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A Model of Price Swings in the Housing Market*

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Abstract

In this paper we use a standard neoclassical model supplemented by some frictions to understand large price swings in the housing market. We construct a two good general equilibrium model in which housing is a composite good produced using structures and land. We revisit the connection between changes in interest rates, credit conditions —as measured by maximum loan-to-value ratios— and expectations in influencing housing prices in a setting in which the stock of housing can be used as collateral for borrowing and credit markets are segmented. We find that changes in interest rates and credit conditions can generate significant price swings. Under rational expectations (perfect foresight) our model is able to explain 50% of the recent movements in U.S. house prices. When we allow shocks to expectations, the model's ability to match the evidence increases significantly. Contrary to conventional wisdom, we show that standard asset pricing formulas seem to correctly describe the behavior of house prices if the appropriate pricing kernel is used.

Keywords: Residential investment, mortgages rates

J.E.L. codes: E2, E6

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1. Introduction

In the past two decades, there have been important movements in real estate values in many developed economies. In the United States, house prices increased by 55% in the period between 2000 and 2006, but have been declining since 2007.[1] The recent bust in house prices wiped out essentially all of the appreciation relative to the historical trend. These large swings in the price of an asset that accounts for a significant fraction of the wealth of U.S. households are widely viewed as a major factor contributing to the 2008 financial crisis.

The standard approach to pricing houses essentially views them as an asset whose dividends are the actual or imputed rents. Using the standard pricing formula within a frictionless general equilibrium model in which all assets of similar characteristics earn the same returns fails to deliver the observed changes in house prices. To put it simply, house prices moved too much relative to the movement in fundamentals.

In this paper, we revisit this approach but deviate from the standard view in what we believe are reasonable but important dimensions: First, we assume that financial markets are segmented and that the return on mortgage-backed securities falls short of the return on capital. Second, we assume that access to these favorable loans requires the housing stock to be used as collateral. We embed this view of financial markets in a general equilibrium semi open economy model. In the model, the boom in house values is driven by decreases in interest rates, the relaxation of borrowing conditions (i.e., changes in the loan-to-value ratio) and, possibly, shocks to expectations about future interest rates and financial conditions.

We first analyze some theoretical properties of the economy that we study. We derive a pricing formula and show that it is the sum of two components: a "frictionless" value, which essentially discounts rents at the market interest rate, and an additional term that captures the effect of segmentation in financial markets. The model is highly nonlinear and displays strong general equilibrium effects. We show that, in the steady state, decreases in interest rates have a positive effect on housing prices, but liberalizations of the credit market (i.e., permanent increases in the loan-to-value ratio) have ambiguous effects. Moreover, the size of the effects depends on the level of interest rates due to the nonlinearity of the model.

Since there is no closed form that can be used to analyze the dynamics of the model, we calibrate it to match the pre-boom U.S. evidence and then use the calibrated version to study how the model economy responds to changes in interest rates and financing conditions that approximate what was observed in the U.S. in recent years. In our first experiment, we study the perfect foresight dynamics and find that the model is able to explain about 50% of the boom in housing prices and matches the bust reasonably well. Moreover, unlike other general equilibrium models, the large changes in house prices are accompanied by relatively modest changes in non-housing consumption (4%) and non-housing investment (17%).

We then explore the role of expectations about interest rates played in accounting for the movement in asset prices. To this end we study two scenarios. In the first we posit that,

[1] Other countries that had significant movements in house prices include Australia, Canada, China, France, India, Ireland, Itally, Korea, Spain, and the U.K.

starting in 1997, households perceive that low interest rates and a more flexible financial environment (higher loan-to-value ratio) will be permanent. We then assume that there is a shock to expectations around 2008. In this new environment, households expect the low interest rates to prevail for another 15 years, and assume financial conditions will return to their pre-boom level. In this scenario, the model can account for 90% of the increase in prices but does not perform so well in terms of the timing of price changes. Finally, we consider an environment in which each of the observed changes in interest rates and the financial environment is viewed as permanent. Thus, each year there is a new shock to expectations. We assume that around 2008 households revise their beliefs and estimate that interest rates would slowly return to their original (normal) levels starting in 2023. In this case, the model matches not only the magnitude but also the timing of price increases and decreases. Moreover, it accounts for large movements in asset prices with small movements in consumption and investment.

The remainder of the paper is organized as follows. In the next section we present a brief literature review. In Section 3 we describe the relevant data for the U.S. economy. Section 4 presents the model and derives some of the theoretical findings. Section 5 reports the numerical results and Section 6 offers some concluding comments.

2. Related Literature

Traditionally the understanding of house price dynamics has been viewed as a question for urban economists. The literature in urban economics has proceeded by estimating user cost equations at the national and metropolitan level for example Poterba (1984), Himmelberg, Mayer, and Sinai (2005), and Glaeser, Gyourko, and Saks (2005). There seems to be a consensus in the literature that most of the increase in house prices in the postwar period was driven by rising housing quality, construction costs and, after 1970, restrictions on the supply of housing. The recent boom and bust has posed a challenge to the traditional view. For instance, Shiller (2007) argues that the user cost approach fails to connect house prices and fundamentals. He conjectures that the driving force during the boom was a widespread perception that houses were a great investment, where the coordination of expectations brings self-fulfilling booms. More recently, Glaeser, Gottlieb, and Gyourko (2010) generalize the user cost model of home valuation by allowing mean-reverting interest rates, mobility, prepayment, an elastic housing supply, and credit-constrained home buyers. The model predicts that lower real rates can explain only one fifth of the rise in prices from 1996 to 2006. However, the model cannot rationalize a collapse of house prices in a period with low interest rates.

The recent experience in the U.S. and many European countries has shown that large movements' in house prices can have important aggregate effects. However, there are few quantitative equilibrium models that are useful to understand the dynamics of house prices. Traditionally most of the macro literature has focused on the role of residential investment, for example Davis and Heathcote (2005), or on the role of monetary policy with nominal mortgage contracts, Iacoviello (2005). While these models are successful in reproducing the volatility of residential investment, in general they fail to reproduce the observed variability in house prices.[2]

More recently, some macro models explore the connection between house prices and fundamentals such as productivity. For example, Kahn (2008) uses a neoclassical growth model with a Markov regime-switching specification for productivity growth in the nonhousing sector and learning as a plausible candidate to explaine the large low-frequency changes in housing price trends. However, the model fails to generate large house price movements. Kiyotaki, Michealides, and Nikolov (2011) focus on the wealth and welfare implications of fluctuations in home values driven by fundamentals in a small open economy with heterogeneous households. They find that generating relatively large movements in house prices requires a permanent increase in productivity and a permanent decrease in the interest rate. In their model this also causes, counterfactually, large changes in consumption and investment.

Other researchers argue that market segmentation is an important channel to understand the dynamics of house prices. Ortalo-Magne and Rady (2006) characterize the effects of a relaxation of credit constraints in an economy with two types of homes. Landvoigt, Piazzesi, and Schneider (2011) use an assignment model to understand the cross section of house prices in San Diego County during the boom of the 2000s. They find that cheaper credit for poor households was a major driver of prices, in particular at the low end of the market. At a more aggregate level, Ríos-Rull and Sánchez-Marcos (2008) quantitatively test the importance of this mechanism in a model that endogenously determines the distribution of house prices and financial wealth. In general, they find that house prices move far less in their model than they do in the data in response to shocks to earnings, interest rates, and mortgage premiums.

An alternative channel is the interaction between credit market conditions and house prices. Changes in available credit or the liquidity terms of housing can have an important impact on house prices. For example, Favilukis, Ludvigson, and Van Nieuwerburgh (2012) explore the role of time-varying risk premia for fluctuations in home values and consumption and wealth heterogeneity. When housing competes with other assets as an insurable vehicle for labor income risk, house prices should increase. In the quantitative analysis they find that this channel, combined with expectations shocks, rationalizes one third of the increase in prices. He, Wright, and Zhu (2011) argue that in economies where houses facilitate transactions because credit is imperfect, housing can enjoy a liquidity premium. Since liquidity is endogenous, depending at least partially on beliefs, even when fundamentals are constant and agents are fully rational, house prices can display complicated equilibrium paths resembling bubbles.

[2] There are some notable exceptions. For example, Iacoviello (2005), Iacoviello and Neri (2010), and Liu, Wang, and Zha (2011) reconcile the movements identifying the relevant shocks that affect the determination of house prices. However, these models are not capable of rationalizing the magnitude of the recent boom-and-bust episode.

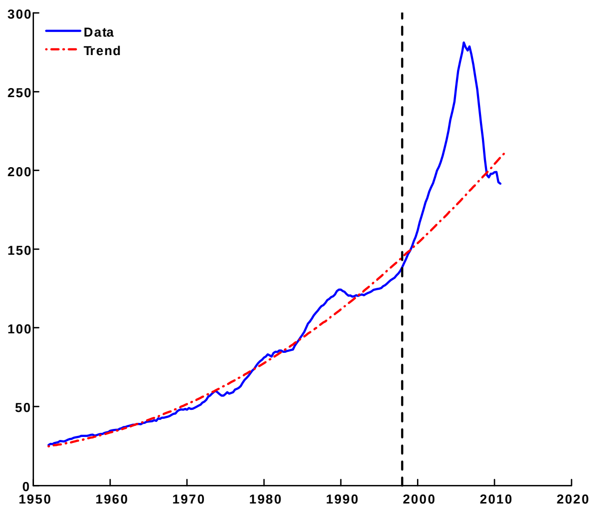
Other recent papers explore the role of learning in the formation of expectations. For instance, Burnside, Eichenbaum, and Rebelo (2011) provide a mechanism by which housing booms are generated by heterogeneous beliefs about the long-run fundamentals. The exogenous entry of new buyers drives the dynamics of house prices. Adam, Kuang, and Marcet (2011) use a small open economy model where the dynamics of beliefs about the price behavior can temporarily decuple house prices from fundamentals.

Our model integrates some of the features of existing models within a framework of financial markets segmentation.

3. Empirical Evidence

This section provides empirical evidence on the boom-and-bust cycle in the United States. Figure 1 summarizes the evolution of house prices between 1970 and 2011, as well as the trend estimated using the pre-boom years 1950-1998. The recent boom and bust episode represents a sizable deviation from the historical trend; prices at the peak were about 50% above trend, whereas the bust erased all gains achieved during the previous increase relative to the trend.

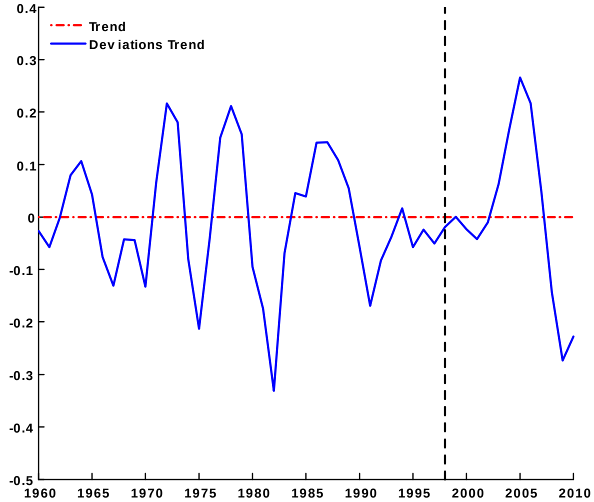
Figure 1: House Prices in the United States (1953-2011)



Source: NIPA index and authors calculations of the trend.

The increase in house prices was associated with a relatively large but not unprecedented increase in the physical volume of housing capital as shown in Figure 2. Thus, it follows that it is land prices that must account for a large share of the appreciation in the housing stock as argued by Davis and Heathcote (2007).

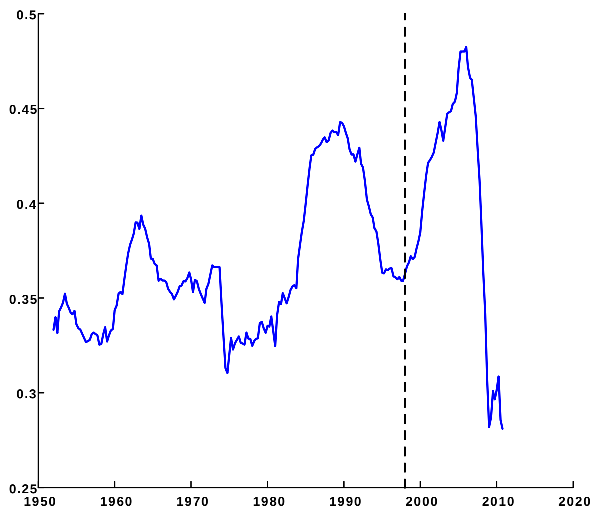
Figure 2: New Privately Owned Housing Capital



Source: NIPA detrended.

Figure 3 illustrates the fraction of the value of housing attributed to land. Two features are important: In the period during which houses appreciated, the share of land increased, while during the bust it dropped below its long term average.

Figure 3: Contribution of Value of Land in Housing Capital



Source: Davis and Heathcote (2007).

4. The Model

We consider an economy where time is discrete and indexed by $t = 0, 1, 2, ...$ There is a representative household that lives forever and has preferences defined over non-housing consumption and housing services. We use non-housing consumption as the numeraire.

Preferences can be represented by

$$U = \sum_{t=0}^{\infty} \beta^t u(c_t, h_t),$$

where u and β satisfy the usual assumptions Households have an endowment of one unit of time per period, which they supply inelastically to the market in order to receive a wage rate w_t. They are also the owners of non-housing capital, K_t, which they rent to firms at rate r_t. The stock of non-housing capital evolves following the standard law of motion,

$$K_{t+1} = x_t + (1 - \delta_k)K_t,$$

where $0 \leq \delta_k \leq 1$ is the depreciation rate, and x_t is non-housing investment. Households own a stock of residential structures, S_t, which depreciates at rate δ_s, and land, L_t, which does not depreciate. Following Davis and Heathcote (2007), structures and land produce a flow of housing services according to function $h_t = G(S_t, L_t)$. Purchases of land (at price p_t^ℓ) are denoted by ℓ_t. Land will be assumed to be in fixed supply, but from the perspective of the household, the stock of land follows

$$L_t = \ell_t + L_{t-1}.$$

We assume that investment in residential structures, s_t, is irreversible. Hence, we must distinguish the price of installed structures, p_t^s, from the price of new residential investment goods which, in the base case, will be equal to 1 in equilibrium. We let households choose their total purchases of installed structures for this period, S_t^d, while taking into account that their current holdings (after depreciation) are valued at $p_t^s(1 - \delta_s)S_{t-1}$; following the standard approach, we assume they sell their current holdings and are allowed to purchase new structures. Thus, the stock of available residential structures at time t satisfies

$$S_t = s_t + S_t^d,$$

where s_t is the (non-negative) investment in new structures which, in our base case, has price 1. Moreover, in equilibrium it follows that $S_t^d = (1 - \delta_s)S_{t-1}$. By a slight abuse of notation we specify that the aggregate law of motion of structures is

$$S_t = s_t + (1 - \delta_s)S_{t-1}.$$

Given the representative household construct, in equilibrium $S_t^d = (1 - \delta^s)S_{t-1}$.

We assume that financial markets are segmented. We view the market for collateralized borrowing (the market for mortgages) as distinct from the financial market that is used to finance capital investments.[3] We denote by B_t the stock of collateralized debt at the

[3] Formally, we assume that the relevant interest rate on mortgages is determined by international investors.

beginning of period t, and by r_t^* the interest rate, while D_t indicates the stock of non-collateralized debt (and the relevant interest rate is denoted by r_t^d).

The law of motion of B_t is given by

$$B_{t+1} = b_{t+1} + (1 - \triangle)B_t,$$

where $0 \leq \triangle \leq 1$ is the fraction of the stock of debt that must be repaid in every period.[4] Since we study a deterministic economy we abstract away from default.

In this exercise we concentrate on equilibria in which $r_t^d \geq r_t^*$, that is, the domestic interest rate —which will equal the rate of return on capital— exceeds the rate at which the rest of the world is willing to hold mortgage backed assets. It follows that to prevent arbitrage, it is necessary to restrict the amount of foreign borrowing. Our specification is very simple: we set the upper bound on mortgage debt to a fraction of the market value of the stock of housing. Thus, borrowing must satisfy

$$b_{t+1} \leq \max\{0, \phi_t(p_t^s S_t + p_t^\ell L_t) - (1 - \triangle)B_t\},$$

where ϕ_t is a measure of the maximal loan-to-value ratios at time t. Note that when $\phi_t(p_t^s S_t + p_t^\ell L_t) \geq (1 - \triangle)B_t$ —that is, when the adjusted value of the housing stock exceeds the market value of outstanding mortgages net of repayments— this specification implies that next period's (i.e., $t+1$) stock of debt equals $\phi_t(p_t^s S_t + p_t^\ell L_t)$. Thus the model implies that the private sector refinances its mortgage debt continuously to take advantage of interest rate differentials. This is, of course, an extreme implication but it appears consistent with the trend in the data.

If the value of the housing stock drops below the value of the mortgage, our specification requires repayment of at least $\triangle B_t$ of the existing stock of mortgages (this follows from the law of motion and $b_{t+1} = 0$).

The relevant constraints for the household problem are the standard non-negativity constraints and

$$\begin{gathered}
c_t + (r_t^* + \triangle)\, B_t + p_t^\ell l_t + x_t + s_t + p_t^s S_t^d + (1 + r_t^d) D_t = \\
r_t K_t + w_t + p_t^s (1 - \delta_s) S_{t-1} + b_{t+1} + D_{t+1}, \\
K_{t+1} = x_t + (1 - \delta_k) K_t \\
B_{t+1} = b_{t+1} + (1 - \triangle) B_t, \\
S_{t+1} = s_t + S_t^d,
\end{gathered}$$

See Favilukis, Kohn, Ludvigson, and Van Nieuwerburgh (2012) for a discussion of the role of international lenders. Alternatively, a similar financial structure emerges in a model with heterogeneous agents that are willing to lend at a rate below the discount factor of the borrowers.

[4] This specification is a simple approach to capturing the real world heterogeneity in the average duration of mortgage contracts. It implies that the average maturity of the debt is approximately $1/\Delta$.

$$L_t = L_{t-1} + \ell_t,$$
$$b_{t+1} \leq \max\{0, \phi_t(p_t^s S_t + p_t^\ell L_t) - (1 - \triangle)B_t\}$$
$$h_t = G(S_t, L_t),$$

where p_t^s is the price of existing structures and D_t is the stock of domestic debt.

The final element of our economy is a representative firm that produces the non-housing good which, in turn, is used to produce non-housing consumption, non-housing investment, and investment in structures. This firm rents capital and labor from households and uses a constant returns to scale technology $F(K_t, N_t)$ to produce non-housing goods. Wages and the rental rate on capital are competitively determined and are given by marginal productivities.

$$r_t = F_K(K_t, N_t), w_t = F_N(K_t, N_t).$$

Our definition of competitive equilibrium is standard and, hence, we omit it. The only special feature is that market clearing in the market for land requires that, in equilibrium, $\ell_t = 0$ and $L_t = \bar{L}$. The aggregate feasibility constraint in this open economy is

$$c_t + x_t + s_t + (1 + r_t^*)B_t = F(K_t, N_t) + B_{t+1}.$$

5. Analysis of the Model

In this section, we describe some simple properties of the model during the transition after a shock and in the long run.

5.1. The Price of Land

In the model, the market value of the stock of housing is the sum of the value of the structures, $p_t^s S_t$, and the value of land, $p_t^\ell L_t$. As financial conditions change the demand for housing changes. Changes in quantities can be met only through changes in the stock of structures, while changes in the value of the stock of housing are driven both by changes in the level of structures (given their prices) and changes in the price of land. Any model that is a reasonable approximation to the U.S. experience cannot be driven by changes in the level of structures: Standard measures of housing consumption show that, even though there have been changes, these are far too small compared with the price swings. Thus, it must be that a successful model relies on large increases (and subsequent decreases) in the price of land as the intermediate step to account for changes in house prices. For that reason, in this section we describe how the details of the financial market influence the price of land, using a standard asset pricing approach.

It is useful to decompose the price of land into a "frictionless" component and a deviation. Let $R_\ell^h(t)$ be the product of the rental price of a unit of housing times the marginal product of land in the production of housing. Thus,

$$R_\ell^h(t) = \frac{u_c(t)}{u_h(t)} G_L(t).$$

A standard derivation shows that the price of a unit of land satisfies

$$p_t^\ell = \hat{p}_t^\ell + \sum_{j=0}^{\infty} m_t(j)\eta_t(j) R_\ell^h(t+j), \tag{5.1}$$

where

$$\hat{p}_t^\ell = \sum_{j=0}^{\infty} m_t(j) R_\ell^h(t+j) \tag{5.2}$$

is the "frictionless" —using domestic interest rates— price of land, where

$$m_t(j) = \Pi_{k=1}^{j} \left(\frac{1}{1+r_{t+k}^d} \right) \text{ for } j \geq 1, \text{ and } m_t(0) = 1$$

is the relevant discount factor.

The term $\eta_t(j)$ is given by

$$\eta_t(j) = \Pi_{k=0}^{j} \left(\frac{\phi_{t+k} \upsilon_{t+k+1} \frac{r_{t+k+1}^d}{1+r_{t+k+1}^d}}{1 - \phi_{t+k} \upsilon_{t+k+1} \frac{r_{t+k+1}^d}{1+r_{t+k+1}^d}} \right) \tag{5.3}$$

is an "amplification factor" that captures the impact of our model of financial markets. Here, to simplify the presentation, we use $1 - \upsilon_t$ to denote the ratio of r_t^* and r_t^d, with $0 \leq \upsilon_t < 1$. Thus, this amplification factor depends both on flexibility of the financial regime —as represented by the sequence ϕ_t— and the wedge between the rate of return on domestic non-housing investments and the interest rate on mortgage backed securities —as captured by the term $\upsilon_t = 1 - r_t^*/r_t^d$.

Equation (5.1) shows that if there is either no foreign financing (i.e., $\phi_t = 0$), or no market segmentation (i.e., $\upsilon_t = 0$) our pricing formula is completely standard. Whether this amplification factor has a large effect is a quantitative issue, it is useful to try to gain some insight on how changes in ϕ_t or υ_t influence the equilibrium price of land.

From the point of view of this pricing formula, for given sequences $\{R_\ell^h(t), r_t^d\}$, all that matters is the behavior of $\phi_t \upsilon_{t+1}$ which we denote γ_t. In the next section we show, using the steady state results, that this equivalence holds only in partial equilibrium. To put it differently: The general equilibrium effects of changes in ϕ_t are significantly different from the consequences of changes in υ_{t+1}.

Consider the case in which the sequence γ_t is given by

$$\gamma_{t+k} = \gamma + e^{-\psi k}(\gamma_t - \gamma),$$

where γ is viewed as the long run level of this variable and γ_t is the size of the shock at time t. In this parameterization, if $\psi = 0$ the shock is permanent, while in the limit as $\psi \to \infty$, the specification captures the idea of a purely temporary change in γ_t. Most of our numerical analysis falls between these two cases.

Given equation (5.1), to understand the impact of changes in γ_t on the price of land, it suffices to analyze their effect on the amplification factor, as all the other elements are independent (in this partial equilibrium perspective) of developments in financial markets. Simple manipulations show that the elasticity of the amplification factor $\eta_t(j)$ with respect to γ_t is

$$\frac{\partial \eta_t(j)}{\partial \gamma_t} \frac{\gamma_t}{\eta_t(j)} = \sum_{k=0}^{j} \frac{1}{1 - \gamma_{t+k} \frac{r^d_{t+k+1}}{1+r^d_{t+k+1}}} \frac{e_t^{-\psi k} \gamma}{\gamma + e^{-\psi k}(\gamma_t - \gamma)}.$$

It follows that permanent changes (i.e., $\psi = 0$) maximize the last term and, hence, deliver the largest impact. This highlights the role played by expectations in our setting: If households believe that a change will be permanent, the consequence is a large and immediate impact on the price of land. The expression shows that the effects are fairly nonlinear in the sense that they depend on the initial "size" of the wedge, γ_t, as well as on the speed at which it is expected to converge to the long run level.

The model predicts that the elasticity of the amplification factor with respect to the interest rate is higher than the elasticity with respect to the loan-to-value ratio. Simple algebra shows that these two elasticities are related according to

$$\frac{\partial \eta_t(j)}{\partial r^*_{t+1}} \frac{r^*_{t+1}}{\eta_t(j)} = -\frac{r^*_{t+1}}{r^d_{t+1} - r^*_{t+1}} \frac{\partial \eta_t(j)}{\partial \phi_t} \frac{\phi_t}{\eta_t(j)}.$$

For reasonable parameterizations —and, in particular, for values that are roughly consistent with the evidence— the ratio $r^*_{t+1}/(r^d_{t+1} - r^*_{t+1})$ is fairly large. Thus, the model implies that in a partial equilibrium framework —that is, taking the sequences $\{R^h_\ell(t), r^d_t\}$ as given— changes in interest rates have a larger impact on land prices than changes in financial conditions. The size of the effect, though, depends on both the level of interest rates and financing conditions.

5.2. Steady State

In the steady state —with the domestic rate denoted by r^d— the following relations hold

$$p^\ell = (1 + r^d) \frac{u_h}{u_c} G_L(S, L) \frac{1}{r^d - \phi(r^d - r^*)},$$

$$1 = (1 + r^d) \frac{u_h}{u_c} G_S(S, L) \frac{1}{r^d + \delta_s - \phi(r^d - r^*)},$$

$$V = S + p^\ell L,$$

$$Y - C - \delta_s S = \phi r^* V,$$

where

$$Y = F(K^*, 1) - \delta_k K^*,$$

where K^* is the steady-state capital stock, which is independent of any of the factors we are interested in.

These equations imply that

$$p^\ell = \frac{r^d + \delta_s - \phi(r^d - r^*)}{r^d - \phi(r^d - r^*)} \frac{G_L(S, L)}{G_S(S, L)}.$$

To better understand the workings of the model, we next explore the implications imposing the functional forms that we use in our numerical exercise. Let

$$u(c, h) = \frac{[\alpha_c c^{-\rho} + (1 - \alpha_c) h^{-\rho}]^{-\frac{1-\theta}{\rho}}}{1 - \theta},$$
$$G(S, L) = z_h [\alpha_s S^{-\mu} + (1 - \alpha_s) L^{-\mu}]^{-\frac{1}{\mu}},$$

and we assume that both μ and ρ are positive. The steady state is completely characterized by the vector (p^ℓ, c, S, V) and its properties are described in the following proposition.

Proposition 1. *The steady state exists and is unique. Moreover,*

1. *Decreases in r^* increase the value of the housing stock, V, and the stock of structures, S.*

2. *Changes in ϕ have ambiguous effects on both V and S. It is possible for increases in ϕ to lower both V and S. Sufficient conditions for this are that either $r^d - r^* \to 0$, $\phi \to 0$, or $1/(1 + \rho) \to 0$.*

Proof. Simple computations show that a steady state is the solution to the following system of equations:

$$p^\ell = \frac{r^d + \delta_s - \phi(r^d - r^*)}{r^d - \phi(r^d - r^*)} \frac{1 - \alpha_s}{\alpha_s} \left(\frac{S}{L}\right)^{1+\mu}, \tag{5.4}$$

$$c(S, \phi, r^*) = \left[\frac{r^d + \delta_s - \phi(r^d - r^*)}{1 + r^d} \frac{\alpha_c}{\alpha_s(1 - \alpha_c)} S^{1+\mu} G(S, L)^{\rho-\mu}\right]^{\frac{1}{1+\rho}}, \tag{5.5}$$

$$V = V^1(S, \phi, r^*) = S\left[1 + \frac{1 - \alpha_s}{\alpha_s} \frac{r^d + \delta_s - \phi(r^d - r^*)}{r^d - \phi(r^d - r^*)} \left(\frac{S}{L}\right)^{1+\mu}\right], \tag{5.6}$$

$$V = V^2(S, \phi, r^*) = \frac{Y - c(S, \phi, r^*) - \delta_s S}{\phi r^*}. \tag{5.7}$$

In order to understand the effect of some shocks it is useful to exploit the recursive nature of the economy. In particular, equations (5.6) and (5.7) can be used to pin down (V, S).

Given this, equation (5.5) determines the level of non-housing consumption and equation (5.4) gives the price of land. Simple inspection shows that the functions $V^1(S, \phi, r^*)$ and $V^2(S, \phi, r^*)$ are continuously differentiable and satisfy:

$$\lim_{S \to 0} V^1(S, \phi, r^*) = 0, \;\; \lim_{S \to \infty} V^1(S, \phi, r^*) = \infty, \;\; V_S^1 > 0, \;\; V_\phi^1 > 0, \;\; V_{r^*}^1 < 0$$
$$\lim_{S \to 0} V^2(S, \phi, r^*) = \frac{Y}{\phi r^*}, \;\; \exists S^H(\phi, r^*), \text{ such that } V^1(S^H, \phi, r^*) = 0 \text{ and}$$
$$V_S^2 < 0, \, V_{r^*}^2 < 0.$$

Given the continuity of $V^1(S, \phi, r^*)$ and $V^2(S, \phi, r^*)$ and their monotonicity, there is a unique point in (V, S) at which they intersect, and this result holds even at the boundary when $r^* = r^d$ and $\phi \in \{0, 1\}$. Given this point, there are unique values of c and p^ℓ that satisfy equations (5.5) and (5.4). First we study the effect of a decrease in r^*. This change shifts the $V^1(S, \phi, r^*)$ and the $V^2(S, \phi, r^*)$ functions up and unambiguously increases the value of the housing stock, V. In order to determine the impact on the equilibrium quantity note that

$$r^* \phi \delta_s \leq (r^d - \phi(r^d - r^*))(r^d + \delta_s - \phi(r^d - r^*))$$

holds for all $\phi \in [0, 1]$ and $r^* \leq r^d$ and this, in turn, implies that

$$\mid \frac{\partial V^2}{\partial r^*} \mid_{S=S^*} \leq \mid \frac{\partial V^1}{\partial r^*} \mid_{S=S^*},$$

and, hence, that $\partial S / \partial r^* \leq 0$. An increase in ϕ shifts the $V^1(S, \phi, r^*)$ up and has an ambiguous effect on $V^2(S, \phi, r^*)$. A sufficient condition for such an increase to lower both V and S is that $\partial V^2 / \partial \phi \leq 0$. It is possible to show that

$$\frac{\partial V^2}{\partial \phi} = -\frac{V^2}{\phi} + \frac{c(S, \phi, r^*)}{(1 + \rho)\phi r^*} \frac{r^d - r^*}{r^d + \delta_s - \phi(r^d - r^*)}$$

and, hence, that

$$sign[\lim_{\frac{1}{1+\rho} \to 0} = \frac{\partial V^2}{\partial \phi}] = sign[\lim_{r^d - r^* \to 0} = \frac{\partial V^2}{\partial \phi}] = sign[\lim_{\phi \to 0} = \frac{\partial V^2}{\partial \phi}] < 0.$$

It follows that if either the mortgage relevant interest rate is close to the market rate (i.e., $r^d - r^*$ close to zero), the loan-to-value ratio is very low (i.e., ϕ close to zero), or non-housing and housing consumption are extremely complementary goods, an increase in the loan-to-value ratio can result in a decrease in the value of housing and in the quantity consumed. ■

The proposition shows that, in the long run, permanent changes in interest rates have larger effects than permanent changes in financial conditions. The reason —as argued in the previous section— cannot be discovered by looking at the asset pricing equation since, from that perspective the impact is similar. The key difference has to do with income effects. A decrease in r^* lowers the amount that domestic residents have to pay to the rest of the world, while an increase in ϕ, even though it initially allows domestic consumers to gain from the interest rate differential, in the long run reduces non-housing consumption since a larger amount of non-housing goods must be paid to the rest of the world. These two effects work in opposite directions and, for extreme values, the income effect dominates and relaxation of the financial constraint has a negative impact on housing variables. The results also show that, even in the steady state, the nonlinearity of the model implies that the impact of changes in a given variable must depend on the equilibrium values of all other variables.

6. Quantitative Analysis: Engineering Boom-and-Bust Episodes

In this section, we calibrate the model and study the implications for the housing market and macro aggregates of several shocks.

6.1. Calibration

The quantitative evaluation of the model requires specifying parameter values and functional forms. The parameters of the model are set such that key steady state variables and ratios match the long-run averages of their data counterparts between 1952 and 1997 (from the postwar period to the start of the housing boom when home prices significantly departed from trend). The implied parameter values are relatively robust to the choice of the sample period.

The specification of utility and the housing production function we use for our quantitative analysis have the CES specification given in the previous section. We assume that the production function of the non-housing good is Cobb-Douglas,

$$F(K, L) = zK^{\alpha}N^{1-\alpha},$$

where α represents the capital share and z indexes the productivity of the goods sector.

Several adjustments must be made to the data to make them comparable with the aggregates in the model. First, the model has neither a government nor a foreign sector. Therefore, the model's notion of GDP refers only to the private sector (i.e., total GDP minus government consumption and investment expenditures). Second, the model makes an explicit distinction between consumption and housing services. In the NIPA personal consumption expenditures include housing services. During the sample period, housing services averaged 8.97% of GDP. In the model, non-housing consumption corresponds to NIPA consumption − housing services + net exports. The last term adjusts for the lack of a foreign sector in our model. The average value for non-housing consumption during the relevant period is 68.5% of GDP. Finally, proprietors' income cannot be unambiguously attributed to either labor or capital. The standard convention is to assign a constant fraction of this income to each factor as in the overall economy.

The steady state conditions can be used to determine the majority of the relevant parameters. The remaining are solved numerically as a system of nonlinear equations.

- In the model, the share of labor in non-housing output (defined as private GDP minus housing services) corresponds to $1-\alpha$. Labor income maps into NIPA compensation of employees (excluding the government) plus $(1-\alpha)$ of proprietors' income. The average value for this share observed in the data is matched by setting $\alpha = 0.259$.

- The discount rate β is chosen to pin down the domestic interest rate in a steady-state, $r^d = \frac{1}{\beta} - 1$. The target value is 4% which implies $\beta = 0.96$.

- In steady state the ration between non-residential capital and non-housing output equals
$$\frac{K}{Y} = \frac{\alpha\beta}{1-\beta(1-\delta_k)},$$
with $Y = zK^{\alpha}N^{1-\alpha}$. For the sample period, this ratio averaged 1.7 in the U.S. data, and this allows to solve for the non-residential capital depreciation rate, δ_k. We normalize non-housing output to 100, which gives a value for z.

- The aggregate resource constraint can be used to determine the level of leverage. In particular, we have
$$\frac{C}{Y} + \delta_k \frac{K}{Y} + \delta_s \frac{S}{Y} + r^* \phi \frac{[p^{\ell} L + S]}{Y} = 1.$$
During our sample period, non-housing consumption, the value of structures, and the value of residential real estate as ratios to non-housing output averaged 0.77, 1.16, and 1.84, respectively. Setting the depreciation rate to $\delta_s = 0.015$, which is standard in the literature, normalizing the stock of land to 100, and considering an effective real cost of borrowing of $r^* = 0.03$ uniquely determines the economy's leverage ratio. The implied value is $\phi = 0.50$, which is roughly consistent with mortgage debt reported by the Flow of Funds.

- The elasticity of substitution parameter in the technology that combines structures and land is consistent with the estimates in the literature and is given by $1/(1+\mu) = 0.25$.[5] The technology shifter, z_h, is chosen so that housing services equal 100. Finally, we set the preference parameter ρ, so that $1/(1+\rho) = 0.5$.

- Given $\theta = 1.5$, the last two parameters (the shares α_c and α_s) are calibrated using the steady state Euler equations for structures
$$1 = \beta\left(1 - \delta_s + R_S^h\right) + (1 - \beta(1+r^*))\phi,$$

[5] See McDonald (1981).

and land holdings[6]

$$p^\ell = \left(\beta p^\ell + R_L^h\right) + (\frac{1}{\beta} - (1+r^*))\phi p^\ell,$$

where

$$R_j^h = \frac{u_c}{u_h} G_j(t), \text{ for } j = S, L.$$

Since these equations do not have a close form solution, the parameters are determined as part of the steady-state calculations. The parameter values used in the numerical simulations are summarized in Table 1.

Table 1: Parameter Values

Parameter		**Value**
Productivity goods technology	$z =$	26.44
Productivity housing technology	$z_h =$	0.89
Discount rate	$\beta =$	0.96
Share of consumption goods	$\alpha_c =$	0.88
Share of structures	$\alpha_s =$	0.80
Capital share	$\alpha =$	0.26
Depreciation of capital	$\delta_k =$	0.11
Depreciation of structures	$\delta_s =$	0.015
Collateral constraint	$\phi =$	0.50
Elasticity parameter $u(c,h)$	$\rho =$	1
Intertemporal elasticity parameter	$\theta =$	1.5
Elasticity parameter $G(S,L)$	$\mu =$	3

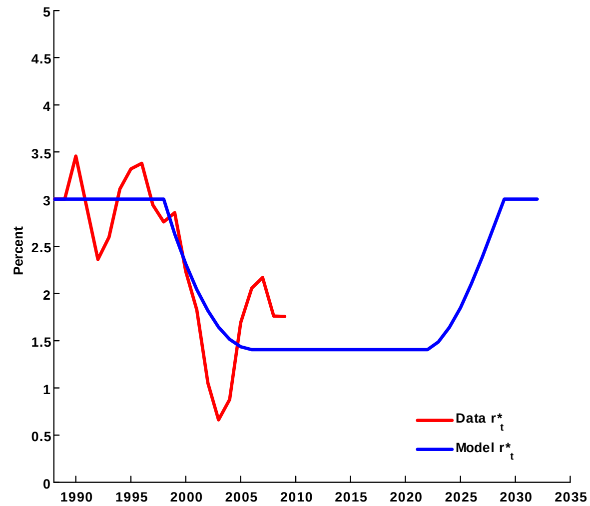
6.2. The Dynamics of Interest Rates and Financial Conditions

In this section, we consider the quantitative impact of shocks to the cost of borrowing, r^*, the tightness of credit markets, ϕ, as well as unanticipated shocks to expectations of their possible trends. Figures 3 and 4 display the data together with a smooth trend and our assumptions about paths of interest rates and credit market tightness, which we will use to

[6] Even though it does not have any economic interpretation, we use the price of land given by $p^\ell = 1.84 - \frac{S}{Y} = 0.68$, which follows from the estimates of the value of housing, the values of structures, and the normalization of the stock of land $L = 100$.

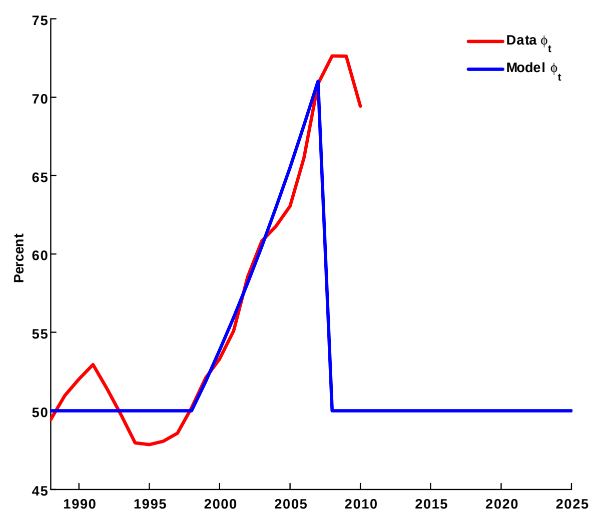
drive the model in our quantitative exercises.

Figure 3: Cost of Borrowing (r_t^*)



Source: Authors calculations.

Figure 4: Financial Conditions (ϕ_t)



Source: Authors calculations

We assume that (i) the interest rate gradually decreases, starting in 1999, from the initial level of 3% to reach 1.5% in 2006, and, (ii) it stays at that level until 2023, at which time it gradually increases until it hits its original level.[7] The parameter ϕ starts from the steady state level of 0.50 and increases starting in 1999 to 0.70 in 2007, and then it rapidly returns to its original level. The different experiments vary in terms of both the variables that are

[7]The data suggest that there was an increase in the cost of borrowing between 2005 and 2007 and there is some uncertainty about the exact timing of the tightening of borrowing conditions. In the model, allowing some short-run changes in interest rates to mimic the 2005-07 episode and delaying the tightening of borrowing conditions has a small effect on the results. To highlight the important factors we have chosen to model simple paths for interest rates and loan-to-value ratios.

allowed to move and the expectations held by the public.

Our analysis focus on the transition from an original steady state in response to these shocks. We solve the model searching for equilibrium quantities that satisfy the first order conditions corresponding to the optimization problems faced by workers and firms. We impose the condition that the model converges after 130 periods, which results in a highly accurate solution (our maximum Euler equation residuals along simulations are of the order 10^{-16}).

6.3. Perfect Foresight

In the first set of experiments, we assume that individuals perfectly anticipate the evolution of all the variables after an initial, unanticipated, change.

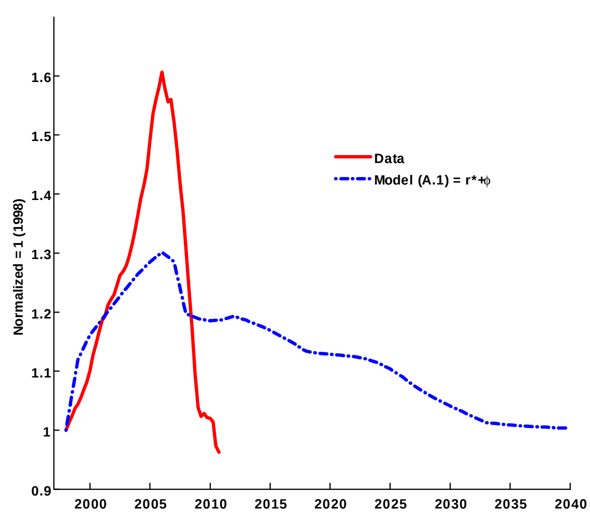
1. **Experiment A.1**: This experiment allows simultaneous changes in the cost of borrowing, r^*, and in the parameter ϕ.

2. **Experiment A.2:** This experiment illustrates the effects of changes in each of the variables while the other is held constant.

6.3.1. Experiment A.1: Joint Changes in the Cost of Credit and Financial Conditions

In this experiment, we assume that households have perfect foresight and, after an initial surprise, correctly anticipate future changes in interest rates and financing conditions. As summarized in Figure 5, the model predicts that house prices should increase about 30% from the late 1990s to the mid-2000s . The data suggest an increase of 60% with respect to trend.

Figure 5: House Values: Changes in r_t^* and ϕ_t



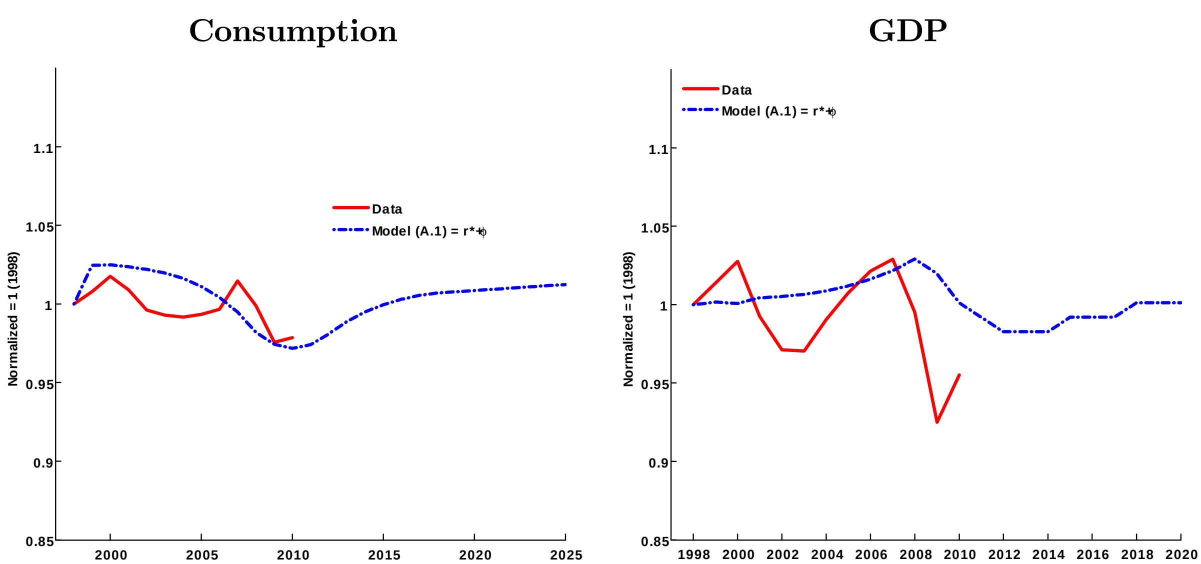
Source: Adjusted NIPA and model simulated data.

Thus, this experiment explains about 50% of the observed increase in housing values. There are several mechanisms at work. First, the lower effective cost of capital is capitalized in the value of land and house prices increase. Second, since the value of collateral rises and households can borrow against the value of the housing stock at below domestic market rates, this is equivalent to an income shock —given by the present discounted value of the interest rate differentials— which results in higher consumption of both goods. Since households increase their desired saving to smooth consumption, they choose to save some of the extra income. This drives domestic interest rates down and domestic investment up. From a quantitative perspective, the model is consistent with large movements in asset prices accompanied by small changes in real variables (non-housing consumption and output) as suggested by the results in Figure 6.[8]

The model implies that there is an asymmetry between booms and busts: Symmetric changes in interest rates result in an asymmetric response of house prices. This is due to two factors. First, it is not possible to disinvest in structures that have a very low depreciation rate. Thus, in the bust, the price of structures, but not the level adjusts. The second factor is that the paths of the driving variables are asymmetric. While the increase is unanticipated, the decrease is anticipated by about 15 years. The tightening of credit conditions generates an 8% decline in house prices. Under perfect foresight the model implies that, contrary to the evidence, the decrease in house prices is a slow process.

Even though changes in house prices can potentially generate large income effects, the model implies that non-housing quantities do not move much (see Figure 6). This is due to the complementarity between housing and non-housing consumption implied by our calibration.

Figure 6: Macro Aggregates

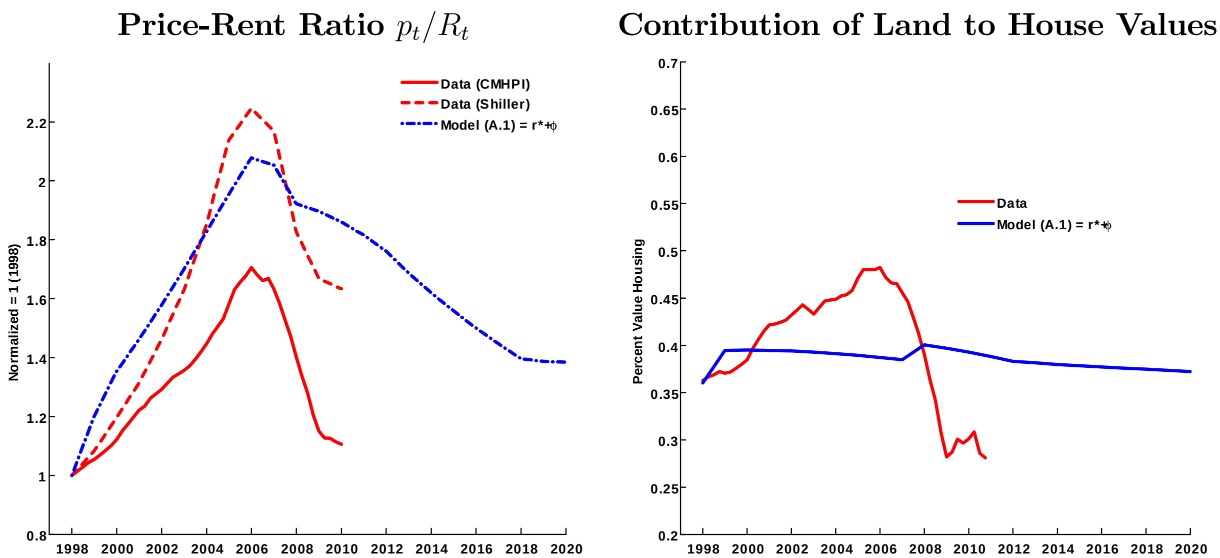


Source: Adjusted NIPA and model simulated data.

[8]We choose to present the model simulated data with the data counterpart.

Figure 7 summarizes the model's prediction for some key housing statistics.

Figure 7: Housing Aggregates



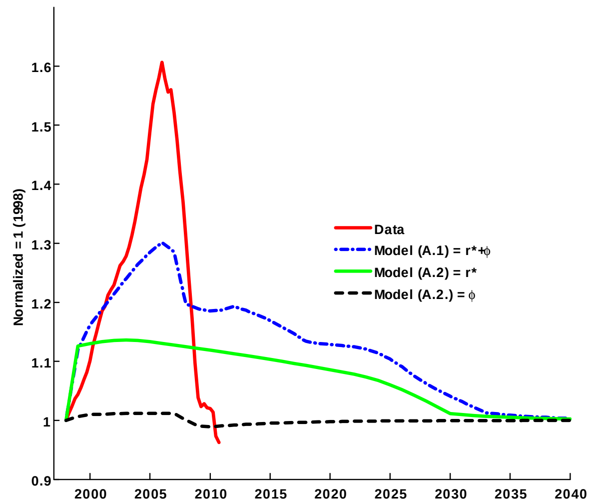
Source: Adjusted NIPA and model simulated data.

The model underestimates the contribution of land values to house prices. The perfect foresight version of our exercise generates a significant increase in house values, but it is driven by an expansion of structures. The expansion of the stock of structures —and hence in the consumption of housing— generates a decline of the rental price. The model implies that the price-rent ratio increases significantly. The combination of the increase in house values with a decline in rents increases the price-rent ratio to levels consistent with Shiller's p/R index and larger than the baseline economy that uses the Conventional Mortgage Home Price Index (CMHPI). Thus, this exercise illustrates the danger of using the price-rent ratio as a measure of changes in housing markets since the model does no succeed in matching prices or rents but performs much better when the price-rent ratio is used as the main criterion.

6.3.2. Experiment A.2: Single Changes to Interest Rates and Financial Conditions

The objective of the second experiment is to study the impact of each of the changes in isolation. The theoretical analysis in Section 4 suggests that the response of house values to the relaxation of financial conditions is stronger when interest rates are low. For the parameterized version of the model, we assess the quantitative importance of the two main drivers of house prices in the model. Figure 8 illustrates the responses to the change in each factor.

Figure 8: House Values: Changes in r_t^* or ϕ_t

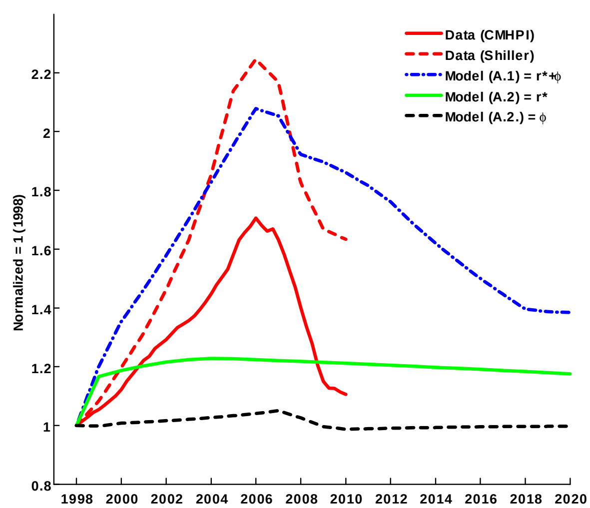


Source: Adjusted NIPA and model simulated data

We find that interest rates still have a positive effect on house prices, but the quantitative impact has been reduced to the initial impact in 1998. On the contrary, the relaxation of financial conditions has almost no effect on house prices. Moreover, the effect of the joint change (also shown in Figure 8) exceeds the sum of the individual effects, which illustrates the essential nonlinearities in the model.

The small role of interest rates on house prices is consistent with the findings by Glaeser, Gottlieb, and Gyourko (2010). Their estimates of the user cost model suggest that interest rates cannot directly explain more than one-third of the increase in the price-to-rent ratio.

Figure 9: Price-Rent Ratio p_t/R_t



Source: Adjusted NIPA and model simulated data

Figure 9 depicts the impact on the price-rent ratio of changes in interest rates and financial conditions in isolation. Either factor appears to have a small impact. This contrasts with their significant role when both factors change simultaneously.

The perfect foresight model is a useful benchmark, and in the next sections we explore the role of the arrival of information in the determination of house prices, as well as the response of the main macro and housing aggregates.

6.4. Shocks to Expectations

In this set of experiments we allow expectational shocks at different points in time. We do this to better understand what role surprises could have played in the movement of house prices.

1. **Experiment B.1:** In this experiment we assume that, starting from the steady state, households are surprised by a gradual change in mortgage rates that they view as permanent that is, that interest rates will remain forever at 1.5% after they reach that level. We then model a second shock —chronologically it corresponds to 2008— that is a revision to the previous expectations: Households assume that interest rates will remain low until 2023, and then will rise slowly to their previous steady state level.

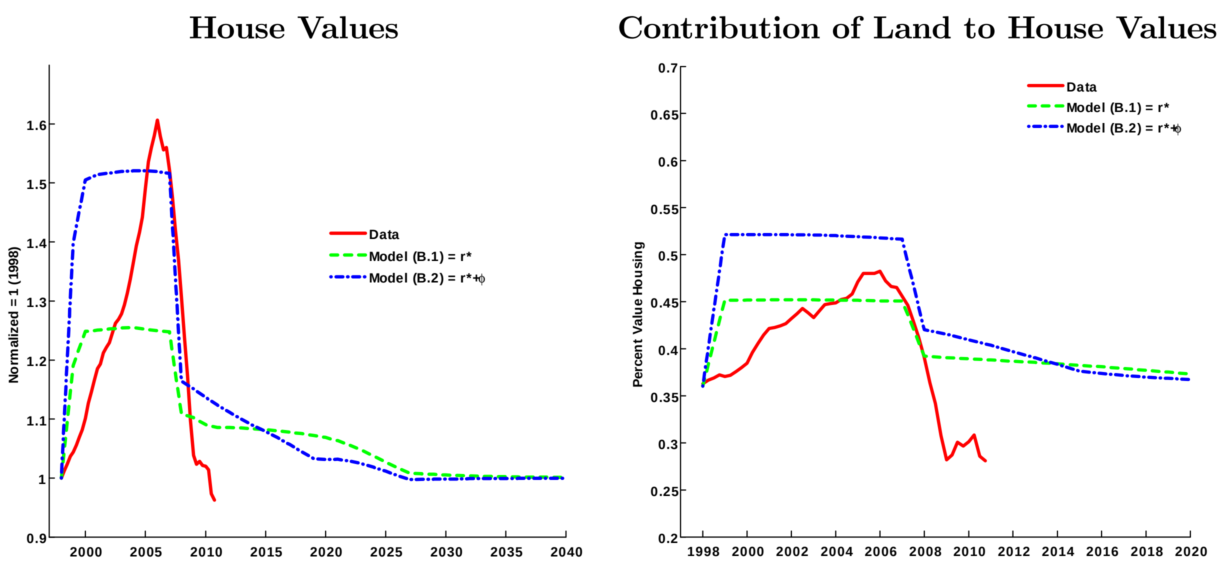
2. **Experiment B.2:** This experiment is similar to the first, except that we add changes in credit market conditions: In 1999 the maximum loan-to-value ratio increases and, as with interest rates, households view this change as permanent. At the time of the second shock, the maximum loan-to-value ratio decreases to the previous steady state level.

3. **Experiment B.3:** Finally, the third experiment deviates from the second in this section by assuming that rather than a discrete adjustment to lower interest rates in 1999, households view each annual change from 1999 to 2008 as permanent. As in the previous two economies, expectations adjust again in 2008.

6.4.1. Experiment B.1-B.2: Two Shocks to Expectations

The anticipation of a long period with low rates and relaxed credit standards has a significant effect on house prices. This can be interpreted as households having overly optimistic expectations about future low rates and credit conditions. The bust is not anticipated and house prices increase vis-à-vis much more than in the perfect foresight model. Moreover, the response is immediate as asset prices capitalize expected changes.

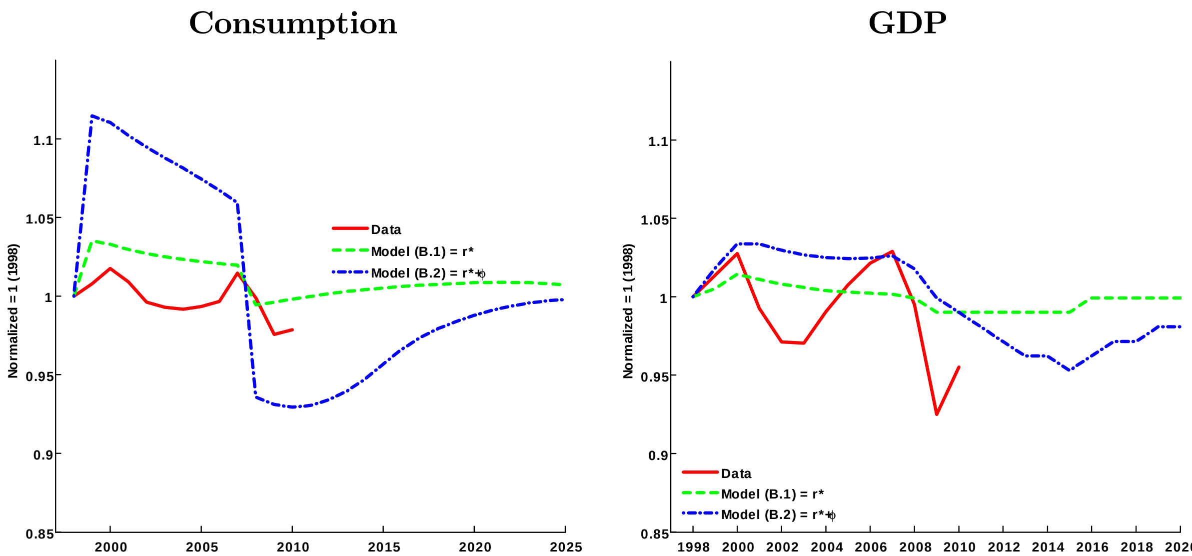
Figure 10: House Prices and Land: Changes in r_t^* and ϕ_t



In Experiment B.1 changes in interest rates can account for almost 40% of the increase in house prices (versus only 15% in the perfect foresight case). This simulation improves the model's predictions about the contribution of land values to house prices. Adding changes in credit conditions almost doubles the impact on housing prices in the boom and comes very close to reproducing the drop in the bust. The combination of interest rates with credit conditions captures 90% of the housing boom. In this case, land's share changes slightly more than in the data.

The arrival of news in 2008 of future reversals of the interest rate in 2023 generates a dramatic collapse in house prices. Relative to 2008, households find themselves with too much housing and too much debt (debt overhang). Since the value of outstanding mortgages exceeds the market value of the housing stock, homes cannot be used to increase borrowing. Thus, housing loses some of its value as collateral and this exacerbates the price decrease.

Figure 11: Macro Aggregates



The bust generates a process of deleverage where consumption declines and aggregate activity decreases. The reversal is very slow and the economy operates below trend during a significant number of years.

The experiment that adds a tightening of credit conditions (Experiment B.2.) has a more significant deleveraging process. In 2008 consumers receive the news about future interest rate increases (starting in 2023) and an immediate reversal of credit conditions to 1998 levels. As a result, consumption declines on impact and rental prices fall. In the next period, households decrease the stock of structures (no investment) and rental prices slowly grow until the economy converges to the new steady state.

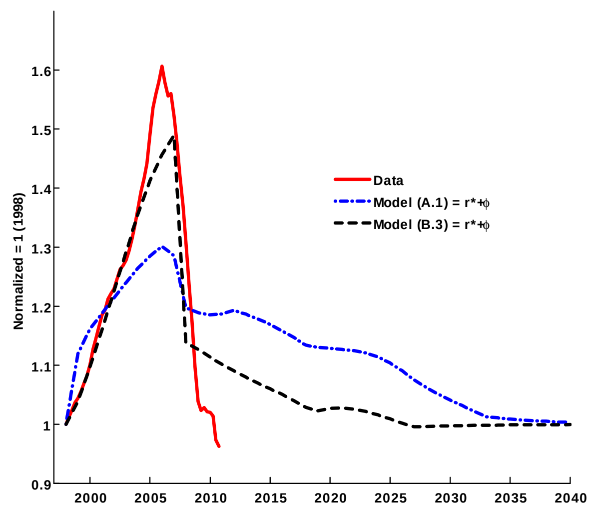
The economy with two shocks improves along some important dimensions over the perfect foresight economy. First, it can better capture the magnitude of the increase in house prices, as well as the changes in the share of total value corresponding to land and structures. Second, the predictions about the behavior of housing quantities (structures and rental prices) improve substantially. Third, the model is consistent with a negative effect of the existing mortgage debt on house prices; that is, it illustrates that the inability to borrow when house prices decline magnifies the initial reduction in the market value of the housing stock.

6.4.2. Experiment B.3: Multiple Shocks to Expectations

Even though the combination of changes in interest rates and credit conditions can generate a boom and a subsequent bust, the experiment reveals two weaknesses: The model predicts a too fast increase in house values and an excessive response of non-housing consumption. To understand the role of expectations, we consider the case in which households view each change in interest rates in the 1999-2006 period as permanent, even though their expectations turn out to be incorrect. Thus, our experiment traces the impact of a particular sequence of shocks to expectations.

The predictions of the model for house values are shown in Figure 12.

Figure 12: House values



The slow arrival of news about the changes in the cost of credit and credit conditions generates a path of house prices that is very close to the one observed in the data. The asymmetry between the boom and the bust is driven in part by the role of the collateral constraint. Without the large wealth effects prices increase at a low rate until rates stop falling. As in the previous case, during the bust the collateral value of housing greatly decreases and this contributes to the fall in prices. This suggests that a slow arrival of news combined with an asymmetric borrowing constraint are important elements to replicate the boom-and-bust episode.

Figure 13 summarizes the impact of the shocks on macro aggregates. Overall, the model implies that large swings in house prices need not imply large changes in aggregates. Even though non-housing consumption and output move in response to the shocks we study, the fluctuations are small.

Figure 13: Macro Aggregates

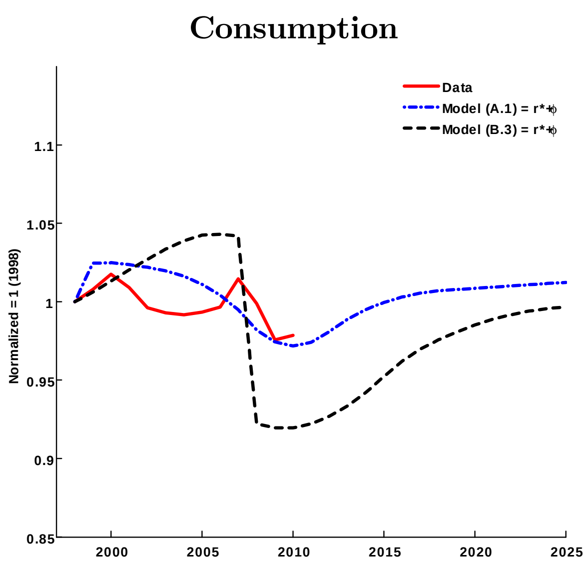
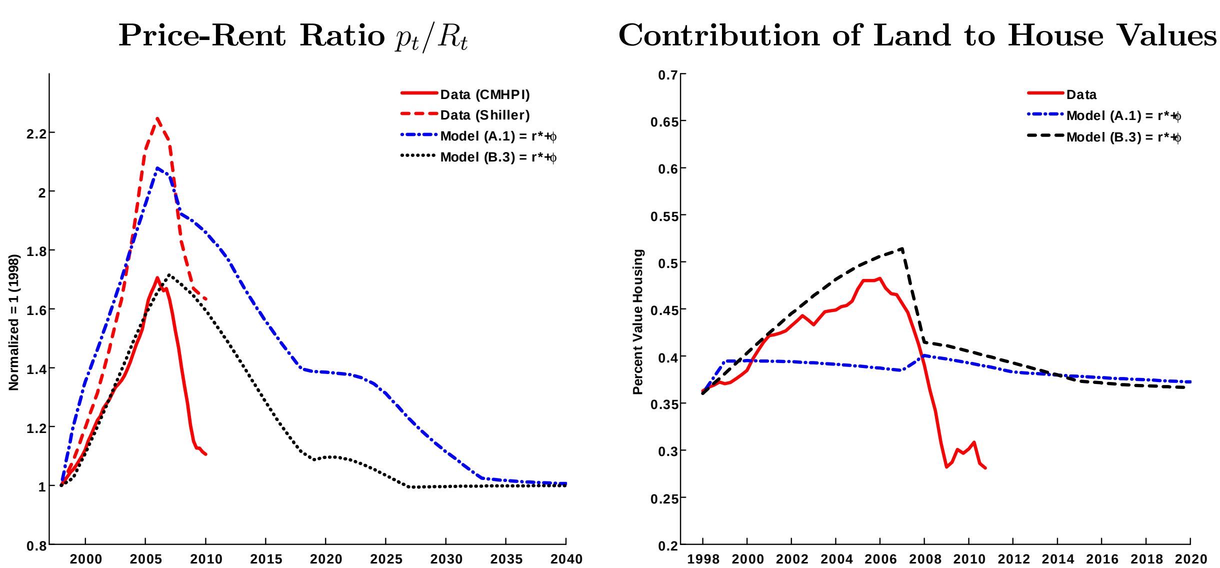


Figure 14 summarizes the implications of the model for the price-rent ratio and the share of the total value of the housing stock attributable to land. The model is capable of reasonably reproducing the movements in the price-rent ratio. This reaffirms our view that this is probably not a good statistic to study, as its behavior appears to be robust to very different specifications and movements in other housing aggregates. This version of the model tracks the increase in land's share during the boom fairly well. However, it falls short of matching the decrease associated with the bust.

Figure 14: Housing Aggregates



Source: Adjusted NIPA and model simulated data

6.5. Decomposing House Prices: The Role of Frictions

The model can be used to determine the contribution of the two frictions that we modeled to the change in house prices. In particular, let the value of the housing stock be given by

$$V_t^h = p_t^s S_t + p_t^\ell L.$$

An argument analogous to that used to derive (5.1) shows that

$$V_t^h = \hat{V}_t^h + \sum_{j=0}^{\infty} m_t(j)\eta_t(j)R^h(t+j)G(S_{t+j}, L), \quad (6.1)$$

where

$$R^h(t) = \frac{u_c(t)}{u_h(t)}$$

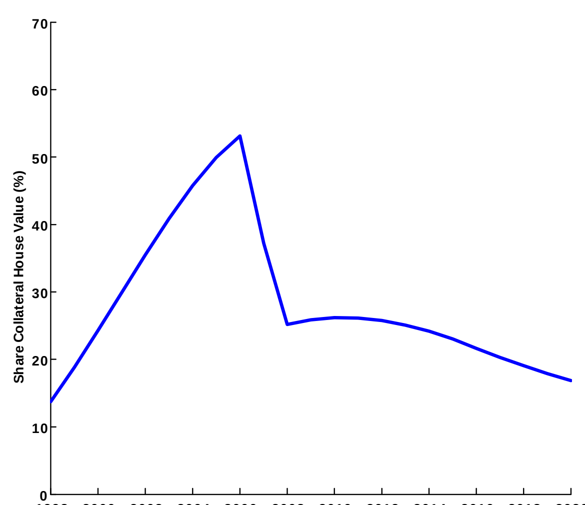
is the rental price of one unit of housing, and

$$\hat{V}_t^h = \sum_{j=0}^{\infty} m_t(j)R^h(t+j)G(S_{t+j}, L)$$

is the frictionless value of the housing stock in an economy with a real interest rate similar to the domestic rate in the model. This frictionless value is given by the present discounted value of future rents using the domestic interest rate. As before, the term $\eta_t(j)$ captures both the impact of market segmentation and the additional of value that housing because it can be used as collateral. Equation (6.1) shows that the market price is the sum of the frictionless component and an additional term that captures the contributions of market segmentation and financial conditions to the value of a house. It is an empirical question how significant is the "friction" component in accounting for the change in prices.

Figure 15 summarizes the decomposition in equation (6.1) corresponding to Experiment B.3.

Figure 15: Contribution of collateral to house values (%)



In the baseline steady state, the model predicts that the fact that housing can be used as collateral adds approximately 14% to its value. During the boom, the composition changes because rents decline and the collateral value of homes increases. During this period frictions account for over 50% of the total value. The model seems to reconcile the disconnect between rents and house prices in periods with very rapid growth in house values.

7. Conclusions

In this paper, we revisit the connection among changes in interest rates, loan-to-value ratios, and expectations in influencing housing prices. We construct a two good general equilibrium model in which housing is a composite good produced using structures and land. Overall, we find that the model provides reasonable insight into the features of an economy that can generate swings in housing prices of the magnitude observed in the U.S. In particular, by allowing land, and structures as well as housing and non-housing consumption, to be complements, the model can accommodate changes in asset prices that do not generate large wealth effects provided that agents learn slowly about the actual change in financial variables. We show that changes in interest rates and credit conditions that are viewed as permanent can have a large impact on house prices. We also show that if the model is to account for the observed timing and magnitude of the swings in house prices, it must be the case that households were exposed to multiple expectations shocks. Our results suggest that the price-rent ratio is not a good indicator of whether a model performs well since we find that even specifications that fail to account for important aspects of the data seem to match the movement in this indicator. Finally, we provide a decomposition of the price of houses using the appropriate pricing kernel that shows that market segmentation and the collateral role of houses can reconcile the apparent divergence of housing prices from their fundamental value. In the model that we study, the difference is driven by the capitalized value of the implicit subsidy to mortgage financing.

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