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A Macroeconomic Model of Price Swings in the Housing Market*

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Abstract

This paper shows that a macro model with segmented financial markets can generate sizeable movements in housing prices in response to changes in credit conditions. We establish theoretically that reductions in mortgage rates always have a positive effect on prices, whereas the relaxation of loan-to-value constraints has ambiguous effects. A quantitative version of the model under perfect foresight accounts for about half of the observed price increase in the U.S. in the 2000s. When we include shocks to expectations about housing finance conditions the model's ability to match house values improves significantly. The framework reconciles the observed disconnect between house prices and rents since, in general equilibrium, financial shocks can decrease rents and increase prices.

Keywords: Residential investment, mortgages rates, leverage

J.E.L. codes: E2, E3

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1 Introduction

In recent years housing prices have displayed significant changes on a global scale. This happened concurrently with increased availability of credit and low interest rates. In the case of the United States, house prices displayed a very rapid appreciation during the period 2000-06 before collapsing in 2007 and—in the view of many—contributing to the Great Recession. Even though house prices have fluctuated in the past, the magnitude of the changes during this episode is unprecedented in the postwar years. In the aftermath of the financial crisis, interest rates have remained low and house prices have continued to grow.¹ From a theoretical perspective, the standard approach to pricing houses essentially views them as an asset whose dividends are the actual or imputed rents. 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 sizeable changes in house prices that we observed in the United States. and, hence, it casts doubt on the view that financial shocks that induce price changes can significantly impact the economy.

In this paper, we explore whether realistic changes in mortgage rates and credit supply can account for large changes in house prices in the context of a macro model. We first consider a stylized model with an inelastic housing supply, collateralized credit, and segmented financial markets—there is a wedge between the mortgages rate and the return of other assets, including capital—that can deliver significant increases in house prices in lax credit conditions. In particular, the response of house prices to changes in credit conditions depends not only on the level and the spread of interest rates, and the maximal loan-to-value ratio but, crucially, on the expected duration of the “new” financial conditions. Moreover, the model implies interesting asymmetries between the effects of lower interest rates (they always increase prices) and more generous access to credit (they have ambiguous effects).

Even though the simple model reveals the potential for changes in credit conditions to explain the movement in house prices, it has limitations for how these changes interact with the macroeconomy. The key observation is that housing services are not a marginal component of consumption, as they represent about 10 percent of value-added. Thus, any changes that potentially change the demand for housing must have aggregate effects through their impact on consumption, saving and investment decisions. To evaluate whether the effects that we identified are consistent with the macro evidence, we develop a general equilibrium macro model that studies a “semi-open” economy with segmented financial markets. The key drivers are changes in the rate of return on mortgages—the return on capital is endogenous—and in the maximal loan-to-value ratio. In the model, we view the segmenta-

¹The experience is not unique to the United States as other countries had or are currently having significant movements in house prices, for example Australia, Brazil, Canada, China, France, India, Ireland, Korea, New Zealand, Spain, Sweden, Taiwan, and the United Kingdom.

tion as being driven by foreign demand for mortgage backed securities, which is consistent with the evidence discussed in Section 3. This is a shortcut to capture segmentation in an equilibrium setting. In the model, we allow foreigners to purchase assets collateralized by the value of the housing stock but keep the economy otherwise closed.² We allow for an elastic supply of housing which is not only consistent with the behavior of residential investment, but also essential for matching the comovement between rents and house prices observed in the data. In addition, we assume that households make standard saving and investment/portfolio allocation decisions.

We show that in the steady state—which we view as the long run in the case of permanent shocks to credit conditions—reductions in the interest rates on mortgages always have a positive impact on prices. The effect of increases in the maximal loan to value ratio is theoretically ambiguous. The reason is simple: A lower cost of financing housing has an impact that is akin to a positive income effect (in the steady state the rate of return on capital is fixed and hence has no impact on investment), while the relaxation of lending standards (higher loan-to-value ratios) requires that larger loans be repaid eventually. Thus, the income effect can be smaller and—depending on the details—actually change sign.

To assess the model’s ability to account for the U.S. experience, we study a quantitative version calibrated to match the appropriate moments of the data during and before the housing boom. We use the model to study the response of house prices and macro aggregates to changes in mortgage rates and loan-to-value ratios—our driving shocks—that match the data during the housing boom-bust (1998-2010). In terms of the information about credit conditions, we consider two views that probably bracket most options: perfect foresight—where we mimic as close as possible the actual data—and a sequence of shocks to expectations that captures alternative views about the duration of changes in financial conditions.

Under perfect foresight, the model predicts an increase in house values that ranges between 25 to 45 percent. Since the magnitude of the price change depends on the long-run properties of mortgage rates, we consider several scenarios. Our results show that changes in financial conditions can induce large movements in house prices and relatively small changes in non-housing consumption, as in the data. Also, consistent with the evidence, a large fraction of the increase in house values corresponds to the value of land and a more modest fraction to the change in the stock of structures. Even though the model predicts that a reduction in the cost of borrowing accounts for a much larger fraction of the change in house values than changes in financial market conditions, the total effect of a joint change is not

²It is possible to view the wedge between the return on mortgages and the marginal product of capital as arising from portfolio constraints imposed on financial intermediaries or extremely risk averse agents as in Caballero and Farhi (forthcoming). However, this alternative would require adding a significant amount of heterogeneity to model the lending side of the market, which we do not believe would have much impact on the results for the housing sector.

well approximated by a simple sum: The model is highly non-linear.

In the simulations with shocks to expectations, we assume that in each period households view the change in mortgage rates and maximal loan-to-value ratios as permanent. However, period after period they receive an “expectation shock” as a surprise. The model indicates that the timing of information arrivals about housing finance conditions is key to mimic the timing of the boom and the bust and at the same time keeping the impact on macroeconomic aggregates small. Comparing the path during the boom with the most conservative estimate from the perfect foresight simulations shows that adding shocks to expectations increases the contribution of the model to account for house values by 50 percent and making the model consistent with the observed movements of house prices.

Our results illustrate that financial shocks have asymmetric effects depending on the details of the households’ balance sheet. In line with the evidence, the boom in the housing sector is not associated with large changes in the rest of the economy. However, credit reversals generate a housing bust with large periods of deleverage as the value of the outstanding debt exceeds the debt limit (debt overhang) requiring households to adjust consumption and investment (capital and housing). However, since investment in housing is irreversible this requires that non-housing consumption adjusts. The deleveraging process can rationalize periods of low interest rates that do not generate sizeable house price appreciation when households have too much housing and excessive mortgage debt, something that the literature has found very puzzling.

Finally, our model allows us to estimate the bubble component in house prices and to discover the economic forces that account for the puzzling disconnect between rents and house prices. The key observation is that equilibrium rents depend on both the level of housing and non-housing consumption. A decrease in the cost of mortgages increases investment in structures and, in equilibrium, the amount of housing services. It also increases—through an income effect—investment and non-housing consumption in the short run. If housing consumption increases more than non-housing consumption—as predicted by our calibrated model—the result is a decrease in rents at the same time that house prices increase.

The paper is structured as follows. In the next section, we provide a short review of the literature. In Section 3, we present evidence of the housing boom-bust experience in the United States. In Section 4, we present the simple asset pricing model to highlight the role of market segmentation and the expected duration of the period of relaxed financial conditions to account for the increase in house prices. In Section 5, we present the general equilibrium model and develop some steady state results. Section 6 contains our quantitative findings, and Section 7 provides some concluding comments.

2 Related Literature

The recent literature on macro-housing has emphasized the contribution of housing to the traditional business cycle through various channels such as residential investment (i.e., Davis and Heathcote 2005, Leamer 2007, Fisher 2007, Kydland, Sustek, and Rupert 2012, Boldrin, Garriga, Peralta-Alva, and Sanchez 2013), collateral constraints (i.e., Iacoviello 2005, Iacoviello and Neri 2010, and Liu, Wang, and Zha 2011), and nominal mortgage contracts (i.e., Garriga, Kydland, and Sustek, 2013) to name a few. An extensive summary of the state of this literature is provided by Davis and Van Nieuwerburgh (2015) and Piazzesi and Schneider (2016). While these papers measure the importance of housing to high-frequency movements of the economy, in general, these models fail to reproduce less-frequent episodes characterized by large swings in house prices, such as the recent boom-bust cycle observed in a large number of developed economies.

As a result, the majority of the research analyzing these episodes is making advances by focusing on the factors that influence the market value of the housing stock. From a theoretical perspective one of the main challenges is that the empirical evidence is not conclusive about the nature of the main drivers of house prices. For example, Campbell, Davis, Gallin, and Martin (2010) decompose house price movements using a simple linearization of the user cost (as in Poterba, 1984) that includes rents, interest rates, and a residual. They find that movements in price-rent ratios can be attributed more to time variation in risk-premium and less to expectations of future rent growth. Using variations of the user-cost model, Glaeser, Gottlieb, and Gyourko (2013) and Glaeser and Nathanson (2014) argue that the time variation of interest rates cannot account for the observed movement in price-rent ratios. This view is also shared by Shiller (2007), who argues that the 2000s housing boom cannot be rationalized through the lens of the user cost model, as measured rents remained relatively flat.³ The current literature has tried to reconcile some of these facts using different strategies.

One approach has focused on the role of expectations and irrational exuberance as a driver of house prices. There is a strand of literature that explores the importance of expectations and information in models with a representative agent. For instance, Adam, Kuang, and Marcet (2011) use a small open-economy model where the dynamics of beliefs about price behavior can temporarily decouple house prices from fundamentals. Kahn (2008) uses a Markov-switching model where a change in regime changes the valuation of housing. Gelain, Lansing, and Natvik (2016) use a housing asset pricing model with fixed supply and attempt to reverse engineer the expectations that replicate the observed dynamics of house prices.

³Prior to the 2000s housing boom, most of the postwar movements in house prices can be accounted for by increases in housing quality and construction costs (1950-1970) or regulatory restrictions. These facts are documented in Shiller (2007), Glaeser, Gyourko, and Saks (2005), and Chambers, Garriga, and Schlagenhaut (2015).

However, their best model generates a positive correlation between rents and house prices not found in the data. The importance of information frictions has also been evaluated in models with heterogeneous agents. For example, Barlevy and Fisher (2010) use an endowment economy with heterogeneous buyers subject to housing preference shocks and supply restrictions. In their model when a house price bubble emerges, both speculators and their lenders prefer interest-only mortgages to traditional mortgages with amortization. Burnside, Eichenbaum, and Rebelo (2016) provide a mechanism by which housing booms are generated by heterogeneous beliefs about the long-run fundamentals driven by the entry of new buyers. Ríos-Rull and Sánchez-Marcos (2012) use an endowment economy with incomplete markets, aggregate uncertainty, and imperfect information (non-rational expectations). In response to shocks to earnings, interest rates, and mortgage premiums, house prices in their model move far less than in the data. Relative to this literature, we can show the interaction of housing finance and mortgage rates in the presence of shocks to expectations about future reversals. The model with information frictions captures the dynamic behavior of house prices, rents, and macroeconomic aggregates during the housing boom and the bust.

Another strand in the macro-housing literature uses structural equilibrium models to explore the impact of changes in housing finance (i.e., reductions in mortgage rates, relaxation of loan-to-value constraints, and innovations in mortgage lending) on house prices.⁴ For example, Ortalo-Magne and Rady (2006) show that the relaxation of credit constraints in an economy with two types of homes can have a positive effect on housing demand. Kiyotaki, Michealides, and Nikolov (2011) use a quantitative small open-economy model with heterogeneous households and focus on the redistributive effects of fluctuations in home values. Their model can generate a 30 percent increase in house values, but requires a permanent increase in productivity (household income) and a permanent decrease in the interest rate

⁴There is an extensive micro literature that studies the impact of changes in financial variables on house prices. Research in the area has proceeded by estimating user cost equations at the national and metropolitan level (e.g.; Poterba 1984, Himmelberg, Mayer, and Sinai 2005, and Glaeser, Gyourko, and Saks 2005). There is no consensus in the micro literature on the role of rents, interest rates, and expectations in explaining the large changes in house prices. Some papers find a very weak connection between credit conditions and house prices. For example, 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. Glaeser, Gottlieb, and Gyourko (2013) 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. Other papers find a positive relationship between interest rates and house prices. For example, Hubbard and Mayer (2009) find that an alternative specification of the user cost shows that interest rates can have a positive impact on house prices. Doms et al. (2007) use cross-sectional state level data for the United States and find that low interest rates and higher appreciation are positively correlated.

(the discount rate used to price assets) that also generates a large consumption boom. He, Wright, and Zhu (2011) study an economy where houses provide shelter but can also facilitate market transactions because unsecured credit is imperfect, whereas housing can be used as collateral in trades. In their model, the relaxation of the collateral constraint increases house values displaying complicated dynamics resembling bubbles, even when fundamentals are constant and agents are fully rational. Favilukis, Ludvigson, and Van Nieuwerburgh (2016) explore the role of collateral constraints in the fluctuations in home values in an economy with heterogeneous agents and time-varying risk premia. Housing in addition to service flows can be used to insure labor income shocks, via home equity lines of credit. The relaxation of collateral constraints improves the insurance aspects of housing, and in the quantitative simulations results in an increase of house values of around 20 percent and the price-rent ratio of around 40 percent. 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. In their model, providing cheap credit for poor households increases house values, in particular at the low end of the market. Relative to these papers, our contribution is to provide a sharp theoretical characterization of the drivers of house prices. In the model, borrowers do not trade with other individuals and are not exposed to income risk. The relaxation of collateral constraints operates in conjunction with the cost of borrowing, and the effect on house values is ambiguous.⁵ This provides theoretical ground and can help reconcile the divergent views of the role of credit constraints as presented in the stylized model in Section 4.

Relative to the aforementioned research, the model presented in this paper departs from the previous literature in several dimensions. First, it explicitly models the portfolio effects associated with financial segmentation. We view the evidence as showing that the interest cost of mortgages during the boom period fell relative to the return on capital. Standard asset pricing implies that the return to housing should include the implicit subsidy associated with the difference in returns. This differentiates our pricing formula from Poterba (1984) and Glaeser, Gottlieb, and Gyourko (2013)⁶. Second, we allow for an elastic supply of housing, differentiating land and structures and, through portfolio effects, our model implies that changes in the interest rate on mortgages have an impact on investment and non-housing consumption. This, in turn, is essential to account for the disconnect between rents and prices found in the data. Third, introducing long-term mortgage loans, as in Chambers,

⁵Other researchers argue that regional differences are important to understand the dynamics of house prices. Mian and Sufi (2009) explore the importance of mortgage expansions during this episode. An appendix available upon request develops a model with regional segmentation and the general findings relative to relaxing borrowing constraints are still valid.

⁶In addition, we view the market value of housing rents as an equilibrium object determined by the marginal rate of substitution between housing and non-housing consumption rather than the sum of financial costs of renting out a house as in the urban literature.

Garriga, and Schlagenhauf (2009), allows us to separate stocks and flows of credit affecting the macroeconomic impact of deleveraging when house prices decline. As we show in Section 4, models in which credit reductions are transitory cannot account for large changes in prices. In our simulations, we let the data—to the extent possible—guide our choice of the speed of reversion as well as the expectations about reversals.

3 Empirical Evidence

In recent years several developed and developing economies have experienced or are currently experiencing sizeable movements in house prices.⁷ In this paper we pay close attention to the boom-and-bust experience in the United States from 1998 to 2010, which serves as a lab for evaluating potential explanations of the factors that drive changes in house prices. This section documents the behavior of the housing market and the macroeconomy around this episode.

Figure 1 summarizes the evolution of real housing values and prices in the United States between 1975 and 2015. The indexes for values and prices are calculated as a deviation from a trend calculated for the years 1975-2003. The housing boom in the 2000s is clearly different from other short-run fluctuations observed since 1975. During the housing boom, it is clear that most of the increase in house values was due to appreciation and not an increase in the size of the stock of housing capital. The left panel in Figure 2 shows that the increase in house prices was associated with a relatively large but not unprecedented increase in the physical volume of new privately owned housing structures. Since structures account for only part of the increase, it follows that the price of land must be accounting for a large share of the appreciation in the housing stock, as argued by Davis and Heathcote (2007). The right panel in Figure 2 summarizes the contribution of the value of land to the value of the housing stock. The evidence shows that in the 2000s housing boom, the share of land in house values increased from 35 percent to near 50 percent, while during the bust it dropped below its long-term average to a value of around 28 percent.

In traditional macro-housing models with capital, the cost of borrowing is often related to the marginal product of capital (i.e., Iacoviello 2005, Davis and Heathcote 2005, and Fisher 2007).⁸ The left panel of Figure 3 shows the time series for the after-tax real returns on productive capital (business and residential) and the real mortgage rate. The measure of

⁷Jordá, Schularick, and Taylor (2015) study large movements in housing and equity markets in 17 countries over the past 140 years. They find that periods with easy credit fueled asset price bubbles, increasing financial-crisis risks; upon collapse, these episodes tend to be followed by deeper recessions and slower recoveries.

⁸It is not uncommon to see models where there is an exogenous or endogenous wedges between the borrowing rate, the lending rate, and the cost of capital. The presence of differential tax treatment in returns also provides a natural wedge.

return to capital is based on the estimates of Gomme, Ravikumar, and Rupert (2011) that use National Income and Product Accounts (NIPA) for the U.S. economy. They compute the net return to capital from the marginal product of capital less depreciation and the relative price of investment goods (where consumption plays the role of the numeraire good); their calculation makes a macroeconomic model consistent with data from NIPA. The after-tax real mortgage rate for all residential mortgages (excluding interest paid on mobile homes) is calculated by dividing estimated total interest paid by estimated total debt outstanding for a given quarter. These series take into consideration the type of loan (fixed rate or adjustable rate) and maturity terms. This time series is similar to the mortgage market rates for purchases of single-family new homes or existing homes released by the Federal Housing Finance Agency. The effective mortgage rate takes into account an average mortgage deduction of 25 percent and is converted in real terms using the 10-year CPI.⁹

The right panel of Figure 3 plots the difference between the returns to productive capital and mortgage rates. We interpret the change in this measure as an approximation of market segmentation.¹⁰ Prior to 2000, the spread between the rates remained relatively stable, averaging 260 basis points, but started to diverge at the start of the housing boom, mainly driven by a decline in the cost of mortgage borrowing. During the housing boom, the spread increased significantly, nearly doubling the historical average. During the financial crises, the rate-of-return differential partially declined, and in the aftermath, the continuous decline of mortgage rates has also increased the return differential as house prices have partially recovered from the housing bust. The disconnect between mortgage rates and the return of other assets is consistent with the analysis of Justiniano, Primiceri, and Tambalotti (2017). Using a large data set that allows them to use multiple controls, they find that “following the end of the Federal Reserve expansionary cycle in June 2003, mortgage rates failed to rise according to their historical relationship with Treasury yields, leading to significantly and persistently easier mortgage credit conditions.”

The declining trend of mortgage rates seems to be consistent with the decline in the return of other financial securities pre-crises (i.e., Treasuries and commercial paper). It is not obvious what accounts for this observation; however, Kermani (2012), for example hypothesizes that it is the result of the increase in the holdings of U.S. agency and GSE-backed securities by foreigners. This period coincides with the increase in the demand for safe assets and with an increase in the demand for safe U.S. assets on the part of the rest of the world (see Bernanke 2005, and Caballero, Farhi, and Gourinchas 2008, and Caballero and Farhi 2014). Some estimates indicate the increased importance of U.S. assets in global

⁹Most of the time series are not sensitive to the choice of price index. The 10-year CPI is more appropriate as mortgage lenders price fixed-rate mortgages taking into account inflation expectations over a longer horizon, see Garriga, Kydland, and Süstek (2017) for more details.

¹⁰Of course, given our simple model, there is no obvious way to account for the potential differences in risk characteristics between capital and mortgages.

portfolios amounted to over 17 percent of the rest of the world’s financial wealth around 2004. As Holmstrom (2015) puts it, a house without debt was an ideal parking spot for foreign money searching for a safe home—literally. Underleveraged homes were depriving foreigners of the opportunity to store wealth at low risk. Accordingly, home equity loans exploded.” We take this as suggestive that there was a certain amount of market segmentation around the time of the boom and bust in housing prices.

From a macroeconomic perspective, the housing boom did not seem to be correlated with aggregate income or consumption growth. As discussed by Gelain, Lansing, and Natvik (2016), booms driven by income and consumption growth show a positive correlation between rents and house prices. Figure 4 shows that the de-trended series for output and consumption show modest changes. These observations for the broad aggregates are consistent with the micro analysis performed by Mian, Rao, and Sufi (2011). They find that areas with high appreciation of house values show no evidence of a differential permanent income shock, population growth, or sectorial growth. This suggests that a successful model should be able capture the correct impact of the drivers of housing prices on the rest of the economy.

4 Equilibrium House Prices, Market Segmentation, and Credit Conditions: A Simple Model

In this section, we present a stylized asset pricing model to highlight two important dimensions of our approach: the role of market segmentation and the expected duration of the period of relaxed financial conditions to account for the increase in house prices.

To simplify, we consider only two regimes: the short-run—which we view as the period of lax financial conditions—when interest rates on mortgages are low and loan-to-value ratios are high, and the long-run—which we view as the permanent steady state—when interest rates and loan-to-value ratios return to their normal values. Each regime is characterized by a vector (r_j^*, ϕ_j) for $j \in \{S, L\}$ corresponding to the effective cost of mortgages in that regime, r_j^* , and the maximal loan-to-value ratio, ϕ_j .

We view the steady state of the economy as corresponding to the long-run regime and the recent history as an unexpected switch to the short-run regime followed by an expected return to the steady state. An important parameter is the expected duration of the phase in which financial conditions are lax. We model the transition from the short-run to the long-run—a permanent transition—as governed by a Poisson process with parameter $1/T$. The expected duration of the low interest rate period is then T .

We denote the domestic return on capital by r^d and, ignoring for now general equilibrium effects, we assume that changes in the mortgage rate have no impact on r^d . To simplify, we assume that the output of housing and non-housing goods is given. We relax those

assumptions when we develop the full model presented in the next section.

Since we view a switch to the long-run as permanent, the price of a unit of housing in the long-run, P_L , satisfies the standard asset pricing equation

$$r^d P_L = R_L + \phi_L(r^d - r_L^*)P_L.$$

The first term, R_L , is the implicit rent associated with a unit of housing. We assume that the utility function is of the form $u(c, h) = \alpha_c \ln(c) + (1 - \alpha_c) \ln(h)$, which implies that $R_j = (y - v\phi_j r_j^*)(1 - \alpha_c)/\alpha_c$, where y is the ratio of income to housing stock and v is the fraction of all mortgages held by foreigners (or by individuals with inelastic demand for housing so that their consumption does not influence housing prices). The second term, $\phi_L(r^d - r_L^*)P_L$, is the profit associated with borrowing at the rate r_L^* and lending at the rate r^d . The borrowing limit is proportional to the value of the house maximal amount $\phi_L P_L$, and it is always optimal to borrow at the low rate as much as possible when $r_L^* \leq r^d$.

The price of a unit of housing in the short-run satisfies

$$r^d P_S = R_S + \phi_S(r^d - r_S^*)P_S + \frac{1}{T}(P_L - P_S).$$

The first two terms parallel those in the long-run pricing equation while the last term captures the capital loss associated with a regime change.¹¹

Consistent with Figure 3, we assume that: $r_S^* < r_L^* \leq r^d$ and $1 \geq \phi_S \geq \phi_L$ to capture the view that the early 2000s were a period of temporary low cost mortgages (but with unchanged average return on other investments) and relatively relaxed lending standards.

Simple calculations show that the price $P = P_S/P_L$ —which we take as the model's prediction for the change in prices associated with the short-run switch to lower interest rates and higher loan-to-value ratios—is given by

$$P = \frac{r^d + \frac{1}{T} - \phi_L(r^d - r_L^*) + \frac{1-\alpha}{\alpha}v\phi_L r_L^*}{r^d + \frac{1}{T} - \phi_S(r^d - r_S^*) + \frac{1-\alpha}{\alpha}v\phi_S r_S^*}. \quad (1)$$

Equation (1) reflects several elements that capture some aspects of our view of the housing market: First, market segmentation in the form of a lower r_S^* increases housing prices even if the domestic rate, r^d , is unchanged. Second, the effect of increasing ϕ_S is theoretically ambiguous and it depends on the sign of this expression

$$\frac{1-\alpha}{\alpha}v r_S^* - (r^d - r_S^*),$$

that trade-offs the cost of higher mortgage balances with the benefit of relaxing the borrowing constraint. In the simple parameterization that we use below, the sign is always negative and

¹¹In our example it is a capital loss since the new regime has higher interest rates and potentially stricter limits on borrowing.

hence relaxation of lending standards increase housing prices.¹² Nevertheless it is possible to show that the responsiveness of P to changes in r_S^* exceeds that of changes in ϕ_S . Third, the expected duration of the low interest rate and high loan-to-value phase is important. P is maximized when $T \rightarrow \infty$, and it is equal to 1 for $T = 0$. The responsiveness of the relative price P is low when the change is expected to be short term and high when the change is expected to be permanent.¹³

Equation (1) is a generalization of the standard pricing equation that, in some parameterizations without segmentation (i.e., $r^d - r_j^* \approx 0$), cannot account for large changes in housing prices in response to credit conditions. The introduction of market segmentation and expectations about the duration of lax financial conditions in the housing market increases the sensitivity of house prices to credit conditions. Can the change be quantitatively significant? To answer this question, we report the impact on P of changing the financial conditions in the short-run using a base case (see the calibration in Section 6.1 for justification):

$$r^d = 0.042, r_L^* = 0.031, \phi_L = 0.6525, \alpha_c = 0.91, v = 0.33.$$

The real interest rate, real mortgage rate, and loan-to-value ratio summarize historical averages prior to the housing boom. The last two parameters are consistent with expenditure on housing being approximately 9 percent of income and a third of mortgages being held by foreigners.

Figure 5 shows the appreciation of house values P associated with changes in mortgage rates r_S^* and the expected duration of the phase in which financial conditions are lax for two different values of the loan-to-value ratio (ϕ_S): the baseline level of 65.25 percent, which is the average loan-to-value ratio before 2000 (i.e., $\phi_S = \phi_L$), and 100 percent, which we take to be a very relaxed loan-to-value ratio, (i.e., $\phi_S > \phi_L$). The response of house values to changes in housing finance highlight several properties of our approach. First, for some parameter values, the simple pricing formula can generate large increases in house prices. Even if the loan-to-value ratio is unchanged, large changes in interest rates (basically when r_S^* is close to zero) and expectations that the low interest rate period will last a long time (50 years at the extreme end) can generate increases in house values of about 60 percent. With more relaxed baseline for financial conditions (a loan-to-value ratio of 100 percent), the increase can be as high as 150 percent. For reasonable values, e.g., $r_S^* = 0.015$ and $\phi_S = 0.80$, the model predicts about a 35 percent increase in house prices. Second, for the range of high-price increases, the model displays significant nonlinearities for the relevant dimensions (i.e., low mortgage rates, a high loan-to-value ratio, and a long duration for the expectations of the credit easing).

The take away from this exercise is that—in this setting—the critical factors are the

¹²Proposition 1 in Section 5 discusses cases in which this result is reversed.

¹³For reasonable values, changes in v and α_c have a small impact on P .

wedge between the interest rates and the expected duration of period of credit easing.

In some sense, the simplified version of the model tends to overestimate the price impact of changes in financial conditions. The reason is that, by assumption, the rate of return on other activities, r^d , is held constant. Thus, it seems important to account for this endogeneity because in general equilibrium with endogenous output, changes in r^* have an impact on investment and hence on consumption and on the equilibrium value of rents. These secondary affects must be consistent with the evidence. Along the same line of argument, we believe that the assumption of an inelastic supply of housing is a poor choice for models that rely on differences in rates of return to explain price changes. The reason is simple: If the rate of return on housing increases, there is an incentive to build more housing (structures), and that affects the equilibrium value of housing rents, as discussed in Section 6.6. This, of course, requires an elastic supply of housing and a general equilibrium framework. Finally, the simple model ignores the impact of deleveraging. Formally, the formulas assume that when the price of a unit of housing drops, the individual simply reduces the size of the mortgage but can still borrow the limit. In a more realistic setting in which mortgages are not consols, there are minimum payments that could imply that the value of the outstanding debt exceeds the debt limit. In such a case, consumption and the rental value of housing must adjust. The next section describes a general equilibrium model capable of dealing with all those effects.

5 A General Equilibrium Macroeconomic Model of Housing

We study a discrete time economy $t = 0, 1, 2, \dots$ with a representative infinite-lived household with time separable preferences $\sum_{t=0}^{\infty} \beta^t u(c_t, h_t)$ defined over non-housing consumption (numeraire) and housing services. The discount factor is defined by $\beta \in (0, 1)$, and the utility index u satisfies the usual assumptions. Households have an endowment of 1 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 a rental 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. 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

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

Investment in residential structures, s_t , is irreversible. Hence, it is important to distinguish the price of installed structures, p_t^s , from the price of new residential investment goods equal to 1 in equilibrium. Households choose 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, 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 (nonnegative) investment in *new structures*. By a slight abuse of notation, the aggregate law of motion of structures is specified as

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

Given the representative household construct, in equilibrium, $S_t^d = (1 - \delta_s)S_{t-1}$. Following Davis and Heathcote (2007), the value of housing capital is given by $V_t = p_t^s S_t + p_t^\ell L_t$, and the combination of structures and land generate a flow of housing services according to function $h_t = G(S_t, L_t)$. The function $G(\cdot)$ is homogeneous of degree 1 and satisfies the usual assumption of an aggregator.

The financial markets are exogenously segmented as the market for mortgage loans (collateralized borrowing) is distinct from the financial market that finances capital investments (non-collateralized loans).¹⁴ Formally, B_t denotes the stock of collateralized mortgage debt at the start of period t , with the interest rate given by r_t^* . This financial asset can be held by foreigners. The stock of non-collateralized debt is represented by D_t , and the associated rate is denoted by r_t^d . We assume that this asset is held only by domestic residents. The interest rate r_t^d is endogenously determined in the model, whereas the mortgage rate r_t^* is taken as an exogenous sequence. The assumed segmentation in asset markets allows for a potential wedge between r_t^d and r_t^* , as arbitrage forces are limited by the requirement that borrowing from the rest of the world can only be collateralized with housing.

The law of motion for mortgage debt B_t is given by

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

where $0 \leq \Delta \leq 1$ is the fraction of the stock of debt that must be repaid/amortized every period. Traditionally, the literature assumes one-period mortgage loans ($\Delta = 1$), where borrowers can refinance the loans by rolling over the existing debt into a new one. The other extreme case assumes an infinite consol with no amortization of principal ($\Delta = 0$), where

¹⁴One interpretation is that collateralized loans are traded internationally and that the price is not determined by the domestic economy. See Favilukis et al. (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, as in Iacoviello (2005).

agents only need to make interest payments. In the intermediate case with $\Delta \in (0, 1)$, each period, borrowers need to amortize a fraction of the outstanding mortgage balance, and the value of Δ can be used to approximate the duration of the mortgage.¹⁵

The interesting region of the parameter space is one where equilibria satisfies that the domestic interest rate—which equals the rate of return on capital net of depreciation—exceeds the mortgage rate determined by the rest of the world, $r_t^d \geq r_t^*$. To prevent arbitrage, it is necessary to restrict the amount of foreign borrowing. Our specification sets the upper bound on mortgage debt to a fraction of the net market value of the stock of housing given by ϕ_t that measures the maximal loan-to-value ratios at time t . Thus, borrowing must satisfy

$$b_{t+1} \leq \max\{0, \phi_t V_t - (1 - \Delta)B_t\}.$$

Given the positive spread of interest rates, the borrowers has an incentive to rollover balances, which implies that the next-period's stock of debt equals $B_{t+1} = \phi_t(p_t^s S_t + p_t^\ell L_t)$. When the value of the housing stock drops below the value of the mortgage, $\phi_t V_t < (1 - \Delta)B_t$, the long-term nature of the contracts requires borrowers to repay at least ΔB_t of the existing stock of mortgages (this follows from the law of motion and $b_{t+1} = 0$).¹⁶

The representative agent solves

$$\begin{aligned} U &= \max \sum_{t=0}^{\infty} \beta^t u(c_t, h_t), \\ \text{s.t. } \quad &c_t + (r_t^* + \Delta) B_t + p_t^\ell \ell_t + x_t + s_t + p_t^s S_t^d + D_{t+1} = \\ &r_t K_t + w_t + p_t^s (1 - \delta_s) S_{t-1} + b_{t+1} + (1 + r_t^d) D_t, \\ &K_{t+1} = x_t + (1 - \delta_k) K_t \\ &B_{t+1} = b_{t+1} + (1 - \Delta) B_t, \\ &S_t = s_t + S_t^d, \\ &L_t = L_{t-1} + \ell_t, \\ &b_{t+1} \leq \max\{0, \phi_t(p_t^s S_t + p_t^\ell L_t) - (1 - \Delta)B_t\}, \\ &h_t = G(S_t, L_t), \end{aligned}$$

and the standard non-negativity constraints.¹⁷

¹⁵This specification is a simple approach to capturing the real-world heterogeneity in the average duration of mortgage contracts. The parameter Δ can be chosen to approximate the average maturity of mortgage loans.

¹⁶In the numerical experiments discussed in Section 6, the binding case with no new originations, $b_{t+1} = 0$, drives part of the asymmetric behavior between the boom and the bust.

¹⁷Our approach takes a pure asset pricing perspective and ignores the potential role of homeownership. In the United States the correlation between homeownership and house prices is weak as there are episodes where it is positive (see Chambers, Garriga, and Schlagenhauf 2009, 2016) and others where it is negative. Similar patterns can be observed in other countries.

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, Y_t . Wages and the rental rate on capital are competitively determined and are given by marginal productivities.

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

Given a sequence of credit conditions in the housing market $\{r_t^*, \phi_t\}_{t=0}^\infty$, a competitive equilibrium is a sequence of prices $\{p_t^s, p_t^\ell, r_t^d, r_t, w_t\}_{t=0}^\infty$ and allocations $\{c_t, n_t, x_t, b_t, s_t, l_t\}_{t=0}^\infty$ such that (i) households optimize, (ii) firms maximize profits, and (iii) markets clear. 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 economy is

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

The standard no arbitrage condition implies that $r_t^d = r_t - \delta_k$.

Before describing the quantitative results, it is useful to characterize the steady state response of house values to changes in housing finance. The domestic interest rate is determined by the standard Euler equation

$$1 + r_t^d = \frac{u_c(c_t, h_t)}{\beta u_c(c_{t+1}, h_{t+1})}.$$

In steady state, the domestic interest rate/return to capital is determined by the discount factor, $r^d = 1/\beta - 1$, therefore, the valuation of cash-flows (i.e., housing rental services or capital dividends) is calculated independently of credit conditions in financial markets.

For the housing market, the relevant steady state equilibrium conditions are given by

$$\begin{aligned} p^\ell &= (1 + r^d) \frac{u_h}{u_c} G_L(S, L) \frac{1}{r^d - \phi(r^d - r^*)}, \\ p^s &= 1 = (1 + r^d) \frac{u_h}{u_c} G_S(S, L) \frac{1}{r^d + \delta_s - \phi(r^d - r^*)}, \\ V &= p^s S + p^\ell L. \end{aligned}$$

One can easily separate house prices from house values, $p^h h = V$, by combining the above expressions for V , p^ℓ , and p^s and using the fact that the housing aggregator satisfies $h = G_S(S, L)S + G_L(S, L)L$.

The steady state resource constraint is

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

where aggregate income is $Y = F(K^*, 1) - \delta_k K^*$ and the steady-state capital stock, K^* , is independent of the factors that determine mortgage financing. The stock and the flow

of mortgages are proportional to house values, V , and are given by $B = \phi V$ and $b = \triangle B$, respectively.

To understand the connection between mortgage rates and borrowing limits in a more general model with endogenous supply, consider imposing the functional forms used in the quantitative exercise. The utility function and the housing aggregator are given by

$$u(c, h) = \frac{[\alpha_c c^{-\rho} + (1 - \alpha_c) h^{-\rho}]^{-\frac{1-\theta}{\rho}}}{1 - \theta},$$

$$G(S, L) = z_h [\alpha_s S^{-\mu} + (1 - \alpha_s) L^{-\mu}]^{-\frac{1}{\mu}},$$

where both μ and ρ are positive. The steady state is completely characterized by the vector (p^ℓ, c, S, V) ; its properties are described in the following proposition.¹⁸

Proposition: *The steady state exists and is unique. Moreover, changes in housing finance imply that*

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 $r^d - r^* \rightarrow 0$, $\phi \rightarrow 0$, or $1/(1 + \rho) \rightarrow 0$.*

The proposition shows that, in the long-run, permanent changes in mortgage rates (r^*) have larger effects than permanent changes in financial conditions (ϕ). The reason—as argued in the previous section—cannot be discovered by inspecting the asset pricing equation that determines the valuation of the housing stock since, from that perspective, the impact of the often-called “collateral” effects is similar.

The key difference relates to “income effects”. A decline in r^* reduces the amount of mortgage payments made by borrowers, while an increase in ϕ , even though it initially allows borrowers to gain from the interest rate differential, reduces non-housing consumption in the long-run since a larger amount of resources needs to be devoted to mortgage payments. These two effects work in opposite directions, and, for values of the mortgage rate, 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. The quantitative section illustrates these trade-offs, but also calculates the short-run dynamics in response to changes in the cost of borrowing and loan-to-values.

¹⁸Details about the proof can be found in Appendix D.

6 Quantitative Analysis

6.1 Calibration

The quantitative evaluation of the model requires specifying functional forms, parameter values, and measuring the macroeconomic aggregates in the data to be consistent with the model. The utility function, $u(c, h)$, and the aggregator of housing services, $G(S, L)$, have the constant elasticity of substitution (CES) as defined in Proposition 1. The production function of the non-housing services 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.

The calibration strategy is fairly standard. Some of the parameters in the model are directly selected from the data, and the rest are determined to ensure that the model's initial conditions are consistent with the historical averages of their data counterparts. The long-run targets are calculated using National Income and Product Accounts (NIPA) for the sample period prior to the housing boom-bust episode (1929-1997), but the values are extremely stable even for the full sample (1929-2016).

Several adjustments must be made to NIPA data to make it comparable with the macroeconomic aggregates in the model. The notion of households disposable resources includes personal consumption expenditures and gross private domestic investment to account for the fact that in the model there is no government sector and that the external sector has the limited role of financing mortgages. Relative to traditional macroeconomic models with a single produced good, in this case, it is also important to capture the composition of personal consumption expenditures (distinguishing non-housing consumption from housing services and utilities) and total investment (explicitly separating residential investment from the rest that includes capital/equipment and non-residential structures). The model has two separate technologies producing consumption/investment goods (i.e., capital and residential structures) and housing services. Using value added by industry allows us to separate the housing sector, a component of the real estate and rental and leasing sector, from the output of private industries. The housing sector measures the market value of tenant-occupied housing and the imputed rental value of owner-occupied housing, as both NIPA and the model do not make a distinction between owners and renters. In the model, the housing sector generates services using structures and land, excluding labor as an input. However, the components of value added by industry indicate that the compensation of employees by the housing sector is about 1 percent. In the non-housing sector, proprietor income cannot be unambiguously attributed to either labor or capital. The standard convention in macroeconomic models is to assign a constant fraction of this income to each factor, as in the overall economy.

In the mortgage market, the initial effective real cost of borrowing, r^* , is set to 3.1 percent to be consistent with the data described in Section 3. In the model, the nature of long-term

mortgage contracts distinguishes the flow of newly originated loans from the outstanding stock, $B_{t+1} = b_t + (1 - \Delta)B_t$. In the baseline equilibrium, the choice of Δ needs to capture the fraction of new originations that replaces the outstanding stock of mortgages loans, $b = \Delta B$. Setting the value to 0.09 matches the average number of loans originated relative to the outstanding stock reported by the Federal Reserve Board. The implied value is in-line with the average duration of loans in the U.S. market once you allow for refinancing (i.e., 8-11 years). Under the same logic, the collateral constraint of the household implies a relationship for the parameter $\phi = B/V$, which is then calibrated to 65.25 percent to be consistent with the value reported by the flow of funds data.

With respect to preferences, the intratemporal elasticity of substitution between consumption and housing services is determined by the parameter $\varepsilon_{ch} = 1/(1 + \rho)$. The traditional view has been to use the specification's unitary elasticity, as it yields a constant expenditure share on housing (see Davis and Van Nieuwerburgh, 2015). Some of the recent literature estimates this elasticity to be less than unitary. For example, Flavin and Nakagawa (2008) use a model of housing demand and estimate an elasticity less than 0.2. Other papers (i.e., Song 2010 and Landvoight 2011) use alternative model specifications and estimate less than unitary elasticity. Relative to this literature, this paper considers a more conservative value of $\varepsilon_{c,h} = 0.5$ and, while the baseline elasticity is less than unitary, the implied housing expenditure share remains relatively stable with the fluctuations of house values. For the intertemporal elasticity of substitution, we use a conservative value for macro models, setting θ to 1.5.

For the production function of housing services, 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 $1/(1 + \mu) = 0.25$.¹⁹ The depreciation rate for residential structures, δ_s , is estimated by NIPA and set to an annual rate of 1.5 percent. Land and labor inputs are two factors of production available in fixed supply, with values normalized to a constant.

The joint calibration determines the remaining parameters to match key macroeconomics aggregates, including the size of the housing sector in the economy in terms of quantities and values. Table 1 summarizes all the calibrated parameters and shows that the model replicates the targets and untargeted statistics such as the magnitude of mortgage interest payments in the economy and the rent-price ratio.

6.2 Steady State: House Values and Housing Finance

In this section, we report the quantitative impact of permanent changes in the spread between the domestic rate and the mortgage rate, $r^d - r^*$, and credit limits—as measured by the loan-to-value ϕ —on house values, V . Figure 6 shows that the response of house values to housing

¹⁹See McDonald (1981).

finance is highly nonlinear. There are two important findings:

1. For a given level of ϕ , increases in the interest rates spread $r^d - r^*$ unambiguously increases house values. However, the magnitude of the appreciation depends in a nonlinear fashion to value of ϕ . For example, an increase in the spread from 0.2 percent to 3.2 percent when $\phi = 0.50$, increases house values by around 35 percent, whereas when $\phi = 0.70$, the increase exceeds 70 percent.
2. For a given spread $r^d - r^*$, relaxing the credit limits (i.e., increasing ϕ) has ambiguous effects: house values increase when the spread of rates is large, but the opposite happens when the spread is small (i.e., 1.2 percent). When the spread is nearly zero (i.e., 0.2 percent), the relaxation of credit limits can decrease house values.

These calculations illustrate how the responsiveness of house values to changes in housing finance depends on the magnitude of the spread ($r^d - r^*$) and the credit limits (ϕ). Consistent with the model presented in Section 4, persistent changes have very nonlinear responses; as such, linear approximations can be subject to large errors.²⁰ The computational approach in the quantitative analysis deals with these nonlinearities under different information structures.²¹

6.3 The Dynamics of the Cost of Borrowing and Financial Conditions

Figure 7 displays the smoothed data on mortgage rates and loan-to-value ratios as well as the values used in the quantitative exercise. The left panel shows the path of mortgage rates taken from the data described in Section 3. The effective real rate starts at an initial level of around 3.1 percent in 1998 and rapidly declines in the early part of the 2000s to reach 1.5 percent in 2007. To solve the model it is necessary to make assumptions about the long-run path of interest rates. Since there is uncertainty about this value, we consider three alternative paths. The first path assumes that by 2027 mortgage rate will revert back to the initial level in 1998, the second path assumes that the long-run mortgage rates will converge to 2.15 percent by 2025, and the third path assumes that rates will converge back to 1.5 percent by 2023.²²

²⁰In Appendix A, we show that the response of the rent-price ratio and the land share of the value of housing display similarly nonlinear behavior.

²¹In an appendix available upon request, there are additional examples discussing the relative importance of endogenizing land, as well as introducing heterogeneity in income, credit conditions, and locations.

²²The data suggest there was an increase in short-term rates between 2005 and 2007; however, this tightening had only small effects on long-term mortgage rates. There is also some uncertainty about the exact timing of the tightening of borrowing conditions. In the model, delaying the tightening of borrowing conditions has a small effect on the results.

The right panel of Figure 7 shows that the loan-to-value ratio on new loans starts in 1998 at a steady-state level of 65.25 percent and then steadily increases to 87.0 percent in 2007. As is standard in this literature, the collapse of house prices starts with a tightening of collateral constraints on new loans.²³ Since households use long-term mortgages, the adjustment of the stock of outstanding mortgage debt is endogenously determined.

We now discuss the predictions of the model in response to changes in financial conditions—the paths summarized in Figure 7—under two different information structures: perfect foresight and shocks to expectations. In response to these changes, the analysis focuses on the transition from an initial to a final steady state of the non-linear model.²⁴

6.4 Perfect Foresight

In this section, we report on the results of simultaneously changing the cost of borrowing, r^* , and the parameter ϕ according to the paths described in Figure 7 under the assumption of perfect foresight. Figure 8 shows the implications of the model for house values and rents indexed by the possible values of the long run mortgage rate, r_L^* .

House Values The initial decrease in interest rates and the relaxation of the loan-to-value ratio—around 1998—results in an immediate increase in house prices. The magnitude of the appreciation depends on the value of r_L^* , the long-run rate. When the long-run mortgage rate reverts back to the initial level of 3.1 percent, house prices increase about 25 percent from the late 1990s to the mid-2000s. In the alternative cases— $r_L^* = 1.5\%$ and $r_L^* = 2.15\%$ —house prices increase about 45 percent and 35 percent, respectively. Since the data show that house prices increased about 50 to 60 percent with respect to the trend, the model captures a significant fraction of the observed change in house values.

There are two forces at work underlying this result. First, the lower effective cost of borrowing is capitalized in the value of land and house prices increase on impact. Second, households can borrow—using housing as collateral—at a low rate and obtain a higher return investing in capital. This wedge has an effect similar to a positive income effect that further increases the demand for housing and non-housing goods.

The increase in house values is driven by changes in the quantity of structures and in the price of land. The data suggest that the contribution of land to house values increases during the housing boom, from 35 percent to 50 percent, whereas the model predicts an increase

²³See, for example, Favilukis, Ludvigson, and Van Nieuwerburgh (2016), Gelainy, Lansing, and Natvik (2016), and Kaplan, Mitman, and Violante (2017).

²⁴The computation searches for an equilibrium of prices and quantities that satisfies the first-order conditions corresponding to the optimization problems faced by workers and firms. The terminal condition imposes convergence after 130 periods, which results in a highly accurate solution with Euler equation residuals of the order 10^{-12} .

from the calibrated 35 percent to a value that ranges between 42 to 48 percent depending on assumptions about the path of long-run mortgage rates.

The tightening of the borrowing limit in 2007 generates an immediate decline in house values because individuals need to adjust their mortgage balances, a deleveraging effect. The magnitude of the decline depends on the long-run mortgage rate. When rates converge to the baseline level of 3.1 percent, all the initial appreciation of house values disappears in about 25 years. When the long-run mortgage rate converges to a value lower than the baseline level, the decline in house values during the tightening in 2007 is smaller.

Asymmetric Booms and Busts The model implies an asymmetry between booms and busts as identical changes in interest rates (with the sign reversed) result in an asymmetric response of house prices. This is due to two factors. First, since structures depreciate slowly, disinvestment is necessarily limited. Thus, in a bust, the price of housing—but not the physical quantity—adjusts. Second, the initial relaxation of credit conditions is unanticipated, as it arrives as a surprise in 1998, whereas the tightening in 2007 is perfectly anticipated. Despite that, the tightening of credit limits, ϕ , generates a similar decline across experiments.²⁵

Rents Changes in housing finance have a direct impact on rents. The right panel of Figure 8 shows the dynamics of equilibrium rents during the housing boom. The relaxation of credit conditions generates an initial decline in rents driven by a decrease in the ratio of non-housing to housing consumption associated with the positive income effect (this drives up the demand for both housing and non-housing goods) and the relatively fast response of the housing supply (structures) in the short-run. The decline of rents in the model is consistent with the measure of owner equivalent rent (OER) produced by the Bureau of Labor Statistics, and it is a feature of the data that has proved very challenging to match, as suggested by Kiyotaki, Michealides, and Nikolov (2011) and Gelain, Lansing, and Natvik (2016). The economic mechanism is discussed in more detail in Section 5.6.

Despite the decline in rents and the adjustment in housing consumption, the aggregate housing expenditure share remains relatively unchanged during the boom and the bust even though consumption and housing services have a less than unitary elasticity of substitution. This result depends on general equilibrium effects that we discuss in the next section.²⁶

²⁵The welfare implications of this shock are very sensitive to the time at which they are measured. If we consider the economy in 1997 (pre-shock), then the welfare gain is slightly above 5 percent of consumption. If, on the other hand, we consider the situation in 2005—the peak of the boom—the consumption equivalent variation that the representative agent would be willing to forgo to avoid the continuation utility is a decrease that ranges between 3 percent and 4 percent. Thus, in the model, the housing boom and bust is associated with significant changes in welfare.

²⁶Appendix B describes the dynamics of consumption and output in response to changes in house prices

Decomposing the Contribution of the Mortgage Rates and Loan-to-Value Ratios

Our results are driven by the simultaneous changes in mortgage rates and the loan-to-value ratios. In this section, we provide one (imperfect) measure of the relative contribution of the two shocks. Figure 9 displays the model’s prediction for house values as well as the counterfactual that assumes that the loan-to-value ratio remains at the 1997 level. We take the difference between the baseline price and the counterfactual as a measure of the contribution of interest rates to changes in house prices. During the boom lower interest rates contributed approximately 80 percent of the increase, while during the bust the counterfactual exceeds the baseline prediction. In this region (that is after 2007), the tightening of lending standards decreases the house price by approximately 30 percent. Overall, we find that changes in interest rates play a much larger role than changes in loan-to-value ratios.

The perfect foresight analysis provides a very useful benchmark to understand the dynamics of house values, but it endows agents with too much information, as they can fully anticipate credit-conditions reversals. To understand the sensitivity of the results to alternative information structures, we now extend the model to allow for shocks to expectations.²⁷

6.5 Shocks to Expectations

The next set of experiments changes the information structure of credit conditions by introducing shocks to expectations at different points in time. To incorporate these shocks/surprises in the dynamics of the model, we assume that households have some initial expectations about housing finance variables set by the initial values $r_{97,t}^* = r_{97}^*$ and $\phi_{97,t} = \phi_{97}$ that are expected to remain unchanged in the future.²⁸ In 1998, households are surprised by an *initial credit easing* that is perceived as permanent going forward, $r_{98,t}^* = r_{98}^* < r_{97}^*$ and $\phi_{98,t} = \phi_{98} > \phi_{97}$ for all t . In each subsequent period, households are surprised by unanticipated shocks where the new credit conditions $r_{j,t}^* = r_j^* < r_{j-1}^*$ and $\phi_{j,t} = \phi_j > \phi_{j-1}$ are perceived as permanent. In 2007, there is a *credit reversal*, where the loan-to-value limit, $\phi_{08,t}$, reverts back to the original steady state, ϕ_{98} . The observed path of mortgage rates matches the data from 2008-15 forward, $r_{j,t}^*$, and projects different long-run paths from 2015

under perfect foresight.

²⁷For example, Favilukis, Ludvigson, and Van Nieuwerburgh (2016) have an economy with aggregate shocks, but shocks to credit conditions are not anticipated by the agents.

²⁸The lack of anticipation, modeled as a surprise, is not inconsistent with different measurements of expectations prior to the collapse. For example, Cheng, Raina, and Xiong (2014) explore whether midlevel employees in the mortgage securitization business, such as traders, had the ability to predict problems in this market and avoiding losses in their own homes. Their analysis shows that securitization agents neither managed to time the market nor exhibited cautiousness in their home transactions, as they increased their housing exposure during the boom period by purchasing more expensive homes or second homes. Similarly, Davis and Quintin (2014) show that during the boom period and bust period households fail to anticipate changes in the market value of their homes.

forward. In terms of information, after 2007, there are no additional unanticipated shocks and households have perfect foresight about future credit conditions.²⁹ The important issue is that agents learn that credit constraints will become tighter in 2008 and that mortgage rates will increase after 2023.³⁰ Figure C.1 in Appendix C presents the time paths of credit conditions.

House Values

1997-2007 Period Compared to the perfect foresight case, the slow arrival of news about the future cost of borrowing and leveraging mitigates the immediate response of house values. Figure 10 compares the predictions of the model for two different values of the long-run mortgage rate, $r_L^* \in \{0.031, 0.022\}$, and two different speeds of deleverage, $\Delta \in \{0.09, 0.15\}$.³¹ During the boom, the improvement in conditions in housing finance has immediate effects on house values that capitalize on the persistence of the new low level of mortgage rates and relaxed credit standards. As new information continues to arrive, house values continue to increase.

In the model, the slow arrival of news about future credit conditions (mortgage rates and loan-to-value ratio constraints) results in a path of house values closer to the data. Since the reversal of credit conditions is not anticipated, house values increase much more than in the perfect foresight case. Comparing the path during the boom with the most conservative estimate from the perfect foresight simulations (long-run rates converge back to the baseline level of 3.1 percent) shows that adding shocks to expectations increases the contribution of the model to account for house values by 50 percent. Why is that the case? Adding shocks to expectations eliminates agents' ability to anticipate future increases of mortgage rates. One interpretation of this case is that households had overly optimistic expectations about the future conditions of housing finance.³²

²⁹Appendix C discusses the case where the information about the bust arrives as a set of continuous surprises. While the dynamic path of house prices has some qualitative differences, the general findings are essentially unchanged.

³⁰The speed of the tightening of credit conditions has very small quantitative effects. The arrival of future tightening is the relevant information in this forward-looking model.

³¹The case where long-run mortgage rates converge to 1.5 percent, or half the historical average generates a very minor adjustment of house values as a response to the credit tightening. From the theoretical analysis, it is clear that one can construct a sequence of tighter $\{\phi_t\}$ and higher mortgage spreads $r_t^* - r_t^d$ that are neutral to house values.

³²For instance, Case and Shiller (2004) found that up to 95 percent of home buyers in the year 2003 thought that housing prices would appreciate by an astonishing annual average of 9 percent over the next decade. According to them, this irrational enthusiasm in consumer expectations concerning future prices was clearly a real and important fact about the housing bubble. In our model, if households were asked a similar question between 2003 and 2006, they would also expect positive near-term appreciation, since house prices have not yet converged to the long-run equilibrium.

Post 2008 Even though the housing boom is identical across these different simulations, the arrival of news about the credit tightening in 2008 and a new projected path of interest rates results in lower house values the higher the long-run interest rate on mortgages. Relative to 2008, households find themselves with too much housing and too much debt (overhang). Since the value of outstanding mortgages exceeds the market value of the housing stock, houses cannot be used as collateral to increase borrowing. Thus, housing loses some of its value as collateral, which, in turn, exacerbates the price decrease.

The magnitude of the decline in house values depends on two key factors: Higher expected long-run mortgage rates, r_L^* , and higher values of amortization Δ —both of which are associated with large declines in house values as households are forced to repay part of their mortgage debt. Moreover, this need to deleverage has an additional negative impact on house prices. Figure 10 illustrates how sensitive the predictions are to the (unobserved) long run rate. During the bust, the irreversibility constraint on residential investment binds, $x_t^S = 0$, and the price of structures declines relative to the baseline value (normalized to 1), $p_t^S < 1$. In other words, during the boom, it is easy to build housing collateral, but during the bust the adjustment is mostly along the price dimension, which forces households to adjust consumption in order to reduce their debt. This, of course, has an impact on aggregate output.

Macroeconomic Effects The key macroeconomic variables respond very differently to the dynamics of house prices in boom and bust periods. As discussed in Section 3, developments in the housing sector during the boom were not associated with large changes in macro aggregates. However, the collapse of the housing market was accompanied by a significant decline in consumption, investment (residential and non-residential), and output.

The macroeconomic response in the case with shocks to expectations shows that, during the boom, the spillover from the housing sector to the non-housing sector is consistent with the data.³³ Figure 11 shows the response of consumption, output, and the stock of capital. Initially, consumption does not change much but, after a few periods it slowly grows as housing finance conditions ease. In the data counterpart depicted in the top right of Figure 11, detrended consumption also increased very little during the boom. Ignoring the drop during the 2001 recession, the change between 1998 and 2007 is about 4 percent when consumption includes durable goods and close to 3 percent when durable goods are excluded. Aggregate output has a similar response during the housing boom. Relative to the perfect foresight case, the slow arrival of information reduces the magnitude of the initial income

³³The model assumes abstracts from changes in total factor productivity, so it is not designed to capture changes in the real economy. The results show what would have been the changes in consumption and output in the absence of other shocks. For example, the quantitative importance of some of these features are discussed by Garriga and Hedlund (2016), who use a more complex model that does not provide an explicit expression for the equilibrium house prices.

effect generating small macroeconomic responses.

As mentioned before, the post-2008 drop in prices has a negative impact on consumption, both through an income effect and a portfolio rebalancing effect. The consumption decline predicted by the model, in the cases with the most dramatic declines in house prices, ranges between 12 and 17 percent, and the detrended data shows declines of a similar magnitude.³⁴ The magnitude of these declines depends on the length of the deleveraging process, the number of periods needed by the households to adjust their mortgage balances, but also on the amortization rate of the mortgage contract. The presence of long-term mortgages propagates the adjustments of the household balance sheet by making consumption remain below trend for a substantial amount of time. When this adjustment is fast, the short-run decline in output is significant but the length of the recession is significantly reduced. The longer the deleveraging period, the larger the macroeconomic slump.³⁵

These findings are consistent not only with observed decline in consumption and output, but also with the decline in residential and non-residential investment, as depicted in the bottom of Figure 11. This feature is not present in the standard frictionless model, where shocks that reduce aggregate consumption generate a boom in capital investment. In this model, the collapse of the housing sector, following a period of a buildup of debt and housing capital, generates a drop in residential and capital investment.³⁶ The decline in residential investment comes from the need to reduce the current stock of housing, which is too large relative to mortgage debt, whereas capital investment falls due to a lesser need to produce houses and future consumption.

Mortgage Volumes and Interest Rate Spreads It is instructive to analyze the implications of the model for mortgage debt. Figure 12 presents the implications for mortgage originations and the stock of mortgage debt. The model predicts—consistent with the data—

³⁴For example, Garriga and Hedlund (2016) and Huo and Ríos-Rull (2016) use general equilibrium models of housing to explore the connection between house prices and aggregate consumption. Berger, Guerrieri, Lorenzoni, and Vavra (2016) explore a similar connection using a partial equilibrium model.

³⁵The connection of between housing markets and output has been explored by Boldrin, Garriga, Peralta-Alva, Sánchez (2012) using a multisector model with production linkages. In their, economy a decline in housing demand propagates through the rest of the economy, reducing aggregate output and employment. Similarly, Hall (2011) explores the implications of demand shortages after a period of a buildup of excess stocks of housing.

³⁶Other papers in the literature also discuss the connection between deleveraging and output. For example, Guerrieri and Lorenzoni (2011) explore the implications of an unexpected shock to financial conditions on the interest rate and short-run output. Midrigan and Philippon (2011) analyze the effects of a credit crunch on the household sector in a monetary economy via changes in the level of employment. Eggertsson and Krugman (2011) explore the aggregate implications of a liquidity trap. Mian, Rao, and Sufi (2011) use regional-level data to show that the consumption response to declining house prices was stronger in highly leveraged counties.

a hump-shaped pattern, with originations increasing during the boom and collapsing as house prices decline.³⁷ The dynamics during the bust depend on the length of mortgage contracts implied by the amortization rate (Δ). With one-period mortgage contracts, $\Delta = 1$, the consumption decline is very large on impact, as the balance sheet must be adjusted instantaneously given that all the stock of debt has to be refinanced. During a credit reversal, this forces households to rollover the loans in periods where housing has low value as collateral. If mortgage loans are interest-only loans (consols), which corresponds to $\Delta = 0$, the effect on consumption is mitigated. In the baseline case, $\Delta = 0.09$, the model predicts no new mortgage originations between 2008 and 2014. During this period, households reduce the outstanding debt, and the deleveraging process resembles a negative demand shock. Despite its simplicity, the model performs remarkably well, capturing the behavior of mortgage debt (stocks and flows) during this period.

A key mechanism in our setting is the spread between the rate of return on capital—which is endogenous in the model—and the interest rate on mortgages—which is the most important driving force. In our calibration, we did not target this spread, but we find that the model’s prediction for this interest rate differential is consistent with the data, as can be seen in the bottom panel of Figure 12.

6.6 House Prices and Rents: The Role of Frictions

6.6.1 House Prices

How much do financial frictions contribute to the change in house prices? The answer to that question depends on whether we study the contribution in “normal” times or in periods of fast appreciation. To formalize this point, recall that the equilibrium value of the housing stock is given by $V_t^h = p_t^s S_t + p_t^\ell L$. Let the value of the same physical stock that would have prevailed in an economy without market segmentation be denoted $\hat{V}_t^h = \hat{p}_t^s S_t + \hat{p}_t^\ell L$. We define the contribution of market segmentation to the value of the housing stock as

$$Z_t = \frac{V_t^h - \hat{V}_t^h}{\hat{V}_t^h}.$$

Our model implies that the price of land is given by

$$p_t^\ell = \hat{p}_t^\ell + \sum_{j=0}^{\infty} m_t(j) \eta_t(j) R^h(t+j) G_L(t+j), \quad (2)$$

³⁷In the model, the drivers of mortgage debt result from an exogenous increase in the supply of credit (i.e., relaxation of the lending standards) and a reduction in the cost of borrowing (i.e., mortgage rates), but not a change in productivity. This would be consistent with the empirical work of Mian and Sufi (2009) and Fernald (2014).

where the appropriate discount factor j periods into the future is

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

In terms of notation, $R^h(t) = \frac{u_h(t)}{u_c(t)}$ represents the “implicit” rental price of 1 unit of housing, $G_L(t+j)$ is the marginal product of land, and $\eta_t(j)$ is a term that captures both the impact of market segmentation and the additional value of housing because it can be used as collateral.³⁸ The term $\hat{p}_t^\ell = \sum_{j=0}^{\infty} m_t(j) R^h(t+j) G_L(t+j)$ is the frictionless value of 1 unit of land 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, which is the standard valuation approach.

Since with the exception of a few periods the price of structures is independent of financial frictions, it is the changes in the price of land and the share of land in the price of housing that influence the value of Z . In the steady state, we have that equation (2) is

$$p^\ell = \hat{p}^\ell \frac{r^d}{r^d - \phi(r^d - r^*)},$$

and the value of Z is given by

$$Z = \frac{\phi(r^d - r^*)}{r^d - \phi(r^d - r^*)} \times \frac{\hat{p}^\ell L}{S + \hat{p}^\ell L}.$$

There are two terms that determine the wedge. The first term is the percentage increase in the price of land due to market segmentation and the second is the (endogenous) share of land in the value of housing.

For the initial steady state, the model predicts that the fact that housing can be used as collateral adds approximately 22 percent to the house price relative to the house value if there are no financial distortions. During the boom, p_t^ℓ and \hat{p}_t^ℓ move in opposite directions because rents decline (which lowers \hat{p}_t^ℓ) and the collateral value of homes increases (which increases p_t^ℓ). Figure 13 reports the time series for Z_t corresponding to the model with shocks to expectations with $r_L^* = 0.031$, and $\Delta = 0.09$. During the boom, frictions account for 70 percent of house prices.³⁹ The other important component is the expectations that

³⁸The frictional component, $\eta_t(j)$, is given by

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

where $v_t = 1 - r_t^*/r_t^d$ is the wedge between the cost of a mortgage and the return on capital.

³⁹Our result is consistent with the findings of Campbell et. al. (2010), who decompose movements in the rent-to-price ratio at each date into the expected present discounted values of rent growth, real interest rates, and housing premium over real rates and find a large unexplained component in housing prices. In our model, the variation in housing finance (non-fundamental component) rationalizes the dynamics of house values.

capture a significant fraction of the increase. During the bust, prices do not converge to the fundamental value because the collateral constraint only stops binding for a finite number of periods, but the continuation price takes into account that they will bind again.

As our model nests the traditional frictionless approach to housing valuation, it provides a clear interplay between the forces that drive house prices that are not directly tied to traditional fundamentals. This approach can rationalize the lack of sensitivity of house prices to interest rates (discount rates), as documented by Glaeser et. al. (2013), as in the model the relevant discount rate for cash flows is r_t^d , which is closely tight to consumption growth, whereas mortgage rates r_t^* appear only in the non-fundamental component in the valuation equation.

6.6.2 Rents

Can the model reconcile large changes in house prices with small (or even negative) changes in rents (see Shiller, 2007)? As it turns out, the same forces that mediate the impact of financial variables on house prices account for the disconnect between prices and rents in periods of very rapid growth in house values. To understand the basic forces, it is useful to recall that equilibrium rents are given by

$$R^h(t) = u_h(t)/u_c(t) = \frac{1 - \alpha_c}{\alpha_c} \left(\frac{c_t}{h_t} \right)^{1+\rho}.$$

Consider what happens when r^* declines. The reduction in mortgage rates generates a positive income effect that increases c_t , but also an investment boom in housing that results in increases in h_t driven by the additional impact of a higher value of housing as collateral. Since the second effect is larger (structures adjust to increase the supply of housing) and $1 + \rho$ is positive, rents decrease during the housing boom. This result depends crucially on an elastic supply of housing.⁴⁰

During the bust it is necessary to distinguish between short and long-run effects. In the short run, h_t does not change but non-housing consumption falls resulting in a decrease in $R^h(t)$. Over time, as the debt overhang problem is reduced and the stock of housing adjusts to its new steady state, rents increase. The dynamics of rents in the model and the data are summarized in Figure 14. The model's predictions are consistent with the detrended measure of owner equivalent rent (OER) measured by the Bureau of Economic Analysis. For the boom period, the model predicts about a 10 percent decline in measured rents

⁴⁰Conventional wisdom suggests that models with a fixed housing supply have a better chance at rationalizing house price dynamics. This is the argument made by Glaeser, Gyourko, and Saiz (2008). However, as Gelain, Lansing, Natvik (2016) show in a version of the model where the housing supply is fixed, the dynamics of rents are driven entirely by the growth of aggregate consumption that absorbs all the income effects, resulting in a positive correlation between rents and house prices that it is inconsistent with the data.

associated with owner-occupied housing, and a further decline during the bust.⁴¹

In this model, rents are a poor “sufficient statistic” to understand house prices, as rents are endogenous and respond to changes in the cost of mortgages and financial conditions. Moreover, the intrinsic nonlinearity of the problem (e.g., depending on whether deleveraging plays a role) makes it impossible to establish a simple relationship between rents and house prices. From the point of view of the model that we study, there is no rent disconnect puzzle. What we do find is simply nonlinear responses to shocks.

7 Conclusions

This paper revisits the general equilibrium interaction among changes in interest rates, loan-to-value ratios, and expectations and their impact on housing prices. We study a two-good general equilibrium model in which housing is a composite good produced using structures and land. The model is successful in accounting for the joint behavior of house prices and macro aggregates. 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 agents learn slowly about the actual change in financial variables. Since houses are valued as collateral, in addition to the housing services, a decrease in their market value implies that households must repay a fraction of their mortgage obligations and this, in turn, reduces consumption due to a negative income effect. The model is successful in capturing the very asymmetric impact of increases and decreases of house prices on macroeconomic variables.

In summary, we find that changes in broadly defined financial conditions and shocks to expectations produce time paths of housing prices and aggregate variables that are consistent with the boom-bust experience in the United States in the 2000s.

The model contains only one location and, by construction, cannot confront the heterogeneity of changes in the market value of housing at the regional level. Future extensions should consider exploiting regional differences in the variables to assess the importance of the key variables identified as influencing the market value of houses.

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⁴¹The dynamic response of rents in this model is similar to the one in the Favilukis, Ludvigson, and Van Nieuwerburgh (2016) model with incomplete markets and time-varying risk premia, but during the housing boom, house values are more sensitive to housing finance.

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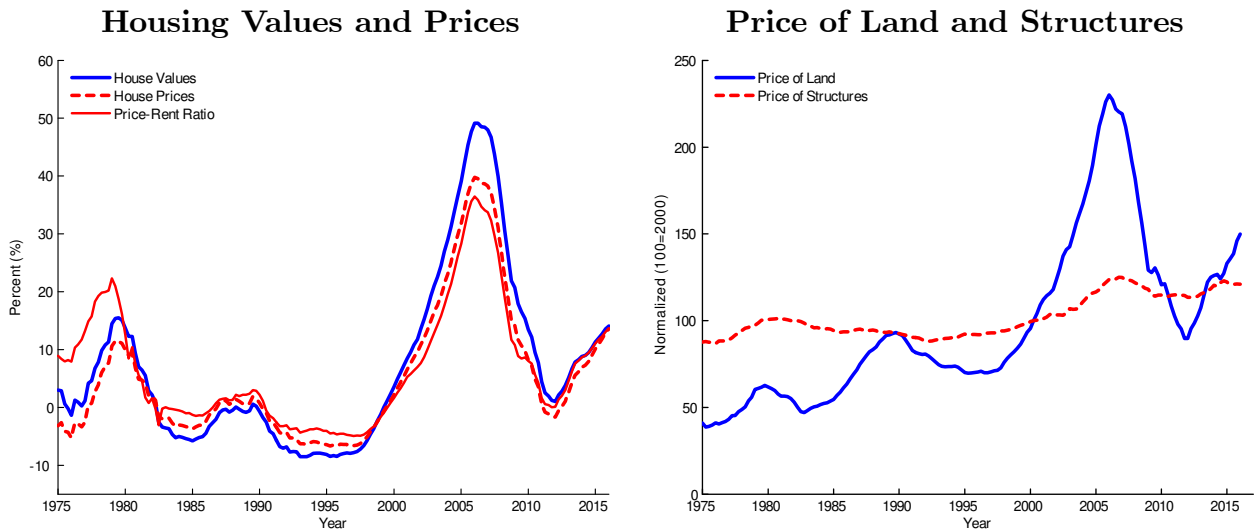
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Table 1: Model Calibration

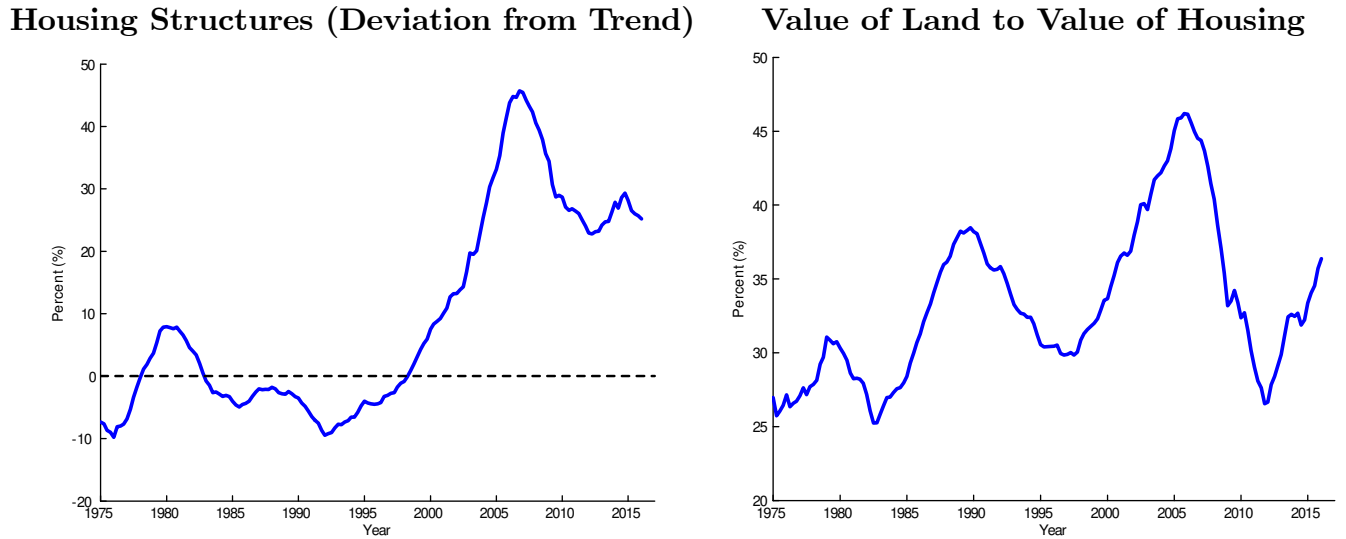
Description	Parameter	Value	Target	Model	Source
Calibration: Independent Parameters					
Elasticity Substitution $u(c, h)$	ρ	1			Various
Intertemporal Elasticity of Substitution	θ	1.5			Various
Elasticity Substitution $G(S, L)$	μ	3			Various
Collateral Constraint	ϕ	65.2%			Flow of Funds
Amortization Rate of Mortgages	\triangle	9%			Federal Reserve Board
Mortgage Rate (Real)	r^*	3.2%			Federal Reserve Board
Depreciation of Structures	δ_s	1.5%			BEA
Calibration: Jointly Determined Parameters					
Consumption-Output, C/Y	α	0.26	78.8%	78.4%	BEA
Investment(k)-Output, x^K/Y	z	26.3	21.2%	21.6%	BEA
Capital-Output, K/Y	δ_k	0.11	1.70	1.76	BEA
Structures-Output, S/Y	z_h	0.89	1.16	1.20	BEA
Value Housing-Output, V/Y	α_s	0.80	1.85	1.90	BEA and Flow of Funds
Housing Services-Output, $R \cdot S/Y$	β	0.962	9.5%	9.5%	BEA
Land Value-Value Housing Stock, $p^\ell L/V$	α_c	0.88	36.0%	36.9%	Flow of Funds
Model Fit (Not Targeted)					
Mortgage Interest Payments-Output			3.3%	3.5%	Federal Reserve Board
Rent-Price Ratio (incl.Depreciation)			5.0%	5.0%	Sommer et al (2016)

Figure 1: Housing Values and Prices in the United States (1975-2016)



Source: Bureau of Economic Analysis and land values from Davis and Heathcote (2007).

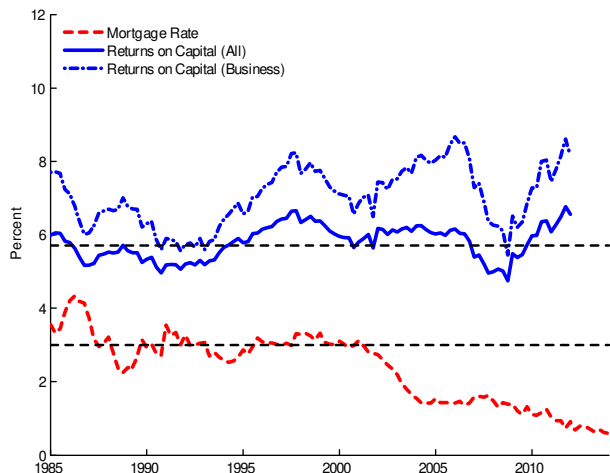
Figure 2: Housing Markets in the United States (1975-2016)



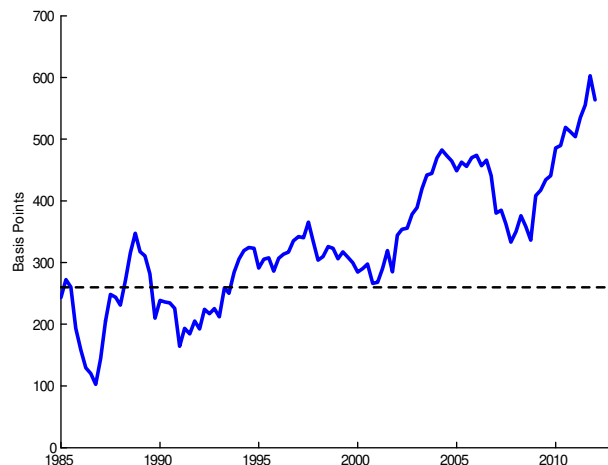
Source: NIPA index and land values from Davis and Heathcote (2007).

Figure 3: Rates of Return in the U.S.

Returns on Capital and Mortgage Rate



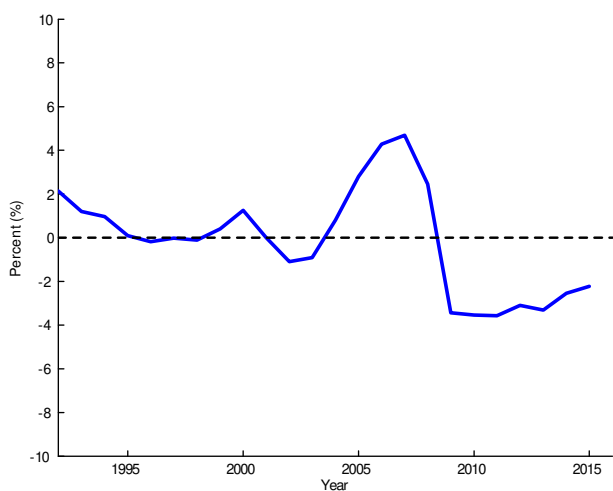
Rate Return Differential



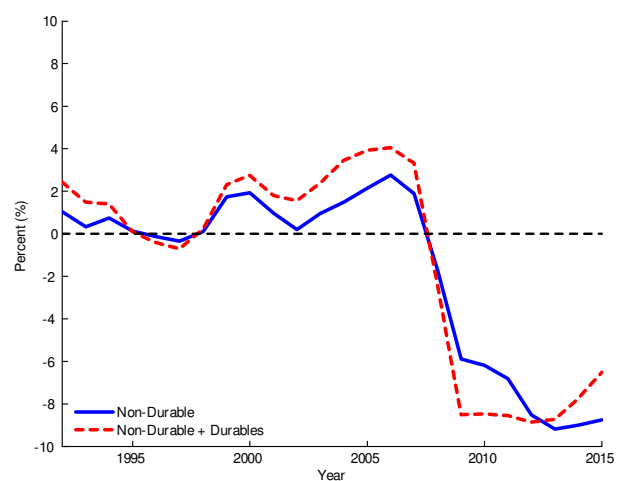
Source: Gomme, Ravikumar, and Rupert (2011) and authors' calculations.

**Figure 4: Macroeconomic Aggregates during the Housing Boom-Bust (1992-2016)
(Deviation from trend)**

GDP



Consumption

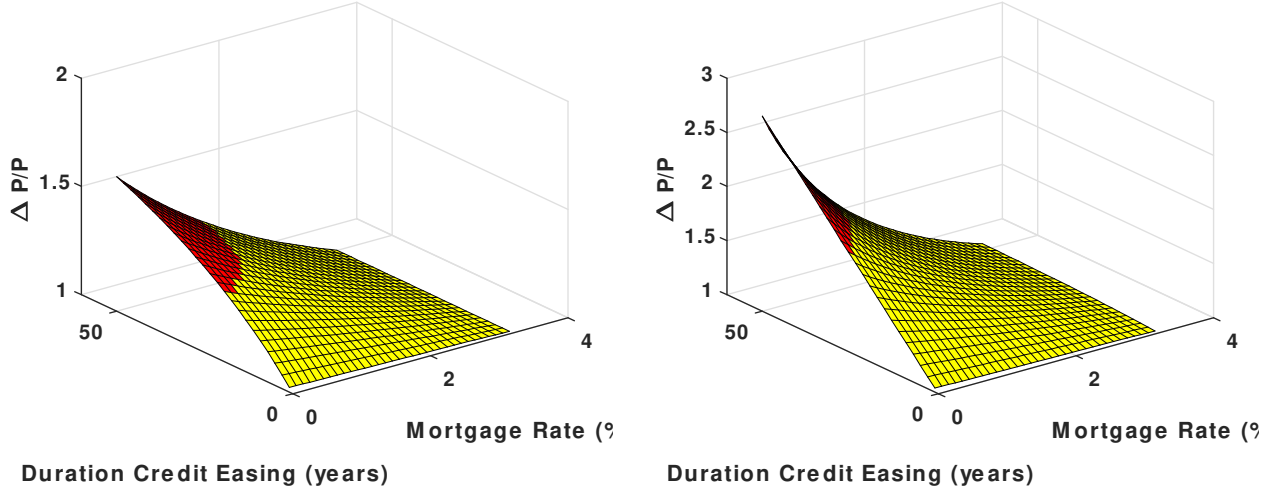


Source: NIPA index and authors' calculations of the trend.

Figure 5: House Prices and the Duration of a Credit Easing

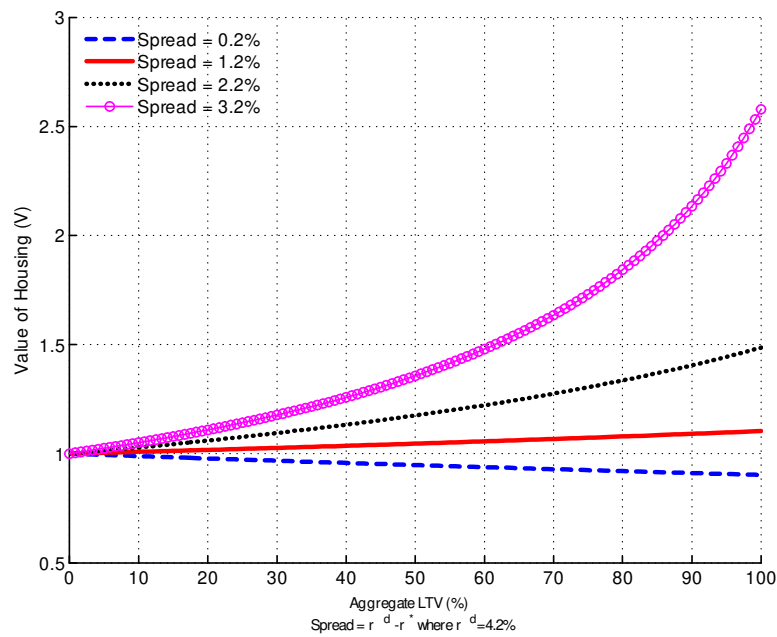
Loan-to-Value (LTV) Remains at 65%

Loan-to-Value (LTV) Increases to 100%



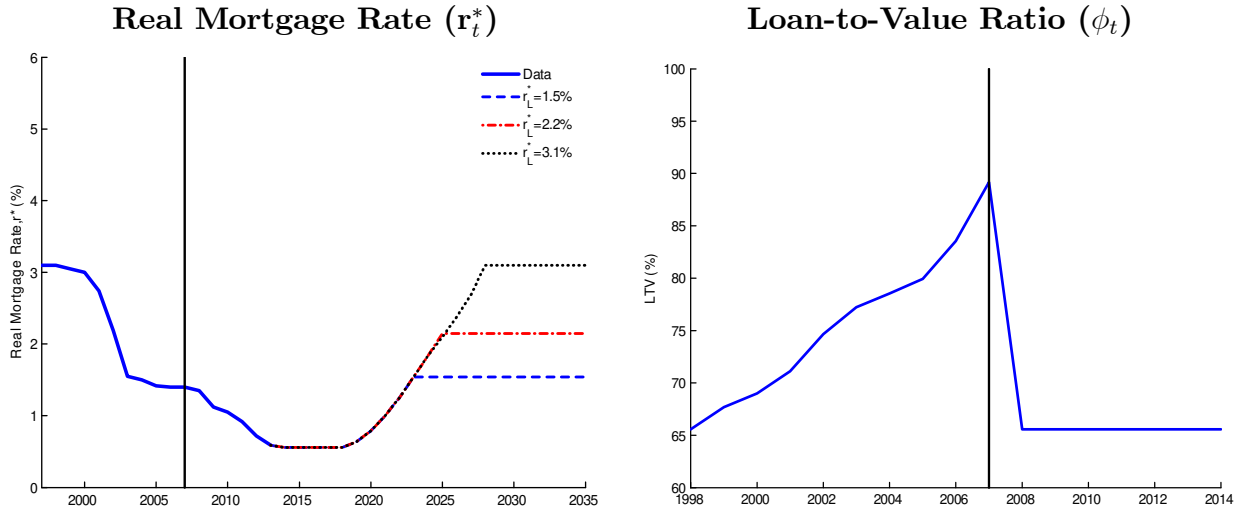
Source: NIPA index and authors' calculations of the trend.

Figure 6: Response of House Values to Permanent Changes in Housing Finance



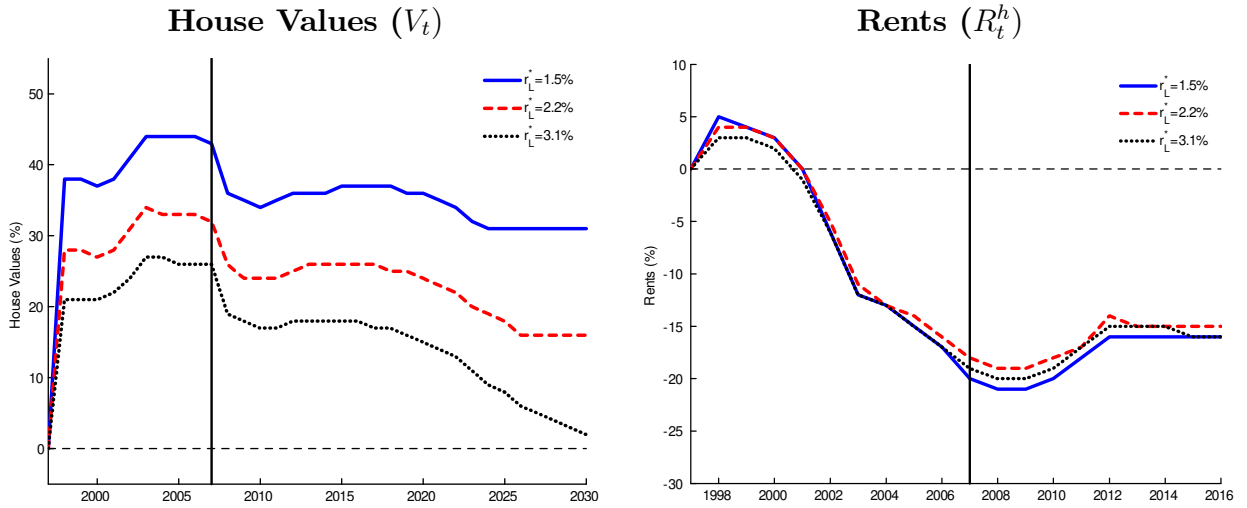
Source: Authors' calculations.

Figure 7: Exogenous Changes in Housing Finance



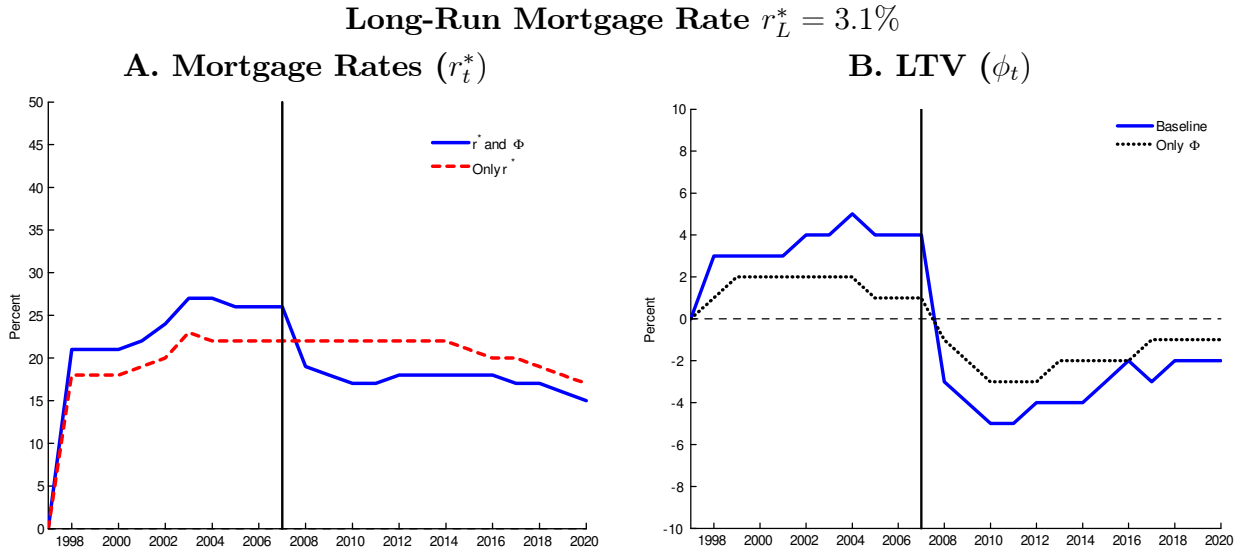
Source: Authors' calculations.

Figure 8: House Values with Perfect Foresight



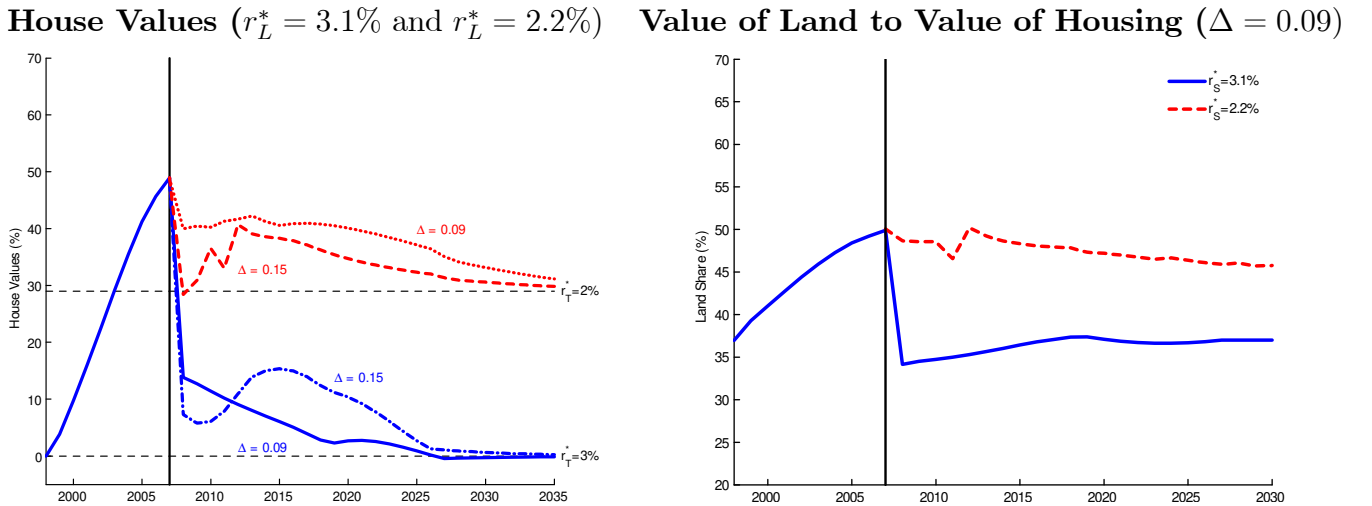
Source: Model-simulated data.

Figure 9: Decomposing Movements in Housing Values



Source: Model-simulated data.

Figure 10: Housing Values with Shocks to Expectations



Source: Model-simulated data.

Figure 11: Macroeconomic Aggregates ($r_L^* = 3.1\%$)

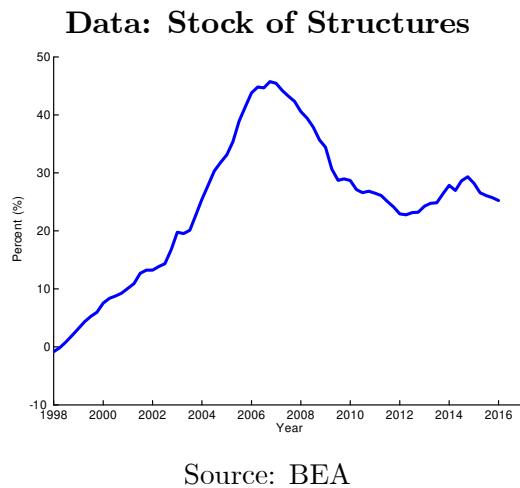
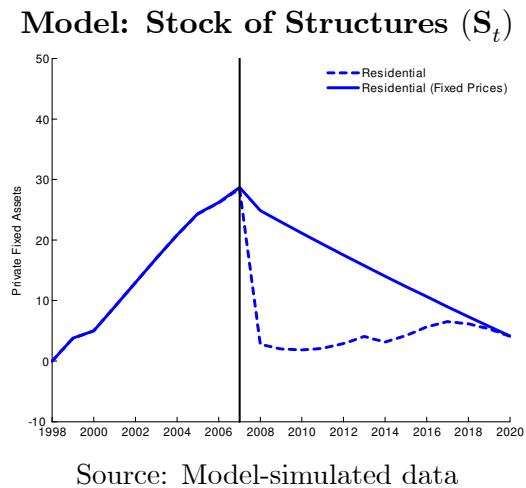
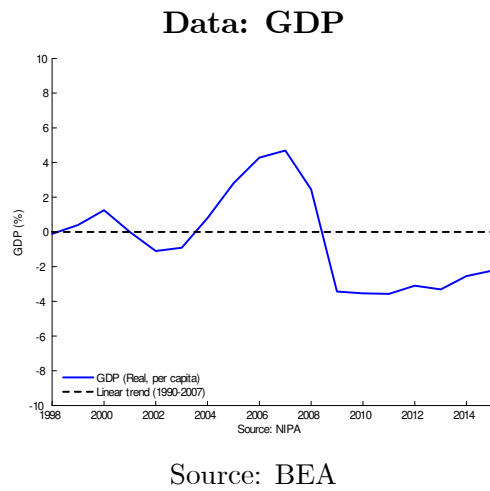
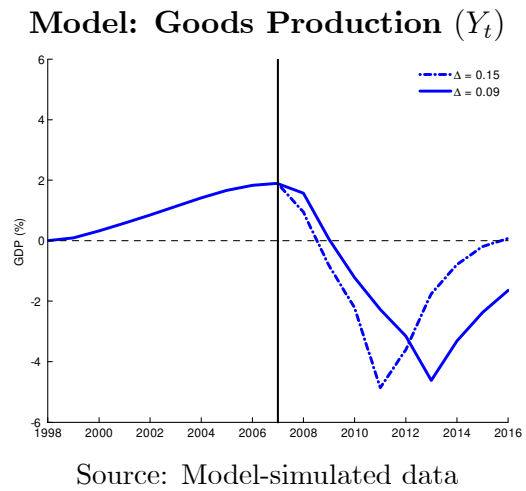
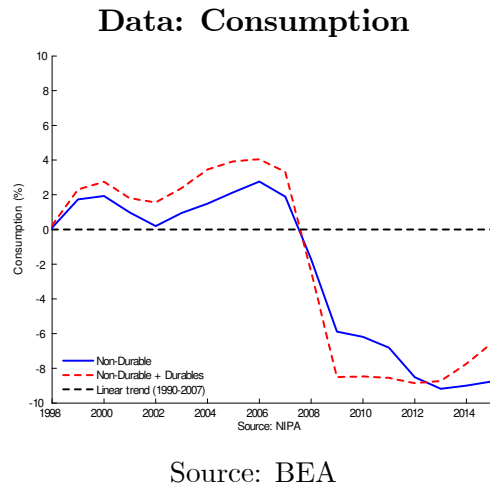
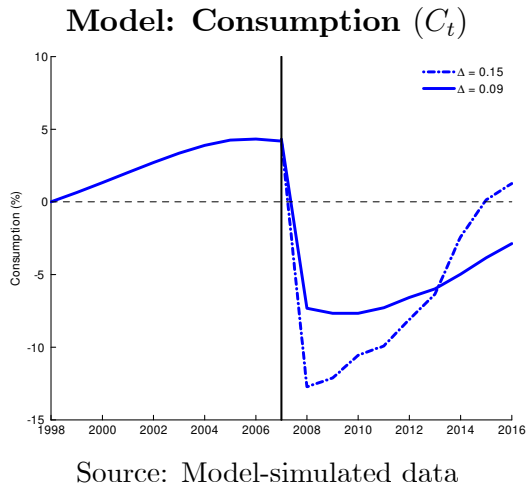
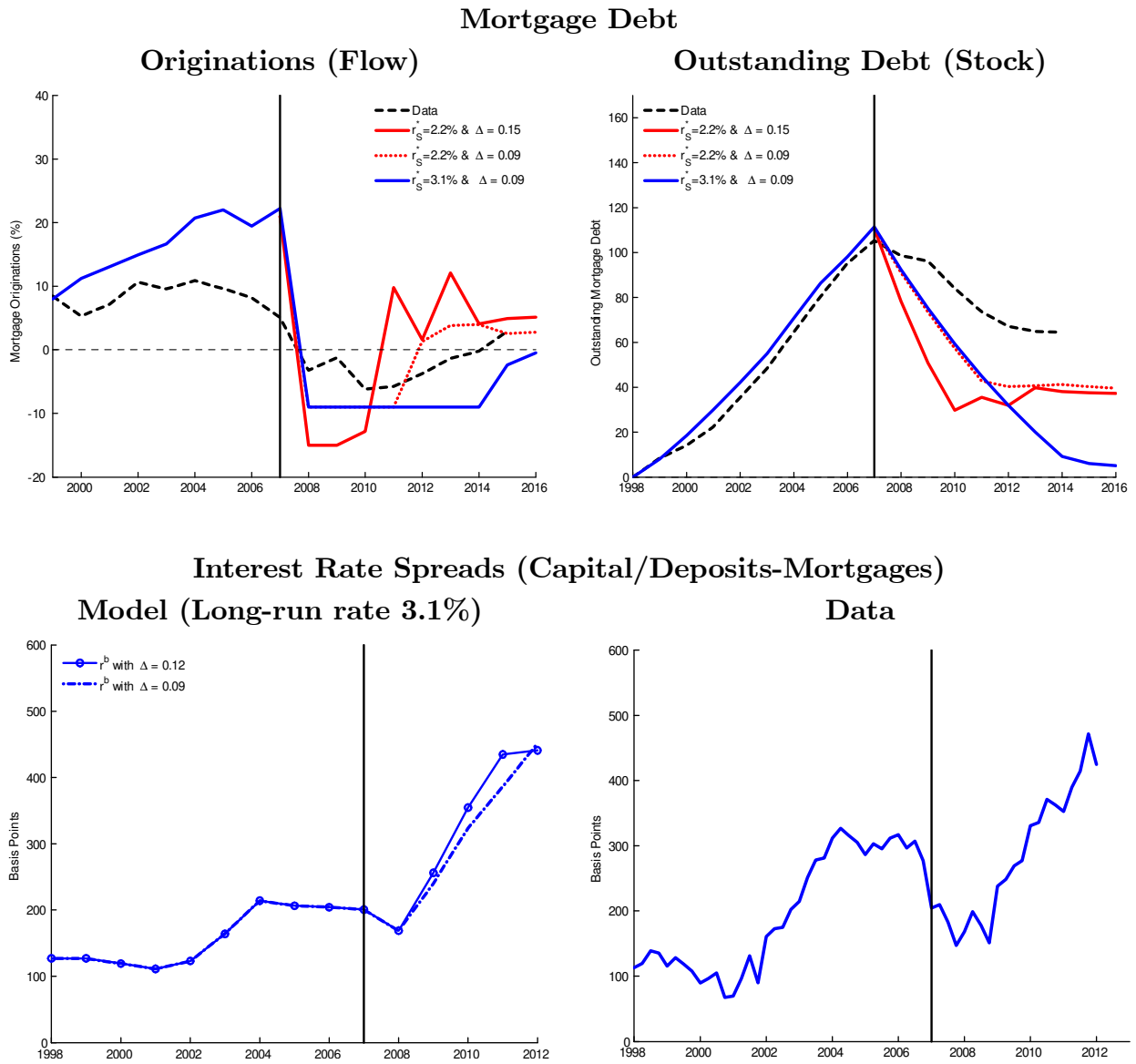


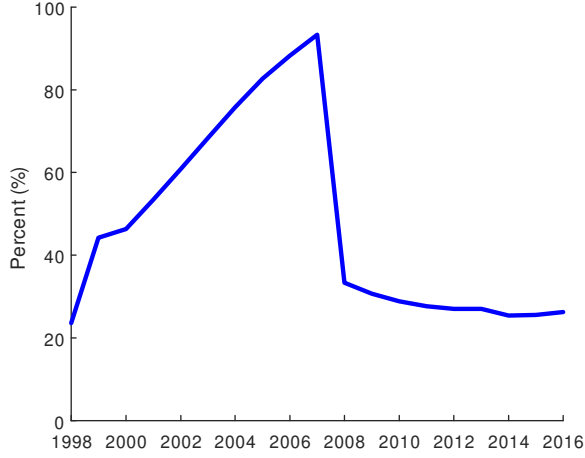
Figure 12: Housing Finance, Mortgage Debt, and Interest Rates



Source: Flow of funds and authors' calculations.

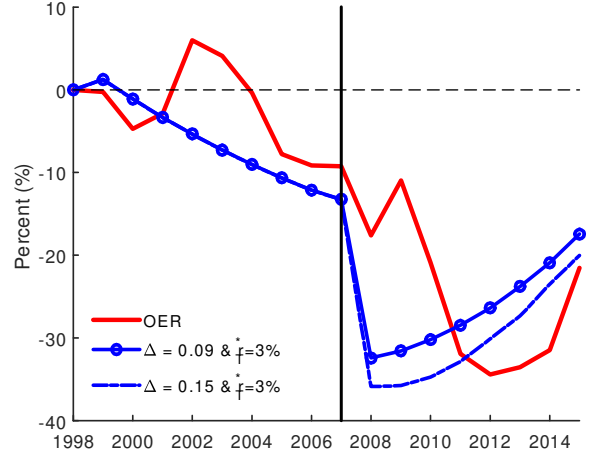
Figure 13: Prices, Rents, and Frictions ($r_L^* = 3.2\%$)

Contribution of Market Segmentation (Z_t)



Source: Model-simulated data

Rents (R_t^h): Model vs. Data



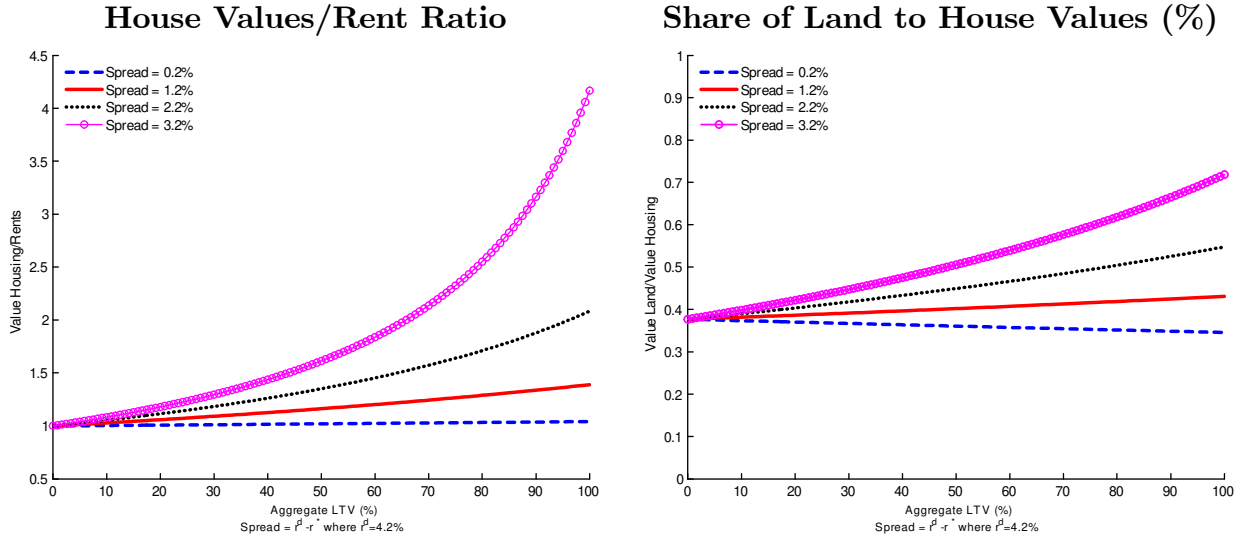
Source: Bureau of Labor Statistics and
Model-simulated data

9 Appendices

9.1 Appendix A: Steady State: Sensitivity to Housing Finance

The left panel of Figure A.1 shows house values relative to rents, or the price-rent ratio in the calibrated economy for different loan-to-value ratios and paths of interest rates. The right panel of Figure A.1 effectively shows the contribution of land to house values.

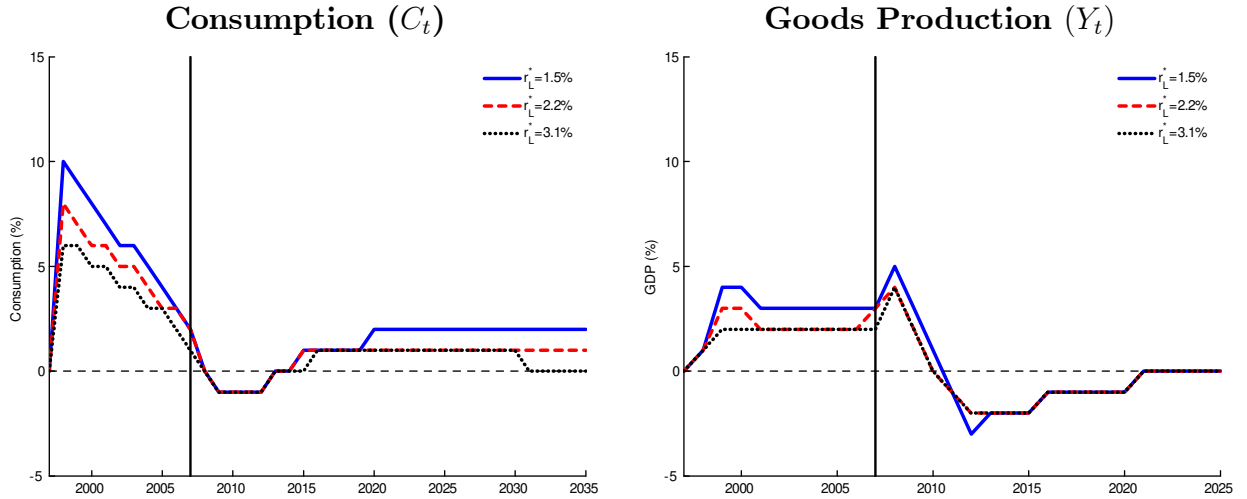
Figure A.1: Steady State House Values and Housing Finance



9.2 Appendix B: Perfect Foresight: Macroeconomic Aggregates

Here we report the level of macroeconomic aggregates in the perfect foresight case. The initial and final steady states are not determined by conditions in housing finance, hence, the different simulations converge to the same level of production, $Y^* = C^* + \delta_s S^* + r_L^* \phi V^*$.

Figure B.1: Macroeconomic Aggregates



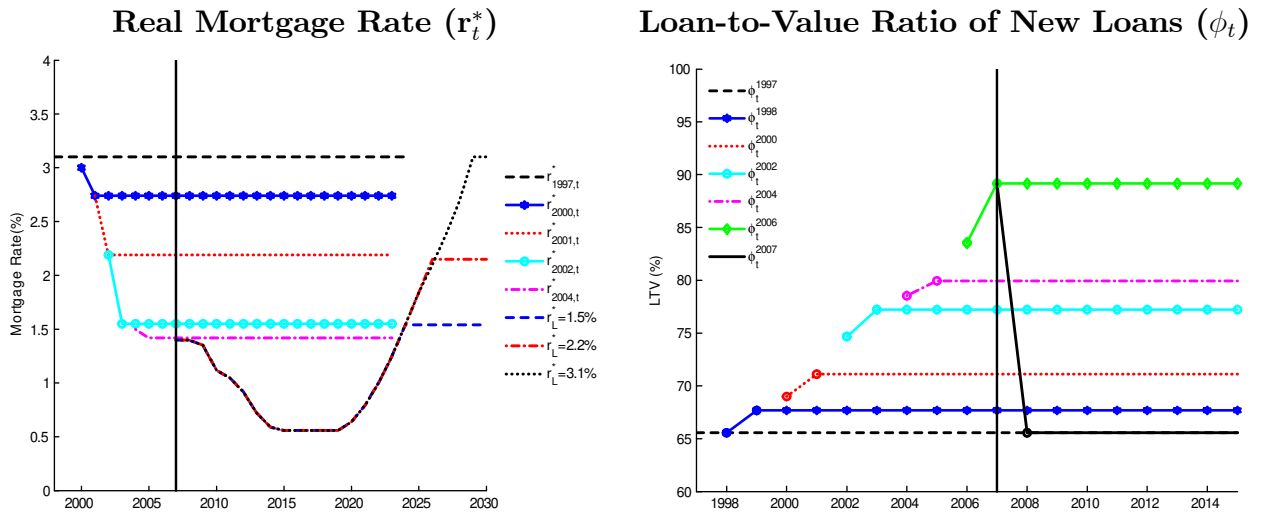
Source: Model-simulated data.

9.3 Appendix C: Shocks to Expectations

9.3.1 Timing of News about Financial Variables

Figure C1 depicts the timing of news about financial variables described in Section 6.5

Figure C.1: Time Path of Financial Variables



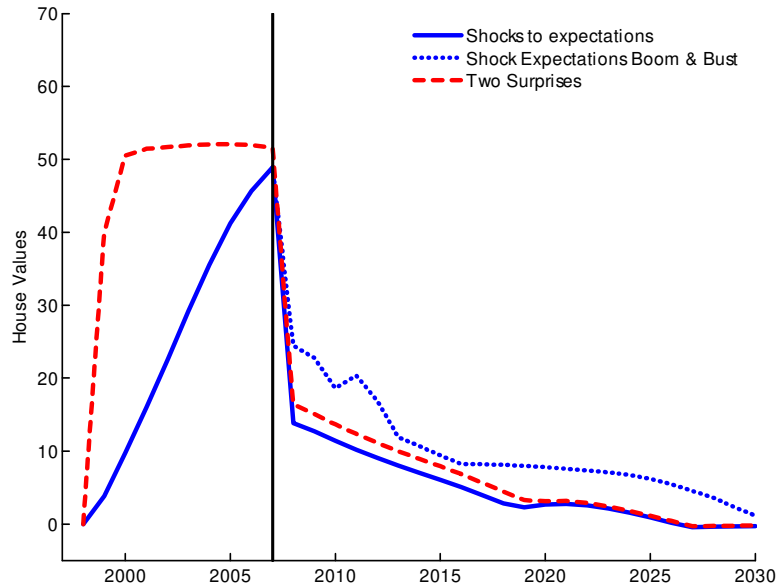
Source: Authors' calculations.

9.3.2 Sensitivity Analysis: The Timing of News about Financial Variables

This Appendix explores how sensitive house values are to the particular path of shocks to expectations. We present the predictions of the model for house values in two scenarios. In the first scenario, labeled “Shock to Expectations: Boom and Bust,” we assume that news about the changes in financial conditions during the post-2008 period arrive as expectational shocks. The second experiment, labeled “Two Surprises,” assumes that there is a “boom” shock in 1998 and delivers a path of mortgage rates and loan-to-value ratio constraints consistent with the observed path until 2007 because households initially believed the shock was permanent. The second surprise happens in 2007. At this point, the households learn that the path of the for housing finance variables behaves is as in the main body of the paper.

The results of these two alternative specifications of expectations as well as the baseline case with shocks to expectation are in Figure C.2. The predictions are relatively close, taking into account how radically different the implied expectations are. We find this robustness test somewhat reassuring.

Figure C.2: Housing Values and the Arrival of Information



Source: Model-simulated data.

9.4 Appendix D: Proof of Proposition 1

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

$$p^\ell = \frac{r^d + \delta_s - \phi(r^d - r^*)}{r^d - \phi(r^d - r^*)} \frac{1 - \alpha_s}{\alpha_s} \left(\frac{S}{L} \right)^{1+\mu}, \quad (3)$$

$$c(S, \phi, r^*) = \left[\frac{r^d + \delta_s - \phi(r^d - r^*)}{1 + r^d} \frac{\alpha_c}{\alpha_s(1 - \alpha_c)} S^{1+\mu} G(S, L)^{\rho-\mu} \right]^{\frac{1}{1+\rho}}, \quad (4)$$

$$V = V^1(S, \phi, r^*) = S \left[1 + \frac{1 - \alpha_s}{\alpha_s} \frac{r^d + \delta_s - \phi(r^d - r^*)}{r^d - \phi(r^d - r^*)} \left(\frac{S}{L} \right)^{1+\mu} \right], \quad (5)$$

$$V = V^2(S, \phi, r^*) = \frac{Y - c(S, \phi, r^*) - \delta_s S}{\phi r^*}. \quad (6)$$

It is useful to exploit the recursive nature of the economy to understand the effect of some shocks. In particular, equations (5) and (6) can be used to pin down (V, S) . Given this, equation (4) determines the level of non-housing consumption and equation (3) 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

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

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 (4) and (3). First, consider 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 $r^* \leq r^d$; this, in turn, implies that

$$\left| \frac{\partial V^2}{\partial r^*} \right|_{S=S^*} \leq \left| \frac{\partial V^1}{\partial r^*} \right|_{S=S^*},$$

and, hence, that $\partial S / \partial r^* \leq 0$. Second, an increase in ϕ shifts the $V^1(S, \phi, r^*)$ function 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

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

It follows that if 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 if 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.