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

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Abstract

Can temporary departures from the Taylor rule trigger pronounced boom-bust cycles in house prices and create persistent business cycles? We address this question by building behavioral mechanisms into an otherwise standard DSGE model. By applying heuristics to take account of cognitive limitations of agents, waves of optimism and pessimism drive house prices, which, in turn, have repercussions on the real economy. Persistent boom-bust cycles cannot be explained in the DSGE counterpart model. Our findings suggest that a standard Taylor rule is not suited to maintain output stability in the wake of monetary policy shocks. Instead, an augmented rule that incorporates house prices or debt is shown to be superior.

Keywords: Animal spirits, house prices, monetary policy.

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1 Introduction

Can temporary departures from the Taylor rule trigger pronounced boom-bust cycles in house prices and create persistent business cycles? We adress this question by building a behavioral macroeconomic model following the approach by De Grauwe (2010). In particular, we incorporate the notion of agents using heuristics to form their expectations that is well established in a large body of literature of behavioral finance (Brock and Hommes, 1997; Lux and Marchesi, 2000; De Grauwe and Grimaldi, 2006) into a dynamic stochastic general equilibrium (DSGE) model along the lines of Campbell and Hercowitz (2005), Iacoviello (2005), Monacelli (2009) and Calza et al. (2009).

The aim of this paper is to provide a qualitative analysis of the relationship between monetary policy actions, the housing market and the real economy when agents have cognitive limitations. The reason to do so are threefold. First, the Greenspan easing in the early 2000s and the parallel boom in US house prices has led many to raise concern that the lax interest rate policy was an important driving force of the housing boom. Second, the extreme scale of the house price increase and its sharp decline afterward suggests that, beyond fundamental factors, behavioral mechanisms have to be taken into account to explain the large fluctuations in house prices. Third, from a modeling point of view, the notion of cognitive limited agents is substantial because the standard literature on DSGE models assumes agents to built rational expectations on the future track of the economy which implies that agents understand the underlying structure of the economy and use all available information when they make decisions.

Key to our approach is that we assume agents to use biased heuristics (rules) to form expectations on the future evolution of house prices. For simplicity, we assume agents to choose among either an optimistic or a pessimistic forecasting rule. Thus, at each point in time some agents bias the future house price upward, while others bias the future house price downward. Following De Grauwe (2010), although, we suspend the notion of rational expectations, agents are assumed to behave rational in the sense that they adaptively learn from their forecasting errors and are willing to switch among forecasting rules (see also Anderson et al., 1996; Brock and Hommes, 1997). As agents switch from one heuristic to the other depending on the forecast performance in the past, the fraction of optimists (pessimists) endogenously varies over time. Agents that were pessimistic (optimistic) about the further track of the housing cycle might learn that their beliefs were wrong.

Depending on their willingness to change their mind, they might take this experience as a reason to change their beliefs and form optimistic (pessimistic) expectations 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 across agents happens, expectations on strong (weak) house prices can initiate a sustaining house price boom (bust).

Our DSGE modeling framework is along the lines of Campbell and Hercowitz (2005), Iacoviello (2005), Monacelli (2009), Calza et al. (2009), and Iacoviello and Neri (2010), among others. On the supply side it features two sectors, producing consumption goods and new homes. On the demand side, it consists of two types of agents (households), namely savers and borrowers, where the latter is subject to a collateral constraint tied to the expected present value of its housing stock. As borrowers are more impatient than savers, debt is generated in equilibrium with borrowers being up to their borrowing limit.

The collateral constraint has important implications for the dynamics of our behavioral model. As expectations on the future value of the housing stock determines the amount of borrowing, changes in beliefs on the future track of house prices directly alters credit availability, which, in turn, has repercussions on the real economy. Consider, for the sake of argument, a monetary policy loosening. When house prices are more flexible than consumption goods prices, a monetary policy loosening causes the real house price to increase. With rising real house prices, some households will take this experience as a reason to switch from pessimism to optimism on the future track of house prices. If a sufficient fraction of households switch to the optimistic forecasting rule, a self-fulfilling wave of optimism on house prices translates via the collateral constraint into a broader macroeconomic boom. Wider credit availability allows borrowers to expand consumption and investment in houses. Thus, when demand rises, prices increase which reinforce households to be optimistic on future house prices.

Our modeling approach succeeds well in terms of generating endogenous cycles in economic activity. Key to our success are three factors. First, it is a stylized fact that prices in the durable sector are more flexible than prices in the consumption sector. We succeed to replicate very persistent changes in relative prices between the durable and non-durable sector of the economy. The evolution of housing prices leads the business cycle while prices in the consumer sector only gradually follow. Second, monetary authorities follow a standard Taylor rule that predominantly response to the evolution of the overall inflation rate. In particular, in the early stage of the house price boom, given the relative irrelevance of the housing sector, the overall inflation rate remains low such that the monetary policy is accommodative. Only when consumer spending starts to accelerate, the overall inflation rate gradually increases. Thus, the flat slope of the Phillips curve in the non-durable sector is the second key ingredient to generate persistent boom-bust cycles. Third, our model approach hinges on the collateral constraint mechanism which states that increases of the value of collateral are transformed into credit. Thereby a credit driven boom is initiated. Potentially opposing channels such as that house prices in relation to consumer prices are relatively expensive which subdues demand for new houses are only of minor importance.

Given that monetary shocks might trigger long lasting cycles, we explore the implications for monetary policy and illustrate to what extend an augmented Taylor rule has its merits. Our findings suggest that there is a meaningful role for augmented Taylor rules as they potentially rule out that monetary policy itself might become a major source of economic disturbance. In particular a rule that responds to the evolution of credit volumes seems promising. We provide evidence that a DSGE counterpart model comes to the same conclusions but underestimates quantitatively the benefits of augmented rules. In comparison the behavioral model is able to mimic eruptive and sustained endogenous outbreaks of asset prices which the DSGE model cannot. This difference between the models leads to quantitatively important differences in terms of policy recommendations to augment the Taylor rule.

The paper is structured as follows. In the next section we illustrate the model and the heuristics on which agents condition their actions. In section 3 we provide the implied business cycle dynamics. In section 4, we show that an augmented Taylor rule is well suited to limit the detrimental impact of monetary shocks on the economy.

2 A behavioral macroeconomic model

In this section we follow the approach by De Grauwe (2010) and build a behavioral macroeconomic model that allows for cognitive limitations of agents to study the effects of monetary policy shocks on house prices and business cycle fluctuations. In a first step, we present the model economy of the DSGE framework. In a second step, we specify the formation of agents' expectations and illustrate how endogenous and self-fulfilling waves of optimism and pessimism on future house prices are generated.

2.1 The DSGE framework

The model economy is a variant of the standard New Keynesian model (e.g. Goodfriend and King (1997)) along the lines of Campbell and Hercowitz (2005), Iacoviello (2005), Monacelli (2009) and Calza et al. (2009). In a seminal paper, Iacoviello (2005) enhances a two-sector NK model to allow for nominal debt and collateral constraints tied to housing stocks and stresses their role in business fluctuations. In this model, agents with different discount rates trade nominal debt in equilibrium, whereas the debt level of borrowers is endogenously determined by the expected present value of their housing stock times a loan to value ratio (LVT).

Firms. There is a two-sector economy ($j = c, d$), producing nondurable goods and housing. In each sector a perfectly competitive final good producer purchases units of the intermediate goods i and bundles them according to the following technology

$$Y_{j,t} = \left(\int_0^1 Y_{j,t}(i)^{\frac{\epsilon_j - 1}{\epsilon_j}} di \right)^{\frac{\epsilon_j}{\epsilon_j - 1}}, \qquad \epsilon_j > 1, j = c, d, \tag{1}$$

where $Y_{j,t}$ is the final good in the sector j, $Y_{j,t}(i)$ is the intermediate goods indexed by $i \in (0,1)$, and ϵ_j is the elasticity of substitution between the different types of the intermediate goods. The maximization of profits leads to the demand for the intermediate good i

$$Y_{j,t}(i) = \left(\frac{P_{j,t}(i)}{P_{j,t}} \right)^{-\epsilon_j} Y_{j,t}, \qquad j = c, d, \tag{2}$$

where $P_{j,t}(i)$ is the price of the intermediate good i, and $P_{j,t}$ represents the price of the final good. With profits being zero in equilibrium, the price of the final good is given by

$$P_{j,t} = \left(\int_0^1 P_{j,t}^{(1-\epsilon_j)}(i) di \right)^{\frac{1}{1-\epsilon_j}}, \qquad j = c, d. \tag{3}$$

In each sector intermediate goods are produced by monopolistically competitive firms according to the following linear production function

$$Y_{j,t}(i) = N_{j,t}(i), \qquad j = c, d, \tag{4}$$

where $N_{j,t}(i)$ represents total labor input. In each sector intermediate goods producers are constrained by a Calvo-type staggered price setting framework. In each period, a fraction $(1-\theta_j)$ of firms is allowed to reset prices optimally. The intermediate good producer, that receives permission to adjust prices, chooses his price to maximize his expected discounted sum of nominal profits taking the demand curve as given. In each sector, the optimal price of producer i in period t is given by

$$P^{**}_{j,t}(i) = \left(\frac{\epsilon_j}{\epsilon_j - 1}\right) \frac{E_t \sum_{k=0}^{\infty} (\theta_j \beta)^k MU^j_{t+k} P^{(\epsilon_j - 1)}_{j,t+k} MC_{j,t+k}(i) Y_{j,t+k}}{E_t \sum_{k=0}^{\infty} (\theta_j \beta)^k MU^j_{t+k} P^{\epsilon_c - 1}_{j,t+k} Y_{j,t+k}}, \qquad j = c, d, \tag{5}$$

where MU^j_{t+k} is the marginal utility of nondurable ($j = c$) and durable ($j = d$) consumption of the owners of firms, and $MC_{j,t+k}(i)$ stands for the marginal costs of production and is defined as

$$MC_{j,t+k}(i) = \frac{W_{t+k}}{\partial Y_{j,t+k}(i)/\partial N_{j,t+k}(i)} = W_{t+k}, \qquad j = c, d, \tag{6}$$

where W_t is the nominal wage, which is assumed to be equal across sectors. Following Gali et al. (2001), firms who are able to reset prices are further separated into two groups. Only a fraction $(1-\omega_j)$ of firms sets prices optimally, while the remaining fraction ω_j indexes prices according to a backward looking rule of thumb

$$P^{index}_{j,t}(i) = P^*_{j,t-1} \frac{P_{j,t-1}}{P_{j,t-2}}, \qquad j = c, d, \tag{7}$$

where $P^*_{j,t-1}$ is the average reset price and $P_{j,t-1}$ is the aggregate price level. The reset price $P^*_{j,t}$ in each sector evolves as

$$P^*_{j,t} = P^{**(1-\omega_j)}_{j,t} P^{index(\omega_j)}_{j,t}, \qquad j = c, d. \tag{8}$$

The aggregate price level is given by

$$P_{j,t} = \left[\theta_j (P_{j,t-1})^{(1-\epsilon_j)} + (1-\theta_j)(P^*_{j,t})^{(1-\epsilon_j)}\right]^{\frac{1}{1-\epsilon_j}}, \qquad j = c, d. \tag{9}$$

Households. There is a continuum of infinitely-lived households indexed by $h \in (0,1)$ who receive utility from consumption of nondurable goods and housing and disutility from labor supply. Households belong to two different groups according to their intertemporal discount factor. A fraction $(1-\omega)$ of households is relatively more patient and is labeled as savers. The remaining fraction ω of households is relatively impatient and is named as borrowers. The assumption of different discount factors guarantees that private debt is generated in equilibrium as a result of intertemporal borrowing between the two groups of households. To avoid that impatient households accumulate debt indefinitely, they are restricted to a collateral constraint. In particular, the borrowing value is tied to the expected value of the housing stock. This has two implications. First, besides providing instantaneous and future utility, housing allows households to borrow against its value. Second, as the ability of borrowing depends on the future price of housing, asset price fluctuations feedback into the economy through varying the borrowing capacity of debtors and with it the demand for nondurable goods and housing.

Savers. The saver h maximizes his expected lifetime utility in each period t

$$E_t \sum_{k=0}^{\infty} \beta^k U_{t+k}(h), \tag{10}$$

where E_t is the expectation operator conditional on information up to time t, $\beta \in (0,1)$ is the saver's discount factor, and $U_t(h)$ is the period utility function, which is separable in consumption and labor and is described by

$$U_t(h) = (1-\alpha)log(C_t(h)) + \alpha log(D_t(h)) - \frac{1}{2}N_t(h)^2, \tag{11}$$

where $D_t(h)$ denotes the housing stock at the end of the period t, $C_t(h)$ stands for the consumption of nondurable goods and services and $N_t(h)$ describes labor supply.[1] In period t, the saver h decides on $\{C_{t+k}(h), D_{t+k}(h), N_{t+k}(h), B_{t+k}(h)\}_{k=0}^{\infty}$ to maximize his expected utility function subject to the budget constraint and the accumulation equation for the housing stock. The period budget constraint is given by

$$P_{c,t}C_t(h) + P_{d,t}X_t(h) + R_{t-1}B_{t-1}(h) = B_t(h) + W_tN_t(h) + \Gamma_{c,t}(h) + \Gamma_{d,t}(h) + \Xi_t(h). \tag{12}$$

It is assumed that $P_{c,t}$ is the price of one unit of the nondurable good, $P_{d,t}$ is the price of one unit of houses, $X_t(h)$ is real residential investment in period t, $B_t(h)$ is the end-of-period

[1] Note that our specification of the period utility function excludes habit persistence and assumes that both the inverse elasticity of labor supply and the coefficient of relative risk aversion is one.

nominal one-period debt, R_{t-1} is the gross nominal lending rate of contracts entered in period $t-1$, $\Gamma_{c,t}(h)$ and $\Gamma_{d,t}(h)$ are the aggregate nominal profits from the owning of the monopolistic competitive firms in sector c and d, and $\Xi_t(h)$ is a stream of income coming from state-contingent claims. In real terms (units of the nondurable goods) the budget constraint reads

$$C_t(h) + q_t X_t(h) + R_{t-1}\frac{b_{t-1}(h)}{\Pi_t^c} = b_t(h) + \frac{W_t}{P_{c,t}}N_t(h) + \frac{\Gamma_{c,t}(h)}{P_{c,t}} + \frac{\Gamma_{d,t}(j)}{P_{c,t}} + \frac{\Xi_t(h)}{P_{c,t}}, \quad (13)$$

where $q_t = \frac{P_{d,t}}{P_{c,t}}$ is the relative price of a unit of housing, b_{t-1} is real debt, and $\Pi_t^c = \frac{P_{c,t}}{P_{c,t-1}}$ depicts the gross inflation rate of nondurable goods. The accumulation equation for the housing stock is

$$D_t(h) = X_t(h) + (1-\delta)D_{t-1}(h), \quad (14)$$

where δ is the depreciation rate. Let $MU_t^c(h) = \frac{\partial U_t(h)}{\partial C_t(h)}$ be the marginal utility of an additional unit of nondurable consumption, $MU_t^N(h) = \frac{\partial U_t(h)}{\partial N_t(h)}$ the marginal disutility of an additional unit of labor supply, λ_t the Lagrange multiplier on the budget constraint (13) and γ_t the Lagrange multiplier on the accumulation equation of the housing stock (14), the corresponding set of first-order conditions are

$$\lambda_t = MU_t^c, \quad (15)$$

$$\frac{\gamma_t}{MU_t^c} = q_t, \quad (16)$$

$$-\frac{MU_t^N}{MU_t^c} = \frac{W_t}{P_{c,t}}, \quad (17)$$

$$MU_t^c = \beta E_t\left(MU_{t+1}^c \frac{R_t}{\Pi_{t+1}^c}\right). \quad (18)$$

Borrowers. The borrower h decides on $\{\tilde{C}_{t+k}(h), \tilde{D}_{t+k}(h), \tilde{N}_{t+k}(h), \tilde{B}_{t+k}(h)\}_{k=0}^{\infty}$ to maximize his expected utility function

$$E_t \sum_{k=0}^{\infty} \tilde{\beta}^k \tilde{U}_{t+k}(h), \quad (19)$$

subject to his budget constraint

$$\tilde{C}_t(h) + q_t\tilde{X}_t(h) + R_{t-1}\frac{\tilde{b}_{t-1}(h)}{\Pi_{c,t}} = \tilde{b}_t(h) + \frac{W_t}{P_{c,t}}\tilde{N}_t(h) + \frac{\tilde{\Xi}_t(h)}{P_{c,t}}, \quad (20)$$

the accumulation equation of the housing stock

$$\tilde{D}_t(h) = \tilde{X}_t(h) + (1-\delta)\tilde{D}_{t-1}(h), \tag{21}$$

and the collateral constraint, which is given in nominal terms by

$$R_t \tilde{B}_t(h) \leq (1-\chi)(1-\delta)E_t\{\tilde{D}_t(h)P_{d,t+1}\}. \tag{22}$$

The parameter $\chi \in (0,1)$ is the fraction of the housing stock that cannot be used as collateral. According to Iacoviello (2005), it is assumed that equation (22) is binding in the neighborhood of the deterministic steady state. In real terms (units of nondurable goods) the collateral constraint reads

$$\tilde{b}_t(h) = (1-\chi)(1-\delta)E_t\left\{\frac{\tilde{D}_t(h)q_{t+1}}{R_t/\Pi^c_{t+1}}\right\}. \tag{23}$$

The set of first-order conditions to the maximization problem of the borrower is given by

$$\tilde{\lambda}_t = \widetilde{MU}^c_t, \tag{24}$$

$$\frac{\tilde{\gamma}_t}{\tilde{MU}^c_t} = q_t, \tag{25}$$

$$-\frac{\widetilde{MU}^N_t(h)}{\widetilde{MU}^c_t} = \frac{W_t}{P_{c,t}}, \tag{26}$$

$$\widetilde{MU}^c_t = \tilde{\beta}E_t\left(\widetilde{MU}^c_{t+1}\frac{R_t}{\Pi^c_{t+1}}\right) + R_t\widetilde{MU}^c_t\tilde{\phi}_t, \tag{27}$$

where $\tilde{\phi}_t$ is the Lagrange multiplier on the collateral constraint.

Market clearing and monetary policy. The final good markets $j = c, d$ are in equilibrium, if the following holds

$$Y_{total,t} = Y_{c,t} + Y_{d,t} = C_{total,t} + X_{total,t} = \omega\tilde{C}_t + (1-\omega)C_t + \omega\tilde{X}_t + (1-\omega)X_t. \tag{28}$$

The market clearing condition in the labor market is

$$N_{total,t} = \omega\tilde{N}_t + (1-\omega)N_t = N_{c,t} + N_{d,t}. \tag{29}$$

For the debt market it holds that

$$\int_0^1 B_t(h)dh = \omega\tilde{B}_t + (1-\omega)B_t = 0. \tag{30}$$

To close the model, it is assumed that the central bank follows a Taylor-type interest rate rule

$$R_t = R_{t-1}^{\mu_R}\left(\bar{R}\left(\frac{\Pi_t}{\bar{\Pi}}\right)^{\mu_\pi}\left(\frac{Y_{total,t}}{\bar{Y}_{total}}\right)^{\mu_Y}\right)^{(1-\mu_R)} exp(u_{R,t}), \tag{31}$$

where $\bar{R}$ stands for the steady state gross nominal interest rate, Π_t is a composite inflation index defined as $\Pi_t = \Pi_t^{c(1-\alpha)}\Pi_t^{d(\alpha)}$, $\bar{\Pi}$ represents the steady state gross inflation rate, and $u_{R,t}$ is a white noise monetary policy shock with zero mean and variance $\sigma^2_{u_R}$.

2.2 Formation of expectations

In a standard DSGE framework, it is assumed that households form rational expectations about the future value of economic variables. When households build rational expectations, their forecast error is zero on average, that is, their predictions are not systematically biased. In contrast, we departure from the notion of rational expectations and follow the approach of De Grauwe (2010). In this model, agents are assumed to formulate simple rules (heuristics) to predict future values of economic variables. However, agents are able to learn from the history of their forecast errors in an adaptive way, which implies that agents switch between different heuristics whenever they judge to do so. Agents endogenously choose the heuristic that is assumed to be the best forecast rule given its performance in the past. De Grauwe (2010) shows that the specification of animal spirits in an otherwise standard NK model is able to generate endogenous waves of biased beliefs and endogenous business cycles.

In our model, there are two different heuristics about future housing prices. While other households are optimistic and systematically predict the housing price upwards, some households are pessimistic and predict the housing price downward. We assume homogeneity in each camp, irrespectively whether the household is a saver or a borrower. The heuristics are formulated over housing prices and read

$$\tilde{E}_t^{opt}\hat{P}_{d,t+1} = g_t, \tag{32}$$

$$\tilde{E}_t^{pes}\hat{P}_{d,t+1} = -g_t, \tag{33}$$

where $\hat{P}_{d,t}$ denotes the log-deviation of the housing price from its steady state value and $g_t > 0$ expresses the degree of bias in the house price forecasts. The degree of bias is time-varying and is defined as $g_t = \frac{d_t}{2}$, where d_t is the absolute divergence in beliefs that is

$$d_t = \beta_d + \delta_d \sigma(\hat{P}_{d,t}), \tag{34}$$

where $\beta_d > 0$ is a fixed component, $\delta_d \geq 0$ is a parameter governing the variable component of the divergence of beliefs $\sigma(\hat{P}_{d,t})$, which is the standard deviation of housing prices conditioned over an window of past observations. The logic behind this formulation is quite intuitive. If volatility of house prices is high, uncertainty about future prices rises, and the forecasts of the heuristics diverge more. The aggregate forecast is defined as a weighted average of the heuristics and reads

$$\begin{aligned} \tilde{E}_t \hat{P}_{d,t+1} &= \alpha_{opt,t} \tilde{E}_t^{opt} \hat{P}_{d,t+1} + \alpha_{pes,t} \tilde{E}_t^{pes} \hat{P}_{d,t+1}, \qquad (35) \\ \tilde{E}_t \hat{P}_{d,t+1} &= \alpha_{opt,t}\, g_t - \alpha_{pes,t}\, g_t, \end{aligned}$$

and

$$\alpha_{opt,t} + \alpha_{pes,t} = 1, \tag{36}$$

where $\alpha_{opt,t}$ is the probability that an agent chooses the optimistic heuristic, while $\alpha_{pes,t}$ is the probability that an agent chooses the pessimistic rule. These probabilities are time-varying and related to the forecast performance of the heuristics in the past. The probabilities are defined as

$$\alpha_{opt,t} = \frac{exp(\gamma U_{opt,t})}{exp(\gamma U_{opt,t}) + exp(\gamma U_{pes,t})}, \tag{37}$$

$$\alpha_{pes,t} = \frac{exp(\gamma U_{pes,t})}{exp(\gamma U_{opt,t}) + exp(\gamma U_{pes,t})}, \tag{38}$$

where $U_{opt,t}$ and $U_{pes,t}$ are the mean squared forecasting errors (MSFEs) of the two rules and γ is the intensity of choice parameter. It governs how intense agents rely on the MSFEs when they choose the rule to forecast future house prices. If $\gamma = 0$, agents do not evaluate the forecast performance of the heuristics when they decide to be optimistic or pessimistic. The probability of being optimistic or pessimistic is then 0.5. If $\gamma = \infty$, all agents decide either to be optimistic or to be pessimistic depending on the heuristic with the best performance.

$$U_{opt,t} = -\sum_{k=1}^{z} \omega_k \left[\hat{P}_{d,t-k} - \tilde{E}^{opt}_{t-k-1} \hat{P}_{d,t-k} \right]^2, \tag{39}$$

$$U_{pes,t} = -\sum_{k=1}^{z} \omega_k \left[\hat{P}_{d,t-k} - \tilde{E}^{pes}_{t-k-1} \hat{P}_{d,t-k} \right]^2, \tag{40}$$

where z measures the length of the evaluation period, and ω_k are geometrically declining weights.

In order to simulate the model we apply the following solution strategy. First, we compute a log-linear approximation of the model in section 2.1 around a nonstochastic steady-state.[2] Second, we substitute the expectation operators for the housing price gap by the heuristics as specified in section 2.2. For the case of consumer price inflation, we assume that the central bank is perfectly credible in the sense that inflation expectations by households are anchored by the central bank's inflation target, which is assumed to be zero.[3] Additionally, income expectations are set to zero to rule out that endogenous cycles are triggered by income expectations. Third, the solution of the model reads

$$\mathbf{Z_t} = \mathbf{A^{-1}} \left(\mathbf{B\tilde{E}_t Z_{t+1}} + \mathbf{CZ_{t-1}} + \mathbf{V_t} \right), \tag{41}$$

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

3 Calibration

When we calibrate the model we apply parameter values such that time units are considered to be quarters. The discount rate of the savers β is assumed to be 0.99, implying a discount rate of 4% annually. The corresponding parameter value for the borrowers $\tilde{\beta}$ is 0.97. The share of borrowers is 50%, that is, $\omega = 0.5$. The annual depreciation rate for housing is assumed to be 4% per year, which implies $\delta = 0.01$. The parameter χ is set at

[2]For a complete description of the log-linear model see Appendix A.

[3]Note that we additionally conducted sensitivity analysis where only a fraction of agents belief in the central bank's inflation target, while the remaining fraction simply extrapolates past inflation. We found that in an environment with low inflation variability all results reported remain unchanged for our baseline calibration.

0.25, which means that 25% of the expected housing value cannot be used as collateral. The elasticities of demand for the intermediate goods are $\epsilon_j = 6$ for $j = c, d$, to yield a steady-state mark-up of 20% in each sector. We assume that nondurable goods prices are sticky, while house prices exhibit a moderate degree of price stickiness. We set θ_c such that consumer prices are reset every ten quarters, implying $\theta_c = 0.9$, and assume that house prices are reset every 1.4 quarters, so that $\theta_d = 0.3$. The degree of price indexation ω_j is assumed to be zero in each sector. The economic size of residential investment in total output $\Delta_{\bar{D}}$ is 6%. The steady state values of hours worked are assumed to be equal across households. It holds that $\bar{\tilde{N}} = \bar{N} = 1/3$. The weight of the housing stock α in the period utility function of households is numerically determined such that the steady state share of housing in total output is 6%. As for monetary policy, it is assumed that $\mu_R = 0.75$, $\mu_\pi = 1.5$, and $\mu_Y = 0.5$. Turning to the modeling of heuristics, we assume that both the intensity of choice γ and the fixed component of the divergence in beliefs β_d is one. Furthermore, $delta_d$ is assumed to be two. Finally, the parameter governing the memory of agents ρ is set to 0.50 and the evaluation period z is 20.

4 Animal spirits and semi-endogenous business cycles

In the following section we study the business cycle dynamics of our model and shed some light on the importance of the role of cognitive limitations of agents for the persistence of output.

4.1 Animinal spirits and monetary policy shocks

Figure 1 highlights the dynamics of the model for an arbitrary draw of interest rate shocks. Interest rate shocks reflect departures from rule based behavior. As many feel that the last boom-bust cycle in the US-economy was triggered by a loose monetary policy in the years 2002-2004, we analyze to what extend a temporary departure from the Taylor rule can be a candidate to trigger persistent cycles.

Although the model is only driven by white noise shocks, it is able to generate very persistent cycles which its DSGE counterpart model cannot. To be more concrete, we observe that around quarter 755 the economy is hit by a sequence of negative interest rate shocks which increase housing prices. In the vague of this negative shocks those households that were optimistic on housing prices gain on ground as their forecast performance improves, while the forecast performance of those that expected decreasing housing prices sharply deteriorates. This has macroeconomic implications as revisions in expectations are highly correlated among households. As the wave of optimism on housing markets gains on ground, they trigger self-fulfilling expectations over the Phillips curve in the durable sector of the economy. Thereby a sustained upturn in housing prices is geared. As prices in the nondurable sector are substantially stickier than in the housing sector, real house prices sharply rise in the early stage of the economic boom. In our simulations the real price of housing is high for about 30 quarters. The asset price channel implies that collateral constrained consumers expand their debt as real house prices rise, which, in turn, boosts their demand for consumption goods and residential investment. Additionally, in the environment of low interest rates at the early stage of the boom consumption of creditors is high as their incentive to postpone consumption is low. In total, the simulation illustrates that these effects are sufficient to engineer a sustained boom in total output. Due to the rise in consumer spending, firms that operate in the nondurable goods sector have to expand production. Those firms that are able to reset prices adjust them upwards as response to the rise in consumer spending. Only gradually endogenous mechanisms lead to a turnaround in the business cycle. The central bank which is assumed to follow a standard Taylor rule reacts to the positive output gap and the rise in inflation rates by increasing the real rate of interest. Thereby the central bank dampens consumption of households as their incentive to postpone consumption into the future increases. Moreover, higher real interest rates tightens the collateral constraint of borrowers such that their demand for housing and consumption goods decreases even further. Furthermore, as the real house price is high, savers decrease their demand for housing. Both effects, higher real interest rates and the high real house prices, trigger a downturn of the economy. As production in the durable sector lowers, prices start to move back towards a balanced cycle. At a certain point this leads to a significant improvement in the heuristic of those households which expect house prices to decrease. Thereby expectations on lowering prices in housing markets starts a new wave of pessimism which leads to a new housing driven cycle as the balance sheet positions of collateral constraint consumers deteriorates.

Key to the endogenous housing boom-bust cycle is the relative degree of price stickiness in the housing vs. nondurable goods sector. We observe that the amplitude of housing prices is much higher than the amplitude in consumer prices and importantly that housing prices lead consumer prices, which is a direct result of the more flexible durable prices. As the housing sector only makes up for round about 6 percent of the economy the central bank does not care on housing inflation at the early stage of the cycle as its impact on the overall inflation rate is negligible. Only when a boom in the nondurable goods sector is triggered the central bank starts to step in as consumer price inflation starts to rise. The existence of distinct boom-bust cycle hinges on three factors. First, the housing sector and the housing price inflation only plays a minor role for total output and for the overall inflation rate on which the central bank reacts. Thereby the central bank largely remains accommodative at the early stages of the boom. Second, in a sticky price environment with flat Phillips curves, pronounced output cycles only have a mild impact on the inflation cycle. But given a Taylor rule, inflation is the most important argument for the central bank to change the real rate of interest. This creates an environment which increases the propensity for long boom-bust cycle. Third, the collateral effect needs to dominate the relative price effect such that the economy follows the waves of optimism and pessimism.

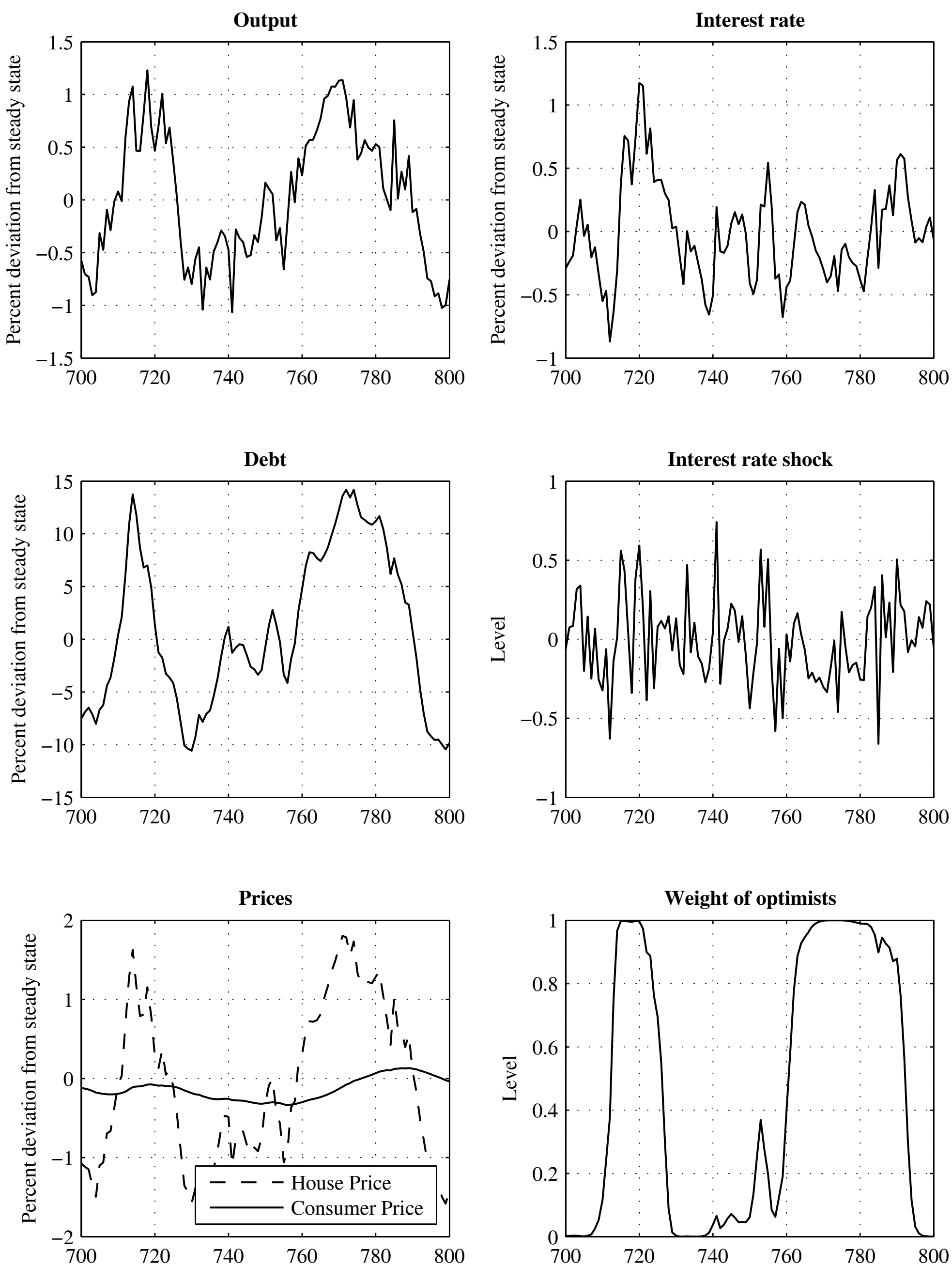

Figure 1: Simulation results.

4.2 Animal spirits, memory and divergence of belief

In this section we dig a little deeper and investigate to what extend the nature of biased expectations is key to generate endogenous persistence in the business cycle. A simple way to analyse the interrelation between beliefs and the business cycle is to report how the persistence in the business cycle changes as a function of the deep parameters that govern the beliefs of households. To do so we change key parameters in the heuristics agents use to form expectations. A key parameter in the switching function is the intensity of choice parameter γ. For higher values of γ agents are more easily willing to change their camp from optimists to pessimists and vice versa if the performance of the rule deteriorates. For the border case of $\gamma = 0$ utility is purely stochastic. In the upper panel the figure illustrates that there exists a stable positive correlation between the business cycle as measured by the output gap and the change in the fraction of optimists. Thus for values of $\gamma > 0.3$ the persistence in the cycle is driven by waves of optimism and pessimism that hit the economy. Somewhat surprisingly we see that for very low values of γ well below 0.2 a negative correlation prevails between the intensity of choice and the business cycle. This result is somewhat special and can be explained as follows. If the intensity of choice parameter γ does not pass a certain critical threshold value the model is not able to generate any meaningful swings in optimism and pessimism. Nevertheless the share of optimists somewhat varies in a range between 0.45 to 0.55. Thereby short lived spikes are driven into house prices relative to consumer prices. These short lived spikes make investment into housing for non-constrained consumers less attractive such that they cut back residential investment. The collateral constraint effect is not well pronounced for minor blips in optimism or pessimism. Therefore the investment effect dominates the collateral effect which drives our results and somewhat depresses the economy and thus establishes a negative correlation.

The parameter δ reflects the divergence in belief between optimists and pessimists. We see that more pronounced cycles exist as the divergence in belief increases. Obviously a higher divergence in belief makes one heuristic at a time more preferable as those that where optimistic or pessimistic on error did a greater forecast error such that switching between camps is more likely. Therefore a higher value of δ increases the propensity for more persistent waves in optimism and pessimism and thus increases the correlation between animal spirits and the business cycle.

The parameter ρ determines the memory of agents while forming their expectations on housing markets. The figure illustrates that within a range of 0 to 0.75 there exists a tight relationship between the change in optimism or pessimism in housing markets and the business cycle independently of the length of the memory parameter ρ. Only for very a long memory the correlation between the business cycle and the way people form expectations becomes less important. Obviously as ρ increases both rules tend to convergence in performance as periods of optimism and pessimism are almost equally distributed along a long time horizon.

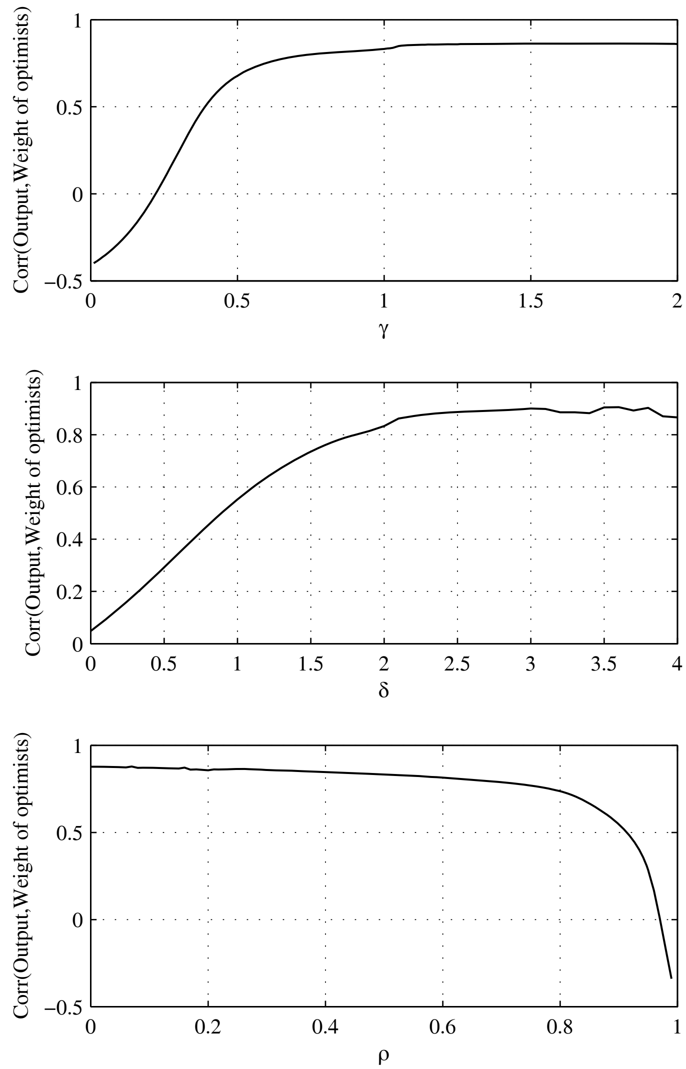

Figure 2: Animal spirits and the business cycle.

5 Implications for monetary policy

In the last section we have explored to what extend self-full filling revisions in expectations and herding behavior can lead to long self-sustaining boom-bust cycles. In this section we will explore to what extend modifications in the Taylor rule can be beneficial in terms of stabilizing economic cycles which are triggered by departures from the Taylor rule itself.

5.1 An augmented Taylor rule

We propose as an obvious prime candidate that monetary authorities should respond to factors that are directly related to the boom-bust cycle. We propose either that the central bank additionally responds to credit evolution such that a credit driven boom is prevented or that the central bank responds to real housing prices which signal booms in the housing sector before they spread to the rest of the economy. To investigate the role of credit volumes we proceed as follows: In a first step we augment the Taylor rule by an additional term $(B_t/\bar{B})^{\mu_B}$ that reflects that monetary policy monitors credit volumes and increases nominal interest rates if credit volume starts to increase. The augmented Taylor rule is then given by

$$R_t = R_{t-1}^{\mu_R} \left(\bar{R} \left(\frac{\Pi_t}{\bar{\Pi}} \right)^{\mu_\pi} \left(\frac{Y_{total,t}}{\bar{Y}_{total}} \right)^{\mu_{\Delta Y}} \left(\frac{B_t}{\bar{B}} \right)^{\mu_B} \right)^{(1-\mu_R)} exp(u_{R,t}). \tag{42}$$

To shed a light on the role of real housing prices q_t we apply the following rule

$$R_t = R_{t-1}^{\mu_R} \left(\bar{R} \left(\frac{\Pi_t}{\bar{\Pi}} \right)^{\mu_\pi} \left(\frac{Y_{total,t}}{\bar{Y}_{total}} \right)^{\mu_{\Delta Y}} \left(\frac{q_t}{\bar{q}} \right)^{\mu_q} \right)^{(1-\mu_R)} exp(u_{R,t}). \tag{43}$$

To explore the benefits of these two rules compared to the standard Taylor rule we proceed as follows. Figure 3 shows in the left hand side panel how the AR(1)-coefficient of the output gap changes if all parameters remain fixed at their baseline value while we alter μ_B in a range between 0 to 0.5 for the credit-augmented Taylor rule and μ_q in a range between 0 to 2 for the Taylor rule including the real house price as an additional factor. For each policy rule we simultaneously report the effect of changing Taylor rule coefficients. For the inflation coefficient we report the tuple $\{\mu_\pi = 1.1; \mu_\pi = 1.9\}$, for the output coefficient $\{\mu_Y = 0; \mu_Y = 1.00\}$ and for the interest rate coefficient $\{\mu_R = 0.60; \mu_R = 0.90\}$.

As a reference point we also report the corresponding statistic of the DSGE counterpart model. Thereby we are able to identify and judge the merits of biased expectations and animal spirits in our framework compared to the standard rational expectations approach followed in the DSGE model.

Figure 3 (upper panel) reports the effects of increasing μ_B on the persistence of the economic cycle while simultaneously changing the Taylor rule coefficients as stated above. Starting from our baseline scenario we can report a sharp decline in the persistence measure for a modified Taylor rule which is able to prevent self-sustaining boom-bust cycles. By responding to credit, monetary authorities become more restrictive in the early stage of the housing boom. Thereby, they detract the sources that sustained the boom. On the one hand, credit becomes more expensive which subdues the consumption among credit-constrained households. On the other hand, a more restrictive monetary policy subdues the investment in the housing sector itself. Additionally higher interest rates at the early stage of a housing-price boom depress consumption among nonconstrained consumers and thereby stabilize the business cycle. Accordingly, we can report that a policy that augments the Taylor rule by a credit component functions well in terms of preventing monetary policy itself to become a source of self-sustaining booms in the housing sector driven by animal spirits. With respect to variations in the other Taylor rule coefficients the following results stand out. Altering the inflation coefficient on inflation, from $\mu_\pi = 1.10$, to $\mu_\pi = 1.90$ is not suited to prevent boom-bust cycles, when these are triggered by departures from the Taylor rule. In an environment where the Phillips curve is flat cycles in output do not lead to sustained cycles in inflation. A similar result prevails for the output gap coefficient. Switching between $\{\mu_Y = 0; \mu_Y = 1.00\}$ does not seem to make any substantial difference. In contrast to the previous graphs it prevails that the degree of interest rate smoothing has a big impact on the autocorrelation coefficient. This result is not surprising as a highly inertial policy is known to be more effective in terms of influencing the business cycle, therefore persistent departures from the Taylor target rate are more likely to trigger a herding cycle. For the case of uncorrelated departures from the Taylor rule, a draw of shocks that goes into the same direction is less likely. Therefore waves of optimism and pessimism are less likely to occur.

The lower panel on the left hand side in figure 3 reports the same exercise for the Taylor rule that is augmented by the real house price q_t. All results are qualitatively identical to the case of a policy rule that responds to the evolution of credit. For the rule that is augmented by q_t it holds that changing coefficients from 0 to 2.00 lowers the AR(1)-coefficient in output from 0.85 in the baseline towards 0.2. For the case of the credit rule a similar effect could be engineered by changing the coefficient from 0 to 0.27. The different sizes of the coefficients can be easily explained by the different amplitudes of the credit cycle and the real housing price over the business cycle. Put differently, as the credit cycle is more pronounced in terms of log-deviations from the steady state value a smaller response coefficient is well suited to engineer the same response in the real interest rates compared to the case of a rule that responds to credit.

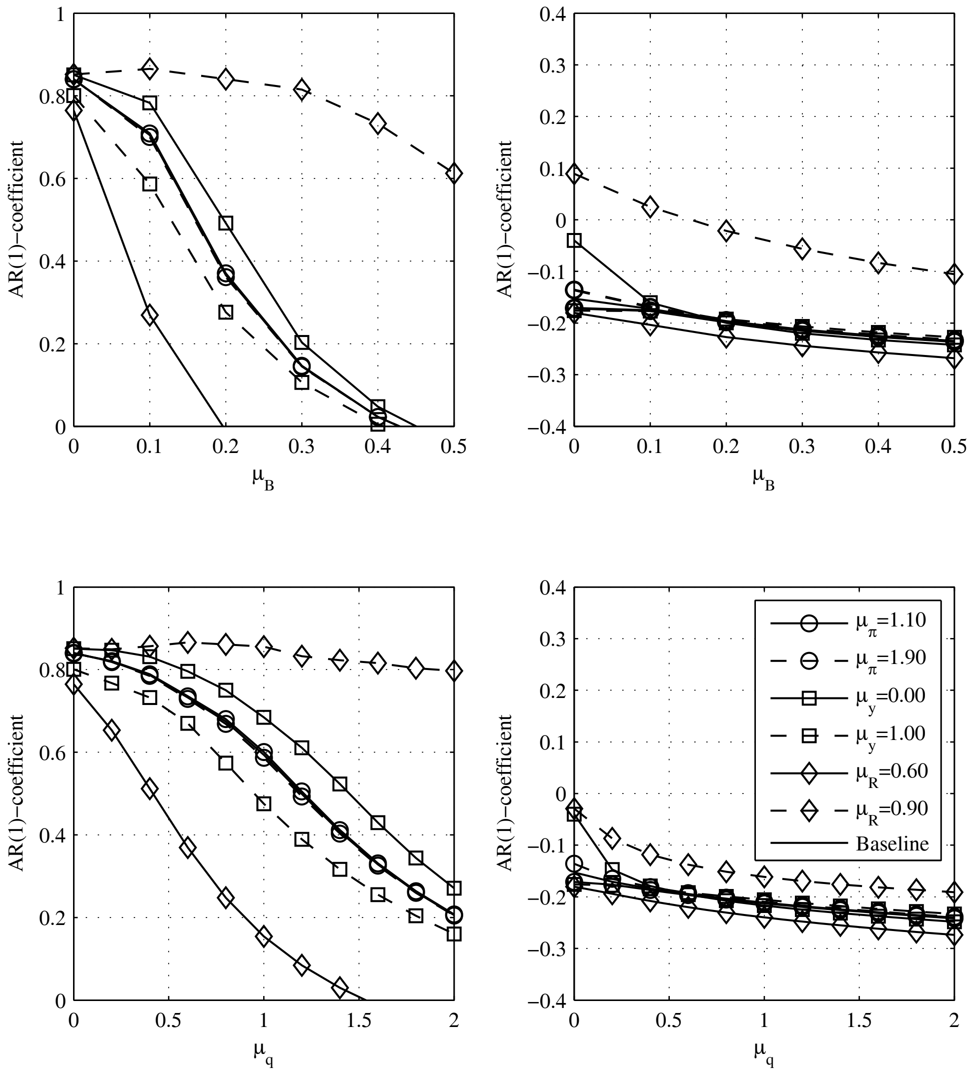

Figure 3: Augmented Taylor Rule: Behavioral vs. DSGE model.

All figures underline the non-linearity introduced by the switching mechanisms in expectations. As soon as the policy coefficient reaches a critical threshold value the AR(1)-coefficient sharply drops. In contrast the DSGE figures all illustrate that the AR(1)-coefficient drops gradually along a convex path, while in the behavioral model the descent is more pronounced and the curvature turns from concave to convex reflecting the more steeper descent of the persistent measure.

Therefore we conclude that a policy analysis that relies on a DSGE model might underestimate the benefits of augmenting a Taylor rule by an additional component. The existence of non-fundamental booms might be hard do address in DSGE models whereas behavioral models seem to be well suited for this exercise.

5.2 Impulse Responses Analysis and predictability of monetary transmission

Another dimension along which we can motivate the modification of the Taylor rule can be illustrated by means of impulse response analysis. In the following section we provide evidence that augmenting the Taylor rule by a credit component makes the effects of a monetary policy shock predictive, while for the case of a standard Taylor rule the effects of a monetary shock are surrounded by a high degree of uncertainty and will be largely unpredictable.

Computing impulse responses in a non-linear model is not a straight forward exercise. In the linearized DSGE framework where the additivity principle holds the effects of a standard deviation shock are always exactly identical independent on the history of shocks and state variables. This does not hold true for the behavioral model. If monetary authorities increase interest rates by a standard deviation shock its impact on the economy will strongly depend on the share of optimists versus pessimists present at the time. It might be that a well timed shock initiates a wave of optimism or pessimism and thus has a large impact on the evolution of the economy. At other times it might be that the same shock, which might hit during a wave of optimism does almost have no effect on the further course of the economy. To take care of this non-linearity we follow De Grauwe (2010) when computing impulse responses. Concretely we proceed as follows. We simulate the model economy over 1070 quarters, where we set in period 1050 a standard deviation shock of 0.25 basis points. Then we keep the stochastic draw fixed and repeat exactly the same exercise except that we set the monetary policy shock in period 1050 equal to 0. In the next step we compute for each variable of interest the difference between the first and the second economy. Thereby we succeed to isolate the effect of the monetary policy shock which occurs in period 1050 on the further course of the economy. To take care of the non-linearity we repeat this exercise 200 times and plot the mean and provide additionally information on the distribution by tracking two standard deviations.

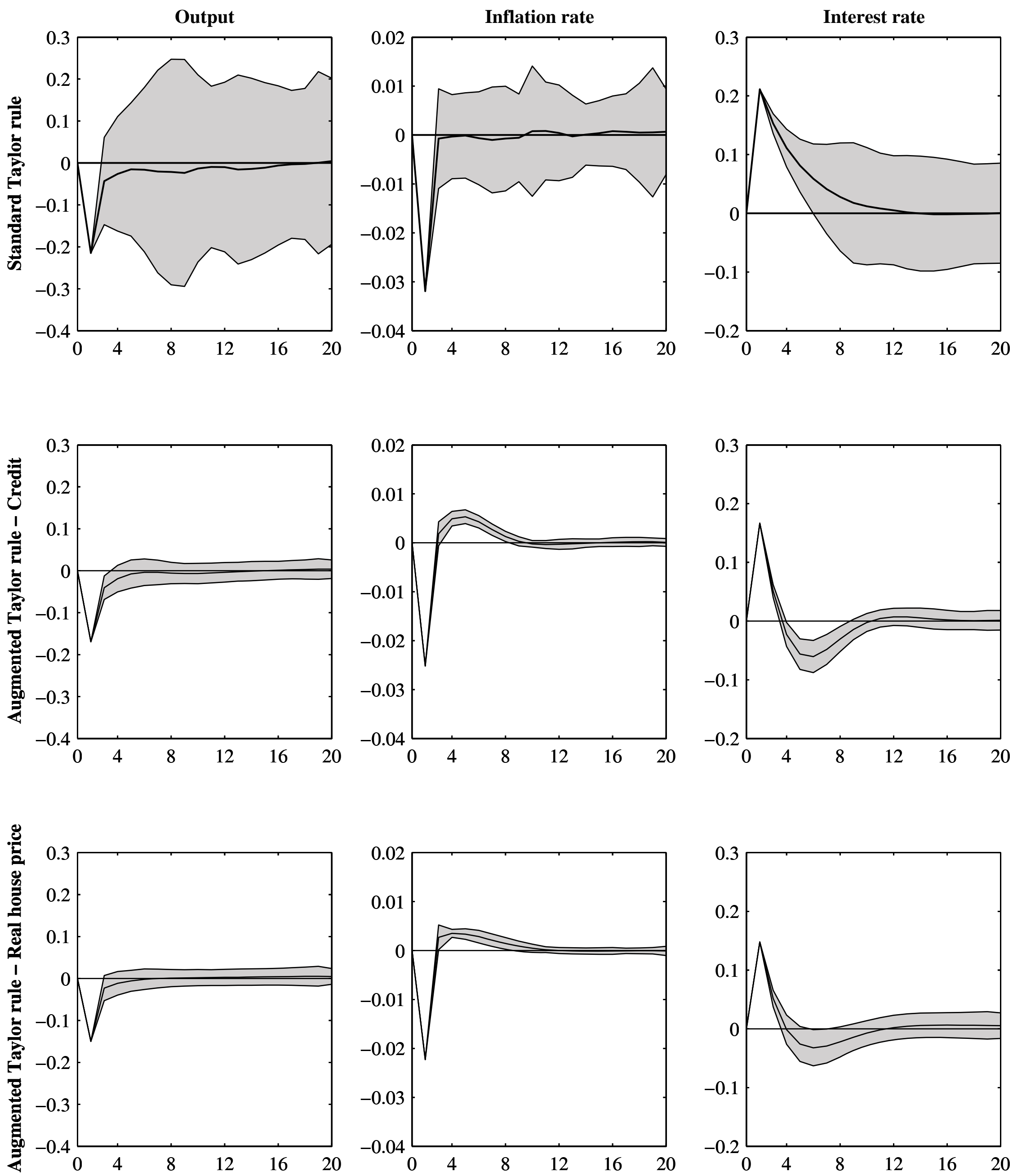

Figure 4: Impulse response functions: Standard Taylor rule vs. augmented Taylor rules.

Notes: The Figure shows the responses of output, the inflation rate and the interest rate to interest rate shocks of 25 basis points for three alternative Taylor rules. Due to the non-linearity in the model, the shock can have different effects on the economy. Therefore, we provide information on the mean and compute additionally two standard deviations around the mean.

The results are clear cut. The effects of departures from the Taylor rule which is not augmented by a component that reacts on credit are largely unpredictable. Thus for the case of a standard Taylor rule the effects of a monetary policy shock largely depend on the history of shocks that hit the economy. Without knowledge on these shocks the impact of an increase in interest rates are surrounded by a high degree of uncertainty as the distribution of impulse responses is largely dispersed. When on the contrary monetary policy is also conditioned on the evolution of credit the impact of a standard deviation shock on the economy is largely independent of the history of shocks. Thus the effects are almost identical as indicated by the narrow distribution of standard deviations. This result underlines that monetary policy can well control the impact of departures from the Taylor rule on housing markets if the Taylor rule is augmented by a term that responds sufficiently strong to credit volumes.

6 Conclusion

In this paper we processed a DSGE model with expectations mechanisms that are well established in a large body of literature in behavioral finance (Lux and Marchesi (2000); De Grauwe and Grimaldi (2006); De Grauwe (2010)). Additionally, the idea of animal spirits has recently popularized by Akerlof and Shiller (2009) in academia.

Concretely we substituted rational expectations by biased expectations where we conjectured that the further evolution of housing prices is forecasted by agents by relying on simple heuristics. Thus although people gradually evaluate their own forecast against the actual realization they do not rely on the true data generating process but on simple adaptive updating schemes. Given these biased expectations we have explored to what extend departures from the Taylor rule can ignite self-fulfilling boom-bust cycles. We saw that contagious outbreaks of optimism lead to self-fulfilling prophecies and increase housing prices as firms operating in the housing sector price in expectations on further increases in the durable sector. Thereby the collateral value on which impatient households can borrow increases. This boosts consumer spending and initiates an economic boom. Our analysis indicates that a standard Taylor rule is not well suited to prevent a boom in the housing market in its early stages. The failure of the Taylor rule can be traced back to the relative degrees of stickiness in the durable versus non-durable sector of the economy. While housing prices are relatively flexible and sharply increase at the early stage of a housing price boom the inflation rate only gradually picks up in the non-durable sector of the economy. As the residential investment sector only makes up for six percent of the overall economy the central bank remains accommodative. Only at later stages of the cycle when the overall inflation rate starts to increase the central bank acts somewhat stabilizing by increasing the real rate of interest, which then enhances the propensity that the economy will be contagioned by a wave of pessimism which leads to a slump in the economy.

Our analysis suggests that for the case of monetary shocks an augmented Taylor rule is well suited to steer the economy. If the central bank reacts to credit volume or housing prices its monetary stance switches towards restrictive at an early stage of a potential housing price boom. Thereby it prevents impatient households from taking up loans as the collateral constraint gets tighter and sets incentives to nonconstrained households to postpone consumption into the future. In total this prevents a credit driven cycle at the very early stages.

As a benchmark model we also analyze the DSGE counterpart model. Our analysis suggests that the DSGE model comes qualitatively to the same conclusion as the behavioral model but sharply underestimates the beneficial impact of augmenting Taylor rules by a credit component. The advantage of the behavioral model compared to the standard DSGE framework is that it is able to trigger sudden eruptive outbursts in housing prices that are ignited by animal spirits. If the central bank responds to the evolution of credit or housing prices it is able to prevent waves of optimism and pessimism from driving the business cycle.

Appendix

A The log-linear model

Here, we summarize the log-linear approximation of the model's equations around a non-stochastic steady state. Variables with (without) a tilde refer to borrowers (savers). Variables with a overline denote steady state values and hatted variables describe log-deviations from the steady state value of the variable. The model consists of the following 28 variables: $C_t, X_t, D_t, B_t, N_t, \tilde{C}_t, \tilde{X}_t, \tilde{D}_t, \tilde{B}_t, \tilde{N}_t, \tilde{\phi}_t, Y_{c,t}, Y_{d,t}, Y_{total,t}, \phi_{c,t}, \phi_{d,t}, N_{c,t}, N_{d,t}, W_t, q_t, \pi_{c,t}, \pi_{d,t}, \pi_t, p_{c,t}$, $p_{d,t}, \xi_t, R_t, RR_t$. The 17 parameters are: $\beta, \tilde{\beta}, \omega, \epsilon, \delta, \chi, \alpha, \Delta_{\bar{D}}, \omega_d, \omega_c, \theta_c, \theta_d, \mu_R, \mu_\pi, \mu_{\Delta Y}, \bar{\tilde{N}}, \bar{N}$. There is one shock in the model: u_t^R.

Savers. The *consumption equation* is given by

$$\hat{C}_t = E_t\hat{C}_{t+1} - (\hat{R}_t - E_t\hat{\pi}_{c,t+1}). \tag{44}$$

For the *consumption of housing* it holds that

$$-\hat{D}_t + \hat{C}_t = [1 - \beta(1-\delta)]^{-1}[\hat{q}_t + \beta(1-\delta)(\hat{R}_t - E_t\hat{\pi}_{c,t+1} - E_t\hat{q}_{t+1})]. \tag{45}$$

The *labor supply* is

$$\hat{N}_t + \hat{C}_t = \hat{W}_t - \hat{P}_{c,t}. \tag{46}$$

The *accumulation equation of housing* is determined by

$$\hat{D}_t = \delta\hat{X}_t + (1-\delta)\hat{D}_{t-1}. \tag{47}$$

Borrowers. The *consumption equation* is given by

$$\hat{\tilde{C}}_t = E_t\hat{\tilde{C}}_{t+1} - (\hat{R}_t - E_t\hat{\pi}_{c,t+1}) - \frac{\beta - \tilde{\beta}}{\tilde{\beta}}(\hat{\tilde{\phi}}_t + \hat{\tilde{C}}_t + \hat{R}_t). \tag{48}$$

The log-linear version of the borrowers' budget constraint is

$$\bar{\tilde{C}}\hat{\tilde{C}}_t = \bar{\tilde{B}}(\hat{\tilde{B}}_t - \hat{P}_{c,t}) - \frac{\bar{\tilde{B}}}{\beta}(\hat{R}_{t-1} - \hat{P}_{c,t} + \hat{\tilde{B}}_{t-1}) + \bar{W}\bar{\tilde{N}}(\hat{\tilde{N}}_t + \hat{W}_t - \hat{P}_{c,t}) - \bar{\tilde{X}}(\hat{q}_t + \hat{\tilde{X}}_t). \tag{49}$$

The *labor supply equation* is

$$\hat{\tilde{N}}_t + \hat{\tilde{C}}_t = \hat{W}_t - \hat{P}_{c,t}. \tag{50}$$

The *evolution of debt* is described by

$$\hat{\tilde{B}}_t = \hat{\tilde{D}}_t + E_t\hat{q}_{t+1} - (\hat{R}_t - E_t\hat{P}_{c,t+1}). \tag{51}$$

For the *consumption of housing* it holds that

$$-\hat{\tilde{D}}_t + \hat{\tilde{C}}_t = \tilde{\Phi}^{-1}(1-\delta)\left[\tilde{\Gamma}\hat{q}_t - \tilde{\beta}E_t\hat{q}_{t+1} + \beta\widehat{RR}_t + (\beta - \tilde{\beta})\left(\chi\left(\hat{\tilde{\phi}}_t + \hat{\tilde{C}}_t\right) - \hat{\xi}_t\right)\right], \tag{52}$$

where

$$\tilde{\Phi} = 1 - (1-\delta)[\tilde{\beta} + (1-\chi)(\beta - \tilde{\beta})] \tag{53}$$

$$\tilde{\Gamma} = \frac{1 - (1-\chi)(1-\delta)(\beta - \tilde{\beta})}{(1-\delta)} \tag{54}$$

$\widehat{RR}_t$ is the (ex-ante) real interest rate in terms of nondurable goods with

$$\widehat{RR}_t = \hat{R}_t - E_t\hat{\pi}_{c,t+1}, \tag{55}$$

and $\hat{\xi}_t$ is a composite inflation term, which is defined as

$$\hat{\xi}_t = (1-\chi)E_t\hat{\pi}_{d,t+1} - E_t\hat{\pi}_{c,t+1}. \tag{56}$$

The *accumulation equation of durables* is

$$\hat{\tilde{D}}_t = \delta\hat{\tilde{X}}_t + (1-\delta)\hat{\tilde{D}}_{t-1}. \tag{57}$$

Firms. The production function is given by

$$\hat{Y}_{j,t} = \hat{N}_{j,t} \qquad j = c, d. \tag{58}$$

Note that the following holds

$$\hat{P}_{j,t} = \hat{\pi}_{j,t} + \hat{P}_{j,t-1} \qquad j = c, d. \tag{59}$$

It is true that

$$\hat{q}_t = \hat{P}_{d,t} - \hat{P}_{c,t}. \tag{60}$$

The *evolution of inflation* in both sectors takes the form of a hybrid New Keynesian Phillips curve

$$\hat{\pi}_{j,t} = \gamma_{j,f} E_t \hat{\pi}_{j,t+1} + \gamma_{j,b} \hat{\pi}_{j,t-1} + \kappa_j \hat{\phi}_{j,t} \qquad j = c, d, \tag{61}$$

where

$$\gamma_{j,f} = \frac{\beta\theta_j}{\theta_j + \omega_j[1-\theta_j(1-\beta)]} \qquad j = c, d \tag{62}$$

$$\gamma_{j,b} = \frac{\omega_j}{\theta_j + \omega_j[1-\theta_j(1-\beta)]} \qquad j = c, d \tag{63}$$

$$\kappa_j = \frac{(1-\theta_j)(1-\beta\theta_j)(1-\omega_j)}{\theta_j + \omega_j[1-\theta_j(1-\beta)]} \qquad j = c, d. \tag{64}$$

Real marginal costs are given by

$$\hat{\phi}_{j,t} = \hat{W}_t - \hat{P}_{j,t} \qquad j = c, d. \tag{65}$$

Market clearing and monetary policy. The *goods market equilibrium condition* is

$$\hat{Y}_{total,t} = \frac{\bar{Y}_c}{\bar{Y}_{total}} \hat{Y}_{c,t} + \frac{\bar{Y}_d}{\bar{Y}_{total}} \hat{Y}_{d,t}, \tag{66}$$

where

$$\hat{Y}_{c,t} = \omega \frac{\bar{\tilde{C}}}{\bar{Y}_c} \hat{\tilde{C}}_t + (1-\omega) \frac{\bar{C}}{\bar{Y}_c} \hat{C}_t, \tag{67}$$

and

$$\hat{Y}_{d,t} = \omega \frac{\bar{\tilde{X}}}{\bar{Y}_d} \hat{\tilde{X}}_t + (1-\omega) \frac{\bar{X}}{\bar{Y}_d} \hat{X}_t. \tag{68}$$

The *labor market equilibrium condition* is

$$\bar{N}_c \hat{N}_{c,t} + \bar{N}_d \hat{N}_{d,t} = \omega \bar{\tilde{N}} \hat{\tilde{N}}_t + (1-\omega) \bar{N} \hat{N}_t. \tag{69}$$

The *debt market equilibrium condition* is described by

$$\hat{\tilde{B}}_t = \hat{B}_t. \tag{70}$$

The model is closed by the following Taylor rule

$$\hat{R}_t = \mu_R \hat{R}_{t-1} + (1-\mu_R)(\mu_\pi \hat{\pi}_t + \mu_Y \hat{Y}_t +) u_t^R, \tag{71}$$

where $\hat{\pi}_t = (1-\alpha)\hat{\pi}_{c,t} + \alpha\hat{\pi}_{d,t}$. The augmented Taylor rules are

$$\hat{R}_t = \mu_R \hat{R}_{t-1} + (1-\mu_R)(\mu_\pi \hat{\pi}_t + \mu_Y \hat{Y}_t + \mu_B \hat{B}_t) + u_t^R, \tag{72}$$

and

$$\hat{R}_t = \mu_R \hat{R}_{t-1} + (1-\mu_R)(\mu_\pi \hat{\pi}_t + \mu_Y \hat{Y}_t + \mu_q \hat{q}_t) + u_t^R, \tag{73}$$

respectively.

B Calibration

Table 1: Calibration

Parameter		Calibration
Households		
Discount factor of savers	β	0.99
Discount factor of borrowers	$\tilde{\beta}$	0.97
Share of borrowers	ω	0.50
Inverse of the loan-to-value ratio	χ	0.25
Weight of housing in utility	α	0.11
Inverse of the intertemporal elasticity of substitution	σ	1.00
Inverse of the labor supply elasticity	φ	1.00
Habit formation	h	0.00
Steady state labor supply of savers	$\bar{N}$	0.33
Steady state labor supply of borrowers	$\bar{\tilde{N}}$	0.33
Intensity of choice	γ	1.00
Divergence in beliefs (variable)	δ_d	2.00
Divergence in beliefs (fixed)	β_d	1.00
Memory	ρ	0.50
Evaluation period	z	20
Firms		
Elasticity of substitution	ϵ_j	6.00
Calvo lottery in the nondurable goods sector	θ_c	0.90
Calvo lottery in the housing sector	θ_d	0.30
Price indexation	ω_j	0.00
Gdp		
Size of residential investment	$\Delta_{\bar{D}}$	0.06
Monetary Policy		
Taylor rule: inflation rate	μ_π	1.50
Taylor rule: output gap	μ_Y	0.50
Taylor rule: interest rate smoothing	μ_R	0.75
Shocks		
Std. dev. of the monetary policy shock	σ_R	0.25

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