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ABSTRACT

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

Can monetary policy trigger pronounced boom-bust cycles in house prices and create persistent business cycles? We address this question by building heuristics into an otherwise standard DSGE model. As a result, monetary policy sets off waves of optimism and pessimism ('animal spirits') that drive house prices, which, in turn, have strong repercussions on the business cycle. We compare our findings to a standard model with rational expectations by means of impulse responses. We suggest that a standard Taylor rule is not well-suited to maintain macroeconomic stability. Instead, an augmented rule that incorporates house prices is shown to be superior.

JEL Classification: D83, E32 and E52
Keywords: animal spirits, housing markets and monetary policy

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1 Introduction

The recent boom-bust cycle in the U.S 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.[1] In this paper we take up these issues and incorporate heuristics into an otherwise standard dynamic stochastic general equilibrium (DSGE) model that captures important features of housing and 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, the extreme scale of the U.S house price cycle suggests that beyond monetary policy behavioral mechanisms have to be considered to fully understand the large fluctuations in house prices. Shiller (2005, 2007) states that the recent U.S. 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 emotions of excessive optimism followed by fear.*" Second, from a modeling point of view, the notion of heuristics is substantial because standard DSGE approaches rely on rational expectations implying that people do not make systematic forecast errors. As Rabanal et al. (2011) put it, the main disadvantage of standard models is that "*they do not have the capability to replicate non-linear dynamics often observed in a crisis context, nor can they incorporate bubbles in a tractable way.*"

In a standard DSGE model housing booms and busts merely reflect macroeconomic fundamentals. Behavioral mechanisms, such as Shiller's (2005, 2007) "*new era story*" or 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 non-linearities 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 upwards, while others bias the future real house price downwards. Although agents sys-

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

tematically have wrong beliefs about future real house prices, they are assumed to behave rational 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). Thus, 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.

Our modeling strategy is motivated by the recent work of De Grauwe (2010a,b, 2011). He replicates Keynes' notion of "animal spirits" by incorporating these types of 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.[2] However, despite their use in many financial market models, heuristics are applied only isolated in macroeconomic models. For instance, Brazier et al. (2008) use simple inflation-forecasting rules in an overlapping generation model to study the fall in volatility of inflation in recent decades. 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 that agents apply simple inflation-forecasting rules as well (see Brazier et al., 2008; De Grauwe, 2011).

In deriving the DSGE framework we build on the recent strand in the housing DSGE literature which extends the standard NK model with a housing sector and a collateral constraint.[3] In this model housing has two features: first, it provides housing services and thus utility, and second, for a fraction of households, it serves 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

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

[3] See, for instance, Iacoviello (2005), Pariès and Notarpietro (2008), Monacelli (2009), Calza et al. (2011), Iacoviello and Neri (2010) and Aspachs-Bracons and Rabanal (2010).

would have recommended, as a policy mistake that significantly contributed to the U.S 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 U.S housing market, but that the impact on the overall economy was limited. More recently, Iacoviello and Neri (2010) study the sources and consequences of fluctuations in the U.S. housing market by using an estimated 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 non-negligible 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 goods and housing, which, in turn, reinforces the increase in the real house price. Thus, 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 that 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 DSGE model with rational expectations (RE model) the asset price channel amplifies the effects of expansionary monetary policy shocks on real house prices and the business cycle. With increasing real house prices, however, the forecasting performance of house price optimists improves relative to pessimists. Therefore more and more agents switch to the optimistic forecasting rule and a sustained upward spiral of optimism about future real house prices, higher credit availability, higher demand and increasing real house prices kicks in. Alongside the boom, beliefs about future nondurable goods consumption and consumer price inflation change as consumption of nondurable goods and consumer price inflation rise 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 depend on the state of the economy and on future shocks. In a standard DSGE model the impact of a 25 basis points shock is always the same. Not so in our model.

As the BE model incorporates non-linear features, the fraction of optimists or pessimists present at the time of the shock matters. Thus, in contrast to a standard RE model where a monetary policy shock has always the same marginal impact on the economy, the non-linearity in the BE model calls monetary authorities to carefully analyze the current state of the economy in order to assess the likely impact of monetary policy actions on the future course of the economy. 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 relative high persistence in the BE model is due to the adaptive learning mechanism of agents. When a monetary policy shock hits the economy, agents only gradually learn that their beliefs were wrong. The high persistence holds in particular 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 relative stable in response to monetary policy shocks. Thus, standard monetary policy does not counteract the boom in house prices. Therefore 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. 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 paper is structured as follows. In the next section we derive the standard housing DSGE model. The formation of behavioral expectations is presented in section 3. Section 4 motivates the parameterization of the model parameters. Section 5 shows the business cycle dynamics of the BE model. In section 6 we compare the properties of the BE model with those of the RE model. In section 7 we discuss the implication for monetary policy. Section 8 concludes.

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

The theoretical framework is a two-sector NK model with a collateral constraint. The household side of the economy is split into two groups according to their 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 receive utility from consumption of nondurable goods and housing and disutility from labor supply. 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 ratio. The production side of the economy consists of two sectors producing 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. In what follows, we derive the maximization programs of savers, borrowers and firms. We present the market clearing conditions and close the model by assuming that the central bank follows a Taylor-type interest rate rule. All variables and parameters referring to borrowers are labeled with a tilde.

2.1 Savers

Each saver s ($s \in [\omega, 1]$) maximizes an intertemporal utility function

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

where E_t is the expectation operator to be specified later, β is the discount factor and $U_t(s)$ is the period utility function, which is defined as

$$U_t(s) = (1-\alpha) log(C_t(s) - hC_{t-1}) + \alpha log(H_t(s)) - \frac{L_t(s)^{1+\eta}}{1+\eta}. \tag{2}$$

$C_t(s)$ stands for the consumption of nondurable goods, $H_t(s)$ is housing (the end-of-period housing stock) and $L_t(s)$ is a labor supply index. The parameter h describes the degree of external habit formation in 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

$$L_t(s) = \left[(1-\Delta_H)^{-\iota_L}(L_{C,t}(s))^{1+\iota_L} + (\Delta_H)^{-\iota_L}(L_{H,t}(s))^{1+\iota_L}\right]^{\frac{1}{1+\iota_L}}, \quad \iota_L \geq 0, \tag{3}$$

where $L_{C,t}(s)$ denotes the labor supply in the nondurable goods sector and $L_{H,t}(s)$ is the labor supply in the housing sector. The parameter ι_L governs the degree of labor mobility across sectors and Δ_H is the share of housing in total output. Savers accumulate housing according to

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

where $HI_t(s)$ is housing (residential) investment and δ is the depreciation rate of the housing stock. The period budget constraint of a saver is

$$P_{C,t}C_t(s)+P_{H,t}HI_t(s)+B_t(s) = R_{t-1}B_{t-1}(s)+W_{C,t}L_{C,t}(s)+W_{H,t}L_{H,t}(s)+Div_t(s), \tag{5}$$

where $P_{C,t}$ is the price of nondurable goods, $P_{H,t}$ is the price of housing, $B_t(s)$ is the end-of-period nominal one-period debt, R_{t-1} is the gross nominal interest rate of contracts entered in period $t-1$, $W_{j,t}$ is the nominal wage in sector $j = C, H$ and $Div_t(s)$ are dividends payed by intermediate goods producers because firms are owned by savers. In real terms in units of nondurable goods the budget constraint reads

$$C_t(s) + q_t HI_t(s) + b_t(s) = R_{t-1}\frac{b_{t-1}(s)}{\Pi_{C,t}} + w_{C,t}L_{C,t}(s) + w_{H,t}L_{H,t}(s) + \frac{Div_t(s)}{P_{C,t}}, \tag{6}$$

where $q_t = \frac{P_{H,t}}{P_{C,t}}$ is the real house price, $b_t(s) = \frac{B_t(s)}{P_{C,t}}$ is real debt, $\Pi_{C,t} = \frac{P_{C,t}}{P_{C,t-1}}$ depicts the gross inflation rate of consumer prices and $w_{j,t} = \frac{W_{j,t}}{P_{C,t}}$ is the real wage in sector $j = C, H$.

By defining $MU_t^C(s) = \frac{\partial U_t(s)}{\partial C_t(s)}$ as the marginal utility of an additional unit of nondurable goods, $MU_t^H(s) = \frac{\partial U_t(s)}{\partial H_t(s)}$ as the marginal utility of an additional unit of housing, the first-order conditions for the maximization of the intertemporal utility function with respect to (4) and (6) are[4]

$$w_{C,t} = \frac{L_t^{(\eta-\iota_L)}(1-\Delta_H)^{-\iota_L}(L_{C,t})^{\iota_L}}{MU_t^C}, \tag{7}$$

$$w_{H,t} = \frac{L_t^{(\eta-\iota_L)}{\Delta_H}^{-\iota_L}(L_{H,t})^{\iota_L}}{MU_t^C}, \tag{8}$$

$$MU_t^C q_t = MU_t^H + \beta(1-\delta)E_t\left(MU_{t+1}^C q_{t+1}\right) \tag{9}$$

$$\text{and} \quad MU_t^C = \beta E_t\left(MU_{t+1}^C\frac{R_t}{\Pi_{C,t+1}}\right). \tag{10}$$

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

2.2 Borrowers

Each borrower b ($b \in [0, \omega]$) maximizes an intertemporal utility function

$$E_t \sum_{k=0}^{\infty} \tilde{\beta}^k \tilde{U}_{t+k}(b), \quad \tilde{\beta} \in [0,1] \quad \text{and} \quad \tilde{\beta} < \beta. \tag{11}$$

The period utility function, $\tilde{U}_t(b)$, the labor supply index, $\tilde{L}_t(b)$, and the housing accumulation equation of a borrower have the same functional form as (2), (3) and (4) respectively. In real terms the budget constraint of a borrower is given by

$$\tilde{C}_t(b) + q_t \tilde{H} I_t(b) + R_{t-1} \frac{\tilde{b}_{t-1}(b)}{\Pi_{C,t}} = \tilde{b}_t(b) + w_{C,t} \tilde{L}_{C,t}(b) + w_{H,t} \tilde{L}_{H,t}(b). \tag{12}$$

Following the seminal paper by Iacoviello (2005), real debt holdings of a borrower b are subject to an endogenous limit (collateral constraint) that is

$$\tilde{b}_t(b) \leq (1-\chi)(1-\delta) E_t \left(\frac{\tilde{H}_t(b) q_{t+1}}{R_t / \Pi_{C,t+1}} \right). \tag{13}$$

The collateral constraint ties a borrower's amount of debt to the expected present value of the borrower's future housing stock times a loan to value ratio, $(1-\chi)$.[5] This has an important implication for the monetary transmission mechanism. When house prices are more flexible than consumer prices, expansionary monetary policy increases the real house price and thereby raises the collateral value of borrowers who in turn increase their debt holdings to expand consumption of nondurable goods and housing investment ("asset price channel"). Thus, relative to the standard NK model the positive effect of an expansionary monetary policy shock on the business cycle is amplified.

[5] 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 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).

The first-order conditions to the maximization program above are given by[6]

$$w_{C,t} = \frac{\tilde{L}_t^{(\eta-\iota_L)}(1-\Delta_H)^{-\iota_L}(\tilde{L}_{C,t})^{\iota_L}}{\tilde{MU}_t^C}, \tag{14}$$

$$w_{H,t} = \frac{\tilde{L}_t^{(\eta-\iota_L)}\Delta_H{}^{-\iota_L}(\tilde{L}_{H,t})^{\iota_L}}{\tilde{MU}_t^C}, \tag{15}$$

$$\tilde{MU}_t^C q_t = \tilde{MU}_t^H + \tilde{\beta}(1-\delta)E_t\left(\tilde{MU}_{t+1}^C q_{t+1}\right) + (1-\chi)(1-\delta)\tilde{\lambda}_t^{cc} q_t E_t\left(\Pi_{H,t+1}\right) \tag{16}$$

$$\text{and} \quad \tilde{MU}_t^C = \tilde{\beta}E_t\left(\tilde{MU}_{t+1}^C \frac{R_t}{\Pi_{C,t+1}}\right) + R_t\tilde{\lambda}_t^{cc}, \tag{17}$$

where $\Pi_{H,t} = \frac{P_{H,t}}{P_{H,t-1}}$ is the gross inflation rate of house prices and $\tilde{\lambda}_t^{cc}$ is the Lagrange multiplier on the collateral constraint.

2.3 Final goods producers

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

$$Y_{j,t} = \left(\int_0^1 Y_{j,t}(i)^{\frac{\epsilon_j-1}{\epsilon_j}} di\right)^{\frac{\epsilon_j}{\epsilon_j-1}}, \quad j = C, H, \tag{18}$$

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

$$Y_{j,t}(i) = \left(\frac{P_{j,t}(i)}{P_{j,t}}\right)^{-\epsilon_j} Y_{j,t}, \quad j = C, H, \tag{19}$$

where $P_{j,t}(i)$ is the price of one unit of the intermediate good i and $P_{j,t}$ is the price of one unit of the final good. Given zero profits in equilibrium, the latter reads

$$P_{j,t} = \left(\int_0^1 P_{j,t}(i)^{1-\epsilon_j} di\right)^{\frac{1}{1-\epsilon_j}}, \quad j = C, H. \tag{20}$$

2.3.1 Intermediate goods producers

In each sector the intermediate good i is produced according to the following linear production technology

$$Y_{j,t}(i) = L_{j,t}^{tot}(i), \quad j = C, H, \tag{21}$$

[6] We drop the index b due to the assumed trading of state-contingent securities among borrowers.

where $L^{tot}_{j,t}(i)$ stands for labor. In each period intermediate goods producers maximize their expected profits subject to the demand for their intermediate goods (19). As in Calvo (1983), we assume that intermediate goods producers in sector j reset prices with a probability of $1-\theta_j$. The reset price for good i in sector j is given by

$$P^*_{j,t}(i) = \frac{\epsilon_j}{\epsilon_j - 1} \frac{E_t \sum_{k=0}^{\infty} (\theta_j \beta)^k MU^C_{t+k} P^{\epsilon_j}_{j,t+k} mc_{j,t+k}(i) Y_{j,t+k}}{E_t \sum_{k=0}^{\infty} (\theta_j \beta)^k MU^C_{t+k} P^{\epsilon_j - 1}_{j,t+k} Y_{j,t+k}}, \quad j = C, H, \tag{22}$$

where $mc_{j,t}$ are the real marginal costs of production defined as

$$mc_{j,t} = \frac{W_{j,t}}{P_{j,t}}, \quad j = C, H. \tag{23}$$

Finally, the aggregate price level in sector j can be written as

$$P^{1-\epsilon_j}_{j,t} = \theta_j \left(P_{j,t-1}\right)^{1-\epsilon_j} + (1-\theta_j)\left(P^*_{j,t}(i)\right)^{1-\epsilon_j}, \quad j = C, H. \tag{24}$$

2.3.2 Market clearing and monetary policy

The market clearing conditions in the labor markets are

$$L^{tot}_{C,t} = \omega \tilde{L}_{C,t} + (1-\omega) L_{C,t} \quad \text{and} \quad L^{tot}_{H,t} = \omega \tilde{L}_{H,t} + (1-\omega) L_{H,t}. \tag{25}$$

The debt market equilibrium is

$$\omega \tilde{B}_t = (1-\omega) B_t. \tag{26}$$

The final goods markets are in equilibrium, when

$$Y_{C,t} = \omega \tilde{C}_t + (1-\omega) C_t \quad \text{and} \quad Y_{H,t} = \omega \tilde{H} I_t + (1-\omega) H I_t. \tag{27}$$

Real GDP is defined as the sum of consumption of nondurable goods and residential investment which is

$$Y_t = Y_{C,t} + \bar{q} Y_{H,t}, \tag{28}$$

where $\bar{q} = 1$ is the steady state real house price.

To close the model we assume that the central bank follows a Taylor-type interest rate rule

$$R_t = R^{\mu_R}_{t-1} \left(\bar{R} \left(\frac{\Pi_{C,t}}{\bar{\Pi}_C} \right)^{\mu_\pi} \left(\frac{Y_t}{\bar{Y}} \right)^{\mu_Y} \right)^{(1-\mu_R)} exp(u_{R,t}), \tag{29}$$

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

3 The formation of expectations

In this section we discuss how agents, i.e. savers, borrowers and firms, form their expectations. We assume that agents choose between simple rules to make forecasts and base their choice on the relative forecast performance of these rules. The diversity in beliefs is a key difference to a standard RE model in which expectations are homogeneous. Clearly, it matters at which state of the analysis this diversity is introduced. We follow De Grauwe (2010a,b, 2011) and impose heuristics on the macroeconomic level. That is, we start from the linearized version of the housing DSGE model and assume that the 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.[7,8] 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. In the following, all variables with a hat describe log-deviations from steady state.

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

Agents are assumed to choose between an optimistic and a pessimistic rule to forecast future real house prices.[9] The forecasts of the optimistic and the pessimistic rule are symmetric around zero and given by

$$E_t^{opt}\hat{q}_{t+1} = \frac{d_t^q}{2} \quad \text{and} \quad E_t^{pes}\hat{q}_{t+1} = -\frac{d_t^q}{2}, \tag{30}$$

[7]In appendix A we present the steady state and the log-linear equations of the model.

[8]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.

[9]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 $\hat{q}_{t+1} = \hat{P}_{H,t+1} - \hat{P}_{C,t+1}$ stands for the real house price (gap) in period $t+1$ and $d_t^q > 0$ measures the absolute divergence in beliefs. The latter is assumed to be a function of real house price volatility and reads

$$d_t^q = \beta_d + \delta_d \sigma(\hat{q}), \tag{31}$$

where $\sigma(\hat{q})$ 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 volatility (see De Grauwe, 2010a,b, 2011).

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 use biased rules they behave rationally in the sense that they select the rules according to their recent forecast performance. In particular, agents evaluate the forecast performance of the two rules according to

$$U_{opt,t}^q = \sum_{k=1}^{\infty} \omega_k \left[\hat{q}_{t-k} - E_{t-k-1}^{opt} \hat{q}_{t-k}\right]^2 \tag{32}$$

$$\text{and} \quad U_{pes,t}^q = \sum_{k=1}^{\infty} \omega_k \left[\hat{q}_{t-k} - E_{t-k-1}^{pes} \hat{q}_{t-k}\right]^2, \tag{33}$$

where $U_{opt,t}^q$ is the mean squared forecasting error (MSFE) of the optimistic rule, $U_{pes,t}^q$ is the MSFE of the pessimistic rule and $\omega_k = (1-\rho)\rho^k$ are geometrically declining weights, where ρ governs the memory of agents. The fraction of agents choosing the optimistic, respectively, the pessimistic rule is determined by

$$\alpha_{opt,t}^q = \frac{exp(-\gamma U_{opt,t}^q)}{exp(-\gamma U_{opt,t}^q) + exp(-\gamma U_{pes,t}^q)} \tag{34}$$

$$\text{and} \quad \alpha_{pes,t}^q = \frac{exp(-\gamma U_{pes,t}^q)}{exp(-\gamma U_{opt,t}^q) + exp(-\gamma U_{pes,t}^q)} = 1 - \alpha_{opt,t}^q, \tag{35}$$

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.[10] 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

[10] The intensity of choice can be related to 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.

all agents choose the rule with the highest forecast performance.

The aggregate real house price forecast, $E_t q_{t+1}$, is then defined as the weighted average of optimistic and pessimistic forecasts and is given by

$$E_t \hat{q}_{t+1} = \alpha^q_{opt,t}(E^{opt}_t \hat{q}_{t+1}) + \alpha^q_{pes,t}(E^{pes}_t \hat{q}_{t+1}). \tag{36}$$

For the expectations on future consumption of nondurable goods we assume the same formation process as for the real house price. As, however, the consumption of nondurable goods differ between savers and borrowers we separate the expectation formation between these two types. In a nutshell, the aggregate forecast on future consumption of nondurable goods for savers, $E_t \hat{C}_{t+1}$, is given by

$$E_t \hat{C}_{t+1} = \alpha^C_{opt,t}(E^{opt}_t \hat{C}_{t+1}) + \alpha^C_{pes,t}(E^{pes}_t \hat{C}_{t+1}), \tag{37}$$

where $\alpha^C_{opt,t}$ is the fraction of consumption optimists among all savers. Accordingly, the aggregate forecast on future consumption of nondurable goods for borrowers, $E_t \hat{\tilde{C}}_{t+1}$, is

$$E_t \hat{\tilde{C}}_{t+1} = \alpha^{\tilde{C}}_{opt,t}(E^{opt}_t \hat{\tilde{C}}_{t+1}) + \alpha^{\tilde{C}}_{pes,t}(E^{pes}_t \hat{\tilde{C}}_{t+1}), \tag{38}$$

where $\alpha^{\tilde{C}}_{opt,t}$ is the fraction of consumption optimists among all borrowers.

3.2 Expectations on future inflation

Agents also form expectations on future inflation rates in the nondurable goods sector and the housing sector.[11] 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. Given that there is a central bank that announces an inflation target, the notion of optimists and pessimists does not appropriately model the formation of expectations on future consumer price inflation. Instead, we assume that some agents use the central bank's inflation target to forecast future consumer price inflation, while others, who do not trust the inflation target of the central bank, extrapolate

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

past inflation. The two forecasting rules are given by

$$E_t^{tar}\pi_{C,t+1} = \pi_C^* \quad \text{and} \quad E_t^{ext}\pi_{C,t+1} = \pi_{C,t-1}, \tag{39}$$

where $\pi_{C,t} = \hat{P}_{C,t} - \hat{P}_{C,t-1}$ defines the consumer price inflation rate and $\pi_C^* = 0$ is the central bank's inflation target. The selection mechanism is identical to the previous formations of expectations. Thus, the aggregate forecast for inflation in the nondurable goods sector, $E_t\pi_{C,t+1}$, is given by

$$E_t\pi_{C,t+1} = \alpha_{tar,t}^{\pi}(E_t^{tar}\pi_{C,t+1}) + \alpha_{ext,t}^{\pi}(E_t^{ext}\pi_{C,t+1}), \tag{40}$$

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 that uses the past inflation rate.

As agents already have beliefs about the real house price and consumer price inflation, the inflation rate in the housing sector, $E_t\pi_{H,t+1}$, is implicitly given by

$$E_t\pi_{H,t+1} = E_t\hat{q}_{t+1} - \hat{q}_t + E_t\pi_{C,t+1}, \tag{41}$$

where $\pi_{H,t} = \hat{P}_{H,t} - \hat{P}_{H,t-1}$ is the inflation rate in the housing sector.

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 0.99, 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) points 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 households, cannot be set independently. We determined α numerically such 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%. This value is virtually the average of the LTV ratios of industrialized countries as reported by Calza et al. (2011). The elasticities of substitution between intermediate goods, ϵ_C and ϵ_H, are both set to 11.5 which yields a steady-state mark-up 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.[12] We choose to set $\theta_C = 0.8$, which implies an average frequency of price adjustment of 4 quarters for nondurable goods prices, and $\theta_H = 0.667$, which yields an average price rigidity of 3 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. 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, such that $\beta_d = 1$ and $\delta_d = 2$. 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.[13] Finally, in order to simulate from the model, we bring the model in the following form

$$\mathbf{Z_t} = \mathbf{A^{-1}} \left(\mathbf{B E_t Z_{t+1}} + \mathbf{C Z_{t-1}} + \mathbf{V_t} \right), \tag{42}$$

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.

5 Monetary policy, animal spirits and the business cycle

In this section we investigate the business cycle dynamics of our model and study the role of heuristics agents use to make forecasts in the transmission of monetary policy.

[12] 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 co-movement 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. In general, the collateral constraint model reproduces a positive co-movement in response to a monetary policy shock when a sufficient degree of price stickiness in the durable sector is allowed for.

[13] In Appendix B we outline our calibration strategy for the behavioral parameters and present some sensitivity analysis.

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.

5.1 A simplified BE model

At first, we shed some light on the relationship between monetary policy actions, biased beliefs about future real house prices and the broader economy in a somewhat simplified model. In order 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 long-run equilibrium value. That is, we set the expectation operator on future consumption of nondurable goods, $E_t\hat{C}_{t+1}$ and $E_t\hat{\tilde{C}}_{t+1}$, and on future consumer price inflation, $E_t\pi_{C,t+1}$, to zero. Figure 1 highlights the dynamics of the simplified BE model between the quarter 700 and 800 for an arbitrary draw of i.i.d. monetary policy shocks with a standard deviation of 25 basis points.

Although the model is only driven by uncorrelated monetary policy shocks it is capable to generate endogenous and persistent cycles in real house prices and the broader economy. The monetary transmission mechanism can be described as follows. Between quarter 700 to 720, we observe that the economy is hit by a sequence of negative monetary policy shocks. As prices are sticky, the real interest rate falls and stimulates demand for nondurable goods and residential investment, which, in turn, causes consumer price inflation and house prices to rise as marginal costs increase alongside the expansion. 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 agents who are pessimistic about the future track of real house prices gradually learn that their forecast performance deteriorates. Therefore, pessimists are willing to change their beliefs and switch to the optimistic rule. In response to the increasing optimism about future real house prices firms in the housing sector adjust their prices upwards. Moreover, the increasing optimism about rising future real house prices increases the collateral value of borrowers which allows them to expand their debt holdings in order to raise consumption of nondurable goods and housing investment. The additional demand strengthens the rise in real house prices, which, in turn, reinforces more and more agents to be optimistic about the future track of house prices. This 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

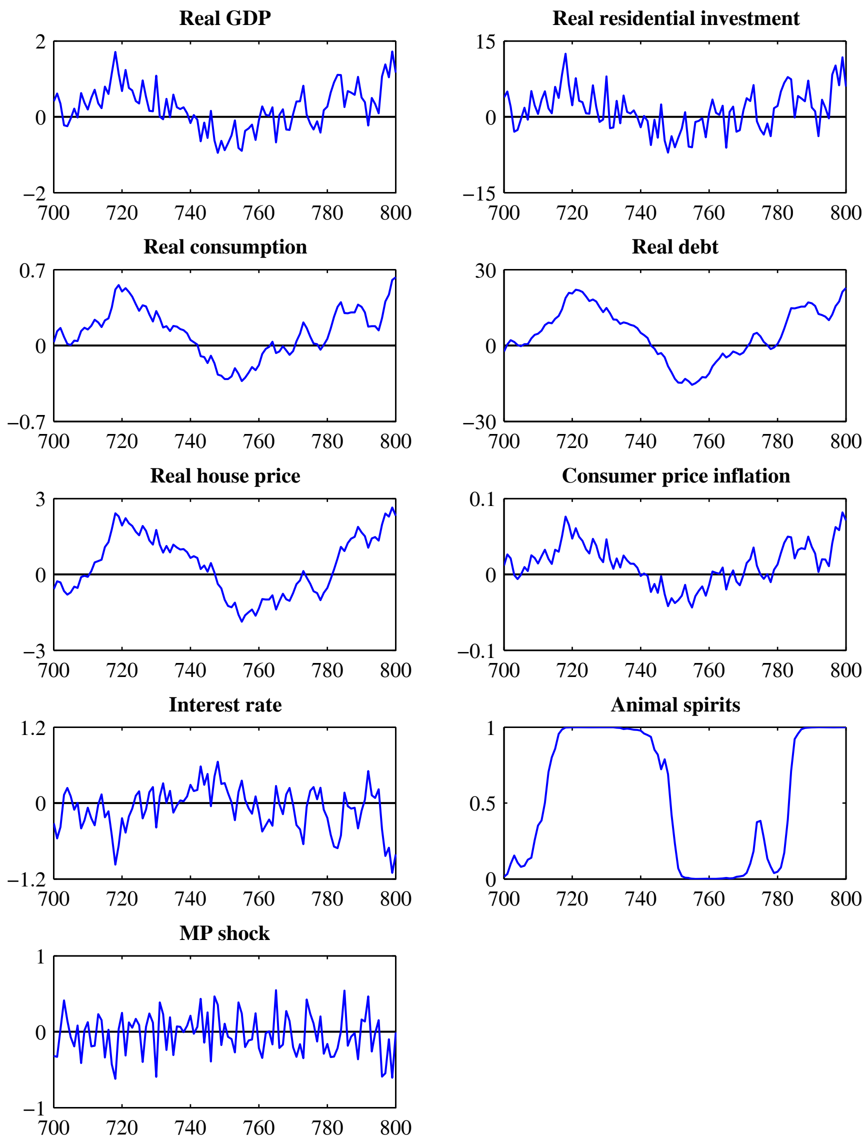

Figure 1: Dynamics of the simplified BE model.

Note: The x-axis is in quarters. The y-axis measures percent deviation from the steady state with one exception. In panel (4,2) the y-axis measures the fraction of real house price optimists.

lead to a turn around in the business cycle and the formation of beliefs. High real interest rates around the quarter 740 strongly depresses the consumption of nondurable goods and housing investment. In turn, real house prices fall below its steady state inducing agents to switch to the pessimistic rule to forecast future real house prices. As the fraction of house price pessimists increases real house prices slump even more carrying down the broader economy, all in a self-reinforcing fashion.

5.2 A full-fledged BE model

It can be argued that the assumption of agents expecting future consumption of nondurable goods and consumer price inflation to be zero and simultaneously being optimistic or pessimistic about future real house prices is somewhat unrealistic as it implies that agents do not internalize the impact of changing real house prices. Therefore, we repeat the simulation exercise of the previous section by assuming that all behavioral expectation operators are at play. Figure 2 shows the dynamics of the full-fledged BE model for the same draw of monetary policy shocks as for the simplified BE model.

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 are subject to a collateral constraint, swings in beliefs about future real house prices have a strong impact on the borrowers' consumption of nondurable goods. Thus, 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 the latter on the borrowers' nondurable goods consumption. Savers, however, are not credit constraint and thus 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 thereby 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

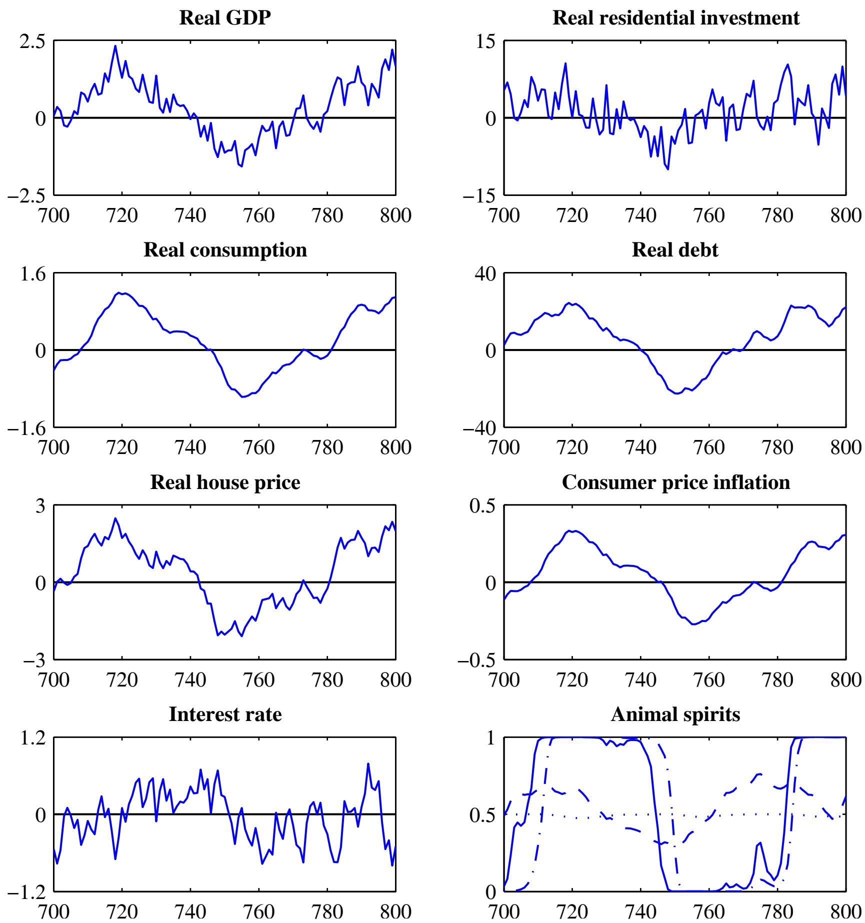

Figure 2: Dynamics of the full-fledged BE model.

Note: The x-axis is in quarters. The y-axis measures percent deviation from the steady state with one exception. In panel (4,2) the y-axis measures the fraction of optimists and inflation targeters. The *solid* line represents the fraction of real house price optimists, the *dashed* line is the fraction of consumption optimists among savers, the *dashed-dotted* line stands for the fraction of consumption optimists among borrowers and the *dotted* line is the fraction inflation targeters.

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 around 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. Clearly, 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 such that their decision whether to use the central bank's inflation target or to extrapolate past inflation to forecast future consumer price inflation is almost random.

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 upwards or downwards, 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 they are perfectly informed about the underlying structure of the economy and the distribution of shocks. Thus, rational agents do not make systematic forecast 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.

Computing impulse responses in the BE model is not a straightforward exercise. In the linear RE model the effects of a monetary policy shock are independent of the state of the economy. Like De Grauwe (2011) points out, this does not hold true for the BE model. As the BE model incorporates non-linear features, the state of the economy matters.

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 a well-timed shock initiates a wave of optimism and thus has a large impact on the evolution of the economy. Then it might be that the same shock has only a minor effect on the further track of the economy. This might be the case when the fraction of optimists is already large at the time of the shock. To take care of the non-linearity of the BE model we follow De Grauwe (2011) when we compute impulse responses. 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 whereas we set the monetary policy shock in period 700 equal to 0. Third, for each variable of interest we compute the difference between the first and the second simulation round. Thereby we isolate the effect of the monetary policy shock in quarter 700 on the further track of the economy. Fourth, to take into account that the realizations of past and future monetary policy shocks affect the impact of the monetary policy shock in quarter 700, we repeat steps 1)-3) 1000 times, each time with a different realizations of shocks. Then, we compute for each variable of interest the median impulse response together with the 95%- and 5%-quantile.

Figure 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 depend on the state of the economy and on future shocks. In a linearized DSGE model the marginal impact of a 25 basis points shock is always the same. Because of its highly non-linear features, this does not hold true for the behavioral model. 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 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. Thus, in contrast to a standard DSGE model where a monetary policy shock has always the same

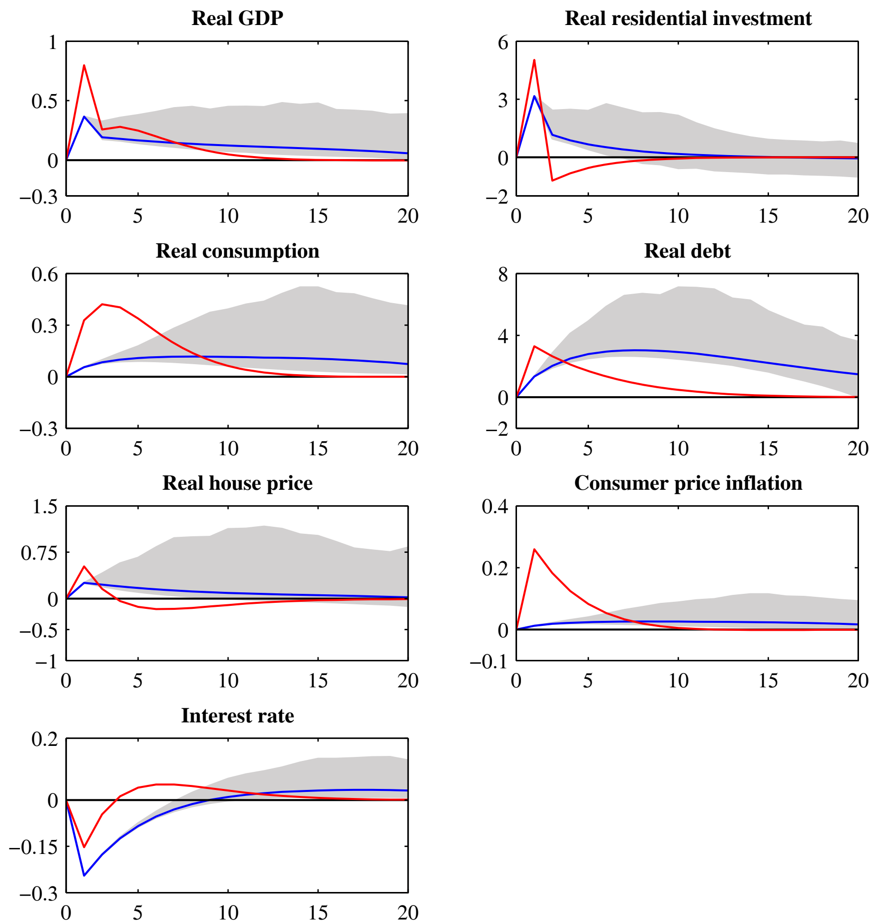

Figure 3: Impulse responses of the full-fledged BE and the RE model to a monetary policy shock of 25 basis points.

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.

impact on the economy, the non-linearity in the BE model calls monetary authorities to analyze the current state of the economy in order to assess the likely impact of monetary policy actions on the future course of the economy. To put it differently, only by carefully analyzing the current state of the economy it is possible to judge the appropriate size of monetary policy actions in order to achieve prespecified targets. Second, the impulse responses of the BE model are much more persistent than the impulse responses of the RE model. This relative high persistence is due to the adaptive learning mechanism of agents. After monetary policy shocks hit the economy, the broader economy slowly adjusts inducing agents to adapt their beliefs. A contagion among beliefs of agents might then 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, the consumer price inflation in the BE model is relative 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 booming economy which is triggered by monetary policy itself. 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. Instead, 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 might reinforce more and more agents to form optimistic beliefs about future developments.

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. Therefore, we suggest the following real house price-augmented Taylor rule

$$\hat{R}_t = \mu_R \hat{R}_{t-1} + (1-\mu_R)(\mu_\pi \pi_{C,t} + \mu_Y \hat{Y}_t + \mu_q \hat{q}_t) + u_t^R. \tag{43}$$

To explore the benefits of an 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.

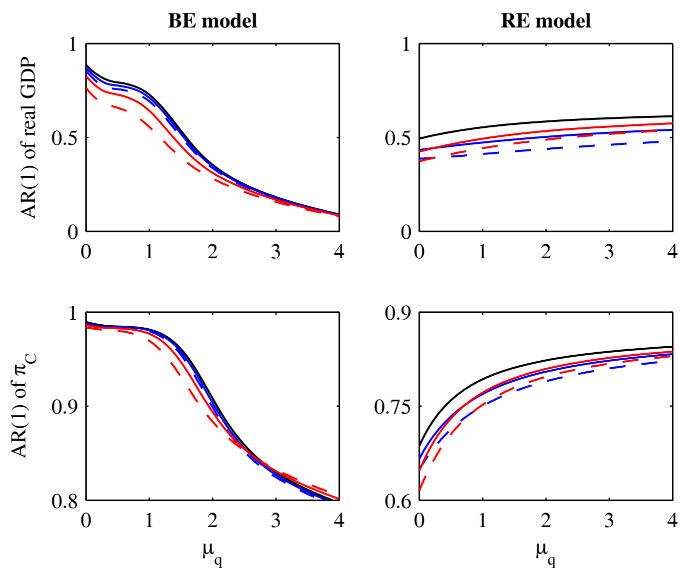

Figure 4: Augmented Taylor rule: full-fledged BE vs. RE model.

Note: The *black solid lines* refer to the baseline calibration for μ_R, μ_π and μ_Y. The *blue solid lines* stands 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 4 summarizes the results for the AR(1)-coefficients.[14] Starting from the baseline scenario we observe a sharp decline in the persistence of real GDP and consumer price inflation when the real house price coefficient, μ_q, rises. By responding to real house prices, the central bank becomes more restrictive in the early stage of the housing boom. Thereby, it detracts the sources that lead to a sustained boom. A more restrictive monetary policy

[14]For the BE model we report the average AR(1)-coefficients obtained by simulating the model 1000 times, each time over 800 periods. For the RE model we report the theoretical AR(1)-coefficients.

subdues demand for nondurable goods and housing investment, which, in turn, lowers the fall in the real house price. As house prices are less volatile, swings in beliefs about future real house prices are less likely to occur preventing that sustained waves of optimism and pessimism drive house prices and thus real GDP and consumer price inflation.

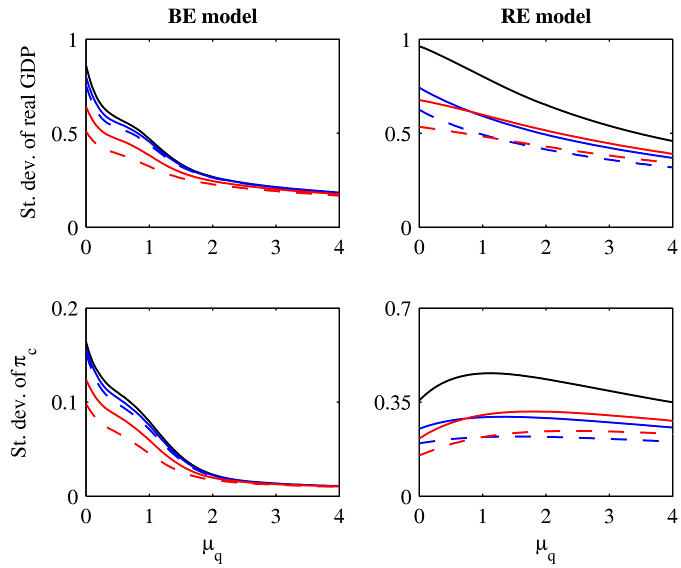

Figure 5: Augmented Taylor rule: full-fledged BE vs. RE model.

Note: The *black solid lines* refer to the baseline calibration for μ_π and μ_Y. The *blue solid lines* stands 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 5 summarizes the results for the standard deviations of real GDP and consumer price inflation.[15] Similar to the previous exercise, the standard deviations fall as the central bank raises its reaction to real house prices. All figures underline the highly non-linear features of the BE model. As soon as the real house price coefficient reaches critical threshold values the AR(1)-coefficients and the standard deviations sharply fall.[16] Moreover, the figures illustrate that the stabilizing effects of a real house price-augmented Taylor rule are almost independent from the parameter values for the output and the inflation coefficient. To put it differently, in the BE model the central bank fails to stabilize the economy by a stronger response to real GDP or consumer price inflation. Given the tremendous impact of swings in real house prices on the broader economy, the central bank succeeds only well in terms of stabilizing economic fluctuations in real GDP and

[15]For the BE model we report the average standard deviations obtained by simulating the model 1000 times, each time over 800 periods. For the RE model we report the theoretical standard deviations.

[16]Model simulations suggests that when μ_q reaches 1, the swings in beliefs about future nondurable goods consumption among savers shrink and that when μ_q reaches 2, the swings in beliefs about future real house price and future nondurable goods consumption among borrowers strongly reduce.

consumer prices by setting interest rates in response to real house prices. The difference in policy implications to be drawn from the DSGE counterpart model is striking. The standard DSGE framework predicts that a stronger response to real house prices is not a promising strategy. The persistence in output and inflation even increases when monetary authorities start to respond to real house price movements while the standard deviation of consumer prices basically stays flat. Thus, the analysis suggests that the standard framework underestimates the beneficial impact of augmenting the Taylor rule by a real house price component. As in the RE model booms and bust periods merely represent macroeconomic fundamentals, because waves of optimism and pessimism driving real house prices and in turn 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 can be illustrated by means of impulse response analysis. In figure 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 non-linearities which call monetary authorities to carefully analyze the current state of the economy in order to assess the likely impact of monetary policy actions on the future course of the economy. However, the effects of a monetary actions 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 6 also illustrates the success of a real house price-augmented Taylor rule in terms of stabilizing the economy. By applying a standard Taylor rule, monetary policy is found to be accommodative at the early stage of the boom in house prices and output as consumer price inflation is relative stable. Instead, when the central 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.

8 Conclusion

In this paper we incorporate heuristics into an otherwise standard DSGE model that captures important features of housing in order to provide qualitatively insights into how

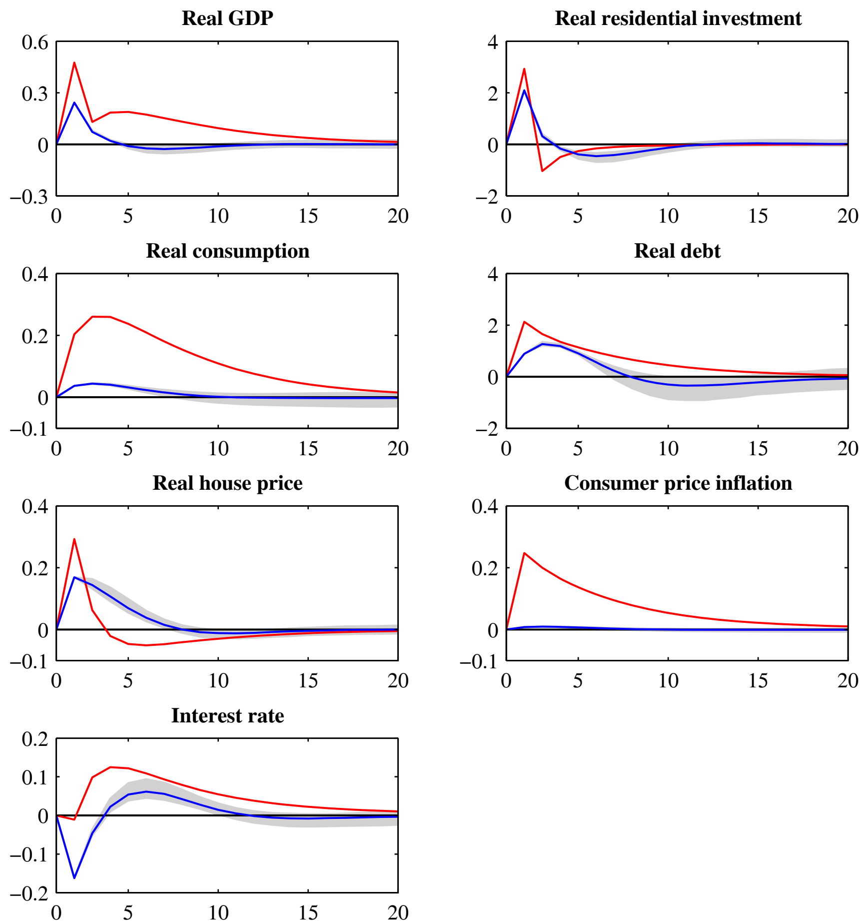

Figure 6: Impulse responses of the full-fledged BE and the RE model with a real house price-augmented Taylor rule to a monetary policy shock of 25 basis points.

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.

monetary policy actions affect the housing market and in turn the overall economy when behavioral mechanisms play a role. That is, we drop the assumption of rational expectations in an otherwise standard model and alternatively assume that agents use heuristics to form expectations. As a key contribution we succeed to implement notions of non-linearities into a DSGE model, a feature which is missing in the standard approach.

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 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 marginal impact of a monetary policy shock on real house prices and the business cycle depend on the state of the economy. As the BE model incorporates non-linear features, the fraction of optimists or pessimists present at the time of the shock matters for the effects of monetary policy actions. Second, the dynamics in the BE model exhibit a much higher persistence as in the RE model. This relative high persistence in the BE model is due to the adaptive learning mechanism of agents. When a monetary policy shock hits the economy, agents only gradually learn that their beliefs were wrong. Third, we find that in the BE model consumer price inflation is relative stable. 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 is underestimated within this framework.

A The log-linear model

Here, we summarize the steady state and the log-linear equations of the model. Variables with a bar denote steady state levels and variables with a hat describe log-deviations.

A.1 Steady state

Prices are constant markups over nominal marginal costs, $\bar{P}_j = \left(\frac{\epsilon_j}{\epsilon_j - 1}\right)\bar{W}_j$ (for $j = C, H$). With $\bar{P}_j = 1$, it follows that $\bar{W}_j = \frac{\epsilon_j - 1}{\epsilon_j}$ and $\bar{q} = 1$. It is assumed that $\epsilon_C = \epsilon_H = \epsilon$, such that $\bar{W}_C = \bar{W}_H = \bar{W}$. For the interest rate it holds true that $\bar{R} = \frac{1}{\beta}$.

The saver's relative consumption of nondurable goods is

$$\bar{\Omega} := \frac{\bar{C}}{\bar{H}} = \left(\frac{1-\alpha}{\alpha(1-h)}\right)(1 - \beta(1-\delta)). \tag{44}$$

The saver's total supply of labor is[17]

$$\left(\frac{\epsilon - 1}{\epsilon}\right)\left(\frac{1-\alpha}{1-h}\right)\left(1 + \delta\bar{\Omega}^{-1}\right) - \bar{\Sigma}\bar{L}^{\varphi} - \bar{L}^{(1+\varphi)} = 0, \tag{45}$$

$$\text{where} \qquad \bar{\Sigma} = \left(\frac{\omega}{1-\omega}\right)\left(\frac{1}{\epsilon}\bar{\tilde{L}} + \left(\frac{1}{\beta} - 1\right)\bar{\tilde{B}}\right). \tag{46}$$

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 saver's steady state consumption of nondurable goods is given by

$$\bar{C} = \left(\frac{\epsilon - 1}{\epsilon}\right)\left(\frac{1-\alpha}{1-h}\right)\bar{L}^{-\varphi}. \tag{47}$$

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

The borrower's relative consumption of nondurable goods is

$$\bar{\tilde{\Omega}} := \frac{\bar{\tilde{C}}}{\bar{\tilde{H}}} = \left(\frac{1-\alpha}{\alpha(1-h)}\right)\left(1 - (1-\delta)[\tilde{\beta} + (1-\chi)(\beta - \tilde{\beta})]\right). \tag{48}$$

The borrower's total supply of labor is

$$\bar{\tilde{L}} = \left[\left(\frac{1-\alpha}{1-h}\right)\left(1 + \frac{\delta + \left(\frac{1}{\beta} - 1\right)(1-\chi)(1-\delta)}{\bar{\tilde{\Omega}}}\right)\right]^{\frac{1}{1+\varphi}} \tag{49}$$

[17] For $\varphi = 1$ this function has an analytical solution.

and 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 borrower's consumption of nondurable goods is given by

$$\bar{\bar{C}} = \left(\frac{\epsilon-1}{\epsilon}\right)\left(\frac{1-\alpha}{1-h}\right)\bar{\bar{L}}^{-\varphi}. \tag{50}$$

The borrower's 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 borrower's debt holdings are $\bar{\bar{B}} = \beta(1-\chi)(1-\delta)\bar{\bar{H}}$.

Technologies are $\bar{Y}_j = \bar{L}_j^{tot}$ (for $j = C, H$), where total labor supply in each sector j is given by $\bar{L}_j^{tot} = \omega\bar{\bar{L}}_j + (1-\omega)\bar{L}_j$. The 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 $\bar{Y}_H = \omega\bar{\bar{HI}} + (1-\omega)\bar{HI}$. GDP equals $\bar{Y} = \bar{Y}_C + \bar{q}\bar{Y}_H$.

A.2 Log-linear approximation

A.2.1 Savers

The *consumption equation of nondurable goods* is given by

$$\hat{C}_t = \frac{1}{1+h}E_t\hat{C}_{t+1} + \frac{h}{1+h}\hat{C}_{t-1} - \frac{1-h}{1+h}(\hat{R}_t - E_t\pi_{C,t+1}). \tag{51}$$

For *housing* it holds true that

$$-\hat{H}_t + \frac{1}{1-h}\hat{C}_t - \frac{h}{1-h}\hat{C}_{t-1} = [1-\beta(1-\delta)]^{-1}[\hat{q}_t + \beta(1-\delta)(\hat{R}_t - E_t\pi_{C,t+1} - E_t\hat{q}_{t+1})]. \tag{52}$$

The *accumulation equation of the housing stock* is determined by $\hat{H}_t = \delta\hat{H}I_t + (1-\delta)\hat{H}_{t-1}$. The *labor supply equations* are

$$\frac{1}{1-h}\hat{C}_t - \frac{h}{1-h}\hat{C}_{t-1} + ((\varphi-\iota_L)(1-\Delta_H)+\iota_L)\hat{L}_{C,t} + (\varphi-\iota_L)\Delta_H\hat{L}_{H,t} = \hat{W}_{C,t} - \hat{P}_{C,t}, \tag{53}$$

$$\frac{1}{1-h}\hat{C}_t - \frac{h}{1-h}\hat{C}_{t-1} + ((\varphi-\iota_L)\Delta_H+\iota_L)\hat{L}_{H,t} + (\varphi-\iota_L)(1-\Delta_H)\hat{L}_{C,t} = \hat{W}_{H,t} - \hat{P}_{C,t}. \tag{54}$$

A.2.2 Borrowers

The *consumption equation of nondurable goods* is given by

$$\begin{aligned}\hat{\tilde{C}}_t = & \frac{1}{1+h}E_t\hat{\tilde{C}}_{t+1} + \frac{h}{1+h}\hat{\tilde{C}}_{t-1} - \frac{1-h}{1+h}(\hat{R}_t - E_t\pi_{C,t+1}) \\ & - \frac{\beta-\tilde{\beta}}{\tilde{\beta}}\frac{1-h}{1+h}\left(\hat{\tilde{\lambda}}_t^{cc} + \frac{1}{1-h}\hat{\tilde{C}}_t - \frac{h}{1-h}\hat{\tilde{C}}_{t-1} + \hat{R}_t\right). \end{aligned} \quad (55)$$

The borrower's *budget constraint* is

$$\begin{aligned}\bar{\tilde{C}}\hat{\tilde{C}}_t = & \bar{\tilde{B}}(\hat{\tilde{B}}_t - \hat{P}_{C,t}) - \frac{\bar{\tilde{B}}}{\beta}(\hat{R}_{t-1} - \pi_{C,t} + \hat{\tilde{B}}_{t-1} - \hat{P}_{C,t-1}) \\ & + \bar{W}_C(1-\Delta_H)\bar{\tilde{L}}(\hat{\tilde{L}}_{C,t} + \hat{W}_{C,t} - \hat{P}_{C,t}) + \bar{W}_H\Delta_H\bar{\tilde{L}}(\hat{\tilde{L}}_{H,t} + \hat{W}_{H,t} - \hat{P}_{C,t}) - \bar{H\tilde{I}}(\hat{q}_t + \hat{H\tilde{I}}_t).\end{aligned} \quad (56)$$

The *evolution of debt* is described by

$$\hat{\tilde{B}}_t - \hat{P}_{C,t} = \hat{\tilde{H}}_t + E_t\hat{q}_{t+1} - (\hat{R}_t - E_t\pi_{C,t+1}). \quad (57)$$

For *housing* it holds true that

$$\begin{aligned}-\hat{\tilde{H}}_t + \frac{1}{1-h}\hat{\tilde{C}}_t - \frac{h}{1-h}\hat{\tilde{C}}_{t-1} = & \tilde{\Phi}^{-1}(1-\delta)\Big\{\tilde{\Gamma}\hat{q}_t - \tilde{\beta}E_t\hat{q}_{t+1} + \beta(\hat{R}_t - E_t\pi_{C,t+1}) \\ & +(\beta-\tilde{\beta})\left[\chi\left(\hat{\tilde{\lambda}}_t^{cc} + \frac{1}{1-h}\hat{\tilde{C}}_t - \frac{h}{1-h}\hat{\tilde{C}}_{t-1}\right) - \hat{\xi}_t\right]\Big\},\end{aligned} \quad (58)$$

$$\text{where} \quad \tilde{\Phi} = 1-(1-\delta)[\tilde{\beta} + (1-\chi)(\beta-\tilde{\beta})], \quad (59)$$

$$\tilde{\Gamma} = \frac{1-(1-\chi)(1-\delta)(\beta-\tilde{\beta})}{(1-\delta)}, \quad (60)$$

and $\hat{\xi}_t$ is a composite inflation term which is defined as $\hat{\xi}_t = (1-\chi)(E_t\hat{q}_{t+1} - \hat{q}_t) - \chi E_t\pi_{C,t+1}$. The *accumulation equation of the housing stock* is determined by $\hat{\tilde{H}}_t = \delta\hat{H\tilde{I}}_t + (1-\delta)\hat{\tilde{H}}_{t-1}$.

The *labor supply equations* are

$$\frac{1}{1-h}\hat{\tilde{C}}_t - \frac{h}{1-h}\hat{\tilde{C}}_{t-1} + ((\varphi-\iota_L)(1-\Delta_H)+\iota_L)\hat{\tilde{L}}_{C,t} + (\varphi-\iota_L)\Delta_H\hat{\tilde{L}}_{H,t} = \hat{W}_{C,t} - \hat{P}_{C,t}, \tag{61}$$

$$\frac{1}{1-h}\hat{\tilde{C}}_t - \frac{h}{1-h}\hat{\tilde{C}}_{t-1} + ((\varphi-\iota_L)\Delta_H+\iota_L)\hat{\tilde{L}}_{H,t} + (\varphi-\iota_L)(1-\Delta_H)\hat{\tilde{L}}_{C,t} = \hat{W}_{H,t} - \hat{P}_{C,t}. \tag{62}$$

A.2.3 Firms

The *technologies* are given by $\hat{Y}_{j,t} = \hat{L}^{tot}_{j,t}$ (for $j = C, H$). *Real marginal costs* are $\hat{mc}_{j,t} = \hat{W}_{j,t} - \hat{P}_{j,t}$. The *evolution of inflation* in both sectors takes the form of a forward-looking New Keynesian Phillips curve $\pi_{j,t} = \beta E_t \pi_{j,t+1} + \kappa_j \hat{mc}_{j,t}$, where $\kappa_j = \frac{(1-\theta_j)(1-\beta\theta_j)}{\theta_j}$. *Sectoral prices* are defined as $\hat{P}_{j,t} = \pi_{j,t} + \hat{P}_{j,t-1}$. The *real house price* is $\hat{q}_t = \hat{P}_{H,t} - \hat{P}_{C,t}$.

A.2.4 Market clearing and monetary policy

The *debt market equilibrium condition* is described by $\hat{\tilde{B}}_t = \hat{B}_t$. The *labor market equilibrium conditions* are

$$\bar{L}^{tot}_C \hat{L}^{tot}_{C,t} = \omega \bar{\tilde{L}}_C \hat{\tilde{L}}_{C,t} + (1-\omega)\bar{L}_C \hat{L}_{C,t} \tag{63}$$

$$\text{and} \quad \bar{L}^{tot}_H \hat{L}^{tot}_{H,t} = \omega \bar{\tilde{L}}_H \hat{\tilde{L}}_{H,t} + (1-\omega)\bar{L}_H \hat{L}_{H,t}. \tag{64}$$

The *goods market equilibrium condition* is

$$\hat{Y}_t = (1-\Delta_H)\hat{Y}_{C,t} + \Delta_H \hat{Y}_{H,t}, \tag{65}$$

$$\text{where} \quad \bar{Y}_C \hat{Y}_{C,t} = \omega \bar{\tilde{C}} \hat{\tilde{C}}_t + (1-\omega)\bar{C}\hat{C}_t, \tag{66}$$

$$\text{and} \quad \bar{Y}_H \hat{Y}_{H,t} = \omega \bar{\tilde{H}I} \hat{\tilde{H}I}_t + (1-\omega)\bar{H}I\hat{H}I_t. \tag{67}$$

The *central bank* sets interest rates according to a Taylor-type rule

$$\hat{R}_t = \mu_R \hat{R}_{t-1} + (1-\mu_R)(\mu_\pi \pi_{C,t} + \mu_Y \hat{Y}_t) + u^R_t. \tag{68}$$

B Sensitivity analysis

In this section we present our calibration strategy for the parameters governing the formation of expectations and present some sensitivity analysis. For the calibration of the behavioral parameters we proceed as follows. We set $E_t C_{t+1} = 0$, $E_t \tilde{C}_{t+1} = 0$, $E_t \pi_{C,t+1} = 0$ and compute the correlation coefficient of $\alpha^q_{opt,t}$ and $\hat{q}_t$ as a function of the behavioral 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 7 we report how the correlation coefficient depends on the most important parameters, namely, the intensity of choice, γ, the sensitivity parameter in the divergence in beliefs, δ_d, and the memory, ρ. In particular, we report the average correlation coefficient (obtained by simulating the model 1000 times, each time over 800 periods) as a function of these behavioral parameters relative to the baseline calibration.

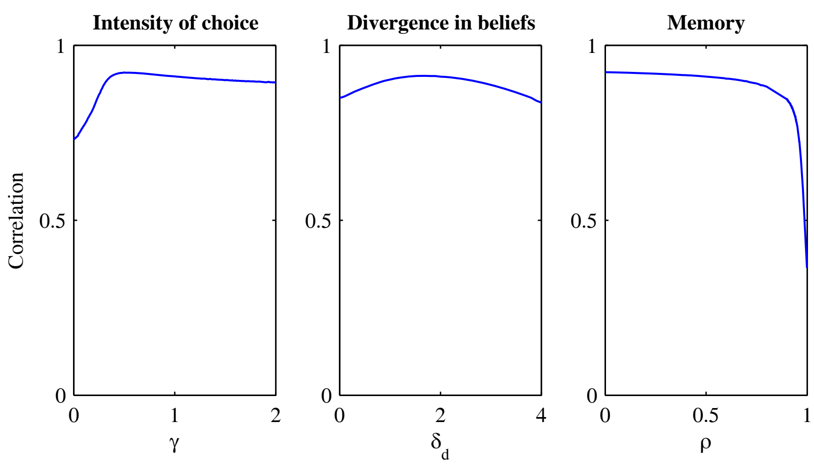

Figure 7: Real house prices and animal spirits.

A key parameter in the selection mechanism is the intensity of choice. For higher values of γ a higher portion of agents uses the better performing forecasting rule. The left panel illustrates that even for small values of γ there exists a high correlation between the fraction of real house price optimists and the real house price. We choose to set $\gamma = 1$. The parameter δ_d measures the sensitivity of the divergence in beliefs between optimists and pessimists to the unconditional volatility of real house prices. The middle panel shows that for $\delta_d = 2$ the correlation reaches its maximum level. If $\delta_d > 2$, the correlation deteriorates. This can be explained as follows. Given a high divergence in beliefs (high δ_d), the penalty is high when agents make wrong forecasts. As a consequence, agents change beliefs more quickly and waves of optimism and pessimism that drive house prices are less likely to occur. The parameter ρ determines the memory of agents when they evaluate the forecasting performances of the rules. If ρ decreases, the memory of agents decreases and agents give more weight to recent observations. The right panel illustrates that for a minimum degree of forgetfulness a high correlation between $\alpha^q_{opt,t}$ and $\hat{q}_t$ occurs. Only for a very long memory (when ρ approaches 1) the link between the way agents form expectations on future real house prices and real house price becomes less important.

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