines to -760.98. In addition, we have estimated a version of the model without collateral constraints ($\omega = 0$). The log marginal likelihood reaches -756.69, which is slightly larger than the likelihood for the baseline model.

frequency of price adjustment of roughly four quarters. In contrast, prices in the housing sector are found to be much more flexible. The posterior mean of θ_D is estimated to be 0.08, which is equivalent to an average frequency of price adjustment of about one quarter. The estimated posterior mean of the parameter governing the degree of price indexation in the nondurable goods sector is 0.14, and in the housing sector we find a posterior mean of 0.43. The risk premium elasticity is estimated to be about 0.02 as in Aspachs-Bracons and Rabanal (2010). For the coefficient on the lagged interest rate in the monetary policy rule we find a posterior mean of 0.71. The posterior estimate of the coefficient on consumer price inflation is estimated to be relatively low, similar to the finding in Aspachs-Bracons and Rabanal (2010). The posterior mean of μ_π is 1.25 and the corresponding 95% confidence interval is ranging from 1.06 to 1.42.

1.3.4 Second-order moments

In table 1.4 we assess the empirical relevance of our model by comparing selected second-order moments of observables with the model's counterparts. For the latter we report posterior median values based on the Metropolis-Hastings algorithm.

Table 1.4: Comparison of second-order moments

St. dev.	Data	Model	Corr.	Data	Model
Home country			*Home country*		
ΔC_{obs}	1.78	1.97	$\Delta C_{obs}, q$	0.27	0.20
$\Delta Y_{I,obs}$	11.41	10.00	$\Delta C_{obs}, \Delta Y_D$	0.10	0.02
ΔY_D	4.31	7.98	$\Delta Y_D, q$	0.28	0.55
π_C	0.41	0.74	*Foreign country*		
π_D	2.52	2.12	$\Delta C^*_{obs}, q^*$	0.20	0.56
R	0.33	0.40	$\Delta C^*_{obs}, \Delta Y^*_D$	0.41	0.22
Foreign country			$\Delta Y^*_D, q^*$	0.22	0.54
ΔC^*_{obs}	0.32	0.66	*Cross-country*		
$\Delta Y^*_{I,obs}$	1.02	1.06	$\Delta Y_D, \Delta Y^*_D$	0.33	0.14
ΔY^*_D	1.37	3.14	q, q^*	0.36	0.12
π^*_C	0.24	0.43			
π^*_D	0.45	0.84			
R^*	0.24	0.36			

Focusing on Ireland, we find that the model hits the volatilities of nondurable consumption, nonresidential investment, house price inflation, and interest rates. The volatility of residential investment and the volatility of consumer price inflation, however, is overestimated with respect to the data. The model reproduces the sign of selected, housing-related correlations. The model matches the correlation between nondurable consumption and real house prices. For the correlation between nondurable consumption and residential investment, however, the model reproduced correlation is relatively low, and for the correlation between residential investment and real house prices the model generated correlation is relatively high. Turning to the rest of the EMU, we find that the model exceeds the volatilities of observables with the exception of nonresidential investment. Similar to the case of Ireland, the model matches the sign of selected housing-related correlations.

Overall, we can conclude that the estimated model explains the dynamics of the data reasonably well. For both countries the model replicates the relative volatility differentials between real aggregates as well as prices and reproduces the sign of the correlation of selected variables. Finally, the model accounts for the higher volatility of all Irish observables compared with those of the rest of the EMU, and the model reproduces the sign of cross-country correlations of real house prices and residential investment.

1.4 Irish housing market dynamics

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

1.4.1 Variance decomposition

Table 1.5 displays the results from the variance decomposition of Irish observables. Apparently, domestic housing preference and technology shocks are the main determinants of the overall fluctuations in the Irish housing market. In particular, housing preference shocks explain about 60% of the variance of residential investment and housing technology shocks account for about 30%. The bulk of the variation of house prices is explained by housing preference shocks, which is about 87%. Moreover, we find that monetary policy and risk premium shocks have a negligible effect on the fluctuations in the Irish housing market, which is in line with what Aspachs-Bracons and Rabanal (2010) report for Spain. Monetary policy and risk premium shocks explain together about 3% of the variation of residential investment and house prices.

Overall, the variance decomposition confirms the existing evidence that demand factors have contributed the most to fluctuations in the Irish housing market (see, for instance, Malzubris, 2008; Rae and van den Noord, 2006). Note that our finding of a negligible role of monetary policy shocks does not challenge the view that the low levels of real interest rates especially at the beginning of Ireland's EMU membership have contributed to the housing boom. Given that Ireland's weight in the EMU harmonized index of consumer prices is small, the estimated monetary policy shocks are not very informative on monetary conditions for Ireland. Instead, the impact of low levels of real interest rates on Irish housing market dynamics are endogenously given in the model through their impact on housing demand implied by equations (1.11) and (1.26).

Table 1.5: Unconditional variance decomposition

	ΔC_{obs}	$\Delta Y_{I,obs}$	ΔY_D	π_C	π_D	R
Home and foreign country						
u_A	0.01	0.00	2.89	0.21	0.00	0.14
Home country						
u_{AC}	14.6	1.53	1.74	52.1	4.36	2.93
u_{AD}	0.01	0.00	29.3	0.00	0.41	0.00
u_I	3.39	97.9	2.61	18.9	4.36	24.1
u_β	76.8	0.40	1.19	9.43	1.01	4.27
u_D	2.08	0.11	59.0	2.90	86.6	0.48
u_{Risk}	0.73	0.00	0.82	0.17	0.90	6.48
Foreign country						
u^*_{AC}	0.62	0.01	0.22	9.89	1.27	46.12
u^*_{AD}	0.00	0.00	0.00	0.00	0.00	0.01
u^*_I	0.01	0.00	0.02	1.68	0.12	4.00
u^*_β	0.01	0.00	0.01	1.37	0.10	3.68
u^*_D	0.01	0.00	0.00	0.22	0.03	1.01
u^*_R	1.70	0.00	2.23	3.13	2.21	6.81

1.4.2 Historical decomposition

In figures 1.2 and 1.3 we present the historical contribution of each of the structural shocks to the movements of residential investment and real house prices over the sample period. As we have 13 structural shocks in the model, we group monetary policy and risk premium shocks into one category and do the same with the shocks coming from the rest of the EMU (excluding monetary policy shocks), the EMU-wide technology shock, and initial conditions.

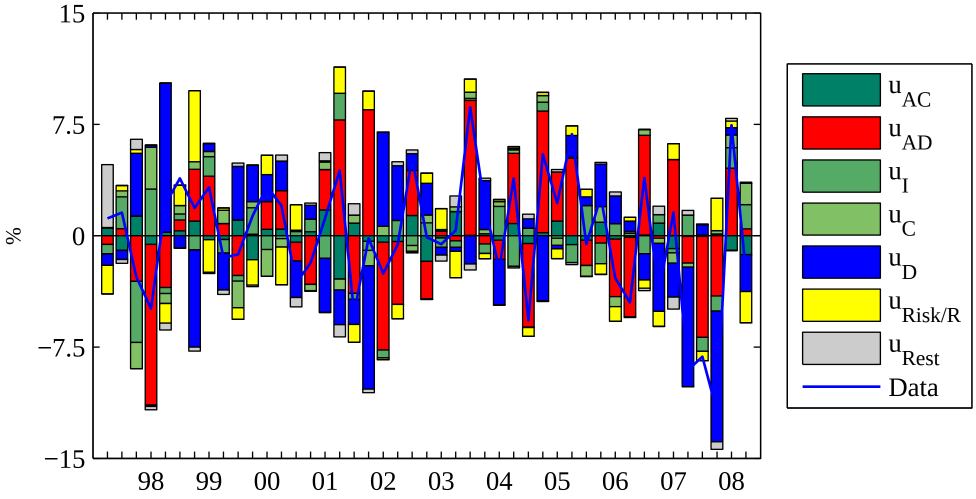

Figure 1.2: Historical decomposition of real residential investment (q-o-q growth rate)

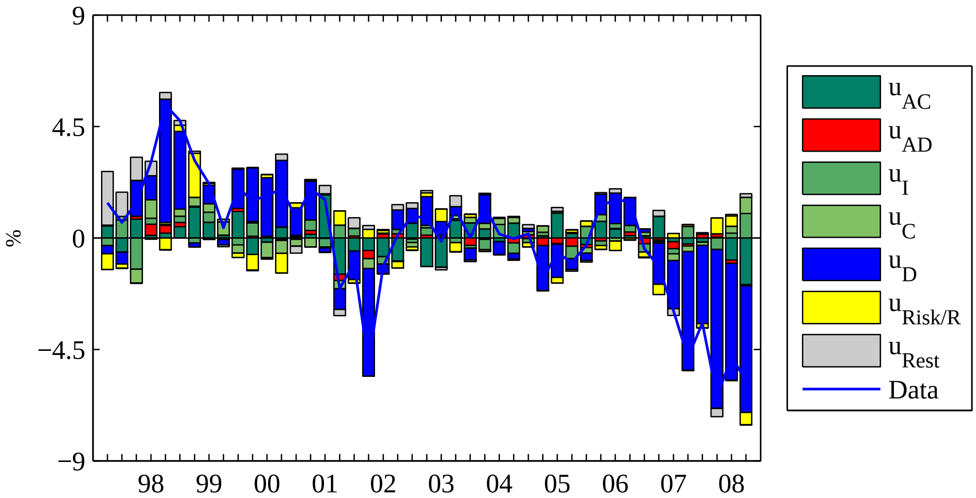

Figure 1.3: Historical decomposition of real house prices (q-o-q growth rate)

In line with the results from the variance decomposition, domestic housing preference and housing technology shocks are the main contributors to the movements of residential investment in Ireland. Over the sample period housing preference and technology shocks have sometimes an offsetting effect. However, we observe large negative housing technology and preference shocks toward the end of the sample period when residential investment dramatically drops. The historical decomposition of real house prices shows that housing preference shocks are the main drivers during the 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. Also, technology shocks emerging in the nondurable goods sector have their impact on real house price fluctuations, but they are not dominant. As it is already clear from the previous section, monetary policy shocks do not contribute much to the overall variability of Irish house prices. Monetary shocks are neither supportive in the mid 2000s when monetary conditions were pretty loose, nor play a more important role around the slump of house prices toward the end of the sample period when monetary conditions tightened. Finally, we do not find that risk premium shocks contributed too much to real house price fluctuations at the beginning of the sample period when the risk premium essentially vanished.

1.4.3 Impulse responses

Using a standard impulse response analysis, we rationalize the results from the previous decomposition analyses and highlight the model's ability to account for key features of the data. In figures 1.4 to 1.6 we concentrate on the propagation of housing-related and monetary policy shocks. For each shock we plot impulse response functions for key variables obtained from evaluating the model at its posterior mean. As in Iacoviello and Neri (2010), we highlight the role of collateral constraints as well as sticky wages by providing impulse responses for counterfactual model simulations in which we shut off collateral effects ($\omega = 0$) or in which we allow for flexible wages ($\theta_{WC} = \theta_{WD} = 0$).

In figure 1.4 we look at a positive housing preference shock. As can be seen, real house prices and residential investment significantly rise in response to the shock. While the response of residential investment is relatively short-lived, a long-lasting response of house prices can be observed. House prices are well above its steady state after 20 quarters. As is apparent from the figure, collateral effects are key to explain the model's ability to replicate a positive correlation between consumption of nondurable goods and real house prices with respect to the data (see section 1.3.4). In response to the increase in real house prices, borrowers expand their debt holdings and increase consumption, so that aggregate consumption slightly rises in the first quarter following the shock. Absent collateral constraints, consumption of nondurable goods drops in response to the shock, as preferences are shifted from nondurable goods toward housing. Moreover, the figure illustrates that sticky wages are crucial to generate a strong response of residential investment in response to the shock and thus account for the model's ability to generate a positive correlation between residential investment and real house prices as measured in the data. Otherwise, the high sensitivity of residential investment to housing preference shocks implied by wage rigidity explains why the model tends to overestimate the volatility of residential investment.[20]

In figure 1.5 we display the responses to a positive housing technology shock. A positive technology shock in the housing sector leads to an increase in residential investment and to a decline in house prices by standard mechanisms. Again, collateral effects are key to produce significant spillover effects to the nonresidential goods sector. Relative to housing preference shocks, however, the quantitative implications of housing technology shocks for consumption of nondurable goods and nonresidential investment are small.

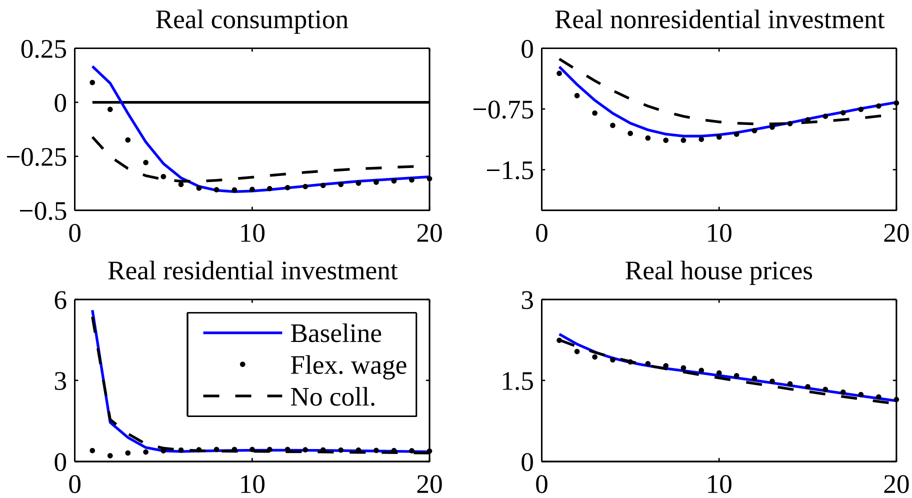

Figure 1.4: Posterior impulse responses to a housing preference shock

In figure 1.6 we provide responses to a positive monetary policy shock. In response to the monetary policy tightening, all aggregate quantities as well as real house prices significantly drop. The drop of residential investment and consumption of nondurable

[20]We have also estimated a version of the model in which we allow for flexible wages in both sectors ($\theta_{WC} = \theta_{WD} = 0$). We find that this version of the model hits the volatility of residential investment and real house prices with respect to the data, but it cannot account for the positive comovement between these aggregates. The log likelihood of this model is found to be substantially lower relative to the baseline.

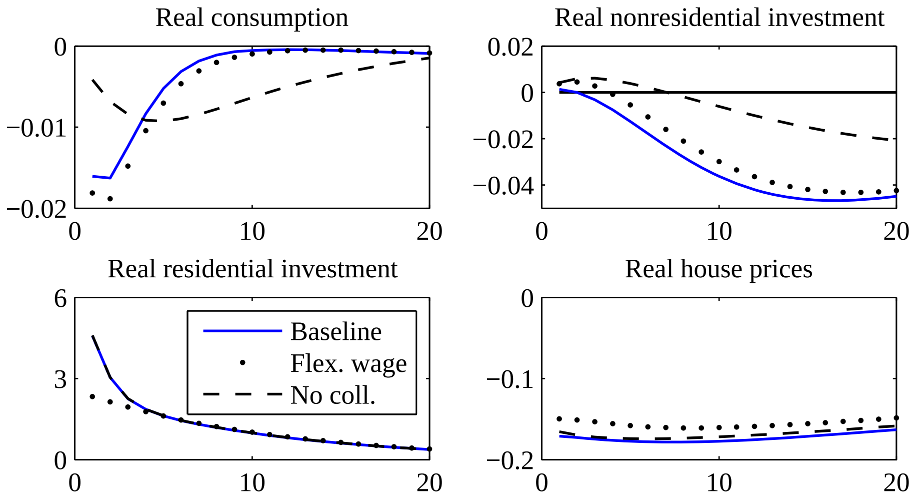

Figure 1.5: Posterior impulse responses to a technology shock in the housing sector

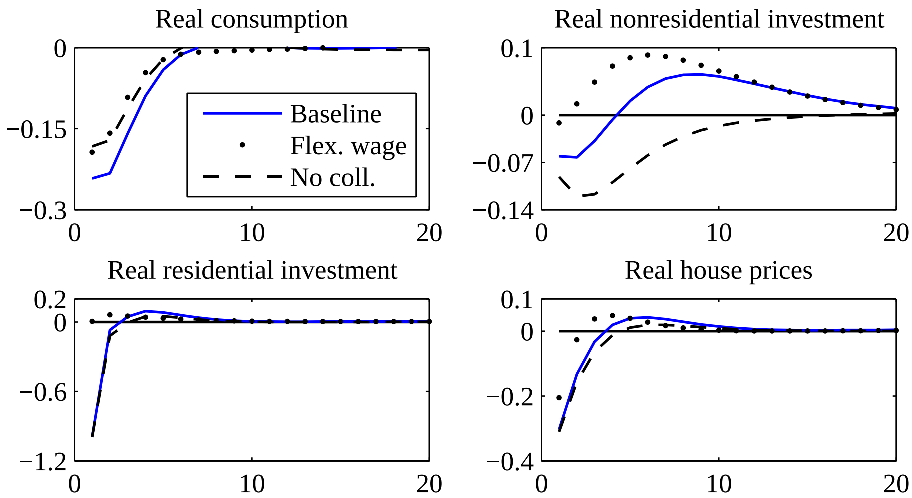

Figure 1.6: Posterior impulse responses to a monetary policy shock

goods reflects the positive comovement of these quantities in response to a monetary policy shock that is generally found in VAR models (see, for instance, Monacelli, 2009; Calza et al., 2011; Aspachs-Bracons and Rabanal, 2011). As argued in Barsky et al. (2007), a simple two-sector NK model is at odds with these facts. If durable goods prices are fully flexible and consumption goods prices are sticky, a monetary contraction implies that nondurable goods consumption decreases, while durable goods consumption increases due to the fall of its relative price. Apparently, sticky wages are key to solve for this comovement problem. As already pointed out by Carlstrom and Fuerst (2006), wage rigidity implies that real house prices are more rigid, which then leads to a fall in residential investment in response to a monetary policy contraction (see also Iacoviello and Neri, 2010; Aspachs-Bracons and Rabanal, 2011). As for the effects of collateral constraints, we obtain that the fall in nondurable goods consumption following the monetary contraction is larger if collateral constraints are present. The responses of residential investment and real house prices, however, remain almost unaffected by shutting off collateral effects with respect to the baseline specification (see also Iacoviello and Neri, 2010).

1.5 Robustness analysis

Given the dominant role of housing preference shocks in explaining Irish housing market dynamics, we now test whether the housing preference shocks implied by the model can be traced back to unmodeled demand factors that have been considered in the empirical literature as relevant determinants of Irish house prices. In particular, we follow the approach of Iacoviello and Neri (2010) and test whether the estimated innovations to housing preferences ($u_{D,t}$) can survive simple exogeneity tests by estimating the following equation

$$u_{D,t} = \alpha u_{D,t-1} + \beta x_{t-1} + v_t, \tag{1.66}$$

where v_t is an IID-normal process with zero mean, and x_t is a vector containing explanatory variables for housing demand (see also Neri, 2010).

Our choice for the set of explanatory variables is as follows. 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 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 consider private mortgage finance. In addition, we include real interest rates and consumer price inflation into the set of explanatory variables, even though they have been used for the estimation of the model. The introduction of real interest rates is meant to assess whether the mechanisms embedded in the model are sufficient to account for the actual impact of real interest rates on Ireland's housing boom. In the same vein, we consider consumer price inflation to test whether inflation illusion matters for housing demand. If inflation illusion is relevant, consumer price inflation has a stronger impact on housing demand than the mechanisms of the model allow for (see 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 lean against the rise in house prices.

We construct total population (other) as total population minus young population. We obtain the population numbers from the Central Statistics Office. The series are at an annual frequency, so that we convert them by linear interpolation into quarterly series. We get nominal disposable income from Eurostat.[21] The source of the time series for private mortgage finance is the Central Bank of Ireland. We deflate nominal series with the consumer price index. The real interest rate is constructed as $\log(R_t/\Pi_{C,t})$. We express all variables (except real interest rates and consumer price inflation) in first-differences in logs multiplied by 100. Table 1.6 displays the results.

We find that all exogenous variables have the expected sign. The only exception to this is total population growth (other). The coefficients on real disposable income, real mortgage finance growth, and consumer price inflation have the correct sign, but they are not significant. All other explanatory variables are significant at the 5% level. We find that the combined explanatory power of regressors is around 77%. Remarkably, if we omit the lagged innovation to housing preferences from the regression, we find that the coefficients on real disposable income and mortgage finance become significant at the 5% level, while the significance level of the remaining regressors does not change. The adjusted R^2 of this regression falls to 67.2%. Moreover, we find that some part of the fit of the regression in table 1.6 is explained by the dummy variable. If the dummy variable is omitted, the adjusted R^2 falls to 66.1%.

The fact that real interest rates have an effect on the estimated innovation to housing

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

Table 1.6: The predictability of housing preference innovations

Variable	Coefficient	Std. error	T-stat.	Prob.
Innovation	0.400	0.123	3.241	0.003
Population growth (25-44)	0.051	0.020	2.570	0.015
Population growth (other)	-0.194	0.060	-3.243	0.003
Real disposable income growth	0.002	0.002	1.066	0.294
Real mortgage finance growth	0.004	0.002	1.587	0.122
Real interest rate	-0.021	0.007	-3.196	0.003
Consumer price inflation	0.004	0.007	0.599	0.553
Dummy	-0.062	0.005	-13.337	0.000
Sample	1998:Q3-2008:Q2			
R^2, $\bar{R}^2$	0.773, 0.724			
Durbin-Watson stat.	2.755			
Q(4), Q(8), Q(12)	10.193, 14.421, 17.400			

Newey-West standard errors

preferences implies that the mechanisms of the model are likely to be too weak to fully appreciate the role of monetary conditions in driving Ireland's housing boom.[22] One possible explanation for this might be due to the weak transmission mechanisms of monetary policy implied by collateral constraints for house prices and residential investment. As the impulse response analysis in the previous section shows, the presence of collateral constraints has only mild effects on housing market variables in the wake of monetary policy shocks.

1.6 Conclusion

In this chapter, we study the drivers of the fluctuations in the Irish housing market by developing and estimating a NK DSGE model of Ireland as a member of the 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:Q1 to 2008:Q2. 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 preference shocks account for about 87% of the variation of house prices as well as for about 60% of the variation of residential investment. This important role of housing preference shocks in shaping housing market dynamics is generally found

[22]Note that the importance of real interest rates for housing preference shocks is similar to the finding by Neri (2010) in a comment on Aspachs-Bracons and Rabanal (2010).

in the housing DSGE literature. It is what Darracq Pariès and Notarpietro (2008) find for the euro area, Aspachs-Bracons and Rabanal (2010) for Spain, and Iacoviello and Neri (2010) for the US. Using a standard regression analysis, we then show that the estimated innovations to housing preferences can be traced back to unmodeled shifts in the demand for housing that have been typically considered as important determinants of Irish house prices. Our finding that housing preference shocks depend on real interest rates, however, indicates that the model mechanisms are likely to be too weak to fully appreciate the role of monetary conditions in driving Ireland's housing boom. One explanation for this might be due to the limited effects of collateral constraints on housing in the transmission of monetary policy.

Appendix to Chapter 1

A Model equations

Here, we summarize the set of model equations. A ˜ refers to borrowers, a * indicates foreign country variables and variables without a time subscript stand for steady state values.

A.1 Home country

Households

The labor supply indices are

$$\tilde{L}_t = \left[(1-\Delta_D)^{-\iota_L}\tilde{L}_{C,t}^{1+\iota_L} + \Delta_D^{-\iota_L}\tilde{L}_{D,t}^{1+\iota_L}\right]^{\frac{1}{1+\iota_L}} \tag{67}$$

$$L_t = \left[(1-\Delta_D)^{-\iota_L}L_{C,t}^{1+\iota_L} + \Delta_D^{-\iota_L}L_{D,t}^{1+\iota_L}\right]^{\frac{1}{1+\iota_L}} \tag{68}$$

The housing stocks evolve as

$$\tilde{D}_t = (1-\delta)\tilde{D}_{t-1} + \tilde{X}_t \tag{69}$$

$$D_t = (1-\delta)D_{t-1} + X_t \tag{70}$$

The sector-specific capital accumulation equation is ($j = C, D$)

$$K_{j,t} = (1-\delta_j)K_{j,t-1} + \zeta_{I,t}\left[1 - S\left(\frac{I_t^j}{I_{t-1}^j}\right)\right]I_t^j \tag{71}$$

The collateral constraint is

$$R_t\tilde{s}_t = (1-\chi)(1-\delta)E_t\left(q_{t+1}\Pi_{C,t+1}\tilde{D}_t\right) \tag{72}$$

The period budget constraint of a typical borrower reads

$$\tilde{C}_t + q_t\tilde{X}_t + R_{t-1}\frac{\tilde{s}_{t-1}}{\Pi_{C,t}} = w_{C,t}\tilde{L}_{D,t} + w_{D,t}\tilde{L}_{D,t} + \tilde{s}_t \tag{73}$$

The first-order conditions for a typical borrower in the home country are

$$1 = \tilde{\beta} E_t \left(\frac{R_t}{\Pi_{C,t+1}} \frac{\tilde{C}_t - \epsilon \tilde{C}_{t-1}}{\tilde{C}_{t+1} - \epsilon \tilde{C}_t} \frac{\zeta_{\beta,t+1}}{\zeta_{\beta,t}} \right) + R_t \tilde{\psi}_t \tag{74}$$

$$\begin{aligned} \frac{\zeta_{D,t}\alpha}{1-\zeta_{D,t}\alpha} \frac{\tilde{C}_t - \epsilon \tilde{C}_{t-1}}{\tilde{D}_t} &= q_t \left(1 - (1-\chi)(1-\delta) \tilde{\psi}_t E_t \left(\Pi_{D,t+1} \right) \right) \\ &\quad - \tilde{\beta}(1-\delta) E_t \left(\frac{\tilde{C}_t - \epsilon \tilde{C}_{t-1}}{\tilde{C}_{t+1} - \epsilon \tilde{C}_t} \frac{\zeta_{\beta,t+1}}{\zeta_{\beta,t}} q_{t+1} \right) \end{aligned} \tag{75}$$

$$\tilde{C}_{H,t} = \tau \tilde{C}_t \left(\tau + (1-\tau) T_t^{1-\iota} \right)^{\frac{\iota}{1-\iota}} \tag{76}$$

$$\tilde{C}_{F,t} = (1-\tau) \tilde{C}_t \left(\tau T_t^{\iota-1} + 1 - \tau \right)^{\frac{\iota}{1-\iota}} \tag{77}$$

$$\tilde{L}_t^{\eta-\iota_L} (1-\Delta_D)^{-\iota_L} \tilde{L}_{C,t}^{\iota_L} = \frac{1-\zeta_{D,t}\alpha}{\tilde{C}_t - \epsilon \tilde{C}_{t-1}} \frac{w_{C,t}}{M_{C,t}} \tag{78}$$

$$\text{and} \quad \tilde{L}_t^{\eta-\iota_L} \Delta_D^{-\iota_L} \tilde{L}_{D,t}^{\iota_L} = \frac{1-\zeta_{D,t}\alpha}{\tilde{C}_t - \epsilon \tilde{C}_{t-1}} \frac{w_{D,t}}{M_{D,t}} \tag{79}$$

The first-order conditions for a typical saver in the home country are $(j = C, D)$

$$1 = \beta E_t \left(\frac{R_t}{\Pi_{C,t+1}} \frac{C_t - \epsilon C_{t-1}}{C_{t+1} - \epsilon C_t} \frac{\zeta_{\beta,t+1}}{\zeta_{\beta,t}} \right) \tag{80}$$

$$\frac{\zeta_{D,t}\alpha}{1-\zeta_{D,t}\alpha} \frac{C_t - \epsilon C_{t-1}}{D_t} = q_t - (1-\delta) E_t \left(\frac{\Pi_{C,t+1}}{R_t} q_{t+1} \right) \tag{81}$$

$$Q_{j,t} = E_t \left(\frac{\Pi_{C,t+1}}{R_t} \left(Q_{j,t+1}(1-\delta_j) + r_{j,t+1} z_{j,t+1} - a(z_{j,t+1}) \right) \right) \tag{82}$$

$$\zeta_{I,t} Q_{j,t} = \frac{1 - E_t \left(\zeta_{I,t+1} Q_{j,t+1} \frac{\Pi_{C,t+1}}{R_t} S' \left(\frac{I_{t+1}^j}{I_t^j} \right) \left(\frac{I_{t+1}^j}{I_t^j} \right)^2 \right)}{1 - S\left(\frac{I_t^j}{I_{t-1}^j} \right) - S'\left(\frac{I_t^j}{I_{t-1}^j} \right) \left(\frac{I_t^j}{I_{t-1}^j} \right)} \tag{83}$$

$$r_{j,t} = a'(z_{j,t}), \tag{84}$$

$$C_{H,t} = \tau C_t \left(\tau + (1-\tau) T_t^{1-\iota} \right)^{\frac{\iota}{1-\iota}} \tag{85}$$

$$C_{F,t} = (1-\tau) C_t \left(\tau T_t^{\iota-1} + 1 - \tau \right)^{\frac{\iota}{1-\iota}} \tag{86}$$

$$I_{H,t}^j = \tau I_t^j \left(\tau + (1-\tau) T_t^{1-\iota} \right)^{\frac{\iota}{1-\iota}} \tag{87}$$

$$I_{F,t}^j = (1-\tau) I_t^j \left(\tau T_t^{\iota-1} + 1 - \tau \right)^{\frac{\iota}{1-\iota}} \tag{88}$$

$$L_t^{\eta-\iota_L} (1-\Delta_D)^{-\iota_L} L_{C,t}^{\iota_L} = \frac{1-\zeta_{D,t}\alpha}{C_t - \epsilon C_{t-1}} \frac{w_{C,t}}{M_{C,t}} \tag{89}$$

$$L_t^{\eta-\iota_L} \Delta_D^{-\iota_L} L_{D,t}^{\iota_L} = \frac{1-\zeta_{D,t}\alpha}{C_t - \epsilon C_{t-1}} \frac{w_{D,t}}{M_{D,t}} \tag{90}$$

Dividends from labor unions are distributed according to

$$div'_t = \left(1 - \frac{1}{M_{C,t}}\right) w_{C,t}\tilde{L}_{C,t} + \left(1 - \frac{1}{M_{D,t}}\right) w_{D,t}\tilde{L}_{D,t} \tag{91}$$

$$div''_t = \left(1 - \frac{1}{M_{C,t}}\right) w_{C,t}L_{C,t} + \left(1 - \frac{1}{M_{D,t}}\right) w_{D,t}L_{D,t} \tag{92}$$

The wage Phillips curves are

$$\log\left(\frac{\frac{w_{C,t}}{w_{C,t-1}}\Pi_{C,t}}{(\Pi_{C,t-1})^{\gamma_{WC}}}\right) = \beta E_t \log\left(\frac{\frac{w_{C,t+1}}{w_{C,t}}\Pi_{C,t+1}}{(\Pi_{C,t})^{\gamma_{WC}}}\right) - \frac{(1-\theta_{WC})(1-\beta\theta_{WC})}{\theta_{WC}} \log\left(\frac{M_{C,t}}{M_C}\right) \tag{93}$$

$$\log\left(\frac{\frac{w_{D,t}}{w_{D,t-1}}\Pi_{C,t}}{(\Pi_{C,t-1})^{\gamma_{WD}}}\right) = \beta E_t \log\left(\frac{\frac{w_{D,t+1}}{w_{D,t}}\Pi_{C,t+1}}{(\Pi_{C,t})^{\gamma_{WD}}}\right) - \frac{(1-\theta_{WD})(1-\beta\theta_{WD})}{\theta_{WD}} \log\left(\frac{M_{D,t}}{M_D}\right) \tag{94}$$

Firms and prices

The production technologies are

$$\frac{Y_{C,t}}{n} = \exp(u_{A,t})\zeta_{AC,t}\left((1-\omega)K'_{C,t}\right)^{\mu_C}\left(\omega\tilde{L}_{C,t} + (1-\omega)L_{C,t}\right)^{1-\mu_C} \tag{95}$$

$$\frac{Y_{D,t}}{n} = \exp(u_{A,t})\zeta_{AD,t}\left((1-\omega)l\right)^{\mu_l}\left((1-\omega)K'_{D,t}\right)^{\mu_D}\left(\omega\tilde{L}_{D,t} + (1-\omega)L_{D,t}\right)^{1-\mu_l-\mu_D} \tag{96}$$

Effective capital utilization reads ($j = C, D$)

$$K'_{j,t} = z_{j,t}K_{j,t-1} \tag{97}$$

The first-order conditions for intermediate goods firms are

$$r_{C,t} = \frac{\mu_C}{1-\mu_C} \frac{w_{C,t}\left(\omega \tilde{L}_{C,t} + (1-\omega) L_{C,t}\right)}{(1-\omega) z_{C,t} K_{C,t-1}} \tag{98}$$

$$r_{D,t} = \frac{\mu_D}{1-\mu_l-\mu_D} \frac{w_{D,t}\left(\omega \tilde{L}_{D,t} + (1-\omega) L_{D,t}\right)}{(1-\omega) z_{D,t} K_{D,t-1}} \tag{99}$$

$$r_{l,t} = \frac{\mu_l}{1-\mu_l-\mu_D} \frac{w_{D,t}\left(\omega \tilde{L}_{D,t} + (1-\omega) L_{D,t}\right)}{(1-\omega) l} \tag{100}$$

$$mc_{C,t} = \frac{1}{\exp(u_{A,t})\zeta_{AC,t}} \frac{(r_{C,t})^{\mu_C}(w_{C,t})^{1-\mu_C}}{\mu_C^{\mu_C}(1-\mu_C)^{1-\mu_C}} \left(\tau + (1-\tau) T_t^{1-\iota}\right)^{\frac{1}{1-\iota}} \tag{101}$$

$$mc_{D,t} = \frac{1}{\exp(u_{A,t})\zeta_{AD,t}} \frac{(r_{l,t})^{\mu_l}(r_{D,t})^{\mu_D}(w_{D,t})^{1-\mu_l-\mu_D}}{\mu_l^{\mu_l}\mu_D^{\mu_D}(1-\mu_l-\mu_D)^{1-\mu_l-\mu_D}} q_t^{-1} \tag{102}$$

The Phillips curves are

$$\log\left(\frac{\Pi_{H,t}}{(\Pi_{H,t-1})^{\gamma_C}}\right) = \beta E_t \log\left(\frac{\Pi_{H,t+1}}{(\Pi_{H,t})^{\gamma_C}}\right) + \frac{(1-\theta_C)(1-\beta\theta_C)}{\theta_C} \log\left(\frac{mc_{C,t}}{mc_C}\right) \tag{103}$$

$$\log\left(\frac{\Pi_{D,t}}{(\Pi_{D,t-1})^{\gamma_D}}\right) = \beta E_t \log\left(\frac{\Pi_{D,t+1}}{(\Pi_{D,t})^{\gamma_D}}\right) + \frac{(1-\theta_D)(1-\beta\theta_D)}{\theta_D} \log\left(\frac{mc_{D,t}}{mc_D}\right) \tag{104}$$

The consumer price index is

$$\Pi_{C,t}^{1-\iota} = \frac{\tau + (1-\tau) T_t^{1-\iota}}{\tau \Pi_{H,t}^{\iota-1} + (1-\tau)\Pi_{F,t}^{1-\iota} T_t^{1-\iota}} \tag{105}$$

The real house price is

$$q_t = \frac{\Pi_{D,t}}{\Pi_{C,t}} q_{t-1} \tag{106}$$

The terms of trade are

$$T_t = \frac{\Pi_{F,t}}{\Pi_{H,t}} T_{t-1} \tag{107}$$

Market clearing

The goods market clearing conditions are

$$Y_{C,t} = n\left(\omega\tilde{C}_{H,t} + (1-\omega)C_{H,t} + (1-\omega)\left(I^C_{H,t} + I^D_{H,t}\right)\right)$$
$$+ (1-n)\left(\omega^*\tilde{C}^*_{H,t} + (1-\omega^*)C^*_{H,t} + (1-\omega^*)\left(I^{C*}_{H,t} + I^{D*}_{H,t}\right)\right)$$
$$+ n(1-\omega)\left(\tau + (1-\tau)T_t^{1-\iota}\right)^{\frac{1}{1-\iota}}\left(a(z_{C,t})K_{C,t-1} + a(z_{D,t})K_{D,t-1}\right) \tag{108}$$
$$Y_{D,t} = n\left(\omega\tilde{X}_t + (1-\omega)X_t\right) \tag{109}$$

Total GDP is

$$Y_t = Y_{C,t} + Y_{D,t} \tag{110}$$

The net foreign asset position is

$$(1-\omega)b_t = (1-\omega)b_{t-1}\frac{R_{t-1}}{\Pi_{C,t}}$$
$$+ \frac{1-n}{n}\left(\tau + (1-\tau){T_t}^{1-\iota}\right)^{\frac{1}{\iota-1}}\left(\omega^*\tilde{C}^*_{H,t} + (1-\omega^*)C^*_{H,t} + (1-\omega^*)\left(I^{C*}_{H,t} + I^{D*}_{H,t}\right)\right)$$
$$- \left(\tau {T_t}^{\iota-1} + 1 - \tau\right)^{\frac{1}{\iota-1}}\left(\omega\tilde{C}_{F,t} + (1-\omega)C_{F,t} + (1-\omega)\left(I^C_{F,t} + I^D_{F,t}\right)\right) \tag{111}$$

The domestic interest rate is

$$R_t = R^*_t \exp\left(-\kappa(b'_t - b') + \zeta_{Risk,t}\right) \tag{112}$$
$$b'_t = \frac{n(1-\omega)b_t}{q_t^{\Delta_D}Y_t} \tag{113}$$

A.2 Foreign country

Households

The labor supply indices are

$$\tilde{L}^*_t = \left[(1-\Delta_D)^{-\iota_L}\tilde{L}^{*1+\iota_L}_{C,t} + \Delta_D^{-\iota_L}\tilde{L}^{*1+\iota_L}_{D,t}\right]^{\frac{1}{1+\iota_L}} \tag{114}$$
$$L^*_t = \left[(1-\Delta_D)^{-\iota_L}L^{*1+\iota_L}_{C,t} + \Delta_D^{-\iota_L}L^{*1+\iota_L}_{D,t}\right]^{\frac{1}{1+\iota_L}} \tag{115}$$

The housing stocks are given by

$$\tilde{D}_t^* = (1-\delta)\tilde{D}_{t-1}^* + \tilde{X}_t^* \tag{116}$$

$$D_t^* = (1-\delta)D_{t-1}^* + X_t^* \tag{117}$$

The sector-specific capital accumulation equation is $(j = C, D)$

$$K_{j,t}^* = (1-\delta_j)K_{j,t-1}^* + \zeta_{I,t}^* \left[1 - S\left(\frac{I_t^{j*}}{I_{t-1}^{j*}}\right)\right] I_t^{j*} \tag{118}$$

The collateral constraint is

$$R_t^* \tilde{s}_t^* = (1-\chi)(1-\delta)E_t\left(q_{t+1}^* \Pi_{C,t+1}^* \tilde{D}_t^*\right) \tag{119}$$

The period budget constraint of a typical borrower reads

$$\tilde{C}_t^* + q_t^* \tilde{X}_t^* + R_{t-1}^* \frac{\tilde{s}_{t-1}^*}{\Pi_{C,t}^*} = w_{C,t}^* \tilde{L}_{D,t}^* + w_{D,t}^* \tilde{L}_{D,t}^* + \tilde{s}_t^* \tag{120}$$

The first-order conditions for a typical borrower in the foreign country are

$$1 = \tilde{\beta} E_t \left(\frac{R_t^*}{\Pi_{C,t+1}^*} \frac{\tilde{C}_t^* - \epsilon \tilde{C}_{t-1}^*}{\tilde{C}_{t+1}^* - \epsilon \tilde{C}_t^*} \frac{\zeta_{\beta,t+1}^*}{\zeta_{\beta,t}^*} \right) + R_t^* \tilde{\psi}_t^* \tag{121}$$

$$\begin{aligned} \frac{\zeta_{D,t}^*\alpha}{1-\zeta_{D,t}^*\alpha} \frac{\tilde{C}_t^* - \epsilon\tilde{C}_{t-1}^*}{\tilde{D}_t^*} &= q_t^* \left(1 - (1-\chi)(1-\delta)\tilde{\psi}_t^* E_t\left(\Pi_{D,t+1}^*\right)\right) \\ &\quad - \tilde{\beta}(1-\delta)E_t\left(\frac{\tilde{C}_t^* - \epsilon \tilde{C}_{t-1}^*}{\tilde{C}_{t+1}^* - \epsilon \tilde{C}_t^*} \frac{\zeta_{\beta,t+1}^*}{\zeta_{\beta,t}^*} q_{t+1}^* \right) \end{aligned} \tag{122}$$

$$\tilde{C}_{F,t}^* = \tau^* \tilde{C}_t^* \left(\tau^* + (1-\tau^*)T_t^{\iota-1}\right)^{\frac{\iota}{1-\iota}} \tag{123}$$

$$\tilde{C}_{H,t}^* = (1-\tau^*)\tilde{C}_t^* \left(\tau^* T_t^{1-\iota} + 1 - \tau^*\right)^{\frac{\iota}{1-\iota}} \tag{124}$$

$$\tilde{L}_t^{*\eta-\iota_L}(1-\Delta_D)^{-\iota_L}\tilde{L}_{C,t}^{*\iota_L} = \frac{1-\zeta_{D,t}^*\alpha}{\tilde{C}_t^* - \epsilon\tilde{C}_{t-1}^*} \frac{w_{C,t}^*}{M_{C,t}^*} \tag{125}$$

$$\tilde{L}_t^{*\eta-\iota_L}\Delta_D^{-\iota_L}\tilde{L}_{D,t}^{*\iota_L} = \frac{1-\zeta_{D,t}^*\alpha}{\tilde{C}_t^* - \epsilon\tilde{C}_{t-1}^*} \frac{w_{D,t}^*}{M_{D,t}^*} \tag{126}$$

The first-order conditions for a typical saver in the foreign country are $(j = C, D)$

$$1 = \beta E_t \left(\frac{R_t^*}{\Pi_{C,t+1}^*} \frac{C_t^* - \epsilon C_{t-1}^*}{C_{t+1}^* - \epsilon C_t^*} \frac{\zeta_{\beta,t+1}^*}{\zeta_{\beta,t}^*} \right) \tag{127}$$

$$\frac{\zeta_{D,t}^* \alpha}{1 - \zeta_{D,t}^* \alpha} \frac{C_t^* - \epsilon C_{t-1}^*}{D_t^*} = q_t^* - (1-\delta) E_t \left(\frac{\Pi_{C,t+1}^*}{R_t^*} q_{t+1}^* \right) \tag{128}$$

$$Q_{j,t}^* = E_t \left(\frac{\Pi_{C,t+1}^*}{R_t^*} \left(Q_{j,t+1}^* (1-\delta_j) + r_{j,t+1}^* z_{j,t+1}^* - a(z_{j,t+1}^*) \right) \right) \tag{129}$$

$$\zeta_{I,t}^* Q_{j,t}^* = \frac{1 - E_t \left(\zeta_{I,t+1}^* Q_{j,t+1}^* \frac{\Pi_{C,t+1}^*}{R_t^*} S' \left(\frac{I_{t+1}^{j*}}{I_t^{j*}} \right) \left(\frac{I_{t+1}^{j*}}{I_t^{j*}} \right)^2 \right)}{1 - S \left(\frac{I_t^{j*}}{I_{t-1}^{j*}} \right) - S' \left(\frac{I_t^{j*}}{I_{t-1}^{j*}} \right) \left(\frac{I_t^{j*}}{I_{t-1}^{j*}} \right)} \tag{130}$$

$$r_{j,t}^* = a'(z_{j,t}^*) \tag{131}$$

$$C_{F,t}^* = \tau^* C_t^* \left(\tau^* + (1-\tau^*) T_t^{\iota - 1} \right)^{\frac{\iota}{1-\iota}} \tag{132}$$

$$C_{H,t}^* = (1-\tau^*) C_t^* \left(\tau^* {T_t}^{1-\iota} + 1 - \tau^* \right)^{\frac{\iota}{1-\iota}} \tag{133}$$

$$I_{F,t}^{j*} = \tau^* I_t^{j*} \left(\tau^* + (1-\tau^*) T_t^{\iota - 1} \right)^{\frac{\iota}{1-\iota}} \tag{134}$$

$$I_{H,t}^{j*} = (1-\tau^*) I_t^{j*} \left(\tau^* {T_t}^{1-\iota} + 1 - \tau^* \right)^{\frac{\iota}{1-\iota}} \tag{135}$$

$$L_t^{*\eta - \iota_L} (1-\Delta_D)^{-\iota_L} L_{C,t}^{*\iota_L} = \frac{1 - \zeta_{D,t}^* \alpha}{C_t^* - \epsilon C_{t-1}^*} \frac{w_{C,t}^*}{M_{C,t}^*} \tag{136}$$

$$L_t^{*\eta - \iota_L} \Delta_D^{-\iota_L} L_{D,t}^{*\iota_L} = \frac{1 - \zeta_{D,t}^* \alpha}{C_t^* - \epsilon C_{t-1}^*} \frac{w_{D,t}^*}{M_{D,t}^*} \tag{137}$$

Dividends from labor unions are distributed according to

$$div_t'^* = \left(1 - \frac{1}{M_{C,t}^*} \right) w_{C,t}^* \tilde{L}_{C,t}^* + \left(1 - \frac{1}{M_{D,t}^*} \right) w_{D,t}^* \tilde{L}_{D,t}^* \tag{138}$$

$$div_t''^* = \left(1 - \frac{1}{M_{C,t}^*} \right) w_{C,t}^* L_{C,t}^* + \left(1 - \frac{1}{M_{D,t}^*} \right) w_{D,t}^* L_{D,t}^* \tag{139}$$

The wage Phillips curves are

$$\log\left(\frac{\frac{w^*_{C,t}}{w^*_{C,t-1}}\Pi^*_{C,t}}{\left(\Pi^*_{C,t-1}\right)^{\gamma_{WC}}}\right)=\beta E_t\log\left(\frac{\frac{w^*_{C,t+1}}{w^*_{C,t}}\Pi^*_{C,t+1}}{\left(\Pi^*_{C,t}\right)^{\gamma_{WC}}}\right)-\frac{(1-\theta_{WC})(1-\beta\theta_{WC})}{\theta_{WC}}\log\left(\frac{M^*_{C,t}}{M^*_C}\right) \tag{140}$$

$$\log\left(\frac{\frac{w^*_{D,t}}{w^*_{D,t-1}}\Pi^*_{C,t}}{\left(\Pi^*_{C,t-1}\right)^{\gamma_{WD}}}\right)=\beta E_t\log\left(\frac{\frac{w^*_{D,t+1}}{w^*_{D,t}}\Pi^*_{C,t+1}}{\left(\Pi^*_{C,t}\right)^{\gamma_{WD}}}\right)-\frac{(1-\theta_{WD})(1-\beta\theta_{WD})}{\theta_{WD}}\log\left(\frac{M^*_{D,t}}{M^*_D}\right) \tag{141}$$

Firms and prices

The production technologies are

$$\frac{Y^*_{C,t}}{1-n}=\exp(u_{A,t})\zeta^*_{AC,t}\left((1-\omega^*)K'^*_{C,t}\right)^{\mu_C}\left(\omega^*\tilde{L}^*_{C,t}+(1-\omega^*)L^*_{C,t}\right)^{1-\mu_C} \tag{142}$$

$$\frac{Y^*_{D,t}}{1-n}=\exp(u_{A,t})\zeta^*_{AD,t}\left((1-\omega^*)l^*\right)^{\mu_l}\left((1-\omega^*)K'^*_{D,t}\right)^{\mu_D}\left(\omega^*\tilde{L}^*_{D,t}+(1-\omega^*)L^*_{D,t}\right)^{1-\mu_l-\mu_D} \tag{143}$$

Effective capital utilization reads ($j=C,D$)

$$K'^*_{j,t}=z^*_{j,t}K^*_{j,t-1} \tag{144}$$

The first-order conditions for intermediate goods firms are

$$r^*_{C,t}=\frac{\mu_C}{1-\mu_C}\frac{w^*_{C,t}\left(\omega^*\tilde{L}^*_{C,t}+(1-\omega^*)L^*_{C,t}\right)}{(1-\omega^*)z^*_{C,t}K^*_{C,t-1}} \tag{145}$$

$$r^*_{D,t}=\frac{\mu_D}{1-\mu_l-\mu_D}\frac{w^*_{D,t}\left(\omega^*\tilde{L}^*_{D,t}+(1-\omega^*)L^*_{D,t}\right)}{(1-\omega^*)z^*_{D,t}K^*_{D,t-1}} \tag{146}$$

$$r^*_{l,t}=\frac{\mu_l}{1-\mu_l-\mu_D}\frac{w^*_{D,t}\left(\omega^*\tilde{L}^*_{D,t}+(1-\omega^*)L^*_{D,t}\right)}{(1-\omega^*)l^*} \tag{147}$$

$$mc^*_{C,t}=\frac{1}{\exp(u_{A,t})\zeta^*_{AC,t}}\frac{(r^*_{C,t})^{\mu_C}(w^*_{C,t})^{1-\mu_C}}{\mu_C^{\mu_C}(1-\mu_C)^{1-\mu_C}}\left(\tau^*+(1-\tau^*)T_t^{\iota-1}\right)^{\frac{1}{1-\iota}} \tag{148}$$

$$mc^*_{D,t}=\frac{1}{\exp(u_{A,t})\zeta^*_{AD,t}}\frac{(r^*_{l,t})^{\mu_l}(r^*_{D,t})^{\mu_D}(w^*_{D,t})^{1-\mu_l-\mu_D}}{\mu_l^{\mu_l}\mu_D^{\mu_D}(1-\mu_l-\mu_D)^{1-\mu_l-\mu_D}}q_t^{*-1} \tag{149}$$

The Phillips curves are

$$\log\left(\frac{\Pi_{F,t}}{(\Pi_{F,t-1})^{\gamma_C}}\right) = \beta E_t \log\left(\frac{\Pi_{F,t+1}}{(\Pi_{F,t})^{\gamma_C}}\right) + \frac{(1-\theta_C)(1-\beta\theta_C)}{\theta_C}\log\left(\frac{mc^*_{C,t}}{mc^*_C}\right) \tag{150}$$

$$\log\left(\frac{\Pi^*_{D,t}}{(\Pi^*_{D,t-1})^{\gamma_D}}\right) = \beta E_t \log\left(\frac{\Pi^*_{D,t+1}}{(\Pi^*_{D,t})^{\gamma_D}}\right) + \frac{(1-\theta_D)(1-\beta\theta_D)}{\theta_D}\log\left(\frac{mc^*_{D,t}}{mc^*_D}\right) \tag{151}$$

The consumer price index is

$$\Pi^{*1-\iota}_{C,t} = \frac{\tau^* T_t^{1-\iota} + (1-\tau^*)}{\tau^* T_t^{1-\iota}\Pi^{\iota-1}_{F,t} + (1-\tau^*)\Pi^{1-\iota}_{H,t}} \tag{152}$$

The real house price is

$$q^*_t = \frac{\Pi^*_{D,t}}{\Pi^*_{C,t}} q^*_{t-1} \tag{153}$$

Market clearing

The goods market clearing conditions are

$$\begin{aligned} Y^*_{C,t} &= (1-n)\left(\omega^*\tilde{C}^*_{F,t} + (1-\omega^*)C^*_{F,t} + (1-\omega^*)\left(I^{C*}_{F,t} + I^{D*}_{F,t}\right)\right) \\ &+ n\left(\omega\tilde{C}_{F,t} + (1-\omega)C_{F,t} + (1-\omega)\left(I^{C}_{F,t} + I^{D}_{F,t}\right)\right) \\ &+ (1-n)(1-\omega^*)\left(\tau^* + (1-\tau^*)T_t^{\iota-1}\right)^{\frac{1}{1-\iota}}\left(a(z^*_{C,t})K^*_{C,t-1} + a(z^*_{D,t})K^*_{D,t-1}\right) \quad (154) \\ Y^*_{D,t} &= (1-n)\left(\omega^*\tilde{X}^*_t + (1-\omega^*)X^*_t\right) \quad (155) \end{aligned}$$

Total GDP is

$$Y^*_t = Y^*_{C,t} + Y^*_{D,t} \tag{156}$$

Monetary policy

The Taylor rule is

$$R^*_t = R^{*\mu_R}_{t-1}\left(R^*\left(\frac{\Pi^n_{C,t}\Pi^{*1-n}_{C,t}}{\Pi^n_C\Pi^{*1-n}_C}\right)^{\mu_\pi}\right)^{1-\mu_R} exp\left(u^*_{R,t}\right) \tag{157}$$

B Data

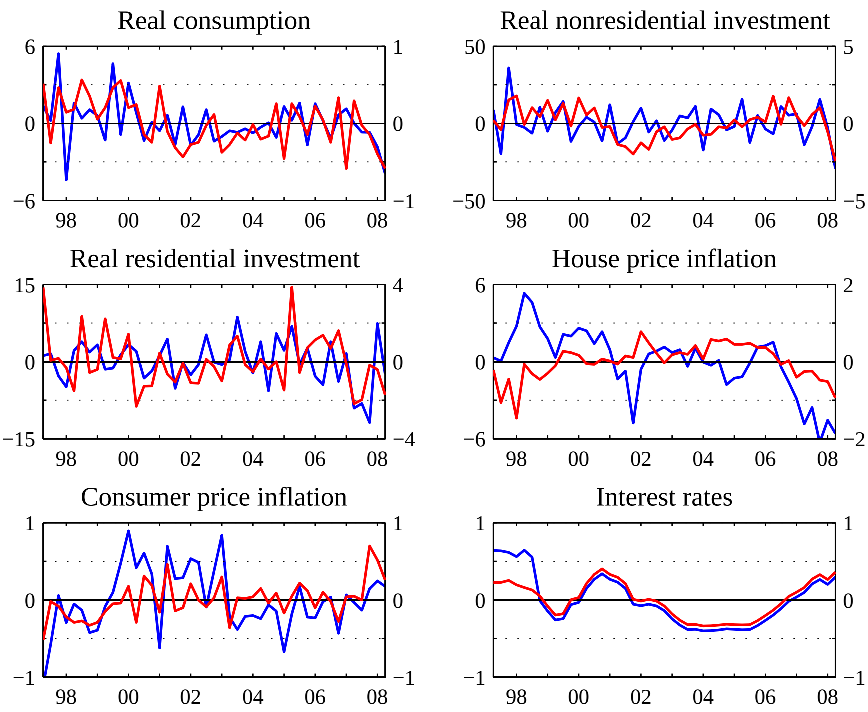

Figure 1.7: Data

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.

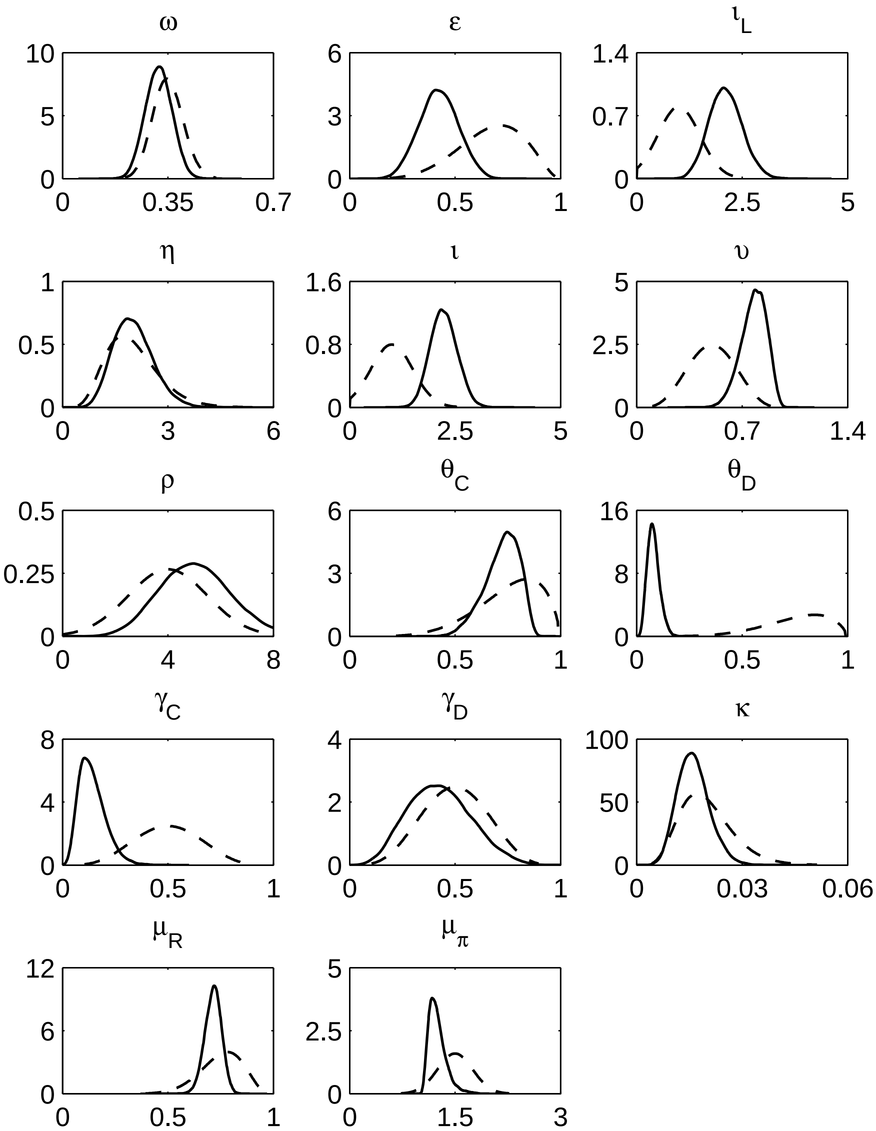

Figure 1.8: Estimated distribution of structural parameters

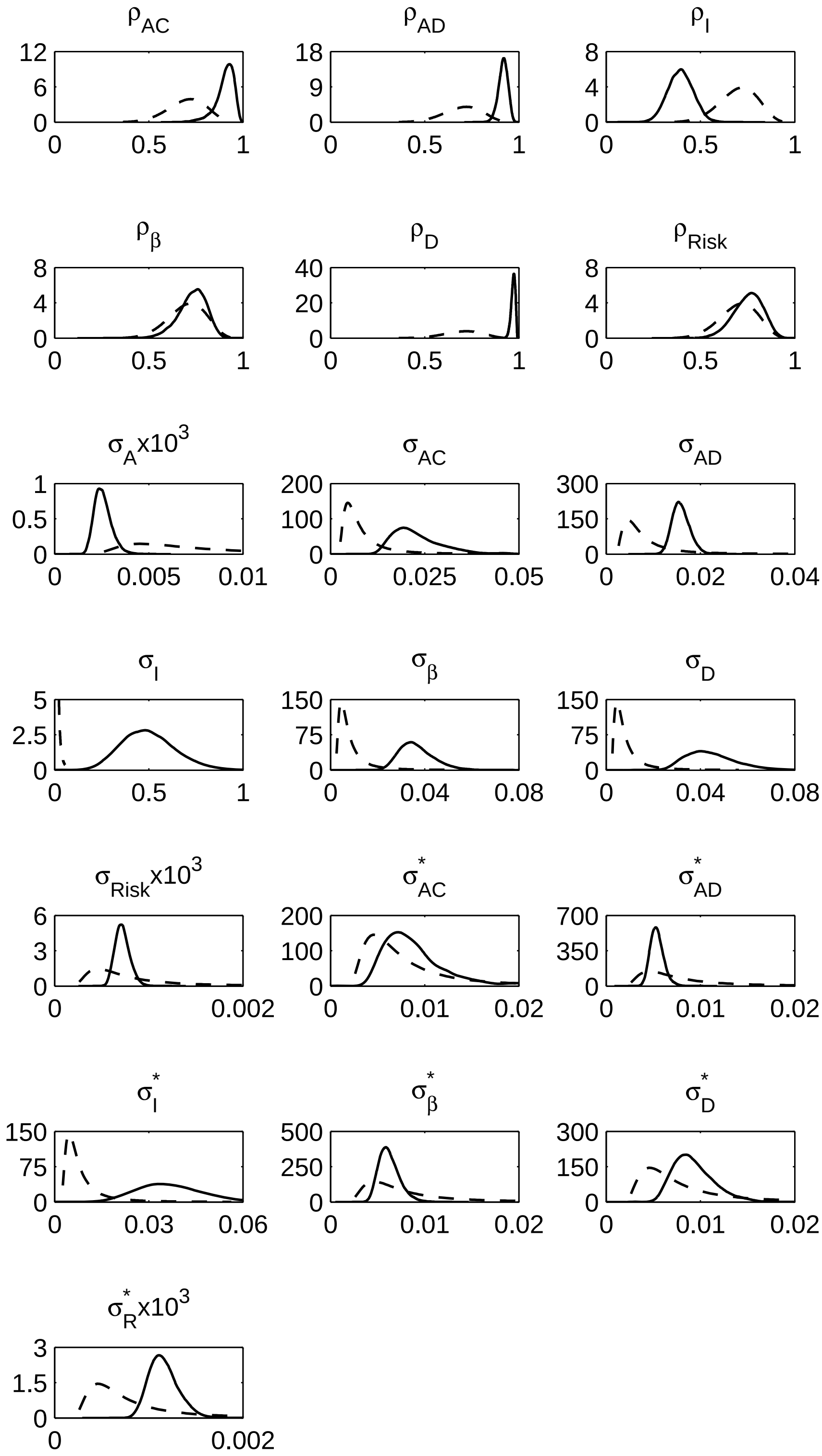

Figure 1.9: Estimated distribution of shock processes

Chapter 2

Financial Market Heterogeneity: Implications for the EMU[1]

2.1 Introduction

In a monetary union housing markets are crucial. Given the strong impact of housing market fluctuations on the business cycle, cross-country heterogeneity with respect to mortgage market characteristics might be a source of asymmetric business cycle fluctuations. Hence, heterogeneity in mortgage market characteristics across member states fundamentally challenges the very existence of a monetary union.

This chapter examines the business cycle and welfare effects of an asymmetric deregulation of mortgage markets within the European Economic and Monetary Union (EMU). Since the launch of the euro on January 1, 1999, housing market developments have been quite heterogeneous across member states. From 1999 to 2007, growth rates of housing loans reached high double-digit rates in countries like Greece, Ireland, Italy, and Spain but were only 3% in Germany (see Drudi et al., 2009). Likewise, the amount outstanding of housing loans as percent of GDP varies substantially across member states. While the euro area level increased from 27% in 1999 to 42% in 2007, countries such as Ireland, the Netherlands, and Portugal reached levels far above 60%. House price movements differed significantly across countries in the last decade also. Nominal house prices have risen by a yearly average of above 10% in Ireland and Spain, while they grew moderately in Finland, Italy, and Portugal and remained almost constant in Germany.

[1]This chapter is based on joint work with Eric Mayer that appeared as Gareis and Mayer (2012b).

Applying a calibrated two-country New Keynesian (NK) dynamic stochastic general equilibrium (DSGE) model, we argue that a change in cross-country institutional characteristics of mortgage markets, i.e., the loan-to-value (LTV) ratio, is likely to be an important driver of an asymmetric development in housing markets and real economic activity of member states. In fact, there is ample evidence that European countries exhibit substantial heterogeneity in institutional characteristics of mortgage markets. A first insight is given by the IMF mortgage market index, which is a composite indicator of the degree of development and completeness of national mortgage markets.[2] For instance, France, Germany, and Italy, which account together for about 65.1% of the euro-area GDP (see ECB, 2012), have a low index value with 0.23 for France, 0.28 for Germany, and 0.26 for Italy. In contrast, smaller member states such as Ireland, the Netherlands, and Spain have index values of 0.39, 0.71, and 0.40 respectively. This overall assessment of substantial divergence in national mortgage market characteristics is also reflected in individual figures. In particular, the degree of heterogeneity with respect to the LTV ratio is immense. The typical LTV ratio in the euro area is about 80% with a variation across member states ranging from 63% to 101% (see Drudi et al., 2009). Moreover, the high degree of cross-country heterogeneity of mortgage markets within the euro area is evident from comparing the share of households holding debt across member states. For instance, Hristov et al. (2010) report that the fraction of indebted households varies from about 25% in Germany and Italy to more than 50% in Spain.

In this chapter, we evaluate the effects on the economic activity and welfare in a monetary union when a single country, which is for the sake of exposition of the size of Spain, implements a deregulation of its mortgage market, while the rest of the union keeps its legal framework fix. Related literature focuses on the analysis of the transmission of shocks in a monetary union setting with existing cross-country heterogeneous characteristics of mortgage markets, but it neglects to analyze the effects of an asymmetric mortgage market reform itself in terms of transition dynamics and welfare consequences. For instance, Hristov et al. (2010) report that empirically plausible degrees of cross-country heterogeneity with respect to the share of indebted households and the LTV ratio can generate cyclical inflation differentials in the wake of monetary policy and technology shocks. Rubio (2009) highlights the role played by cross-country heterogeneity in mortgage markets within the

[2] The index ranges between 0 and 1. A higher value indicates a higher degree of market development and completeness (see IMF, 2008).

EMU with respect to the monetary policy regime and various symmetric and asymmetric shocks. She comes to the conclusion that mortgage market homogenization need not per se to be welfare enhancing except if it implies lower LTV ratios. Finally, Campbell and Hercowitz (2009) study the transition dynamics and welfare consequences of the mortgage market deregulation in the US since the early 1980s. Employing a real business cycle model, they find that loosening the collateral constraint worsen the borrowers' welfare due to unfavorable changes in interest rates, while the savers' welfare rises substantially. As in Campbell and Hercowitz (2009), our analysis focuses on transition dynamics and welfare effects of the mortgage market reform itself.

Our analysis employs a standard two-country NK DSGE model with housing and collateral constraints along the lines of Kiyotaki and Moore (1997) and recent works such as Iacoviello (2005) and Monacelli (2009). In particular, it is assumed that in each country there are two types of households, namely, borrowers and savers. As borrowers are relatively impatient, they borrow from savers in equilibrium. The borrowers' maximum level of debt, however, is constrained by the net present value of their future housing stock times a LTV ratio. The joint monetary policy is implemented by a common central bank, which follows a simple Taylor-type interest rate rule. Consistent with the mandate of the European Central Bank (ECB), we assume that the monetary authority sets interest rates according to EMU-wide aggregates.

Our results suggest that an asymmetric mortgage market deregulation in a small country in a monetary union, as the Spain one, leads to a massive built up of debt in that country, as domestic borrowers take advantage of the loosening of the collateral constraint. According to our projections, an asymmetric mortgage market deregulation that increases the LTV ratio in Spain from 65% to 75% leads to a boost for household debt by about 50% over the initial (pre-reform) steady state. Afterwards, debt slowly reverts to the post-reform steady state, which is according to our estimate 25% higher than the pre-reform steady state. Alongside the massive expansion of collateralized debt, we find that the Spanish economy is subject to a demand-driven boom. Inflation rates for nondurable consumption goods are 1% above the zero steady state, while inflation rates for house prices are almost 2.5% above. One mechanism that fuels the boom is the asset-price channel of the collateral constraint. As real house prices increase in response to the higher demand, the collateral constraint looses further and reinforces the rise in demand and real house prices. We find that the central bank faces a dilemma by setting interest rates according to EMU-wide aggregates. As a consequence of an asymmetric development of consumer price inflation across countries along the transition path to the post-reform steady state, monetary conditions are too loose for the country that implements the reform, while they are too tight for the rest of the union, which suffers from a mild decrease in GDP. Overall, a welfare analysis suggests that the welfare implications for the home country that implements the deregulation of its mortgage market are positive, while the rest of the union exhibits mild welfare losses. The size of the welfare loss for the rest of the union can be directly linked to the size of the country that implements the reform. For a country of the size of Spain, the welfare loss for the rest of the union is negligible.

The remainder of the chapter is as follows. The next section provides the model and calibration. In section 2.3, we present the results following the mortgage market reform in terms of steady state comparison, transition dynamics, and welfare effects. Section 2.4 concludes.

2.2 The model

The model framework is a two-country, two-sector, two-household general equilibrium model of a monetary union.[3] The home country is of size n and the foreign country (rest of the EMU) is of size $1-n$. In each country there are two sectors producing nondurable consumption goods and housing in a standard setup with monopolistic competition and nominal rigidities. In each country households belong to two different groups, namely, borrowers and savers, which are of measure ω and $1-\omega$ respectively. Both types of households consume nondurable goods as well as housing and work. Borrowers and savers have heterogeneous intertemporal discount factors, while the former are more impatient than the latter. Following Iacoviello (2005), borrowers are subject to a collateral constraint tied to housing values.

In the following, we present only the home country block, as the foreign country block is symmetric. We use a tilde to denote variables referring to borrowers. Foreign country variables are indicated with an asterisk.

[3] Similar models can be found in Hristov et al. (2010) and Aspachs-Bracons and Rabanal (2010, 2011).

2.2.1 Borrower's program

Each borrower b, indicated by $b \in [0, \omega]$, receives utility from the following function

$$\sum_{k=0}^{\infty} \tilde{\beta}^k \left((1-\alpha)\log(\tilde{C}_{t+k}(b)) + (\alpha)\log(\tilde{D}_{t+k}(b)) - \frac{(\tilde{L}_{t+k}(b))^{1+\eta}}{1+\eta} \right), \tag{2.1}$$

where $\tilde{C}_t(b)$ stands for an index of nondurable consumption goods composed of home and foreign produced goods, $\tilde{D}_t(b)$ is the end-of-period stock of housing, $\tilde{L}_t(b)$ denotes a labor supply index, $\tilde{\beta}$ is the discount factor, α is the share of housing in private consumption, and η is the inverse elasticity of labor supply. The index of nondurable consumption goods is defined as

$$\tilde{C}_t(b) = \left[(\tau)^{\frac{1}{\iota}} (\tilde{C}_{H,t}(b))^{\frac{\iota-1}{\iota}} + (1-\tau)^{\frac{1}{\iota}} (\tilde{C}_{F,t}(b))^{\frac{\iota-1}{\iota}} \right]^{\frac{\iota}{\iota-1}}, \tag{2.2}$$

where $\tilde{C}_{H,t}(b)$ and $\tilde{C}_{F,t}(b)$ stand for goods produced in the home and the foreign country respectively. The parameter ι is the elasticity of substitution between home and foreign produced goods, and τ governs the relative weight of home produced goods. The housing stock of a typical borrower evolves as

$$\tilde{D}_t(b) = (1-\delta)\tilde{D}_{t-1}(b) + \tilde{X}_t(b), \tag{2.3}$$

where $\tilde{X}_t(b)$ denotes housing investment, and δ is the depreciation rate of the housing stock. As in Aspachs-Bracons and Rabanal (2010), the labor supply index is defined as

$$\tilde{L}_t(b) = \left[(1-\Delta_D)^{-\iota_L} (\tilde{L}_{C,t}(b))^{1+\iota_L} + \Delta_D^{-\iota_L} (\tilde{L}_{D,t}(b))^{1+\iota_L} \right]^{\frac{1}{1+\iota_L}}, \quad \iota_L \geq 0, \tag{2.4}$$

where $\tilde{L}_{j,t}(b)$ is sector-specific labor supply ($j = C, D$), Δ_D is the economic size of the housing sector, and ι_L governs the cost of reallocating labor across sectors (see also Iacoviello and Neri, 2010). The period budget constraint of a borrower is given in nominal terms by

$$P_{C,t}\tilde{C}_t(b) + P_{D,t}\tilde{X}_t(b) + R_{t-1}\tilde{S}_{t-1}(b) = W_{C,t}\tilde{L}_{C,t}(b) + W_{D,t}\tilde{L}_{D,t}(b) + \tilde{S}_t(b), \tag{2.5}$$

where $P_{C,t}$ is the price index of nondurable consumption goods, $P_{D,t}$ denotes the price index of housing, $\tilde{S}_t(b)$ is the nominal amount of end-of-period collateralized debt issued by borrowers, R_t is the gross nominal interest rate, and $W_{j,t}$ is the nominal wage earned in sector $j = C, D$. Each borrower is subject to a collateral constraint that ties the borrowing limit to the net present value of the future housing stock (see Iacoviello, 2005; Monacelli, 2009). It holds that[4]

$$R_t \tilde{S}_t(b) = (1-\chi)(1-\delta)\tilde{D}_t(b) P_{D,t+1}, \tag{2.6}$$

where χ governs the flexibility of the mortgage market by determining the fraction of the housing stock that cannot be used as collateral. Accordingly, the parameter $1-\chi$ provides a measure for the LTV ratio (see also Darracq Pariès and Notarpietro, 2008).

Following Aspachs-Bracons and Rabanal (2010), we assume that households in the home country have to pay a premium above the union-wide riskless nominal interest rate that depends on the home country's aggregate net foreign asset position.[5] It holds that

$$R_t = R_t^* exp\left[-\kappa \left(b_t' - b'\right)\right], \quad \kappa \geq 0, \tag{2.7}$$

where R_t^* is the union-wide gross nominal interest rate controlled by the ECB, b_t' stands for the aggregate net foreign asset position as percent of nominal GDP, b' is the corresponding steady state value, and κ denotes the risk premium elasticity.

The first-order conditions to a representative borrower's program are given by

$$\tilde{U}_{C,t} = P_{C,t}\tilde{\lambda}_t \tag{2.8}$$

$$\text{and} \quad 1 = \tilde{\beta}\frac{R_t}{\Pi_{C,t+1}}\frac{\tilde{U}_{C,t+1}}{\tilde{U}_{C,t}} + R_t\tilde{\psi}_t, \tag{2.9}$$

where $\tilde{U}_{C,t}$ stands for the marginal utility of nondurable goods consumption, $\tilde{\lambda}_t$ is the multiplier on the budget constraint, $\Pi_{C,t}$ is the gross inflation rate of nondurable consumption goods prices, and $\tilde{\psi}_t$ is an auxiliary variable that is proportional to the multiplier on the collateral constraint. The labor supply conditions in both sectors are

$$\frac{W_{C,t}}{P_{C,t}} = \frac{\tilde{L}_t^{(\eta-\iota_L)}(1-\Delta_D)^{-\iota_L}(\tilde{L}_{C,t})^{\iota_L}}{\tilde{U}_{C,t}} \tag{2.10}$$

$$\text{and} \quad \frac{W_{D,t}}{P_{C,t}} = \frac{\tilde{L}_t^{(\eta-\iota_L)}\Delta_D^{-\iota_L}(\tilde{L}_{D,t})^{\iota_L}}{\tilde{U}_{C,t}}. \tag{2.11}$$

[4]As customary in the literature, we assume that the collateral constraint always binds.

[5]This assumption is needed to ensure a well-defined steady state of the model (see Schmitt-Grohé and Uribe, 2003).

The first-order condition to a borrower's choice of housing is

$$\frac{\alpha}{\tilde{D}_t}\frac{1}{\tilde{U}_{C,t}} = q_t\left(1-(1-\chi)(1-\delta)\tilde{\psi}_t\Pi_{D,t+1}\right) - \tilde{\beta}(1-\delta)\frac{\tilde{U}_{C,t+1}}{\tilde{U}_{C,t}}q_{t+1}, \tag{2.12}$$

where $q_t = \frac{P_{D,t}}{P_{C,t}}$ is the real house price, and $\Pi_{D,t}$ is the gross inflation rate of house prices.

The allocation of nondurable consumption goods between home and foreign produced goods is given by

$$\tilde{C}_{H,t} = \tau\left(\frac{P_{H,t}}{P_{C,t}}\right)^{-\iota}\tilde{C}_t \tag{2.13}$$

$$\text{and} \quad \tilde{C}_{F,t} = (1-\tau)\left(\frac{P_{F,t}}{P_{C,t}}\right)^{-\iota}\tilde{C}_t, \tag{2.14}$$

where $P_{H,t}$ and $P_{F,t}$ are the price indices of home and foreign produced goods. The nondurable consumption goods price index (consumer price index) is defined as

$$P_{C,t} = \left[\tau\left(P_{H,t}\right)^{1-\iota} + (1-\tau)(P_{F,t})^{1-\iota}\right]^{\frac{1}{1-\iota}}. \tag{2.15}$$

Terms of trade are given as

$$T_t = \frac{P_{F,t}}{P_{H,t}}. \tag{2.16}$$

2.2.2 Saver's program

Each saver s, indicated by $s \in [\omega, 1]$, behaves like a standard rational forward-looking agent with full intertemporal consumption-smoothing. The key feature that describes a typical saver's behavior is the relatively high intertemporal discount factor ($\tilde{\beta} < \beta$), which implies that savers are more patient than borrowers (see Monacelli, 2009). Moreover, savers have access to international assets trading following Darracq Pariès and Notarpietro (2008) and Aspachs-Bracons and Rabanal (2010), and savers are the owners of firms. The utility function of a saver is given by

$$\sum_{k=0}^{\infty}\beta^k\left((1-\alpha)\log(C_{t+k}(s)) + (\alpha)\log(D_{t+k}(s)) - \frac{(L_{t+k}(s))^{1+\eta}}{1+\eta}\right). \tag{2.17}$$

The saver maximizes the utility function subject to the following period budget constraint

$$
\begin{aligned}
P_{C,t}C_t(s) + P_{D,t}X_t(s) + S_t(s) + B_t(s) = {} & W_{C,t}L_{C,t}(s) + W_{D,t}L_{D,t}(s) \\
& + R_{t-1}S_{t-1}(s) + R_{t-1}B_{t-1}(s) + Div_t(s), \quad (2.18)
\end{aligned}
$$

where $B_t(s)$ are individual holdings of internationally traded assets and $Div_t(s)$ are profits from firms. As the saver's optimal choice is standard, we omit further functional forms here.

2.2.3 Firms

The production structure of the economy is given by two final goods sectors, nondurable consumption and housing. In each sector perfectly competitive final goods producers aggregate a continuum of differentiated intermediate goods that are purchased from intermediate goods producers. Intermediate goods producers operate under monopolistic competition and have some market power. In addition, they face sectoral price setting frictions as in Calvo (1983). It is assumed that producers are able to re-optimize their nominal price with a probability $1 - \theta_j$. Each intermediate goods producer operating in sector $j = C, D$, indexed by $i \in [0, n]$, uses the following production technology

$$
Y_{j,t}(i) = L_{j,t}(i). \quad (2.19)
$$

The production technologies and the assumptions made above lead to the following sectoral Phillips curves

$$
\log(\Pi_{H,t}) = \beta \log(\Pi_{H,t+1}) + \frac{(1-\theta_C)(1-\beta\theta_C)}{\theta_C} \log\left(\frac{mc_{C,t}}{mc_C}\right) \quad (2.20)
$$

$$
\text{and} \quad \log(\Pi_{D,t}) = \beta \log(\Pi_{D,t+1}) + \frac{(1-\theta_D)(1-\beta\theta_D)}{\theta_D} \log\left(\frac{mc_{D,t}}{mc_D}\right), \quad (2.21)
$$

where $\Pi_{H,t}$ is the gross inflation rate of home produced nondurable goods prices, $mc_{C,t} = \frac{W_{C,t}}{P_{H,t}}$ are real marginal costs in the nondurable goods sector, $mc_{D,t} = \frac{W_{D,t}}{P_{D,t}}$ are real marginal costs in the housing sector, and corresponding variables without a time subscript describe steady state values.

2.2.4 Market clearing conditions

The market clearing condition for the home country in the nondurable goods market is

$$Y_{C,t} = n\left(\omega\tilde{C}_{H,t} + (1-\omega)C_{H,t}\right) + (1-n)\left(\omega^*\tilde{C}^*_{H,t} + (1-\omega^*)C^*_{H,t}\right). \tag{2.22}$$

The equilibrium in the housing market is given by

$$Y_{D,t} = n\left(\omega\tilde{X}_t + (1-\omega)X_t\right). \tag{2.23}$$

The home country's total GDP is then

$$Y_t = Y_{C,t} + Y_{D,t}. \tag{2.24}$$

The equilibrium condition in each labor market ($j = C, D$) is

$$\omega\tilde{L}_{j,t} + (1-\omega)L_{j,t} = \int_0^n L_{j,t}(i)di. \tag{2.25}$$

The market clearing in the international bond market is defined as

$$n(1-\omega)B_t + (1-n)(1-\omega^*)B^*_t = 0, \tag{2.26}$$

and the national debt market equilibrium is given by

$$\omega\tilde{S}_t = (1-\omega)S_t. \tag{2.27}$$

Finally, the evolution of the aggregate net foreign asset position of the home country is

$$\begin{aligned} n(1-\omega)B_t &= n(1-\omega)R_{t-1}B_{t-1} \\ &\quad + (1-n)P_{H,t}\left(\omega^*\tilde{C}^*_{H,t} + (1-\omega^*)C^*_{H,t}\right) - nP_{F,t}\left(\omega\tilde{C}_{F,t} + (1-\omega)C_{F,t}\right). \end{aligned} \tag{2.28}$$

2.2.5 Monetary policy

We close the model by assuming that the central bank sets the union-wide riskless interest rate according to a simple Taylor-type rule

$$\frac{R_t^*}{R^*} = \left(\frac{\Pi_t}{\Pi}\right)^{\mu_\pi}, \tag{2.29}$$

where Π_t is the union-wide gross inflation rate with steady state value of $\Pi = 1$. It holds that

$$\Pi_t = \left(\Pi_{C,t}\right)^n \left(\Pi_{C,t}^*\right)^{1-n}. \tag{2.30}$$

2.2.6 Calibration

In the steady state we assume zero inflation and that the trade balance as well as the net foreign asset position of both countries is zero. Also, we assume that the degree of monopolistic competition is equal across sectors and countries. The steady state markup of prices over marginal costs is assumed to be $\frac{1}{\epsilon-1} = 0.2$. In what follows, we use the same parameter values for both countries if not stated otherwise.

Concerning the size and the degree of openness of the home, respectively, the foreign country, we set as the home country Spain, and the foreign country is the rest of the EMU. Using information drawn from Aspachs-Bracons and Rabanal (2010), this implies $n = 0.1$, $\tau = 0.85$, and $\tau^* = 0.98$. The saver's discount factor is set to $\beta = 0.99$, which implies a steady state real interest rate of 4%. The borrower's discount factor is $\tilde{\beta} = 0.97$. As for the parameters related to mortgage market characteristics, we conservatively choose to set the share of borrowers in both economies at $\omega = \omega^* = 0.2$, and the LTV ratio, $1-\chi$, is set to 0.65 in the baseline specification. We fix the depreciation rate of housing at $\delta = 0.0025$, which is 1% annually (see Calza et al., 2011). The inverse elasticity of labor supply is set to $\eta = 1$. We calibrate the labor reallocation cost parameter to $\iota_L = 1$, implying less than perfect labor mobility across sectors. The relative weight of nondurable goods in the utility function is numerically determined in a manner such that the economic size of the housing sector is $\Delta_D = 0.1$. This gives $1 - \alpha = 0.63$.[6] We set the degree of nominal rigidity in the nondurable consumption goods sector to $\theta_C = 0.75$, which implies an average frequency of price adjustment of four quarters. Prices in the housing sector are assumed to be more

[6]When we introduce cross-country heterogeneity in mortgage markets, we take $1-\alpha$ as fixed and allow the size of the housing sector to adjust.

flexible. To facilitate a positive comovement across sectors along the transition path, we set $\theta_D = 0.66$, which gives an average frequency of price adjustment of about three quarters. The elasticity of substitution between home and foreign produced goods is calibrated to $\iota = 1$, so that these goods are not perfect substitutes. The risk premium elasticity is set to $\kappa = 0.02$ as estimated in Aspachs-Bracons and Rabanal (2010). Turning to the parameter governing the monetary policy rule, we set $\mu_\pi = 1.5$.

2.3 Results

In this section, we present the results of a deterministic experiment in which we model an asymmetric mortgage market deregulation in a member state of the EMU. Concretely, we quantitatively investigate the implications for the growth of collateralized debt and its repercussions on the broader economy when a reform in the home country is implemented such that the home country's LTV ratio increases instantaneously from 65% to 75%.

In a first step, we analyze the changes in steady state values by comparing pre-reform steady state values to post-reform steady state values to which the model economy converges after the reform has been implemented. In a second step, we proceed by illustrating the transition path of all key variables. Finally, we investigate the welfare implications of the mortgage market reform.

2.3.1 Steady states

Here, we discuss how the asymmetric mortgage market reform influences the long-run equilibrium of the model economy. The analysis employs the calibrated DSGE model as outlined in the previous sections in which all parameters (except the home country's LTV ratio) stay at their baseline calibration.

Table 2.1: Percentage change in steady state values

	Home				Rest of the EMU			
Saver	C	X	L		C^*	X^*	L^*	
	0.54	0.54	-0.54		-0.00	-0.00	-0.00	
Borrower	$\tilde{C}$	$\tilde{X}$	$\tilde{L}$	$\tilde{s}$	$\tilde{C}^*$	$\tilde{X}^*$	$\tilde{L}^*$	$\tilde{s}^*$
	-2.55	8.69	2.51	25.41	-0.00	-0.00	-0.00	-0.00

Note: The table displays for each variable the percentage change in its steady state value. $\tilde{s}$ and $\tilde{s}^*$ denote real debt using the nondurable goods price index as a deflator.

Table 2.1 indicates a clear cut link between credit growth and the mortgage market deregulation. In response to the permanent shift in the collateral requirement in the home country, domestic real debt increases by 25.41% in the long-run. Moreover, the model predicts that borrowers shift demand toward housing. While their housing demand increases by 8.69%, nondurable goods consumption decreases by 2.55%. Finally, borrowers work more than before the reform, which results in an increase in labor supply by 2.51%. Comparing the steady states of savers before and after the reform, it prevails that the mortgage market reform implies a positive wealth effect. As savers hold the offsetting financial position to the increased stock of domestic debt, they are wealthier than before the reform. Consequently, given that consumption and leisure are normal goods, savers increase consumption in housing and nondurable goods and decrease the steady state labor supply. Apparently, the long-run spillover effects of the reform to the rest of the union are negligible. Based on our numerical simulation results, we find that all variables that directly impact welfare of the rest of the EMU stay almost unaltered up to two decimals.

2.3.2 Transition dynamics

While the last section highlights the change in the long-run equilibrium of the model economy, we now investigate the transition dynamics in the first two years following the mortgage market deregulation in the home country.

Figure 2.1 portrays the adjustment path of selected macroeconomic variables expressed in percentage deviations relative to their pre-reform steady state values. It is apparent from the figure that the reform leads to an immediate rise in households' real debt holdings. As demand rises in response to the increasing credit availability, firms increase production and thus marginal costs of production move pro-cyclically alongside the expansion. Markup pricing implies that inflation rates in both sectors sharply spike. In the nondurable goods sector prices increase by 1% above the ECB's inflation target, and in the housing sector prices increase by about 2.5%. Put differently, as firms in the housing sector are able to adjust prices more frequently than firms in the nondurable goods sector, the real house price increases. The increase in the real house price, in turn, supports the economic boom via the asset-price channel of the collateral constraint. As the collateral constraint looses with increasing real house prices, borrowers raise debt holdings and increase their demand even further, which then reinforces the rise in real house prices and causes debt

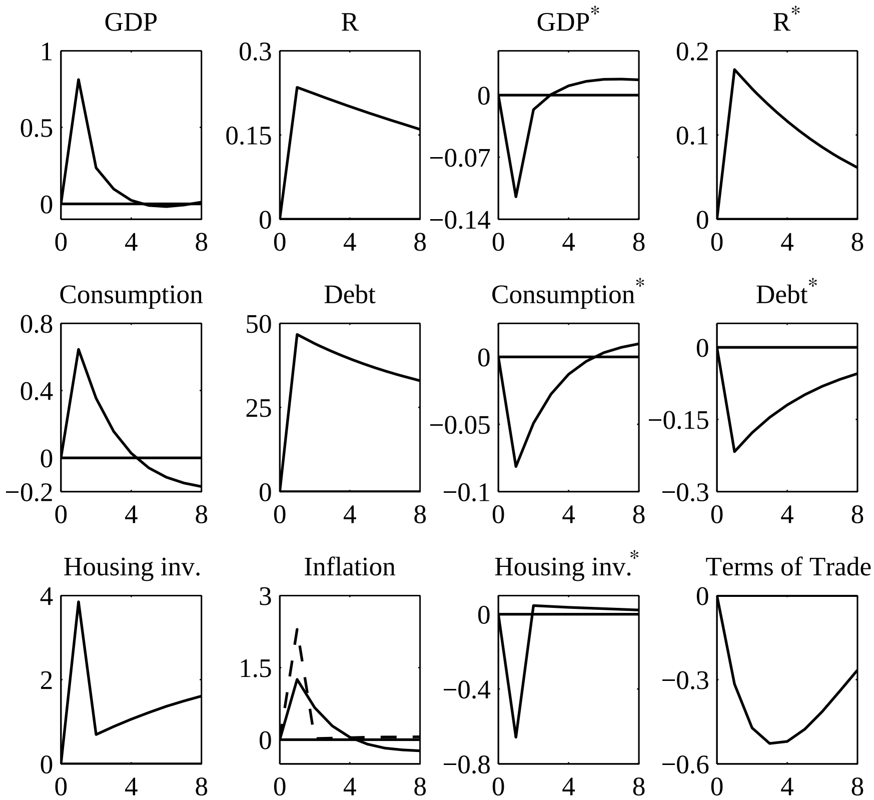

Figure 2.1: Transition dynamics of macroeconomic aggregates

Note: The figure plots the adjustment path of selected macroeconomic aggregates when the LTV ratio in the home country increases from 65% to 75%. All variables are expressed in percentage deviations from initial steady state values. The *solid line* in the inflation subplot stands for consumer price inflation and the *dashed line* represents house price inflation. Interest and inflation rates are given at annual rates.

to overshoot its post-reform steady state. The common central bank faces a dilemma as it is committed to achieve price stability for the EMU as a whole. The boom in the home country, which accounts for 10% in terms of total GDP of the monetary union, mildly increases EMU-wide inflation numbers. Consequently, the ECB increases its nominal rate of interest. The result of setting interest rates according to the EMU-wide aggregate, however, is that real interest rates are temporarily too low in the home country, while they are temporarily too high in the rest of the EMU. The higher interest rates in response to the mortgage market reform in the home country create a negative externality for the rest of the monetary union. Because of higher real interest rates in the rest of the union, foreign savers and borrowers decrease their demand, which then leads to a drop in GDP. On the other hand, real exchange rates as reflected by the terms of trade act as a stabilizing propagation mechanism. The rest of the union becomes more competitive as prices in the home economy increase faster than in the rest of the union. This leads to an increase in net exports from the rest of the union to the home country and thus contributes together with higher interest rates to the rebound in business cycle dynamics.

Figure 2.2 displays the transition path between the pre-reform and post-reform steady state of selected individual aggregates. As described above, borrowers increase consumption of nondurable goods and housing in response to the liberalization of the domestic mortgage market. Via the collateral constraint, rising real house prices and a higher housing stock contribute to the rise in debt, which, in turn, increases the borrowers' demand for nondurable goods and housing. As for the savers, the increase in wealth given by the rise in borrowers' debt allows them to increase both consumption of nondurable goods and housing. Higher interest rates, however, imply that savers smooth consumption of nondurable goods over time, so that consumption of nondurable goods initially drops below the pre-reform steady state. Moreover, as the real house price increases, a typical saver reduces demand for housing. The same economic mechanisms apply for the foreign country households. A rise in interest rates reduces borrowers and savers demand for consumption of nondurable goods and housing. In addition, foreign borrowers suffer from a decrease in real house prices via the asset-price channel of the collateral constraint. As real house prices fall, a typical saver increases housing demand.

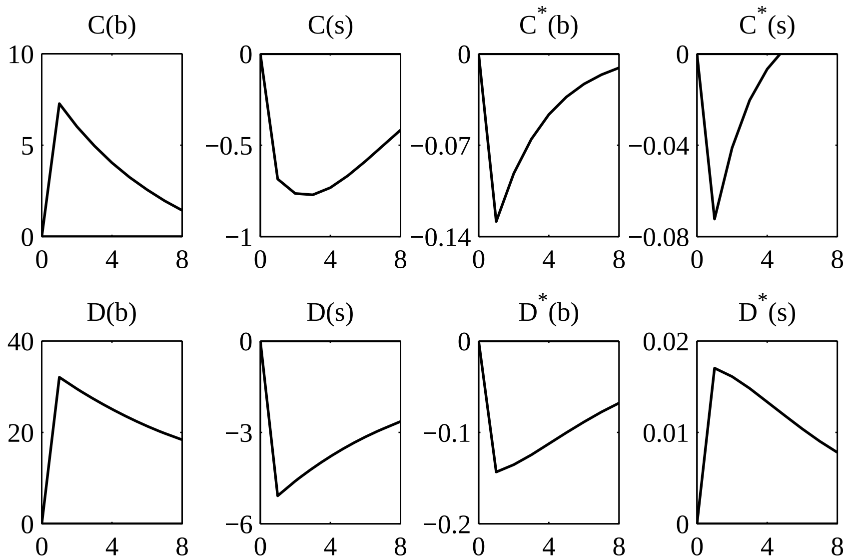

Figure 2.2: Transition dynamics of individual aggregates

Note: The figure plots the adjustment path of selected individual aggregates when the LTV ratio in the home country increases from 65% to 75%. All variables are expressed in percentage deviations from initial steady state values.

2.3.3 Welfare implications

We now shed some light on the welfare implications of the deregulation of the home country's mortgage market. As the deterministic experiment in the previous section provides us with the level values of all variables of interest, it is straight forward to compute welfare measures. The individual welfare measure for a typical saver, respectively, borrower is given by

$$V_t(s) = \sum_{k=0}^{\infty} \beta^k \left((1-\alpha)\log(C_{t+k}(s)) + (\alpha)\log(D_{t+k}(s)) - \frac{(L_{t+k}(s))^{1+\eta}}{1+\eta} \right) \quad (2.31)$$

$$\text{and} \quad \tilde{V}_t(b) = \sum_{k=0}^{\infty} \tilde{\beta}^k \left((1-\alpha)\log(\tilde{C}_{t+k}(b)) + (\alpha)\log(\tilde{D}_{t+k}(b)) - \frac{(\tilde{L}_{t+k}(b))^{1+\eta}}{1+\eta} \right). \quad (2.32)$$

The aggregate welfare of each country is computed according to

$$W_t = \omega\tilde{V}_t + (1-\omega)V_t \quad (2.33)$$

$$\text{and} \quad W_t^* = \omega^*\tilde{V}_t^* + (1-\omega^*)V_t^*. \quad (2.34)$$

To assess the overall welfare implications for the EMU, we use

$$W_t^{EMU} = nW_t + (1-n)W_t^*. \tag{2.35}$$

With this set of equations at hand, we evaluate the asymmetric mortgage market deregulation reform in the home country from a welfare perspective. Table 2.2 displays the results.

Table 2.2: Welfare implications

	Home	Rest of the EMU
Saver	0.05	0.00
Borrower	11.22	-0.08
Country	2.29	-0.01
Union		0.22

Note: The table displays percentage changes in per capita welfare for borrowers and savers as well as percentage changes in the aggregated welfare for individual countries and the EMU when the LTV ratio in the home country increases from 65% to 75%.

Because of the permanent loosening of the collateral constraint, the welfare of borrowers increases substantially.[7] Hence, although borrowers work more and consume less nondurable goods in the long-run (see section 2.3.1), the massive surge in housing consumption dominates the welfare effects. In addition, the increasing consumption of nondurable goods and housing during the transition from the pre-reform to the new steady state contributes to the borrowers' welfare gain. The welfare of savers increases only modestly. As the steady state values in the rest of the EMU are unaltered after the reform, the negative welfare externality for the rest of the union is exclusively driven by the temporarily high real interest rate path in the transition. Because of the relatively small size of the home country, the welfare loss of the rest of the EMU is negligible.

To assess the importance of the share of indebted households for the overall results, we conduct some sensitivity analysis as reported in table 2.3. When the share of borrowers is set to $\omega = 0.5$ in both economies, the model predicts that the welfare gain of savers is larger relative to the simulation results with a lower share of borrowers. This result is

[7] Note that we compute the percentage change in welfare as

$$\Delta V = \frac{V_1 - V_0}{|V_0|}, \tag{2.36}$$

where V_0 denotes the welfare level without the reform, and V_1 denotes the welfare level that reveals after the reform has been implemented.

intuitive. When the economy is composed by less savers, the mortgage market deregulation translates into a larger per capita increase in wealth of savers, because a smaller number of savers holds the offsetting financial position to the increasing debt holdings of borrowers. By the same token, per capita welfare of borrowers decreases. Moreover, when borrowers account for a larger fraction of the overall population, the spillover effects for the rest of the EMU are larger. Given a higher fraction of borrowers, the economic boom in the home country following the increase in the LTV ratio is more pronounced, so that ECB interest rates are higher during the transition to the new steady state compared to the model with a lower fraction of borrowers.

Table 2.3: Welfare implications with high fraction of borrowers

	Home	Rest of the EMU
Saver	0.38	0.02
Borrower	7.63	-0.15
Country	4.01	-0.07
Union		0.34

Note: The table displays percentage changes in per capita welfare for borrowers and savers as well as percentage changes in the aggregated welfare for individual countries and the EMU when the share of borrowers is 50% in both economies and the LTV ratio in the home country increases from 65% to 75%.

At last, table 2.4 highlights the welfare consequences of the mortgage market deregulation reform when it is implemented in the rest of the EMU. We find that the results are quite comparable to what we obtain when the reform is implemented in the home country. Borrowers gain substantially, while the welfare position of savers remains almost unaltered. The main difference is that due to the size of the country where the reform is implemented, the negative spillover effects for the rest of the union are bigger. Therefore, the welfare position of the home country worsens by a larger scale.

2.4 Conclusion

In this chapter, we examine the transition dynamics and welfare consequences of an asymmetric mortgage market deregulation in a monetary union. Related literature, i.e., Rubio (2009) and Hristov et al. (2010), focuses on the role of cross-country heterogeneity of mortgage market characteristics for the transmission of asymmetric and common shocks but neglects to assess the implications of a mortgage market reform itself in terms of

Table 2.4: Welfare implications of mortgage market reform in foreign country

	Home	Rest of the EMU
Saver	0.02	0.07
Borrower	-0.68	10.67
Country	-0.12	2.19
Union	1.96	

Note: The table displays percentage changes in per capita welfare for borrowers and savers as well as percentage changes in the aggregated welfare for individual countries and the EMU when the LTV ratio in the rest of the EMU increases from 65% to 75%.

transition dynamics and welfare. With this chapter we take a step in this direction. By employing a calibrated two-country NK DSGE model with collateral constraints tied to housing values, we quantitatively evaluate the effects of an increase in the LTV ratio from 65% to 75% in a small economy in the EMU, which is for the sake of exposition of the size of Spain. Our results suggest that the mortgage market reform leads to a massive build up of household debt in the Spanish economy. According to our quantitative projections, debt holdings increase by about 50% over the pre-reform steady state and gradually revert back to the post-reform steady state, which is about 25% over the initial. Alongside the massive expansion of collateralized debt, we find that the Spanish economy is subject to a demand-driven boom. One mechanism that fuels the boom is implied by the asset-price channel of the collateral constraint. Moreover, we find that the central bank faces a dilemma by setting interest rates according to EMU-wide aggregates. As a consequence of an asymmetric development of consumer price inflation across countries, monetary conditions are temporarily too low in the Spanish economy, while they are temporarily too tight for the rest of the EMU, which suffers from a mild decrease in GDP. Our welfare analysis reveals that the change in welfare for the country that implements the reform is positive. This effect is dominated by the borrowers' additional availability of credit associated with the deregulation of the mortgage market. As the size of the Spanish economy is small compared to the rest of the EMU, the welfare loss of the rest of the union is negligible.

Overall, our analysis reflects the dilemma of having a common monetary policy in the light of an asymmetric mortgage market deregulation. The common interest rate policy of the ECB is not well-suited to design a one size fits all policy. From a business cycle perspective this explains why asymmetric financial reforms pose a challenge to a monetary union, as one part of the union will experience a boom along the transition path to the new steady state while the rest of the union faces a recession. As our welfare analysis suggests, welfare gains of the country that implements the reform outweigh welfare losses of the rest of the EMU. However, as the home country wins and the foreign country loses, the mortgage market deregulation in a member country of the EMU implies no Pareto-optimal outcome. Thus our analysis also provides some rationale that an asymmetric mortgage market deregulation might be accompanied by national policies to prevent boom-bust cycles in housing and mortgage markets to emerge and/or to restore welfare for the rest of the union.

Chapter 3

Monetary Policy Transmission in a Model with Animal Spirits and House Price Booms and Busts[1]

3.1 Introduction

The recent boom-bust cycle in the US housing market and its repercussions on financial and economic developments have ignited a debate about the driving forces of the recent housing cycle as well as on the role of housing in the monetary policy transmission mechanism in general.[2] In this chapter, we take up these issues and incorporate heuristics into an otherwise standard New Keynesian (NK) dynamic stochastic general equilibrium (DSGE) model that captures important features of housing, and we provide qualitative insights into how monetary policy actions affect the housing market and in turn the overall economy when behavioral mechanisms play a role. The reasons to do so are twofold. First, for many people behavioral mechanisms provide a natural way to explain the emergence of the recent house price cycle in the US. For instance, Shiller (2007) states that the recent US house price rally represented notions of a speculative bubble. Also Kohn (2007) emphasizes that "*when studies are done with cooler reflection, the causes of the swing in house prices will be seen as less a consequence of monetary policy and more a result of*

[1]This chapter is based on joint work with Peter Bofinger, Sebastian Debes, and Eric Mayer that appeared as Bofinger et al. (2012).

[2]See the Jackson Hole Conference "Housing, housing finance and monetary policy" organized by the Federal Reserve Bank of Kansas City on Aug. 30-Sep. 1, 2007, as well as Jarocinski and Smets (2008) and Iacoviello and Neri (2010), among others.

emotions of excessive optimism followed by fear." Second, from a modeling point of view the notion of heuristics is substantial, because the vast majority of NK DSGE models that deal with the role of the housing market in the macroeconomy rely on the rational representative agent approach (see Iacoviello, 2005; Darracq Pariès and Notarpietro, 2008; Monacelli, 2009; Iacoviello and Neri, 2010; Aspachs-Bracons and Rabanal, 2010, 2011; Calza et al., 2011, among others). As a consequence, housing booms and busts merely reflect macroeconomic fundamentals and/or are the outcome of various structural shocks.[3] To put it differently, in standard housing models behavioral mechanisms, e.g., Shiller's (2005, 2007) "*new era story*" and his notion of "*emotional speculative interest in the market*," don't play any role in the determination of house prices. In contrast, in our behavioral expectations (BE) model we take account of these mechanisms. Thereby, we succeed to implement notions of nonlinearities and pronounced boom-bust cycles into an otherwise standard model.

Key to our approach is that agents form heterogeneous and biased expectations. In particular, we assume that agents choose between an optimistic and a pessimistic rule to forecast future real house prices. Thus at each point in time some agents bias the future real house price upward, while others bias the future real house price downward. Although agents systematically have wrong beliefs about future real house prices, they are assumed to behave rationally in the sense that they base their choice on a continuous evaluation of the forecast performance of both rules (see Anderson et al., 1992; Brock and Hommes, 1997). Hence, the fraction of house price optimists or pessimists endogenously varies over time. Agents that were pessimistic (optimistic) about the future track of the real house price cycle might learn that their beliefs were wrong. Depending on their degree of rationality, they take this as a reason to change beliefs and use the optimistic (pessimistic) forecasting rule instead. These switches between the two heuristics are of macroeconomic relevance when a large fraction of agents chooses the same heuristic simultaneously. If such a contagion in beliefs happens, a sustaining house price boom or bust can be initiated. In a full-fledged model we assume that agents not only use an optimistic and a pessimistic rule to forecast future real house prices but also to forecast future consumption of nondurable goods, and we assume that agents apply simple inflation-forecasting rules as well (see Brazier et al., 2008; De Grauwe, 2011).

Our modeling strategy is motivated by the recent work of De Grauwe (2010a,b, 2011)

[3]See Williams (2011) for a brief discussion.

who replicates Keynes' notion of "animal spirits" by incorporating heuristics into a standard New Keynesian (NK) model. He finds that when agents choose between an optimistic and a pessimistic rule to forecast future output and adaptively update their beliefs, endogenous and self-fulfilling waves of optimism and pessimism ("animal spirits") can arise in response to economic shocks. Besides his approach, the notion of agents using heuristics to guide their behavior can be motivated by a large literature of financial heterogeneous agent models.[4] However, despite their use in many financial market models, the rational representative agent approach is dominant in macroeconomic models. Recent studies that introduce heterogeneous forecasting rules, which may not be fully optimal, in otherwise standard models include Branch and Evans (2006, 2010), Brazier et al. (2008), Branch and McGough (2009, 2010), Guse (2010), Massaro (2011), and Anufriev et al. (2012).

In deriving the DSGE framework, we build on the recent strand in the housing DSGE literature that extends the standard NK model with a housing sector and a collateral constraint tied to housing along the lines of Kiyotaki and Moore (1997) and Iacoviello (2005). In this model housing has two features. First, it provides housing services and thus utility, and second, for a fraction of households it acts as collateral in the credit market. With respect to the exogenous driver of the business cycle, we follow the arguments of Taylor (2007), among others. Taylor (2007) identifies the exceptionally low short-term interest rates during the period 2003 to 2006, compared to what a Taylor rule would have recommended, as a policy mistake that significantly contributed to the US housing boom. Using a Bayesian vector autoregressive model, Jarocinski and Smets (2008) find that the Fed's easy monetary policy in 2002 to 2004 has contributed to the boom in the US housing market but that the impact on the overall economy was limited. More recently, Iacoviello and Neri (2010) study US housing market fluctuations by using an estimated NK DSGE model. They show that while monetary policy has played a minor role in the run-up of house prices, it accounted for the entire reversal of house prices in 2005 to 2006. Moreover, they find that housing market spillovers are nonnegligible and occur largely through the effects that fluctuations in house prices have on consumption. This finding is in line with the notion of collateral constrained households. Consider, for the sake of argument, an expansionary monetary policy shock. When house prices are more flexible than consumer prices, expansionary monetary policy increases the real house price and thereby increases the collateral value of debtors. This allows borrowers to raise consumption of nondurable

[4] See LeBaron (2006) and Hommes (2006) for detailed surveys.

goods and housing, which, in turn, reinforces the increase in the real house price. Hence, relative to the standard NK model, the positive effect of an expansionary monetary policy shock on the broader economy is amplified through the impact of the shock on real house prices, which determine the borrowing capacity of borrowers (asset-price channel).

In our BE model the propagation mechanisms of monetary policy works as follows. As in the standard model with rational expectations (RE model), the asset-price channel of the collateral constraint amplifies the effects of expansionary monetary policy shocks on real house prices and the business cycle. However, with increasing real house prices the forecasting performance of house price optimists improves relative to pessimists. Therefore, more and more agents switch to the optimistic forecasting rule, and a sustaining upward spiral of optimism about future real house prices, higher credit availability, higher demand, and increasing real house prices kicks in. Alongside the boom, as consumption of nondurable goods and consumer price inflation rise, beliefs about future nondurable goods consumption and consumer price inflation change and feed back into the economy.

A comparison of the monetary transmission mechanism between our BE model and the standard RE model by means of impulse response analysis reveals three important results. First, we find that in the BE model the effects of a monetary policy shock on real house prices and the business cycle are surrounded by uncertainty. Second, in the BE model the dynamics in response to a monetary policy shock exhibit a much higher persistence as in the RE model. The relatively high persistence in the BE model is due to the fact that agents only gradually adapt their beliefs. The high persistence holds particularly true when a monetary policy shock triggers a wave of optimism or pessimism. Third, we find that in the BE model consumer price inflation is relatively stable in the early stage of the boom. Thus standard monetary policy does not counteract the boom in house prices by raising interest rates. We suggest that in the BE model there is a meaningful role for a real house price-augmented Taylor rule, as it helps to rule out that monetary policy itself becomes a major source of economic disturbance. When the central bank sets interest rates in accordance with real house price developments, it reduces the scope for the emergence of optimism and pessimism about real house prices and thus limits the repercussions of these emotions on the business cycle. As behavioral mechanisms are not present in the standard RE model, we find that the merits of augmenting the Taylor rule with a real house price component is underestimated.

The chapter is structured as follows. In the next section, we derive a standard NK DSGE model with housing features. The formation of behavioral expectations is presented in section 3.3. Section 3.4 motivates the parameterization of model parameters. Section 3.5 shows the business cycle dynamics of the BE model. In section 3.6, we compare the properties of the BE model with those of the RE model. In section 3.7, we discuss the implication for monetary policy. Section 3.8 concludes.

3.2 A NK model with a housing market and a collateral constraint

The theoretical framework is a simplified two-sector NK model with a collateral constraint tied to housing. The household side of the economy is split into two groups according to households' preference for current consumption. A fraction $1-\omega$ of agents is patient and is named as savers. The remaining fraction ω is impatient and is labeled as borrowers. Both types of households receive utility from consumption of nondurable goods and housing and disutility from labor supply. Following Iacoviello (2005), borrowers are assumed to face a binding collateral constraint that ties their borrowing limit to the expected present value of their future housing stock times a loan-to-value (LTV) ratio. The production side of the economy consists of two sectors, which produce nondurable goods and housing. In each sector there is a continuum of intermediate goods producers and final goods producers. While the former produce imperfectly substitutable intermediate goods and have some market power, the latter operate in perfect competition.[5]

In what follows, we derive the maximization programs of savers, borrowers, and firms. We assume that each market is in equilibrium and close the model by assuming that the central bank follows a Taylor-type interest rate rule. As we will implement heuristics into the standard DSGE framework starting from its linearized version, we finally describe all

[5]The DSGE framework used in this chapter builds on that developed by Monacelli (2009) who studies the implications of credit market imperfections in a NK model for the comovement properties of nondurable and durable spending in response to monetary policy shocks. To reduce the overall model complexity, we follow Monacelli (2009) and abstract from business capital formation and sticky nominal wages as is generally modeled in the empirical literature (see Iacoviello, 2005; Darracq Pariès and Notarpietro, 2008; Iacoviello and Neri, 2010). In contrast to Monacelli (2009), the model features habit formation in consumption of nondurable goods, so that the RE model is able to generate a sufficient degree of persistence in total output. Our model also accounts for an imperfect substitutability of labor supply across sectors that dampens the volatility of residential investment in response to monetary policy shocks (see Iacoviello and Neri, 2010; Aspachs-Bracons and Rabanal, 2010, 2011). Aspachs-Bracons and Rabanal (2010, 2011) provide a two-country setup for a similar model used in this chapter.

log-linearized equations of the model for the sake of clarity. Note that all variables and parameters referring to borrowers are labeled with a tilde.

3.2.1 Saver's program

Each saver s ($s \in [\omega, 1]$) maximizes an intertemporal utility function, $E_t \sum_{k=0}^{\infty} \beta^k U_{t+k}(s)$, where E_t is the expectation operator, β is the discount factor, and $U_t(s)$ is the period utility function, which is defined as

$$U_t(s) = (1-\alpha)\log(C_t(s) - hC_{t-1}) + (\alpha)\log(H_t(s)) - \frac{L_t(s)^{1+\eta}}{1+\eta}, \tag{3.1}$$

where $C_t(s)$ stands for the consumption of nondurable goods, $H_t(s)$ is housing (end-of-period housing stock), and $L_t(s)$ is a labor supply index. The parameter h governs the importance of the habit stock, which is past aggregate consumption of nondurable goods, α is the share of housing in total private consumption, and η is the inverse elasticity of labor supply. Following Aspachs-Bracons and Rabanal (2010), the labor supply index is defined as

$$L_t(s) = \left[(1-\Delta_H)^{-\iota_L}(L_{C,t}(s))^{1+\iota_L} + (\Delta_H)^{-\iota_L}(L_{H,t}(s))^{1+\iota_L}\right]^{\frac{1}{1+\iota_L}}, \quad \iota_L \geq 0, \tag{3.2}$$

where $L_{C,t}(s)$ and $L_{H,t}(s)$ denote the labor supply in the nondurable goods and housing sector respectively. Δ_H is the share of real residential investment in total output, and ι_L governs the degree of labor mobility across sectors.[6] Savers accumulate housing according to

$$H_t(s) = HI_t(s) + (1-\delta)H_{t-1}(s), \tag{3.3}$$

where $HI_t(s)$ is real residential investment, and δ is the depreciation rate of the housing stock. In real terms (units of the nondurable goods) the period budget constraint of a saver is

$$C_t(s) + q_t HI_t(s) + b_t(s) = R_{t-1}\frac{b_{t-1}(s)}{\Pi_{C,t}} + w_{C,t}L_{C,t}(s) + w_{H,t}L_{H,t}(s) + div_t(s), \tag{3.4}$$

[6] Note that if $\iota_L > 0$, labor efforts in the two sectors are less than perfect substitutes. Hence, sectoral labor supply responses less to differences in sectoral wages in response to a monetary policy shock (see also Iacoviello and Neri, 2010).

where $q_t = \frac{P_{H,t}}{P_{C,t}}$ is the real house price, which is defined as the ratio of the price of nondurable goods, $P_{C,t}$, and the price of housing, $P_{H,t}$. $b_t(s) = \frac{B_t(s)}{P_{C,t}}$ is real one-period debt, $\Pi_{C,t} = \frac{P_{C,t}}{P_{C,t-1}}$ depicts the gross inflation rate of consumer prices, and R_t is the gross nominal interest rate of contracts entered in period t. $w_{j,t} = \frac{W_{j,t}}{P_{C,t}}$ is the sectoral real wage rate, and $div_t(s) = \frac{Div_t(s)}{P_{C,t}}$ are real dividends payed by intermediate goods producers who are owned by savers.

Defining $U_{C,t}(s) = \frac{\partial U_t(s)}{\partial C_t(s)}$ as the marginal utility of an additional unit of nondurable goods and $U_{H,t}(s) = \frac{\partial U_t(s)}{\partial H_t(s)}$ as the marginal utility of an additional unit of housing, we derive the first-order conditions to the maximization of the intertemporal utility function with respect to (3.3) and (3.4) as follows[7]

$$w_{C,t} = \frac{L_t^{(\eta-\iota_L)}(1-\Delta_H)^{-\iota_L}(L_{C,t})^{\iota_L}}{U_{C,t}}, \tag{3.5}$$

$$w_{H,t} = \frac{L_t^{(\eta-\iota_L)}(\Delta_H)^{-\iota_L}(L_{H,t})^{\iota_L}}{U_{C,t}}, \tag{3.6}$$

$$U_{C,t}q_t = U_{H,t} + \beta(1-\delta)E_t\left(U_{C,t+1}q_{t+1}\right), \tag{3.7}$$

$$\text{and} \quad U_{C,t} = \beta E_t\left(U_{C,t+1}\frac{R_t}{\Pi_{C,t+1}}\right). \tag{3.8}$$

3.2.2 Borrower's program

Each borrower b ($b \in [0,\omega]$) maximizes an intertemporal utility function, $E_t \sum_{k=0}^{\infty} \tilde{\beta}^k \tilde{U}_{t+k}(b)$, where $\tilde{\beta} < \beta$. The period utility function, the labor supply index, and the housing accumulation equation have the same functional form as equations (3.1), (3.2), and (3.3) respectively. The real budget constraint of a borrower is given by

$$\tilde{C}_t(b) + q_t\tilde{H}I_t(b) + R_{t-1}\frac{\tilde{b}_{t-1}(b)}{\Pi_{C,t}} = \tilde{b}_t(b) + w_{C,t}\tilde{L}_{C,t}(b) + w_{H,t}\tilde{L}_{H,t}(b). \tag{3.9}$$

Borrowers are subject to a collateral constraint, which is

$$\tilde{b}_t(b) \leq (1-\chi)(1-\delta)E_t\left(\frac{\tilde{H}_t(b)q_{t+1}}{R_t/\Pi_{C,t+1}}\right), \tag{3.10}$$

where $(1-\chi)$ is the loan-to-value ratio.[8]

[7] We assume that savers trade state-contingent securities among each other, so that all savers behave the same way. Thus we drop the index s.

[8] It can be shown that the collateral constraint is satisfied with equality in the deterministic steady state. Throughout, we follow the general assumption in the literature and assume that the constraint is

The first-order conditions to the borrower's maximization program above are given by[9]

$$w_{C,t} = \frac{\tilde{L}_t^{(\eta-\iota_L)}(1-\Delta_H)^{-\iota_L}(\tilde{L}_{C,t})^{\iota_L}}{\tilde{U}_{C,t}}, \tag{3.11}$$

$$w_{H,t} = \frac{\tilde{L}_t^{(\eta-\iota_L)}(\Delta_H)^{-\iota_L}(\tilde{L}_{H,t})^{\iota_L}}{\tilde{U}_{C,t}}, \tag{3.12}$$

$$\tilde{U}_{C,t}q_t = \tilde{U}_{H,t} + \tilde{\beta}(1-\delta)E_t\left(\tilde{U}_{C,t+1}q_{t+1}\right) + (1-\chi)(1-\delta)q_t\tilde{\psi}_t\tilde{U}_{C,t}E_t\left(\Pi_{H,t+1}\right), \tag{3.13}$$

and $$\tilde{U}_{C,t} = \tilde{\beta}E_t\left(\tilde{U}_{C,t+1}\frac{R_t}{\Pi_{C,t+1}}\right) + R_t\tilde{\psi}_t\tilde{U}_{C,t}, \tag{3.14}$$

where $\Pi_{H,t} = \frac{q_t}{q_{t-1}}\Pi_{C,t}$ is the gross inflation rate of house prices, and $\tilde{\psi}\tilde{U}_{C,t}$ is the Lagrange multiplier on the collateral constraint.

3.2.3 Final goods producers

In each sector ($j = C, H$) final goods producers purchase units of intermediate goods and bundle them according to the following technology $Y_{j,t} = \left(\int_0^1 Y_{j,t}(i)^{\frac{\epsilon_j-1}{\epsilon_j}}di\right)^{\frac{\epsilon_j}{\epsilon_j-1}}$, where $Y_{j,t}$ is the quantity of final goods, $Y_{j,t}(i)$ is the quantity of intermediate good i, and ϵ_j is the elasticity of substitution between intermediate goods. Profit maximization of the final goods producers implies a demand function for the intermediate good i according to $Y_{j,t}(i) = \left(\frac{P_{j,t}(i)}{P_{j,t}}\right)^{-\epsilon_j}Y_{j,t}$, where $P_{j,t}(i)$ is the price of one unit of the intermediate good. Given zero profits in equilibrium, it holds that $P_{j,t} = \left(\int_0^1 P_{j,t}(i)^{1-\epsilon_j}di\right)^{\frac{1}{1-\epsilon_j}}$.

3.2.4 Intermediate goods producers

In each sector intermediate goods are produced according to the following linear production technology $Y_{j,t}(i) = L_{j,t}^{tot}(i)$, where $L_{j,t}^{tot}(i)$ stands for total labor input. Intermediate goods producers maximize expected profits in each period subject to the demand for intermediate goods. As in Calvo (1983), intermediate goods producers in sector $j = C, H$ reset prices with a probability of $1-\theta_j$. The reset price for good i in sector j is given by

$$P_{j,t}^*(i) = \frac{\epsilon_j}{\epsilon_j - 1}\frac{E_t\sum_{k=0}^{\infty}(\theta_j\beta)^k U_{C,t+k}P_{j,t+k}^{\epsilon_j}mc_{j,t+k}Y_{j,t+k}}{E_t\sum_{k=0}^{\infty}(\theta_j\beta)^k U_{C,t+k}P_{j,t+k}^{\epsilon_j-1}Y_{j,t+k}}, \tag{3.15}$$

also binding in a small neighborhood of the steady state, so that the model can be solved by taking a log-linear approximation (see Iacoviello, 2005; Monacelli, 2009).

[9] We drop the index b, as we assume that borrowers trade state-contingent securities.

where $mc_{j,t}$ are the real marginal costs of production defined as $mc_{j,t} = \frac{W_{j,t}}{P_{j,t}}$. Finally, the aggregate price level in each sector can be written as $P_{j,t}^{1-\epsilon_j} = \theta_j \left(P_{j,t-1}\right)^{1-\epsilon_j} + (1 - \theta_j) \left(P_{j,t}^{*}(i)\right)^{1-\epsilon_j}$.

3.2.5 Market clearing and monetary policy

We assume that each market is in equilibrium and that the nominal interest rate is determined by a central bank that follows a simple Taylor-type rule, which is

$$R_t = R_{t-1}^{\mu_R} \left(\bar{R} \left(\frac{\Pi_{C,t}}{\bar{\Pi}_C} \right)^{\mu_\pi} \left(\frac{Y_t}{\bar{Y}} \right)^{\mu_Y} \right)^{1-\mu_R} exp(u_{R,t}), \tag{3.16}$$

where $\bar{R}$ stands for the steady state gross nominal interest rate, $\bar{\Pi}_C = 1$ is the steady state gross inflation rate of consumer prices, $\bar{Y}$ denotes the steady state real GDP, and $u_{R,t}$ is an uncorrelated monetary policy shock with zero mean and variance $\sigma_{u_R}^2$.

3.2.6 The linearized model

Here, we summarize all log-linearized equations of the model and provide a brief description of their basic mechanisms. Note that in the following variables with a bar denote steady state values and variables with a hat describe log-deviations from steady state values.[10]

The dynamics of consumption of nondurable goods for savers are standard and read

$$\hat{C}_t = \frac{1}{1+h} E_t \hat{C}_{t+1} + \frac{h}{1+h} \hat{C}_{t-1} - \frac{1-h}{1+h} (\hat{R}_t - E_t \pi_{C,t+1}). \tag{3.17}$$

The dynamics of the savers' demand for housing depend on past and current consumption of nondurable goods, the (ex-ante) real interest rate, and the current and expected future real house price. It holds that

$$\frac{1}{1-h} \hat{C}_t - \frac{h}{1-h} \hat{C}_{t-1} - \hat{H}_t = [1 - \beta(1-\delta)]^{-1} \left\{ \hat{q}_t + \beta(1-\delta)(\hat{R}_t - E_t \pi_{C,t+1} - E_t \hat{q}_{t+1}) \right\}. \tag{3.18}$$

The accumulation equation of the savers' housing stock is determined by

$$\hat{H}_t = \delta \hat{H} I_t + (1-\delta) \hat{H}_{t-1}. \tag{3.19}$$

[10] In appendix A, we present the steady state of the model.

The savers' sectoral labor supply is

$$\frac{1}{1-h}\hat{C}_t - \frac{h}{1-h}\hat{C}_{t-1} + ((\eta-\iota_L)(1-\Delta_H)+\iota_L)\hat{L}_{C,t} + (\eta-\iota_L)\Delta_H\hat{L}_{H,t} = \hat{w}_{C,t} \quad (3.20)$$

$$\frac{1}{1-h}\hat{C}_t - \frac{h}{1-h}\hat{C}_{t-1} + ((\eta-\iota_L)\Delta_H+\iota_L)\hat{L}_{H,t} + (\eta-\iota_L)(1-\Delta_H)\hat{L}_{C,t} = \hat{w}_{H,t}. \quad (3.21)$$

Due to the effects of the collateral constraint, the borrowers' consumption of nondurable goods is more responsive to monetary policy than that of the savers. It holds that

$$\hat{\tilde{C}}_t = \frac{1}{1+h}E_t\hat{\tilde{C}}_{t+1} + \frac{h}{1+h}\hat{\tilde{C}}_{t-1} - \frac{1-h}{1+h}(\hat{R}_t - E_t\pi_{C,t+1}) - \frac{\bar{\tilde{\psi}}}{\tilde{\beta}}\frac{1-h}{1+h}\left(\hat{R}_t + \hat{\tilde{\psi}}_t\right), \quad (3.22)$$

where $\bar{\tilde{\psi}} = \beta - \tilde{\beta}$. Likewise, the presence of the collateral constraint alters the dynamics of the borrowers' housing demand relative to that of savers by delinking the demand for housing from movements in real house prices. The borrowers' demand for housing follows

$$\frac{1}{1-h}\hat{\tilde{C}}_t - \frac{h}{1-h}\hat{\tilde{C}}_{t-1} - \hat{\tilde{H}}_t = \tilde{\Phi}^{-1}\left\{\tilde{\Gamma}\hat{q}_t - \tilde{\beta}E_t\hat{q}_{t+1} + \beta(\hat{R}_t - E_t\pi_{C,t+1}) + \bar{\tilde{\psi}}\left(\chi\hat{\tilde{\psi}}_t - \hat{\xi}_t\right)\right\}, \quad (3.23)$$

where $\tilde{\Phi} = \frac{1-\delta}{1-(1-\delta)[\tilde{\beta}+(1-\chi)(\beta-\tilde{\beta})]}$, $\tilde{\Gamma} = \frac{1-(1-\chi)(1-\delta)(\beta-\tilde{\beta})}{1-\delta}$, and $\hat{\xi}_t$ is a composite inflation term that is defined as $\hat{\xi}_t = (1-\chi)(E_t\hat{q}_{t+1} - \hat{q}_t) - \chi E_t\pi_{C,t+1}$.[11] The law of motion for real debt holdings depend on the housing stock, the real interest rate, and the expected real house price and reads

$$\hat{\tilde{b}}_t = \hat{\tilde{H}}_t + E_t\hat{q}_{t+1} - (\hat{R}_t - E_t\pi_{C,t+1}). \quad (3.24)$$

The accumulation equation of the borrowers' housing stock and the sectoral labor supply equations are equal to equations (3.19) and (3.20)-(3.21). The borrowers' budget constraint is

$$\bar{\tilde{C}}\hat{\tilde{C}}_t = \bar{\tilde{b}}\hat{\tilde{b}}_t - \frac{\bar{\tilde{b}}}{\beta}(\hat{R}_{t-1} - \pi_{C,t} + \hat{\tilde{b}}_{t-1}) + \sum_j^{C,H}\bar{w}_j\bar{\tilde{L}}_j(\hat{\tilde{L}}_{j,t} + \hat{w}_{j,t}) - \bar{\tilde{H}}I(\hat{q}_t + \hat{\tilde{H}}I_t). \quad (3.25)$$

The dynamics of the real house price are given by

$$\hat{q}_t = \pi_{H,t} - \pi_{C,t} + \hat{q}_{t-1}. \quad (3.26)$$

[11] See Monacelli (2009) and Calza et al. (2011) for a detailed discussion on the implications of the collateral constraint for the transmission of monetary policy in a standard NK model.

The evolution of inflation in each sector takes the form of a forward-looking NK Phillips curve

$$\pi_{C,t} = \beta E_t \pi_{C,t+1} + \frac{(1-\theta_C)(1-\beta\theta_C)}{\theta_C} \hat{w}_{C,t} \tag{3.27}$$

$$\text{and} \quad \pi_{H,t} = \beta(E_t \hat{q}_{t+1} - \hat{q}_t + E_t \pi_{C,t+1}) + \frac{(1-\theta_H)(1-\beta\theta_H)}{\theta_H} (\hat{w}_{H,t} - \hat{q}_t), \tag{3.28}$$

where we have used that $E_t \pi_{H,t+1} = E_t \hat{q}_{t+1} - \hat{q}_t + E_t \pi_{C,t+1}$.

The labor market equilibrium condition can be written as

$$\hat{Y}_{j,t} = \frac{\omega \bar{\tilde{L}}_j}{\bar{Y}_j} \hat{\tilde{L}}_{j,t} + \frac{(1-\omega)\bar{L}_j}{\bar{Y}_j} \hat{L}_{j,t}, \quad j = C, H. \tag{3.29}$$

The debt market equilibrium condition is described by

$$\hat{\tilde{b}}_t = \hat{b}_t. \tag{3.30}$$

The goods market equilibrium conditions are

$$\hat{Y}_{C,t} = \frac{\omega \bar{\tilde{C}}}{\bar{Y}_C} \hat{\tilde{C}}_t + \frac{(1-\omega)\bar{C}}{\bar{Y}_C} \hat{C}_t \tag{3.31}$$

$$\text{and} \quad \hat{Y}_{H,t} = \frac{\omega \bar{\tilde{H}I}}{\bar{Y}_H} \hat{\tilde{H}I}_t + \frac{(1-\omega)\bar{H}I}{\bar{Y}_H} \hat{H}I_t. \tag{3.32}$$

Real GDP evolves as

$$\hat{Y}_t = (1-\Delta_H)\hat{Y}_{C,t} + \Delta_H \hat{Y}_{H,t}. \tag{3.33}$$

Finally, the Taylor rule for the nominal interest rate reads

$$\hat{R}_t = \mu_R \hat{R}_{t-1} + (1-\mu_R)(\mu_\pi \pi_{C,t} + \mu_Y \hat{Y}_t) + u_{R,t}. \tag{3.34}$$

3.3 The formation of expectations

In this section, we discuss how agents, i.e., savers, borrowers, and firms, form their expectations on future real house prices, consumption of nondurable goods, and consumer price inflation. Throughout, we assume that agents choose between simple rules to make forecasts and base their choice on the relative forecast performance of the rules. The diversity in beliefs is a key difference to a standard RE model in which expectations are homogeneous. Following De Grauwe (2010a,b, 2011), we impose heuristics on the macroeconomic level. That is, we use the linearized version of the model described in the previous section and assume that structural relations remain unchanged when we substitute the assumption of rational expectations by the alternative that agents choose among different rules to form their expectations.[12] In this vein, our BE model shares the same macroeconomic relations as the standard model except that rational expectations are replaced with aggregate forecasts that are a combination of the rules agents use to make forecasts.

3.3.1 Expectations on future real house prices and consumption of non-durable goods

When we model the expectation formation on future house prices and consumption of non-durable goods, we assume that agents simply choose between an optimistic, a pessimistic, and a fundamental forecasting rule (see also De Grauwe, 2011). Clearly, these rules are ad hoc and whether they represent a realistic process of how individuals form their beliefs remains open for further debate. However, these rules can be seen as the simplest way to describe the interaction between macroeconomic dynamics and agents' behavior when one accepts that agents have cognitive limitations and do not fully understand the underlying structure of the economy.

As for the expectations on future real house prices, the assumption that agents choose between an optimistic and a pessimistic forecasting rule formalizes Kohn's (2007) idea of "*excessive optimism followed by fear*" as a potential driver of the recent US house price boom and bust.[13] In our model, the optimistic and the pessimistic beliefs that agents use to forecast future real house prices are symmetric around zero and given as[14]

$$E_t^{opt}\hat{q}_{t+1} = \frac{d_t^q}{2} \quad \text{and} \quad E_t^{pes}\hat{q}_{t+1} = -\frac{d_t^q}{2}, \tag{3.35}$$

[12]This also follows the approach within statistical learning models pioneered by Evans and Honkapohja (2001). See, e.g., Bullard and Mitra (2002), Orphanides and Williams (2004), Gaspar et al. (2006), Milani (2007), and Branch and Evans (2010). In contrast to our model in which agents systematically have biased beliefs, those models might nest the RE equilibrium depending on the statistical tools and knowledge agents use to form expectations.

[13]As we will see later, the assumption that agents form optimistic and pessimistic beliefs about future house prices also incorporates the notion of a "*social epidemic of optimism for real estate*" that contributed to the US house price bubble as described by Shiller (2007).

[14]As we assume that savers and borrowers are equally distributed among house price optimists and pessimists, which leads the expectations of savers and borrowers to be equal on the aggregate level, we use the general term "agents".

where $d_t^q > 0$ measures the absolute divergence in beliefs, which is assumed to be a function of real house price volatility and reads

$$d_t^q = \beta_d + \delta_d \sigma(\hat{q}_t), \qquad (3.36)$$

where $\sigma(\hat{q}_t)$ is the unconditional volatility of house prices measured over a window of z observations in the past, $\beta_d > 0$ denotes the average divergence in beliefs, and $\delta_d > 0$ is the sensitivity of the divergence in beliefs to house price volatility (see De Grauwe, 2011). Besides the optimistic and the pessimistic rule, we assume that agents choose a fundamental rule to form their beliefs on future real house prices following the approach in behavioral financial market models (see, for instance, Brock and Hommes, 1998). As the fundamental rule implies that forecasts are unbiased, the introduction of this type of rule may counteract the emergence of purely expectation-driven housing boom-bust cycles that otherwise would occur in the case when agents are allowed to choose either an optimistic or a pessimistic rule. The fundamental forecasting rule is independent of the movements in real house prices and reads

$$E_t^{fun} \hat{q}_{t+1} = 0. \qquad (3.37)$$

The specification of the fundamental forecasting rule follows De Grauwe (2011). In particular, it is assumed that agents are perfectly informed about the steady state value of real house prices, which is normalized at zero, and use this value to predict the future.[15]

Which rule should agents choose? This decision is modeled by applying notions of discrete choice theory (see Anderson et al., 1992; Brock and Hommes, 1997). Although agents are assumed to have cognitive limitations and use simple forecasting rules, they behave rationally in the sense that they select the rules according to their recent forecast performance. In particular, agents evaluate the corresponding forecast performance of the

[15] Note that fundamental expectations do not equal rational expectations. The latter requires agents to incorporate the expectation formation of optimists and pessimists (see De Grauwe, 2012).

three rules according to

$$U^{q}_{opt,t} = \sum_{k=1}^{\infty} \omega_k \left[\hat{q}_{t-k} - E^{opt}_{t-k-1}\hat{q}_{t-k}\right]^2, \tag{3.38}$$

$$U^{q}_{pes,t} = \sum_{k=1}^{\infty} \omega_k \left[\hat{q}_{t-k} - E^{pes}_{t-k-1}\hat{q}_{t-k}\right]^2, \tag{3.39}$$

$$\text{and} \quad U^{q}_{fun,t} = \sum_{k=1}^{\infty} \omega_k \left[\hat{q}_{t-k} - E^{fun}_{t-k-1}\hat{q}_{t-k}\right]^2, \tag{3.40}$$

where $U^{q}_{opt,t}$ and $U^{q}_{pes,t}$ is the mean squared forecasting error (MSFE) of the optimistic, respectively, the pessimistic rule, and $U^{q}_{fun,t}$ is the MSFE of the fundamental rule. ω_k are geometrically declining weights. It holds that $\omega_k = (1-\rho)\rho^k$, where the parameter ρ governs the memory of agents. The fraction of agents that uses the optimistic, pessimistic, or fundamental forecasting rule is then determined by

$$\alpha^{q}_{opt,t} = \frac{exp(-\gamma U^{q}_{opt,t})}{exp(-\gamma U^{q}_{opt,t}) + exp(-\gamma U^{q}_{pes,t}) + exp(-\gamma U^{q}_{fun,t})}, \tag{3.41}$$

$$\alpha^{q}_{pes,t} = \frac{exp(-\gamma U^{q}_{pes,t})}{exp(-\gamma U^{q}_{opt,t}) + exp(-\gamma U^{q}_{pes,t}) + exp(-\gamma U^{q}_{fun,t})}, \tag{3.42}$$

$$\text{and} \quad \alpha^{q}_{fun,t} = \frac{exp(-\gamma U^{q}_{fun,t})}{exp(-\gamma U^{q}_{opt,t}) + exp(-\gamma U^{q}_{pes,t}) + exp(-\gamma U^{q}_{fun,t})} = 1 - \alpha^{q}_{opt,t} - \alpha^{q}_{pes,t}, \tag{3.43}$$

where the parameter γ is the so-called "intensity of choice". This parameter measures the degree of agents' rationality. The higher is γ, the higher is the fraction of agents choosing the better performing rule.[16] The limit $\gamma = 0$ is the case in which the fraction of optimists or pessimists is 0.5 (independent of the MSFEs), and $\gamma = \infty$ represents the case in which all agents choose the rule with the highest forecast performance.

Finally, the aggregate real house price forecast, $E_t\hat{q}_{t+1}$, is defined as the weighted average of the three forecasts and is given by

$$E_t\hat{q}_{t+1} = \alpha^{q}_{opt,t}(E^{opt}_t\hat{q}_{t+1}) + \alpha^{q}_{pes,t}(E^{pes}_t\hat{q}_{t+1}) + \alpha^{q}_{fun,t}(E^{fun}_t\hat{q}_{t+1}). \tag{3.44}$$

Given this line of argument for the modeling of the formation of beliefs on future house

[16] The intensity of choice is associated with noise agents face when they compute the forecast performance of rules (see Anderson et al., 1992; Brock and Hommes, 1997). The higher is γ, the lower is the noise in observing the forecast performance and the higher is the fraction of agents that uses the better performing rule.

prices, we assume that agents choose between these three types of rules when they forecast their future level of nondurable goods consumption and that they base their choice on the relative forecasting performance of these rules. On one side, we do so to keep the modeling assumptions about the formation of expectations as parsimonious as possible. On the other side, it is reasonable to do so, because the Brock-Hommes selection mechanism, as described above, can be viewed as a natural way to limit the types of competing forecasting rules. As the consumption of nondurable goods differs between savers and borrowers, we separate the expectation formation between these two types. That is, borrowers and savers separately choose between an optimistic, pessimistic, and fundamental forecasting rule. Similar to the formation of beliefs on future real house prices, the divergence in beliefs on future nondurable goods consumption implied by the optimistic and pessimistic rule is symmetric around zero and a function of the unconditional volatility of nondurable goods consumption measured over a fixed window in the past. The fundamental rule is independent of the movement in nondurable goods consumption and uses the steady state value of nondurable goods consumption as a predictor.[17]

In a nutshell, the aggregate forecast on future consumption of nondurable goods for savers, $E_t\hat{C}_{t+1}$, is given by

$$E_t\hat{C}_{t+1} = \alpha^C_{opt,t}(E^{opt}_t\hat{C}_{t+1}) + \alpha^C_{pes,t}(E^{pes}_t\hat{C}_{t+1}) + \alpha^C_{fun,t}(E^{fun}_t\hat{C}_{t+1}). \tag{3.45}$$

Accordingly, the aggregate forecast on future consumption of nondurable goods for borrowers, $E_t\hat{\tilde{C}}_{t+1}$, is

$$E_t\hat{\tilde{C}}_{t+1} = \alpha^{\tilde{C}}_{opt,t}(E^{opt}_t\hat{\tilde{C}}_{t+1}) + \alpha^{\tilde{C}}_{pes,t}(E^{pes}_t\hat{\tilde{C}}_{t+1}) + \alpha^{\tilde{C}}_{fun,t}(E^{fun}_t\hat{\tilde{C}}_{t+1}). \tag{3.46}$$

3.3.2 Expectations on future consumer price inflation

As for the expectation formation on future consumer price inflation, we follow Brazier et al. (2008) and De Grauwe (2011) and deviate from the assumption of optimistic or pessimistic forecasting rules. In particular, we assume that some agents use the central bank's inflation target to forecast future consumer price inflation, while others do not trust the inflation target of the central bank and simply extrapolate past inflation.[18] The two

[17]We present the modeling details in appendix B.

[18]Again, we assume that savers and borrowers are equally distributed among the forecasting camps, so that borrowers and savers have the same expectations on the aggregate level.

forecasting rules are given by

$$E_t^{tar}\pi_{C,t+1} = \pi_C^* \quad \text{and} \quad E_t^{ext}\pi_{C,t+1} = \pi_{C,t-1}, \tag{3.47}$$

where π_C^* is the central bank's inflation target, which is zero. The selection mechanism is identical to the previous formations of expectations. Agents evaluate the forecasting performance of the rules according to

$$U_{tar,t}^{\pi} = \sum_{k=1}^{\infty} \omega_k \left[\pi_{C,t-k} - E_{t-k-1}^{tar}\pi_{C,t-k}\right]^2 \tag{3.48}$$

$$\text{and} \quad U_{ext,t}^{\pi} = \sum_{k=1}^{\infty} \omega_k \left[\pi_{C,t-k} - E_{t-k-1}^{ext}\pi_{C,t-k}\right]^2, \tag{3.49}$$

and the corresponding fractions of agents evolve as

$$\alpha_{tar,t}^{\pi} = \frac{exp(-\gamma U_{tar,t}^{\pi})}{exp(-\gamma U_{tar,t}^{\pi}) + exp(-\gamma U_{ext,t}^{\pi})} \tag{3.50}$$

$$\text{and} \quad \alpha_{ext,t}^{\pi} = \frac{exp(-\gamma U_{ext,t}^{\pi})}{exp(-\gamma U_{tar,t}^{\pi}) + exp(-\gamma U_{ext,t}^{\pi})} = 1 - \alpha_{tar,t}^{\pi}, \tag{3.51}$$

where $\alpha_{tar,t}^{\pi}$ is the fraction of agents that uses the inflation target of the central bank, and $\alpha_{ext,t}^{\pi}$ is the remaining fraction of agents that uses the past inflation rate.

Finally, the aggregate forecast for inflation in the nondurable goods sector, $E_t\pi_{C,t+1}$, is given by

$$E_t\pi_{C,t+1} = \alpha_{tar,t}^{\pi}(E_t^{tar}\pi_{C,t+1}) + \alpha_{ext,t}^{\pi}(E_t^{ext}\pi_{C,t+1}). \tag{3.52}$$

3.4 Calibration and solution

We calibrate the model by applying parameter values that are typically reported in the housing DSGE literature. Time is considered to be in quarters. The discount rate of savers, β, is assumed to be 0.9925, which implies an annual real rate of return of 3%. The discount factor of borrowers, $\tilde{\beta}$, is set to 0.97. The share of borrowers in the economy, ω, is fixed at 50%. Habits in consumption, h, the inverse elasticity of labor supply, η, and the parameter governing the degree of labor mobility across sectors, ι_L, are equal for both households and are set to 0.7, 1, and 1 respectively. As Aspachs-Bracons and Rabanal (2010) point out, the steady state share of real residential investment in real GDP, Δ_H, and the parameter α, which denotes the share of housing in total private consumption for both types of households, cannot be set independently. We determine α numerically, so that $\Delta_H = 0.1$. The annual depreciation of housing is 4%, which implies $\delta = 0.01$. The parameter χ is 0.25, which yields a LTV ratio of 75%. The elasticities of substitution between intermediate goods, ϵ_C and ϵ_H, are both set to 11, which yields a steady state markup of 10% in each sector $j = C, H$. The degrees of price stickiness, θ_C and θ_H, crucially determine the dynamics of the model. Throughout, we follow the assumption that house prices exhibit a higher flexibility than nondurable goods prices. However, we do not allow for fully flexible house prices.[19] We choose to set $\theta_C = 0.8$, which implies an average frequency of price adjustment of five quarters for nondurable goods prices, and $\theta_H = 0.66$, which yields an average price rigidity of three quarters for house prices. Turning to the monetary policy rule, we set $\mu_R = 0.75$, $\mu_\pi = 1.5$, and $\mu_Y = 0$ in the baseline calibration. As for the parameters governing the formation of expectations, our calibration strategy is to choose parameter values that maximize the correlation between the movements in the fraction of house price optimists and the real house price gap. We set the fixed component and the variable component of the divergence in beliefs, β_d and δ_d, to 2. The intensity of choice parameter, γ, is equal to 1. The memory parameter, ρ, is assumed to be 0.5, and the number of past observations that are used to evaluate the forecast performance of the rules, z, is 20.[20] Finally, to simulate from the model, we bring the model in the following form

$$\mathbf{Z_t} = \mathbf{A^{-1}} \left(\mathbf{B E_t Z_{t+1}} + \mathbf{C Z_{t-1}} + \mathbf{V_t} \right), \tag{3.53}$$

where $\mathbf{A}$, $\mathbf{B}$, $\mathbf{C}$ are appropriately defined parameter matrices, $\mathbf{Z_t}$ denotes the state vector that contains the relevant variables of the system, and $\mathbf{V_t}$ is a vector that includes the monetary policy shock.

[19] In a seminal paper, Barsky et al. (2007) show that the standard NK model with a full flexibly priced durable goods sector does not replicate the empirically observed positive comovement of nondurable and durable consumption following a monetary policy shock. In response, Monacelli (2009) points out that the introduction of a collateral constraint on borrowing makes the assumption on the degree of stickiness in the durable sector less crucial.

[20] In appendix C, we outline our calibration strategy for the behavioral parameters and present a sensitivity analysis.

3.5 Monetary policy, animal spirits, and the business cycle

In this section, we investigate the business cycle dynamics of the model and study the role of heuristics agents use to make forecasts in the transmission of monetary policy. In particular, we analyze to what extend monetary policy shocks can trigger waves of optimism and pessimism ("animal spirits") that drive house prices and the real economy.

3.5.1 A simplified BE model

At first, we shed some light on the role of behavioral mechanism in a somewhat simplified model. To rule out that endogenously driven business cycles arise due to behavioral mechanisms when agents form beliefs on future consumption and consumer price inflation, we assume that these expectations are fixed at their steady state value. That is, we set the expectation operator on future consumption of nondurable goods, $E_t\hat{C}_{t+1}$ and $E_t\hat{\hat{C}}_{t+1}$, and on future consumer price inflation, $E_t\pi_{C,t+1}$, to zero. A way to rationalize the simplified model is by assuming an economy in which agents form biased expectations when they predict future movements of real house prices, while they form fundamentally grounded expectations on future consumption levels of nondurable goods and consumer price inflation. Put differently, the analysis in this section boils down to the interaction between macroeconomic dynamics and behavioral expectations that only play a role for the determination of asset prices.

Figure 3.1 highlights the dynamics of the model between the quarter 700 and 800 for an arbitrary draw of uncorrelated monetary policy shocks with a standard deviation of 25 basis points. As is apparent from the figure, the BE model is capable to generate endogenous and persistent cycles in real house prices and the broader economy, although the model is only driven by uncorrelated monetary policy shocks. The monetary transmission mechanism can be described as follows. Between quarter 710 to 720, we observe that the economy is hit by a sequence of negative monetary policy shocks, so that the interest rate is well below its steady state for a sustained period of time. Given that prices are sticky, the real interest rate is low and stimulates demand for nondurable goods and residential investment. In turn, consumer price inflation and house prices rise as marginal costs increase alongside the expansion of production. Because firms in the housing sector are able to adjust prices more frequently than firms in the nondurable goods sector, the real house price increases. With increasing real house prices, however, agents who are

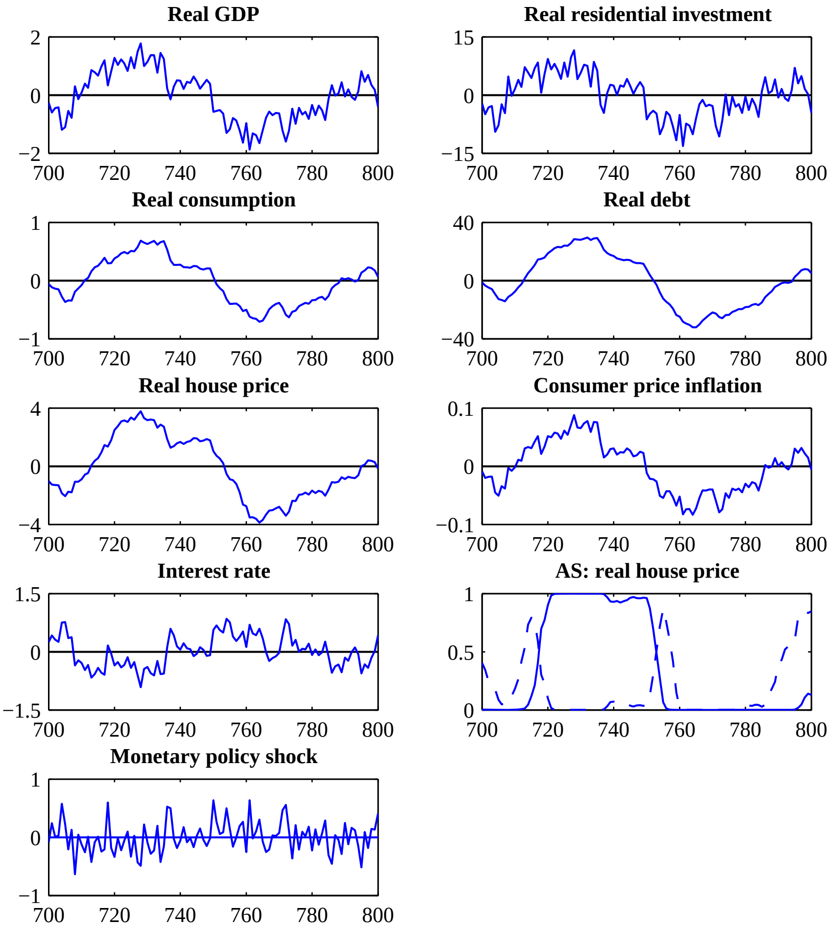

Figure 3.1: Dynamics of the simplified BE model

Note: The x-axis is in quarters. The y-axis measures percent deviation from the steady state except in the AS plot. AS stands for “animal spirits” and measures the fraction of real house price optimists (*solid line*) and fundamentalists (*dashed line*).

pessimistic about the future track of real house prices gradually observe that their forecast performance deteriorates. Hence, pessimists are willing to change their beliefs and switch to the fundamental forecasting rule first. In response to the decreasing pessimism about future real house prices, firms in the housing sector adjust their prices upward. Moreover, the decreasing pessimism about future real house prices increases the collateral value of borrowers, allowing them to expand their debt holdings to raise consumption of nondurable goods and housing investment. The additional demand strengthens the rise in real house prices and reinforces more and more agents to switch to the fundamental rule. After a while, the forecasting performance of the fundamental forecasting rule deteriorates relative to the optimistic rule, so that agents go over to use the better performing rule. The contagion in beliefs and its feedback on the business cycle then creates a sustained boom. At some point in time, however, positive monetary policy shocks and the endogenous reaction of the central bank through the Taylor rule lead to a turn around in the business cycle and the formation of beliefs. High real interest rates around the quarter 750 strongly depresses the consumption of nondurable goods and housing investment. In turn, real house prices fall below its steady state, inducing agents to be less optimistic about the future track of real house prices. As the fraction of house price pessimists increases, real house prices slump and carry down the broader economy, all in a self-reinforcing fashion.

3.5.2 A full-fledged BE model

In this section, we repeat the simulation exercise of the previous section by assuming that agents also use biased beliefs when they forecast their future level of consumption and consumer price inflation. In that sense, agents are now able to internalize the impact of changing real house prices and real house price expectations on the broader economy.

Figure 3.2 shows the dynamics of the full-fledged BE model for the same draw of monetary policy shocks as for the simplified BE model. Apparently, the business cycle dynamics of the full-fledged model are amplified relative to the dynamics of the simple model. In the full-fledged model biased expectations about future nondurable goods consumption and consumer price inflation feed back into the economy through their effects on the current behavior of agents and thus reinforce business cycle fluctuations through their self-fulfilling mechanism. Moreover, the expectation about future real house prices play the dominant role in the transmission mechanism of monetary policy. Because borrowers

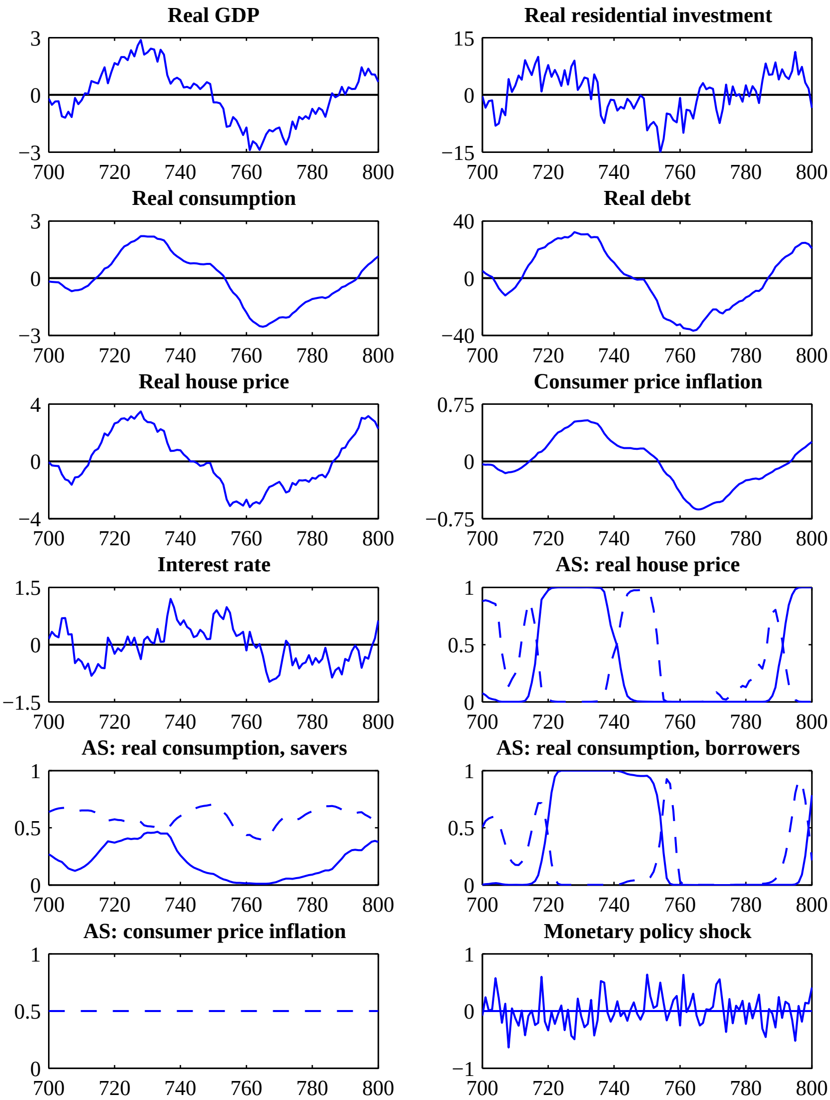

Figure 3.2: Dynamics of the full-fledged BE model

Note: The x-axis is in quarters. The y-axis measures percent deviation from the steady state except in the AS plots. AS stands for "animal spirits" and measures the fraction of corresponding optimists (*solid line*) and fundamentalists/inflation targeters (*dashed line*).

are subject to a collateral constraint, swings in beliefs about future real house prices have a strong impact on their consumption of nondurable goods. Hence, the waves of optimism and pessimism about future nondurable goods consumption among borrowers follow the waves of optimism and pessimism about future real house prices and amplify the effects of house price expectations on the borrowers' nondurable goods consumption. Savers, however, are not credit constrained, and, in turn, house price optimism or pessimism does not dominate the swings in beliefs about their future consumption of nondurable goods. As savers have access to perfect credit markets, movements in the real interest rate are an important factor in the determination of their current nondurable goods consumption and thus their optimism or pessimism about their future nondurable goods consumption. However, swings in beliefs about future real house prices are not completely irrelevant for savers. As rising real house prices induce savers to substitute housing by nondurable goods consumption and vice versa, self-fulfilling swings in beliefs about future real house prices amplify the swings in beliefs about future nondurable consumption. The fraction of agents that uses the central bank's inflation target to forecast consumer price inflation levels off at 50%. Consequently, at each point in time 50% of agents use the last period's consumer price inflation rate to forecast future inflation, which, together with the higher volatility of the output cycle, lead to a more pronounced cycle in consumer price inflation as in the simple BE model in which all agents expect the future consumer price inflation rate to be at the central bank's target level. In contrast to the formation of expectations about future real house prices or nondurable goods consumption, the fluctuations in consumer price inflation do not lead to swings in beliefs. As the central bank sets interest rates in accordance with consumer price inflation, it dampens the scope of "animal spirits" to arise a priori. However, given small fluctuations in consumer price inflation, the central bank's inflation target is not fully credible. This induces agents to be doubtful about future inflation, so that their decision whether to use the central bank's inflation target or to extrapolate past inflation to forecast future consumer price inflation is entirely random.

3.6 BE model vs. RE model

In the previous section, we showed that in the BE model monetary policy shocks might trigger waves of optimism and pessimism that drive house prices and the broader economy. A contagion among the beliefs of agents leads to an environment in which a large fraction of agents systematically biases the future track of real house prices upward or downward, which, in turn, has strong repercussions on the business cycle. Clearly, such features are not present in the standard RE model. When agents have rational expectations and perfect information, they know the underlying structure of the economy and the distribution of shocks. Thus rational agents do not make systematic forecasting errors. In this section, we discuss the implications of heuristics versus rational expectations in the transmission mechanism of monetary policy. We do so by means of impulse response analysis following the approach in De Grauwe (2011).

In particular, to take care of the highly nonlinear features of the model, we do the following. First, we simulate the model economy over 720 quarters, where we fix the monetary policy shock in quarter 700 at a level of -25 basis points. Second, we keep the stochastic draws of monetary policy shocks and repeat the simulation exercise, however, we set the monetary policy shock in period 700 equal to zero. Third, for each variable of interest we compute the difference between the first and the second simulation. Thereby, we succeed to isolate the effect of the monetary policy shock in quarter 700 on the further track of the economy. It is important to note, however, that the transmission of the monetary policy shock occurring in quarter 700 depends on the realizations of monetary policy shocks in the pre-700 as well as the post-700 period. Intuitively, when the central bank decreases the interest rate by 25 basis points, the further track of the economy will strongly depend on the fraction of optimists versus pessimists present at that time. It might be that the shock initiates a wave of optimism and thus has a large impact on the development of the economy. Then it might be that the same shock has only a minor effect on the economy. This might be the case when the fraction of optimists is already large. In line with this, the realizations of monetary policy shocks during the post-700 period also affect the transmission of the shock occurring in quarter 700. Suppose that the policy rate decreases by 25 basis points in the quarter 700 and initiates a wave of optimism. Whether this wave of optimism evolves and holds on for a prolonged period of time strongly depends on the realizations of the monetary policy shock in the post-700 period. Hence, to take this effect into account, we follow De Grauwe (2011) and continue to allow for random disturbances in the post-shock period. In a last step we proceed by repeating steps 1)-3) 1000 times, each time with different realizations of monetary policy shocks. Then we compute for each variable of interest the median impulse response together with the 95%-

and 5%-quantile.

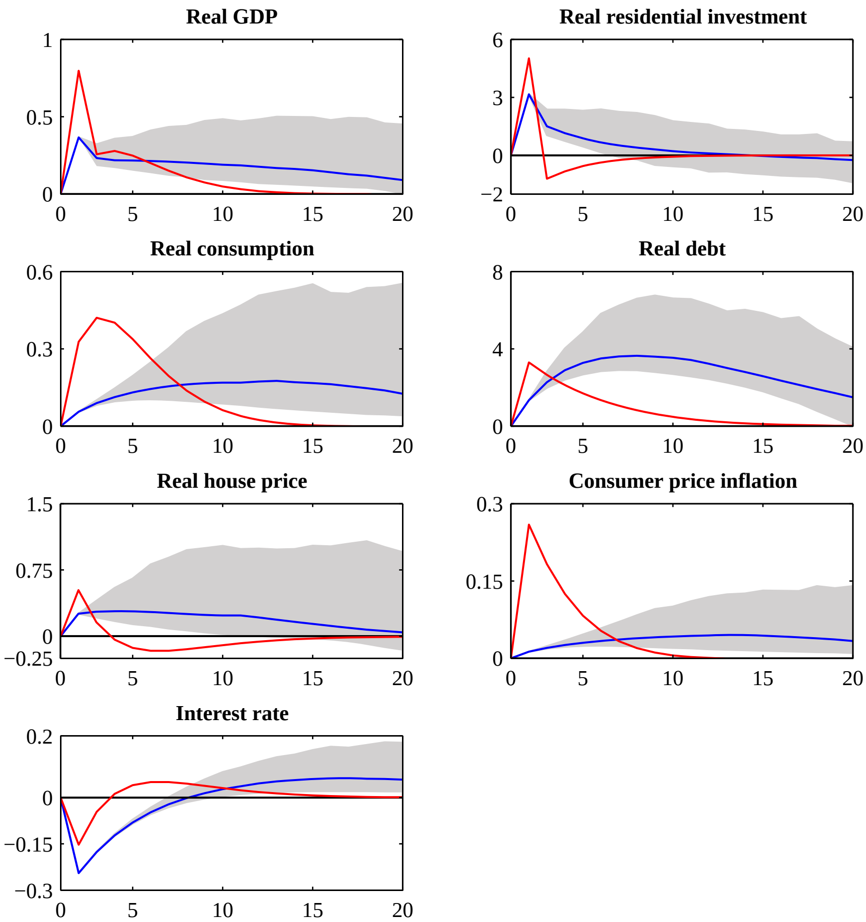

Figure 3.3: Impulse responses of the full-fledged BE and the RE model to a monetary policy shock of 25 basis points

Note: The x-axis is in quarters. The y-axis is measured in percent. The *red lines* are the impulse responses of the RE model. The *blue lines* represent the median impulse responses of the BE model, and the *shaded areas* stand for the 90% confidence intervals.

Figure 3.3 portrays the impulse responses of the full-fledged BE and the RE model to an expansionary policy shock of 25 basis points. Three important results can be found. First, we find that in the BE model the effects of a monetary policy shock on real house prices and the broader economy are highly uncertain.[21] On the one side, the expansionary policy shock might trigger a wave of optimism that leads to a sustained boom in house prices. This might be the case when the shock induces a large fraction of agents to switch to the optimistic rule to forecast future real house prices, which, in turn, leads in a self-reinforcing fashion to booming house prices and a booming economy. On the other

[21]See De Grauwe (2011) for a similar result for the standard NK model.

side, it might be that the same expansionary monetary policy shock has only a minor effect on the further track of the economy. This might be the case when the fraction of optimists about future real house prices is already large at the time of the shock. In sum, the timing of a monetary policy shock matters. Second, the impulse responses of the BE model are much more persistent than the impulse responses of the RE model. This relatively high persistence is due to the fact that agents gradually adapt their beliefs. After a monetary policy shock hits the economy, the economy slowly adjusts, which then induces agents to change their forecasting rules. A contagion among beliefs of agents might lead to a sustained boom. This is in contrast to the RE model in which agents completely internalize the effect of the expansionary monetary policy shock, as they are perfectly informed about the structure of the economy and the distribution of the shock. Thus in the RE model the initial impact of the shock on the economy is relatively high. Third, but interlinked to point two, in the BE model consumer price inflation is relatively stable. As the central bank sets interest rates in accordance with consumer price inflation, it dampens the scope of large swings in beliefs about future inflation to arise a priori. However, this has a crucial implication for the conduct of monetary policy in response to the boom in the economy. As the boom in house prices and the broader economy does not lead to rising consumer price inflation, monetary policy does not counteract the boom by increasing interest rates. Given a Taylor rule in which consumer price inflation is the most important component, monetary policy is accommodative for a prolonged period of time, which then might reinforce more and more agents to form optimistic beliefs about future developments.

3.7 Implications for monetary policy

In this section, we explore to what extend modifications of the Taylor rule can be beneficial in terms of stabilizing economic fluctuations when behavioral mechanism play a role. Given the prominent role of swings in beliefs about future real house prices in shaping the business cycle, we propose as a natural candidate that the central bank should set interest rates in response to real house prices. We suggest the following real house price-augmented Taylor rule

$$\hat{R}_t = \mu_R \hat{R}_{t-1} + (1 - \mu_R)(\mu_\pi \pi_{C,t} + \mu_Y \hat{Y}_t + \mu_q \hat{q}_t) + u_{R,t}. \tag{3.54}$$

To explore the benefits of the augmented Taylor rule relative to a standard Taylor rule, we report how AR(1) coefficients and standard deviations of real GDP and consumer price inflation change when we alter the real house price coefficient, μ_q, while all other parameters are fixed at their baseline value. Additionally, we report the corresponding statistics for changing the output coefficient, μ_Y, or the inflation coefficient, μ_π, relative to their baseline calibration. We test the values $\mu_\pi = \{2; 2.5\}$ for the inflation coefficient and the values $\mu_Y = \{0.25; 0.5\}$ for the output coefficient. As a reference point we repeat this exercise for the RE model.

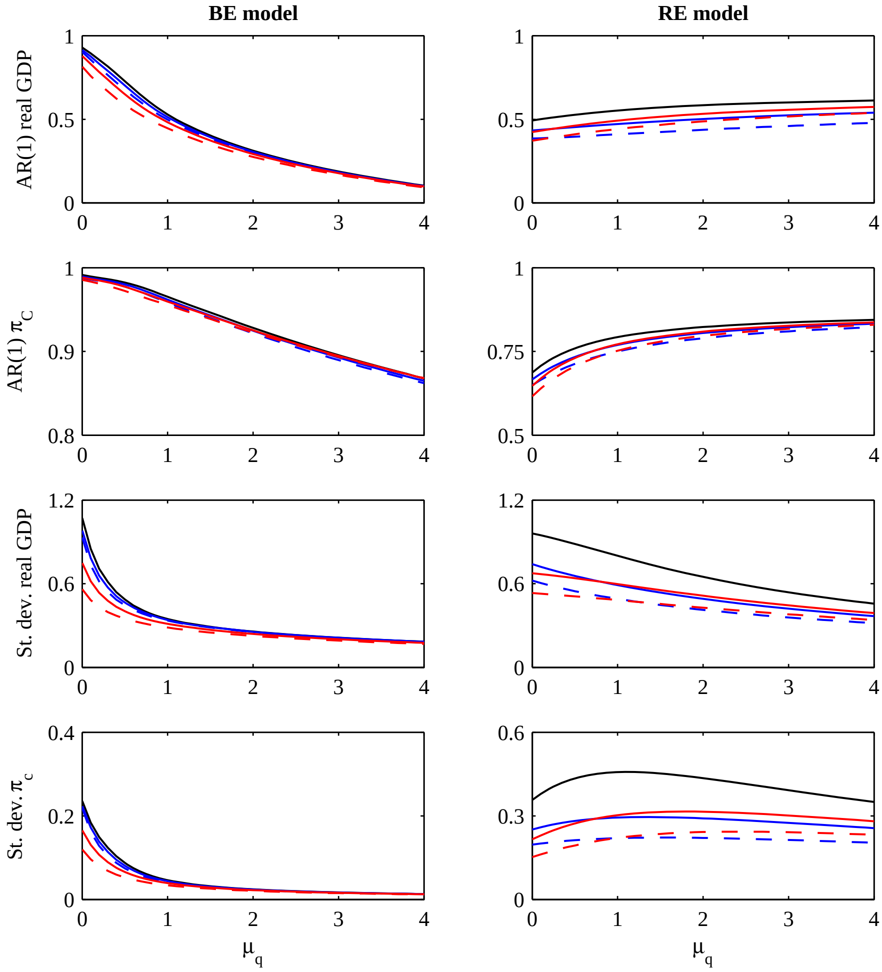

Figure 3.4: Augmented Taylor rule: full-fledged BE vs. RE model

Note: The *black solid lines* refer to the baseline calibration for μ_R, μ_π, and μ_Y. The *blue solid lines* stand for $\mu_\pi = 2$, and the *blue dashed lines* denote $\mu_\pi = 2.5$. For the *red solid lines* it holds that $\mu_Y = 0.25$, and the *red dashed lines* stand for $\mu_Y = 0.5$.

Figure 3.4 summarizes the results.[22] Starting from the baseline scenario, we observe

[22]For the BE model we report median values obtained by simulating the model 1000 times, each time

a sharp decline of the persistence and volatility of real GDP and consumer price inflation when the real house price coefficient rises. This is because the central bank becomes more restrictive in the early stage of the housing boom and detracts the sources that lead to a sustained boom. A more restrictive monetary policy subdues demand for nondurable goods and housing investment, which, in turn, lowers the rise in the real house price. As house prices are less volatile, swings in beliefs about future real house prices are less likely to occur and agents stick to the fundamental forecasting rule when they form their expectations on future real house prices. In sum, by reacting to house prices, the central bank is able to prevent that sustained waves of optimism and pessimism drive house prices and thus real GDP and consumer price inflation.

To give the analysis a more meaningful role in terms of monetary policy evaluation, we summarize the evidence by comparing the monetary policy rules against a prespecified objective function based on the assumption that the ultimate goal of monetary policy is to reduce real GDP and consumer price variability. The objective function can be written as

$$Loss = \lambda\sigma^2(\hat{Y}_t) + (1-\lambda)\sigma^2(\pi_{C,t}), \tag{3.55}$$

where the parameter λ governs the policymakers' relative preferences. We choose to set $\lambda = 0.5$, which implies that policymakers attach an equal weight to minimizing output and consumer price volatility.

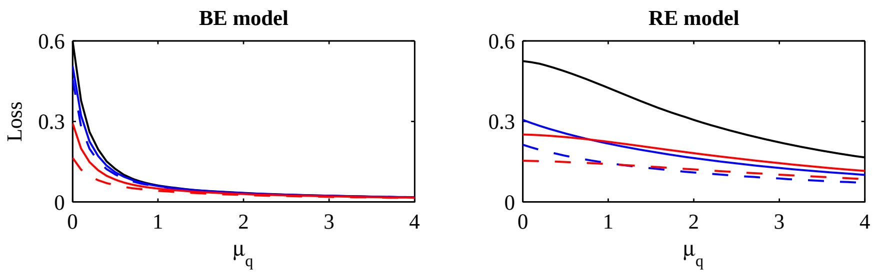

Figure 3.5: Augmented Taylor rule: full-fledged BE vs. RE model

Note: The *black solid lines* refer to the baseline calibration for μ_R, μ_π, and μ_Y. The *blue solid lines* stand for $\mu_\pi = 2$, and the *blue dashed lines* denote $\mu_\pi = 2.5$. For the *red solid lines* it holds that $\mu_Y = 0.25$, and the *red dashed lines* stand for $\mu_Y = 0.5$.

Figure 3.5 underlines the highly nonlinear features of the BE model. As soon as the real house price coefficient reaches a critical threshold value, the central bank's loss

over 800 periods. For the RE model we report theoretical moments.

decreases sharply. Moreover, the figure illustrates that the stabilizing effect of a real house price-augmented Taylor rule is independent from whether policymakers attach a higher weight to consumer price inflation. Even if the Taylor rule coefficient on consumer price inflation is $\mu_\pi = 2.5$, the monetary authority can only achieve stability if it sets interest rates in response to house prices. In comparison, the stabilizing effect of a real house price-augmented Taylor rule is less pronounced when the reaction coefficient on the output gap is high. This is due to the fact that a strong reaction to output variability pushes the beliefs of agents on future consumption levels toward the steady state. However, given the impact of swings in beliefs on future real house prices on the broader economy, policymakers succeed only well in terms of minimizing their loss function by setting interest rates in response to real house price movements.[23] Most importantly, the difference in policy implications to be drawn from the RE counterpart model is striking. The standard DSGE framework predicts that a stronger response to real house prices might not be a promising strategy. Especially in the cases in which policymakers strongly react to real GDP and consumer prices, the beneficial impact of augmenting the Taylor rule by a real house price component is underestimated compared to the outcome in the BE model. As in the RE model booms and bust periods merely represent macroeconomic fundamentals, because waves of optimism and pessimism driving real house prices and the overall economy do not occur, there is no obvious need for a real house price-augmented Taylor rule.

Another dimension along which we can motivate the modification of the Taylor rule in our model can be illustrated by means of impulse response analysis. In figure 3.6 we compute the impulse responses of the full-fledged BE and the RE model for the real house price-augmented Taylor rule. We choose to set $\mu_q = 2$. The results are clear cut. For the case of a standard Taylor rule the effects of an expansionary monetary policy shock are dominated by nonlinearities that make the timing of the monetary policy shock important. However, the effects of a monetary policy shock are highly predictive when the central bank sets interest rates in accordance with real house prices. With a higher sensitivity of interest rates to real house prices, the scope of endogenous and self-fulfilling waves of optimism and pessimism to arise is limited. Figure 3.6 also illustrates the success of a real house price-augmented Taylor rule in terms of stabilizing the economy. Applying a standard Taylor rule, we find that monetary policy is accommodative at the early stage of the boom as consumer price inflation is relatively stable. However, when the central

[23] Note that even in the case in which policymakers set a high weight on output, the loss halves if $\mu_q = 1$.

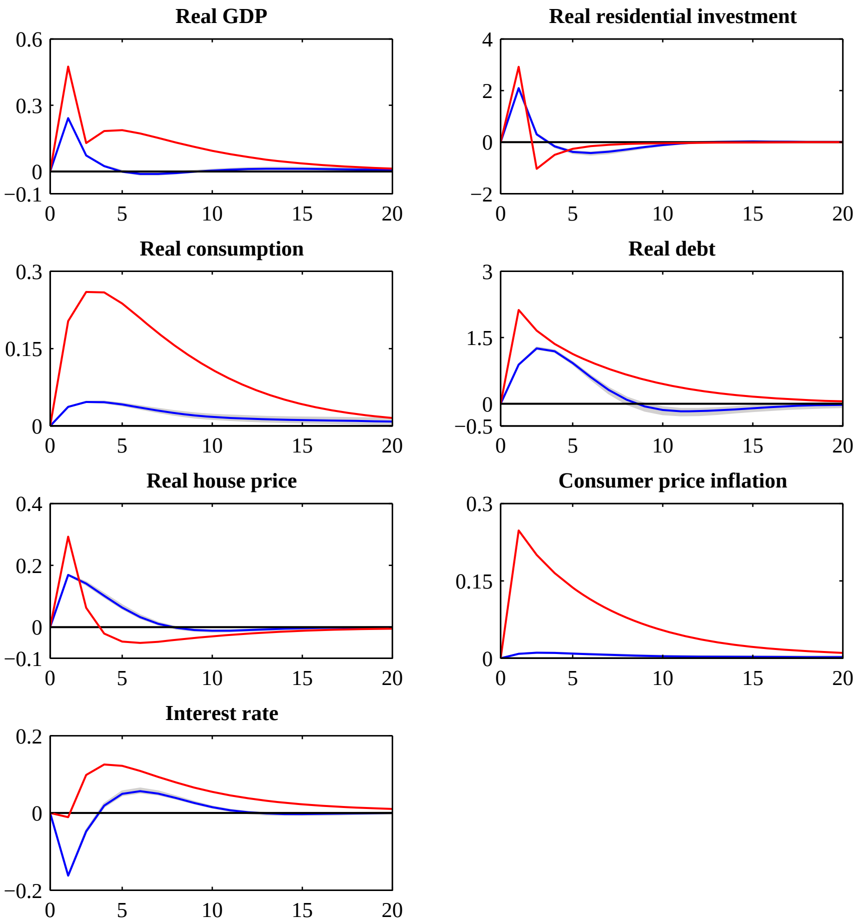

Figure 3.6: Impulse responses of the full-fledged BE and the RE model with a real house price-augmented Taylor rule to a monetary policy shock of 25 basis points

Note: The x-axis is in quarters. The y-axis is measured in percent. The *red lines* are the impulse responses of the RE model. The *blue lines* represent the median impulse responses of the BE model and the *shaded areas* stand for the 90% confidence intervals.

bank sets interest rates in accordance with real house prices, interest rates quickly revert back to the steady state, lowering the persistence and the volatility of the business cycle.

3.8 Conclusion

In this chapter, we incorporate heuristics into an otherwise standard NK DSGE model that captures important features of housing in order to provide qualitative insights into how monetary policy actions affect the housing market and in turn the overall economy when behavioral mechanisms play a role. In particular, we drop the assumption of rational expectations in an otherwise standard model and alternatively assume that agents use heuristics to form expectations.

Key to our approach is that agents form heterogeneous and systematically biased expectations. In particular, we assume that agents choose between an optimistic and a pessimistic rule (heuristic) to forecast future real house prices and base their choice on the relative forecast performance of the rules. In a full-fledged BE model in which all behavioral expectations operators are at play we discuss the propagation mechanisms of monetary policy. We find that monetary policy triggers endogenous and self-fulfilling waves of optimism and pessimism ("animal spirits") that drive real house prices and in turn the broader economy. By means of impulse response analysis we compare our BE model to the standard RE model. Three important findings prevail. First, in the BE model the impact of a monetary policy shock on real house prices is surrounded by uncertainty. Second, the dynamics in the BE model exhibit a much higher persistence as in the RE model. Third, we find that in the BE model consumer price inflation is relatively stable at the early stage of the boom. Thus, standard monetary policy does not counteract the boom in house prices and the broader economy by raising interest rates.

Finally, we suggest that in our BE model there is a meaningful role for a real house price-augmented Taylor rule, as it helps to rule out that monetary policy itself becomes a major source of economic disturbance. As behavioral mechanisms are not present in the standard RE model, we find that the merits of augmenting the Taylor rule with a real house price component are underestimated within this framework.

Appendix to Chapter 3

A Steady state

Prices are given as constant markups over nominal marginal costs and read $\bar{P}_j = \left(\frac{\epsilon_j}{\epsilon_j - 1}\right) \bar{W}_j$, $j = C, H$. Following Aspachs-Bracons and Rabanal (2010), we assume that markups are equal across sectors ($\epsilon_C = \epsilon_H = \epsilon$), which implies that the steady state real house price is $\bar{q} = 1$. As for the steady state interest rate, it holds true that $\bar{R} = \frac{1}{\beta}$.

The savers' total supply of labor is

$$\left(\frac{\epsilon - 1}{\epsilon}\right)\left(\frac{1-\alpha}{1-h}\right)\left(1 + \delta\bar{\Omega}^{-1}\right) - \bar{\Sigma}\bar{L}^{\eta} - \bar{L}^{(1+\eta)} = 0, \tag{56}$$

where $\bar{\Sigma} = \left(\frac{\omega}{1-\omega}\right)\left(\frac{1}{\epsilon}\bar{\bar{L}} + \left(\bar{R} - 1\right)\bar{\bar{b}}\right)$ and $\bar{\Omega} := \frac{\bar{C}}{\bar{H}} = \left(\frac{1-\alpha}{\alpha(1-h)}\right)(1 - \beta(1-\delta))$. The total supply of labor is distributed across sectors according to $\bar{L}_C = (1-\Delta_H)\bar{L}$ and $\bar{L}_H = \Delta_H \bar{L}$. The savers' steady state consumption of nondurable goods is given by

$$\bar{C} = \left(\frac{\epsilon - 1}{\epsilon}\right)\left(\frac{1-\alpha}{1-h}\right)\bar{L}^{-\eta}. \tag{57}$$

The savers' steady state housing stock is $\bar{H} = \bar{C}\bar{\Omega}^{-1}$, and residential investment is defined by $\bar{HI} = \delta\bar{H}$.

The borrowers' total supply of labor is

$$\bar{\bar{L}} = \left[\left(\frac{1-\alpha}{1-h}\right)\left(1 + \frac{\delta + \left(\bar{R} - 1\right)(1-\chi)(1-\delta)}{\bar{\bar{\Omega}}}\right)\right]^{\frac{1}{1+\eta}}, \tag{58}$$

where $\bar{\bar{\Omega}} := \frac{\bar{\bar{C}}}{\bar{\bar{H}}} = \left(\frac{1-\alpha}{\alpha(1-h)}\right)\left(1 - (1-\delta)[\tilde{\beta} + (1-\chi)(\beta - \tilde{\beta})]\right)$. Total labor supply is distributed across sectors according to $\bar{\bar{L}}_C = (1 - \Delta_H)\bar{\bar{L}}$ and $\bar{\bar{L}}_H = \Delta_H \bar{\bar{L}}$. The borrowers' consumption of nondurable goods is given by

$$\bar{\bar{C}} = \left(\frac{\epsilon - 1}{\epsilon}\right)\left(\frac{1-\alpha}{1-h}\right)\bar{\bar{L}}^{-\eta}. \tag{59}$$

The borrowers' housing stock is $\bar{\bar{H}} = \bar{\bar{C}}\bar{\bar{\Omega}}^{-1}$, and residential investment is defined by $\bar{\bar{HI}} = \delta\bar{\bar{H}}$. The borrowers' debt holdings are $\bar{\bar{b}} = \beta(1-\chi)(1-\delta)\bar{\bar{H}}$.

Technologies are $\bar{Y}_j = \bar{L}_j^{tot}$, $j = C, H$, where total labor supply in each sector is given by $\bar{L}_j^{tot} = \omega\bar{\bar{L}}_j + (1-\omega)\bar{L}_j$. The steady state debt market equilibrium is given by $\bar{b} = \left(\frac{\omega}{1-\omega}\right)\bar{\bar{b}}$. Total consumption of nondurable goods is $\bar{Y}_C = \omega\bar{\bar{C}} + (1-\omega)\bar{C}$, and total residential investment is $\bar{Y}_H = \omega\bar{\bar{HI}} + (1-\omega)\bar{HI}$. Real GDP equals $\bar{Y} = \bar{Y}_C + \bar{Y}_H$.

B The formation of expectations on future consumption of nondurable goods

The optimistic, respectively, pessimistic rule that savers ($X = C$) and borrowers ($X = \tilde{C}$) use to forecast future nondurable goods consumption is given by

$$E_t^{opt}\hat{X}_{t+1} = \frac{d_t^X}{2} \quad \text{and} \quad E_t^{pes}\hat{X}_{t+1} = -\frac{d_t^X}{2}, \tag{60}$$

where the absolute divergence in beliefs, d_t^X, is $d_t^X = \beta_d + \delta_d\sigma(\hat{X}_t)$. The MSFEs of the two rules are given by

$$U_{opt,t}^X = \sum_{k=1}^{\infty} \omega_k \left[\hat{X}_{t-k} - E_{t-k-1}^{opt}\hat{X}_{t-k}\right]^2 \tag{61}$$

$$\text{and} \quad U_{pes,t}^X = \sum_{k=1}^{\infty} \omega_k \left[\hat{X}_{t-k} - E_{t-k-1}^{pes}\hat{X}_{t-k}\right]^2. \tag{62}$$

The fundamental forecasting rule reads

$$E_t^{fun}\hat{X}_{t+1} = 0, \tag{63}$$

and the MSFE of the fundamental rule is defined by

$$U_{fun,t}^X = \sum_{k=1}^{\infty} \omega_k \left[\hat{X}_{t-k} - E_{t-k-1}^{fun}\hat{X}_{t-k}\right]^2. \tag{64}$$

The corresponding fractions of optimists, pessimists, and fundamentalists then evolve as

$$\alpha_{opt,t}^X = \frac{exp(-\gamma U_{opt,t}^X)}{exp(-\gamma U_{opt,t}^X) + exp(-\gamma U_{pes,t}^X) + exp(-\gamma U_{fun,t}^X)}, \tag{65}$$

$$\alpha_{pes,t}^X = \frac{exp(-\gamma U_{pes,t}^X)}{exp(-\gamma U_{opt,t}^X) + exp(-\gamma U_{pes,t}^X) + exp(-\gamma U_{fun,t}^X)} \tag{66}$$

$$\text{and} \quad \alpha_{fun,t}^X = \frac{exp(-\gamma U_{fun,t}^X)}{exp(-\gamma U_{opt,t}^X) + exp(-\gamma U_{pes,t}^X) + exp(-\gamma U_{fun,t}^X)} = 1 - \alpha_{opt,t}^X - \alpha_{pes,t}^X. \tag{67}$$

C Sensitivity analysis

In this section, we present our calibration strategy for the parameters governing the formation of expectations and present some sensitivity analysis following De Grauwe (2011).

For the calibration of the behavioral parameters we proceed as follows. As in the simplified BE model, we set $E_t\hat{C}_{t+1} = 0$, $E_t\hat{\tilde{C}}_{t+1} = 0$, and $E_t\pi_{C,t+1} = 0$ and proceed to compute the correlation coefficient between $\alpha^q_{opt,t}$ and $\hat{q}_t$ as a function of the parameters that govern the formation of beliefs about future real house prices. We choose to pick parameter values such that the correlation coefficient is maximized. We then adopt these parameter values for the formation of expectations on future consumption of nondurable goods and consumer price inflation.

In figure 3.7 we present some sensitivity analysis by reporting how the correlation coefficient between house price optimists and actual real house prices and the standard deviation of real house prices depend on the set of behavioral parameters, namely, the intensity of choice, γ, the parameters describing the divergence in beliefs, δ_d and β_d, and the memory parameter, ρ. In particular, we report the median correlation coefficient and standard deviation (obtained by simulating the model 1000 times, each time over 800 periods) as a function of these parameters relative to the baseline calibration.

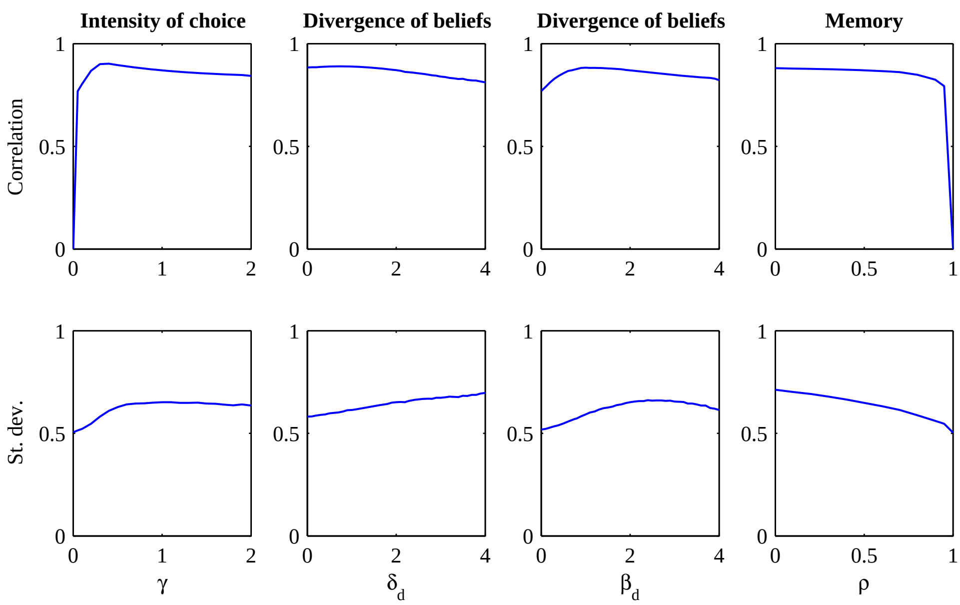

Figure 3.7: Real house prices and animal spirits

A key parameter for the formation of expectations on future real house prices is the intensity of choice. The left upper panel illustrates that even for small values of γ (a minimum degree of rationality) there exists a high correlation between the fraction of real house price optimists and actual real house prices. The correlation coefficient equals zero in the limiting case of $\gamma = 0$. As is apparent from the left lower panel, if $\gamma = 0$, the standard deviation of house prices is lowest. This is because in such an economy there is no systematic feedback mechanism between the swings in beliefs on future real house prices and actual real house prices. The second and third upper panel shows that the correlation between the fraction of real house price optimists and actual real house prices is relatively stable for the parameter values considered for δ_d and β_d. Remarkably, the emergence of "animal spirits" driving real house prices does not critically hinge on the assumption that the divergence of beliefs is a function of the volatility of real house prices. The correlation coefficient between the fraction of real house price optimists and actual real house prices only slightly decreases if $\delta_d > 2$. This finding is due to the fact that a high value of δ_d increases the penalty when agents make wrong forecasts. As a consequence, agents change beliefs more quickly and waves of optimism and pessimism that drive real house prices are less likely to occur. In contrast, the standard deviation of real house prices increases when δ_d is increased. This clear positive relation is due to the positive feedback mechanisms between the divergence of beliefs on future house prices and actual house price volatility. The positive feedback mechanism is less clear cut for β_d. The standard deviation of house prices reaches its maximum if $\beta_d = 2$. The right upper panel illustrates that for a minimum degree of forgetfulness a high correlation between $\alpha^q_{opt,t}$ and $\hat{q}_t$ occurs. Note that if ρ decreases, the memory of agents decreases, which implies that agents will give more weight to recent observations. Only for a very long memory (when ρ approaches 1) the link between the way agents form expectations on future real house prices and the actual real house price becomes less important. Also, the standard deviation of real house prices decreases if the memory of agents increases. A long memory of agents implies that destabilizing swings in beliefs of agents will less likely occur.

Chapter 4

Euler Equations and Money Market Interest Rates: The Role of Monetary Policy and Risk Premium Shocks[1]

4.1 Introduction

The limited performance of consumption Euler equations is well known and documented in the literature on the equity premium puzzle as well as in the literature on the risk free rate puzzle. Recently, Canzoneri et al. (2007) present another failure of consumption Euler equations. Using a new approach, they challenge the view that the money market interest rate targeted by the central bank is equal to the rate implied by a Euler equation, as is commonly assumed in standard New Keynesian (NK) models. Canzoneri et al. (2007) use US data and derive conditional moments of consumption and inflation from an estimated vector autoregression (VAR). These moments and actual observations of consumption and inflation are then used to compute interest rates implied by consumption Euler equations obtained from alternative specifications of preferences. By comparing Euler equation rates with observed money market rates, two important results stand out. First, the behavior of implied rates differs significantly from the Federal Funds rate. In particular, real interest rates implied by Euler equations are strongly negatively correlated with the observed

[1] This chapter is based on joint work with Eric Mayer that appeared as Gareis and Mayer (2012a).

money market rate. Second, Canzoneri et al. (2007) report that the spread between the two rates is systematically linked to monetary policy. Standard regression analysis and impulse response functions show that the Federal Funds rate and the Euler equation rate move in opposite directions following a monetary policy tightening.

The purpose of this chapter is to explore the link between the correlation between implied and actual interest rates and the stance of monetary policy. As explained by Canzoneri et al. (2007), the fact that the two rates do not coincide is intuitive if the representative household has standard, additively separable CRRA preferences. Empirical studies show that consumption responds in a hump-shaped fashion to a monetary contraction (see Christiano et al., 2005). That is, in the quarters following a monetary contraction interest rates and consumption growth are negatively correlated. Standard preferences, however, imply that consumption growth and interest rates are positively correlated. Consequently, using a standard Euler equation to compute implied interest rates results in a negative correlation between actual and implied interest rates.

With this intuition in mind, changing the preference specification of the representative household seems to be a natural way of reconciling the dynamics of money market interest rates with the interest rates implied by Euler equations. In particular, adding habit persistence to household preferences seems to be a promising candidate.[2] It has been proposed to strengthen the asset-pricing implication of consumption-based models (see, for instance, Abel, 1990; Campbell and Cochrane, 1999), and it has proven to be highly relevant from a business cycle perspective. Most prominently, Fuhrer (2000), Christiano et al. (2005), and Smets and Wouters (2007) rely on habit persistence to explain the observed dynamics of output and consumption in response to a monetary policy shock. From this perspective, the finding in Canzoneri et al. (2007) that the implied Euler equation rate and the Federal Funds rate do not coincide across a large number of preference specifications that explicitly allow for habit formation fundamentally challenges conventional models.[3]

To investigate the sources of the negative correlation between implied and actual interest rates, we make use of a Monte Carlo experiment. We assume that the model economy is defined by a full-fledged NK dynamic stochastic general equilibrium (DSGE) model. We

[2]See Schmitt-Grohé and Uribe (2008) and Dennis (2009) for a review on the concept of habit formation in macroeconomic models.

[3]See Canzoneri et al. (2007) for further discussion. By applying data from G7 countries, Ahmad (2005) studies whether the finding in Canzoneri et al. (2007) is an artifact of US data. His study yields correlation coefficients between implied Euler rates and money market rates that are generally low and for some countries also negative.

use this model as a data-generating process and compute replications of simulated data. We then use the simulated data to construct implied Euler equation rates following the methodology set forth by Canzoneri et al. (2007). Based on this setup, counterfactual simulations allow us to explore the sources of the spread between implied and actual interest rates in a direct way.

We choose to use the estimated model in Smets and Wouters (2007) (henceforth, SW) as our data-generating process. We do so because of several reasons. First, the SW model has become a modern workhorse NK model for forecasting and policy analysis. It features complex dynamics with a rich set of structural shocks and aims to describe a fairly complete quantitative description of the US economy. Second, the consumption Euler equation in the SW model deviates from a standard Euler equation along two dimensions. On the one hand, it features habit formation. On the other hand, it allows for nonseparability between consumption and labor effort. This is relevant because Collard and Dellas (2012) find that this feature limits the failure of consumption Euler equations as identified by Canzoneri et al. (2007). The explanation for their result is straightforward. From empirical studies it is known that employment growth declines in response to a monetary tightening. The consumption Euler equation implies that expected employment growth and real interest rates are negatively correlated.[4] Hence, the implied Euler equation rate rises in response to a monetary tightening, which is consistent with the dynamics of the observed money market rate. Third, we choose to use the SW model for our Monte Carlo experiment, because the model features a wedge between the money market interest rate and the interest rate implied by the consumption Euler equation. A shock to this wedge (risk premium shock) distorts the equality between the two rates and causes a change in the consumption pattern of households. Hence, given that in the data-generating process implied by the SW model the spread between Euler equation and actual interest rates is simply a statistical noise, we are able to disentangle the impact of monetary policy on the correlation between the two rates from the effect that arises from the assumption of risk premium disturbances.

In the next section, we use US data to compute interest rates implied by consumption Euler equations for two sets of preferences and compare these rates to the Federal Funds rate. In section 4.3, we use a Monte Carlo experiment to explore the relationship between implied and actual interest rates. Section 4.4 concludes.

[4]Note that this is true if the coefficient of relative risk aversion is larger than one.

4.2 Comparing Euler equation and money market interest rates

Here, we follow the approach in Canzoneri et al. (2007) and compute nominal and real interest rates implied by consumption Euler equations. We consider two sets of preferences. We compute implied interest rates for the specification of preferences as in Smets and Wouters (2007) and for standard, additively separable CRRA preferences.[5] As in Smets and Wouters (2007), the consumer's objective function is assumed to be

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{1}{1-\sigma_c} (C_t - H_t)^{1-\sigma_c} \right) \exp\left(\frac{\sigma_c - 1}{1+\sigma_l} L_t^{1+\sigma_l} \right), \tag{4.1}$$

where E_0 denotes the expectation operator at period $t = 0$, C_t denotes consumption relative to a habit stock, H_t, and L_t is hours worked. The parameter σ_c is the coefficient of relative risk aversion, and σ_l is the inverse elasticity of labor supply. The habit stock is external and is defined by $H_t = \lambda C_{t-1}$, where λ governs the degree of habit formation. Smets and Wouters' specification of consumer preferences nests the standard CRRA utility function with separability between consumption and hours worked and no habit formation. If σ_c approaches 1 and $h = 0$, the period utility function implied by (4.1) approaches to a standard log utility function, so that lifetime utility reads

$$E_0 \sum_{t=0}^{\infty} \beta^t \log(C_t). \tag{4.2}$$

The corresponding Euler equations to conditions (4.1) and (4.2) are

$$\frac{\exp\left(\frac{\sigma_c-1}{1+\sigma_l} L_t^{1+\sigma_l}\right)}{(C_t - \lambda C_{t-1})^{\sigma_c}} = \beta E_t \left(\frac{\exp\left(\frac{\sigma_c-1}{1+\sigma_l} L_{t+1}^{1+\sigma_l}\right)}{(C_{t+1} - \lambda C_t)^{\sigma_c}} \frac{R_t \epsilon_t^b}{\Pi_{t+1}} \right) \tag{4.3}$$

$$\text{and} \quad \frac{1}{C_t} = \beta E_t \left(\frac{1}{C_{t+1}} \frac{R_t \epsilon_t^b}{\Pi_{t+1}} \right), \tag{4.4}$$

where R_t is the gross nominal interest rate controlled by the central bank, Π_t is the gross inflation rate, and ϵ_t^b is a risk premium shock that represents a wedge between R_t and the return on bonds held by households. The shock is assumed to follow an AR(1) process in

[5] In each model it is assumed that the representative household is infinitely lived and chooses consumption, labor effort, and one-period nominal bonds to maximize lifetime utility subject to a budget constraint.

logs. Following the analysis in Canzoneri et al. (2007), we abstract from the shock term when we compute implied Euler equation interest rates.

Log-linearizing (4.3) around the steady state balanced growth path of the model yields the following dynamics of nominal, respectively, real interest rates[6]

$$r_t = (1/c_3)\left(c_1 c_{t-1} - c_t + (1-c_1)E_t c_{t+1} + c_2(l_t - E_t l_{t+1})\right) + E_t \pi_{t+1} \quad (4.5)$$

$$\text{and} \quad rr_t = (1/c_3)\left(c_1 c_{t-1} - c_t + (1-c_1)E_t c_{t+1} + c_2(l_t - E_t l_{t+1})\right), \quad (4.6)$$

where $c_1 = \frac{\lambda/\gamma}{1+\lambda/\gamma}$, $c_2 = \frac{(\sigma_c - 1)(W_*^h L_*/C_*)}{\sigma_c(1+\lambda/\gamma)}$, $c_3 = \frac{1-\lambda/\gamma}{\sigma_c(1+\lambda/\gamma)}$, and γ is the steady state growth rate. The log-linear dynamics of nominal and real interest rates implied by (4.4) are given by

$$r_t = E_t c_{t+1} - c_t + E_t \pi_{t+1} \quad (4.7)$$

$$\text{and} \quad rr_t = E_t c_{t+1} - c_t. \quad (4.8)$$

To compute implied interest rates from equations (4.5)-(4.8), we need to calibrate the model parameters as well as to derive the conditional, one-quarter ahead forecasts of consumption, inflation, and labor effort. As for the former, we use the posterior mean estimates reported in Smets and Wouters (2007). For the conditional first-order moments we follow Canzoneri et al. (2007) and assume that the dynamics of consumption, inflation, and employment can be captured in a VAR defined as

$$Z_t = A_0 + A_1 Z_{t-1} + ... + A_p Z_{t-p} + u_t, \quad (4.9)$$

where u_t is a vector of IID-normal error terms. The variables in the VAR are the log of per capita real consumption expenditures on nondurable goods and services, the inflation rate, a measure of hours worked, the log CRB price index, the log of per capita real disposable income, the log of per capita real nonconsumption GDP and the Federal Funds rate.[7]

[6] A lower case letter stands for the log-linear deviation of the corresponding upper case letter from the balanced growth path, and starred variables refer to steady state values (see Smets and Wouters, 2007). Note that Canzoneri et al. (2007) compute implied interest rates under the assumption of conditional lognormality. As they have already pointed out, the assumption of lognormality results in Euler equations that differ from those derived by log-linearization only by a constant.

[7] The inflation rate is measured as the log change in the deflator for expenditures on nondurable goods and services. The data on hours worked is constructed as in Smets and Wouters (2007). The VAR is estimated over the sample from 1966:Q1 to 2008:Q2. We use two lags. As is common in the literature, we do not detrend real aggregates (see, for instance, Canzoneri et al., 2007; Collard and Dellas, 2012).

In figure 4.1 we present the results by comparing the time series of the Federal Funds rate and the rates implied by the two sets of consumption Euler equations. Table 4.1 summarizes the properties of actual and implied interest rates by reporting second-order moments.

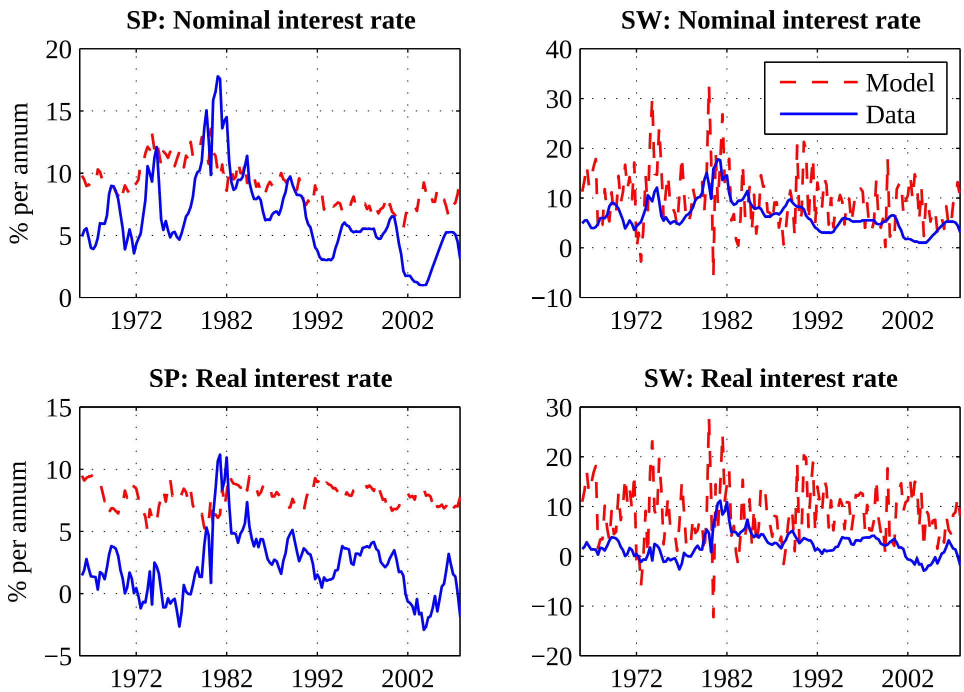

Figure 4.1: Euler equation versus Federal Funds rate

As the figure illustrates, implied Euler equation rates behave significantly different compared to actual interest rates. Remarkably, the real interest rate implied by standard preferences (SP) is found to be negatively correlated with the observed money market rate.[8] As in Collard and Dellas (2012), we do not find a negative correlation when preferences feature habits and nonseparability between consumption and labor effort.

While habit formation and nonseparability lead to a positive correlation between implied and actual real interest rates, we find that the implied Euler equation rates are extremely volatile. On the one hand, this is in line with Canzoneri et al. (2007) who find that excess volatility arises across a number of preference specifications that include habit formation. Clearly, model dynamics derived under habit formation imply a smooth consumption path. Thus if habit persistence is added to household preferences, a higher

[8]We measure actual real interest rates by subtracting VAR inflation forecasts from the Federal Funds rate.

Table 4.1: Statistics for interest rates (% p.a.)

	FFr	Euler equation	
		SP	SW
Nominal interest rates			
St. dev	3.28	1.69	5.86
Corr(FFr, model)	-	0.53	0.19
Real interest rates			
St. dev.	2.53	0.97	5.86
Corr(FFr, model)	-	-0.07	0.10

volatility of implied interest rates is needed to explain the observed volatility of US consumption. On the other hand, the finding of excess volatility of implied interest rates is in contrast to Collard and Dellas (2012). They find that nonseparability between consumption and labor can in principal solve for this issue. Note that our finding of excess volatility does not challenge their result, because we can report that choosing $h = 0.5$ leads to a perfect match between the volatilities of implied and actual real interest rates, while the corresponding correlation remains at about 0.10.

4.3 Monte Carlo experiment

In this section, we challenge the findings in the previous section by making use of a Monte Carlo experiment. We take the estimated model in Smets and Wouters (2007), assuming that it is the true data-generating process, and we compute replications of simulated data. For each replication we then compute implied interest rates as outlined in section 4.2. Finally, counterfactual model simulations allow us to explore the relationship between implied and actual interest rates.

4.3.1 Baseline results

In figure 4.2 we plot the distribution of the correlation between implied and actual (model generated) interest rates based on 1000 replications of simulated time series of consumption, inflation, hours worked, and interest rates of the same length as the data that is used in section 4.2.[9]

[9] We simulate data from the model evaluated at its posterior mean. Hence, we rule out parameter uncertainty when we construct implied interest rates.

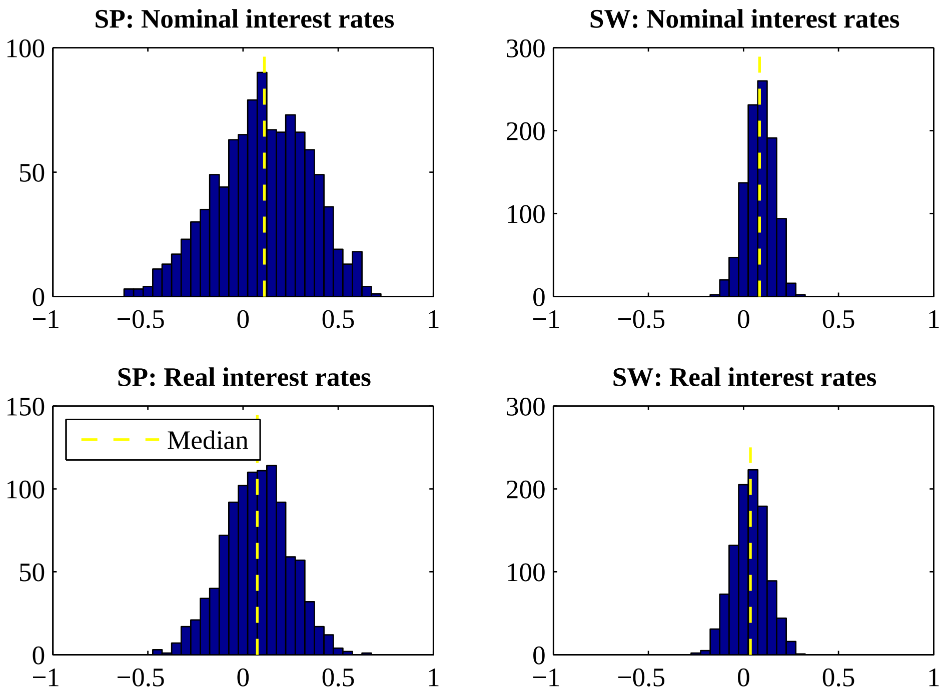

Figure 4.2: Distribution of correlation between actual and implied interest rates

It is apparent from the figure that the standard Euler equation and the SW Euler equation fail to mimic the dynamics of actual interest rates. For both Euler equations the correlation between implied and actual interest rates is centered around zero. While for standard preferences the correlation is highly volatile, the correlation is tight for the specification of preferences as in the SW model. The latter finding is due to the excess volatility of interest rates implied by consumption habits that mechanically ties the correlation to zero. Noteworthy, for both Euler equations the correlation between the Federal Funds rate and the Euler equation interest rate as computed in section 4.2 lies well within the corresponding distribution of the correlation between actual and implied interest rates based on the Monte Carlo experiment.

4.3.2 The role of monetary policy and risk premium shocks

In our experiment we can identify three sources that obviously account for the spread between actual and implied interest rates. A first source is model misspecification. Clearly, this is the case for standard preferences. A second source stems from the fact that in order to compute implied interest rates, information on households' forecasts has to be drawn. In our experiment we can easily address this issue by using the relevant information from the simulated model. By doing so, we find that the baseline results remain virtually unchanged, so that we can conclude that this source of divergence is of little relevance. A third source arises due to the omission of risk premium shocks as implied by equations (4.5)-(4.8). Hence, if actual consumption dynamics are influenced by risk premium disturbances, implied Euler rates and actual interest rates diverge.

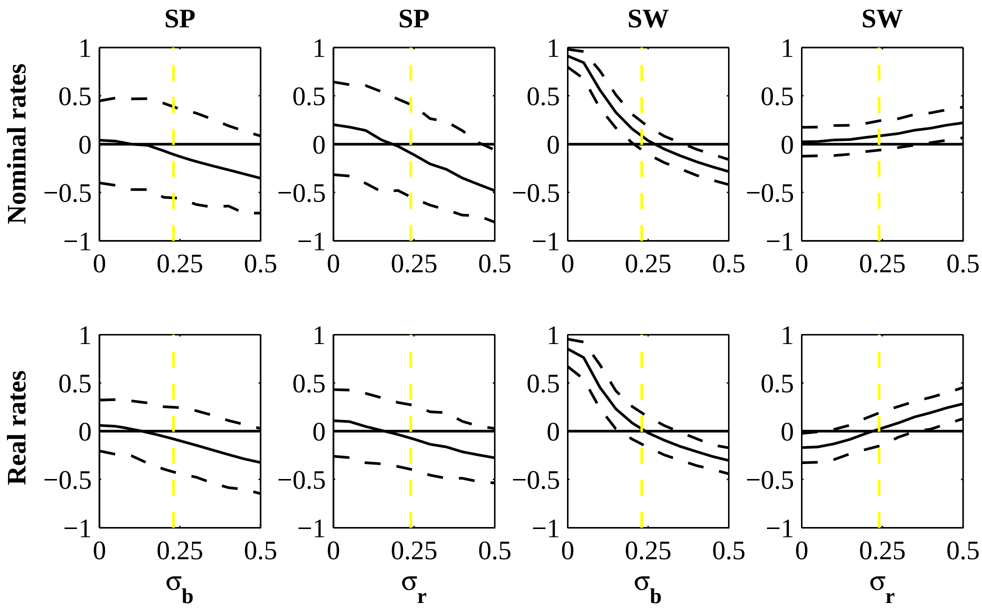

Figure 4.3: Distribution of correlation between actual and implied interest rates

Note: Median and 95% interval. The *dashed vertical line* represents the posterior mean for σ_b, respectively, σ_r as estimated in Smets and Wouters (2007).

To explore whether the spread is systematically linked to monetary policy (see Canzoneri et al., 2007) and to investigate the role of risk premium disturbances, we make use of counterfactual model simulations. Figure 4.3 shows the distribution of the correlation between actual and implied interest rates based on replications of artificial data as a function of the variance of risk premium (σ_b) and monetary policy shocks (σ_r). With this setup at hand, we are able to disentangle the impact of monetary policy shocks on the correlation between the two rates from the effect that arises from the assumption of risk premium disturbances. The results are clear cut. In the case of standard preferences, a higher variance of both monetary and risk premium shocks results in a negative correlation. This is not the case when implied interest rates are computed using the SW Euler equation. While a higher variance of monetary policy shocks induces a positive correlation, a higher variance of risk premium shocks leads to a negative correlation. In that sense, an increasing importance of monetary policy disturbances stabilizes the correlation between implied and actual interest rates. In sum, the analysis reveals that only risk premium shocks have the capability to drive a wedge between actual and implied interest rates, so that the observed correlation between the two rates is negative.

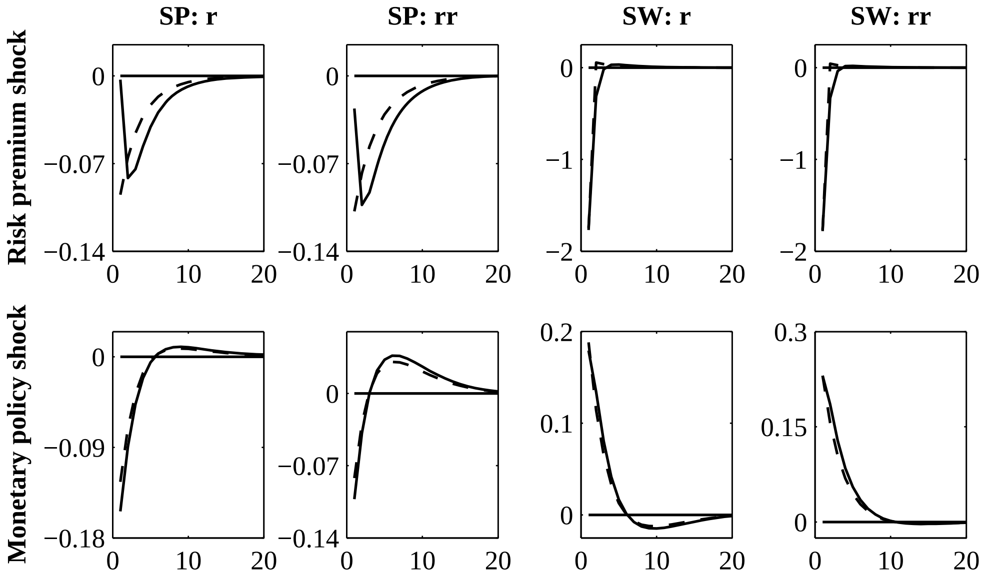

Figure 4.4: Implied interest rate responses for risk premium and monetary policy shock

Note: The *solid lines* represent impulse responses of the baseline model. The *dashed lines* are impulse responses to a serially uncorrelated shock.

In figure 4.4 we gain further insights into the link between implied and actual interest rates by computing impulse response functions of implied interest rates for a risk premium as well as a monetary policy shock. For the sake of completeness, impulse responses of model variables are shown in figure 4.5. As can be seen, the spread between implied and actual interest rates is related to monetary policy in the case of standard preferences. Following a monetary tightening, interest rates rise and consumption responds in a humped-shaped fashion. As standard preferences imply a positive relation between interest rates and consumption growth, implied Euler equation interest rates initially drop. This is not the case when preferences exhibit habits and nonseparability between consumption and labor effort. Interest rate dynamics implied by the SW Euler equation are equal to actual dynamics. In the case of the SW Euler equation, the spread between implied and actual interest rates is linked exclusively to risk premium shocks. As shown in figure 4.5, a negative shock to the wedge between the money market interest rate targeted by the central bank and the return on bonds held by households causes consumption,

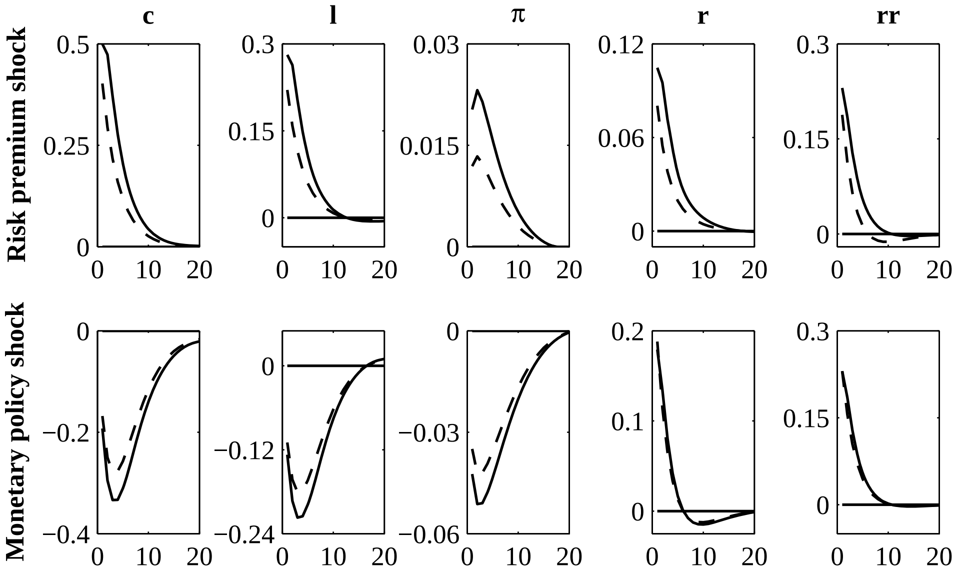

Figure 4.5: Model impulse responses for risk premium and monetary policy shock

Note: The *solid lines* represent impulse responses of the baseline model. The *dashed lines* are impulse responses to a serially uncorrelated shock.

labor, inflation, and interest rates to rise. Interest rates implied by the consumption Euler equation, however, drop initially. Hence, in the wake of risk premium disturbances the observed correlation between implied and actual interest rates is negative.

4.4 Conclusion

At first glance, the message of our analysis for the problem posed by the failure of consumption Euler equations identified by Canzoneri et al. (2007) is straightforward. Given that the model economy of our Monte Carlo experiment is true, we can conclude that risk premium shocks have the capability to drive a wedge between money market interest rates and interest rates implied by consumption Euler equations, so that the observed correlation between the two rates is negative. Moreover, the fact that the spread between actual and implied interest rates is simply a statistical noise is good news for the analysis of monetary policy within the NK framework that equates the two rates. However, the analysis in this chapter is not without controversy, because whether the model put forward by Smets and Wouters (2007) represents the true data-generating process is subject of debate. Chari et al. (2009) make the point that the model lacks a structural modeling of risk premium disturbances and argue that the estimated variance of the risk premium shock seems to be implausible large compared to the variance of the Federal Funds rate. To our opinion, there is no necessary conflict between their concerns and our result that risk premium shocks may resolve the evidence on implied Euler equation rates. In fact, both are simply two sides of the same coin. Nevertheless, we should note that our analysis does not rely on whether shocks to the wedge between the money market interest rate and the Euler equation rate are truly risk premium disturbances. In principal, any disturbance term that alters households' intertemporal optimality condition for consumption has the capability to induce a negative correlation between observed and implied Euler equation interest rates. With respect to this, the message of the chapter is that more has to be done to fully reconcile observed consumption dynamics with the structural underpinning implied by the consumption Euler equation. One promising way is to implement financial factors in the form of collateral constraints along the lines of Kiyotaki and Moore (1997). In a highly influential paper, Iacoviello (2005) extends the standard NK framework to account for borrowing constraints tied to housing values. Using structural estimation, he finds that collateral effects are crucial to explain US consumption dynamics in response to fluctuations in house prices. In a related work, Iacoviello and Neri (2010) provide evidence that housing collateral account for 12% of the total variance of US consumption growth in the period from 1989:Q4 to 2006:Q4. Given this quantitatively large effect of borrowing constraints on US consumption dynamics, this friction might limit the dependence of US consumption dynamics on risk premium disturbances implied by the Smets and Wouters (2007) framework and thereby might be a candidate to resolve the failure of consumption Euler equations given by the analysis in Canzoneri et al. (2007).

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