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 mortgage rates and leverage. We establish theoretically that reductions in mortgage rates always have a positive effect on prices, whereas the relaxation of collateral constraints has ambiguous effects. A quantitative version of the model parameterized to the U.S. boom-bust experience accounts for about half of the observed price movement under perfect foresight. Adding shocks to expectations about housing finance conditions improves the model's ability to match house values. The framework reconciles the observed disconnect between house prices and rents since, in general equilibrium, financial shocks can decrease rents at the same time that they 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 U.S. and, hence, it casts doubt on the view that financial shocks that induce price changes can have significant impact for the economy.

In this paper we explore, in the context of a macro model, whether realistic shocks to mortgage rates and leverage can account for large changes in house prices. We first consider a very simple model with inelastic housing supply that implies that a modified version of the asset pricing formula that takes into account that financial markets are segmented —which creates a wedge between the interest rate on mortgages and the return of other assets, including capital— and that there are limits to the ability of agents to profit from this difference in returns can deliver significant increases in house prices. We show that the response of house prices to changes in credit conditions depends not only on the size of the spread 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 is revealing of the potential of changes in market segmentation to explain the movement in house prices it has limitations. The key observation is that housing is not a marginal component of consumption; housing services are close to 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 survive a full description of the economy we develop a general equilibrium macro model that considers a "semi-open" economy with segmented financial markets. The key drivers are changes in the rate of return on

[1] The experience is not unique to the U.S. 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, Sweeden, Taiwan, and United Kingdom.

mortgages —the return on capital is endogenous— and in the maximal loan-to-value ratio. In the model we view the segmentation as being driven by foreign demand for mortgage backed securities which is consistent with the evidence. 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] In the model the supply of housing is elastic —this is not only consistent with the evidence but also essential to match the comovement between rents and house prices observed in the data— and individuals make standard saving and investment/portfolio allocation decisions.

We show that equilibrium house prices are the sum of two components: a "frictionless" value, which discounts rents at the market interest rate, and an additional term, a type of bubble, that captures the effect of segmentation in financial markets. While the level of interest rates are essential to determine the frictionless component of the price, it the wedge between mortgage rates and the return on capital as well as the loan-to-value ratio that are the fundamental determinants of the bubble component. In the steady state, the full model's predictions mirror those of the simple setting when shocks to financial conditions are viewed as permanent.

We study a calibrated version of the economy that matches the appropriate moments of the pre housing boom evidence. We use the model to study the response of house prices and macro aggregates to changes in mortgage rates and loan-to-value ratios that approximate the conditions and events observed in the United States 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 duration of changes in financial conditions.

Under perfect foresight, the model is able to rationalize a sizeable appreciation in house values that ranges between 25 to 45 percent. The magnitude of the initial increase depends on the long-run properties of mortgage rates. The lower the "new" long run rates the larger the appreciation of house values. The model can produce sizeable movements in house prices with relatively small changes in non-housing consumption which is consistent with U.S. data. Also, as in the data, a large fraction of the increase in house values corresponds to the value of land and a more modest component 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 housing values than changes in financial market conditions, the

[2] It 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 to add a significant amount of heterogeneity to model the lending side of the market that we do not believe would have much impact on the results on the housing sector.

total effect of a joint change is not 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 changes in interest rates and financial conditions as permanent. However, period after period they receive an expectation shock as a surprise. The model indicates that the timing of arrival of information about conditions in the mortgage market is important to mimic the timing of the boom and the bust while, 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. In the model, the interaction between interest rates and house prices is complex. In particular, current house prices move significantly in response to future changes in interest rates. Thus, the model shows that changes in interest rates can be the driver of changes in house prices even if contemporaneous mortgage rates are not responding.

The final contribution of this paper is to illustrate the asymmetric effects that prices have in the macroeconomy through the households' balance sheet. In line with the evidence, movements in the housing sector during the boom are not associated with similarly sized 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, the presence of irreversibility conditions on investment forces the adjustment on non-housing consumption. In the short-run, the housing supply is relatively inelastic and combined with a decline in consumption makes the implicit housing rents decline (the fundamental component). This reinforces the decline in house values. This deleverage process can rationalize periods of low interest rates that do not generate massive price swings as households have too much housing and excessive mortgage debt, something that the literature has found very puzzling. The adjustment process generates a recession fueled by financial conditions that can have lasting effects because residential and non-residential investment falls. Generating a decline in consumption and investment has proven to be very challenging for traditional macroeconomic models, but it is natural in a macro model with housing and long-term mortgages.

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 U.S. 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 we 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, like the recent boom-bust cycle observed in a 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 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) as he 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 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 decuple house prices from fundamentals. Kahn (2008) uses a Markov-switching model where the change in regime changes the valuation of housing. Gelain, Lansing, 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. However, their best model generates a positive correlation between rents and house prices not found in the data.

[3]Prior to the 2000s housing boom, most of the postwar movements in house prices can be accounted by increases in housing quality and construction costs (1950-70) or regulatory restrictions. These facts are documented in Shiller (2007), Glaeser, Gyourko, and Saks (2005), and Chambers, Garriga, and Schlagenhauf (2015).

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. For instance, 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 the model move far less than in the data. Kaplan, Mitman, and Violante (2017) use a similar model with rental markets and mortgage default. Shocks to expectations and preferences for housing combined with rental firms that arbitrage between owner and tenant occupied housing drive the movements in house values. In this literature, exogenous beliefs about future appreciation increases current prices. These structural models formalize some of the conjectures suggested by Shiller (2007). 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 house 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. Kiy-

[4] There 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 U.S. and find that low interest rates and higher appreciation are positively correlated.

otaki, Michealides, and Nikolov (2011) use a quantitative small open economy model with heterogeneous households and focuses on the redistributional 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's income) and a permanent decrease in the interest rate (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 around 20 percent and the price-rent ratio about 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 helps reconcile the divergent views of the role of credit constraints as presented in the stylized model in Section 3.

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) or Glaeser, Gottlieb, and Gyourko (2013)[6]. Second, we allow for an elastic supply of housing

[5] Other 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.

[6] In addition, we view the market rent 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 Glaeser, Gottlieb, and Gyourko (2013)

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, 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 during the years 1998 and 2010 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 U.S. between 1975 and 2015. The index 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 only account for 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 housing stock. The evidence shows that in the 2000's 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 around 28 percent.

In traditional housing-macro 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

[7] Jordá, 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.

Fisher, 2007).[8] The left panel of Figure 3 shows the time series for the after-tax real returns on productive capital (all and business) and the real mortgage rate. The measure of 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 be 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. The 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 rates takes into account an average mortgage deduction of 25 percent, and the measure is converted into real using a 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 both 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 increases significantly, nearly doubling the historical average. During the financial crises the rate of return differential partially declines, and in the aftermath, the continuous decline of mortgage rate 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 dataset 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, but for example Kermani (2012) hypothesizes

[8] It is not uncommon to see models where there is an exogenous or endogenous wedge 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.

[9] Most of the time series are not sensitive to the choice of price index. The 10-year CPI is more appropiate as mortgage lenders price fixed-rate mortgages taking into account inflation expectations over a longer horizon.

[10] The return of productive capital is has different risk properties than mortgage rates. Our analysis using a macroeconomic model ignores higher moments and focuses on contribution of rates on house prices.

that this is the result of the increase in the holdings of US 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, Caballero and Farhi 2014). Some estimates indicate the increased importance of US assets in global portfolios that 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, Natvik (2016), booms driven by income and consumption growth show a positive correlation between rents and house prices. Figure 4 shows the detrended series for output and consumption show modest changes in these macro aggregates. Fernald (2014) finds that the contribution of productivity to economic growth was also very modest during this period. 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 to isolate the impact of the drivers of housing prices on the rest of the economy. In the next section, we describe a simple macro model designed to be consistent with these observations.

Our approach takes a pure asset pricing perspective and ignores the potential role of homeownership. In the U.S. 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 patters can be observed in other countries.

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— in which interest rates on mortgages are low and loan-to-value ratios high, and the long-run —which we view as the permanent steady state— in which 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 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

$$R_j = \frac{1-\alpha_c}{\alpha_c}\left(y - \upsilon\phi_j r_j^*\right),$$

where y is the ratio of income to housing stock and υ 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 r^d. The maximal amount —and it is always optimal to borrow at the low rate as much as possible if $r_L^* \leq r^d$— is $\phi_L P_L$.

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 unchanged average return on other investments) and relatively liberal lending standards.

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

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

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

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 the price of housing even if the domestic rate, r^d, are unchanged. Second, the effect of increasing ϕ_S is theoretically ambiguous and it depends on the sign of

$$\frac{1-\alpha}{\alpha}\upsilon r_S^* - (r^d - r_S^*).$$

In the simple parameterization in this section it is always negative and hence relaxation of lending standards increase the 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 $T \to \infty$, and it is equal to one for $T = 0$. The responsiveness of the relative price P is high for low expected durations and zero when the change is permanent.[13]

Equation (1) is basically the standard pricing equation that, in some parameterizations, cannot account for large changes in housing prices. The introduction of market segmentation and expectations about the duration of lax financial conditions in the housing market could account for significant increases in housing prices. To verify this conjecture, we report the impact on P of changing the financial conditions in the short-run using a base case (see the calibration section 6.1 for justification).

$$r^d = 0.042,\ r_L^* = 0.032,\ \phi_L = 0.6525,\ \alpha_c = 0.91,\ \upsilon = 0.33.$$

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 impact of changes in T and r_S^* on P for two values of the loan-to-value ratio: 65.25 percent (which is the average loan-to-value ratio before 2000) and 100 percent, which we take to be a very relaxed financial condition. 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 for r_S^*

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

[13] For reasonable values changes in υ and α_c have a small impact on P.

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 of about 60 percent. With more generous financial conditions (LTV 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, in the range of high price increases the model displays significant non-linearities for the relevant dimensions (i.e., low mortgage rates, high LTV, and a large duration of the credit easing).

The take away from this exercise is that —in this setting— the critical factors are the 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 since 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 it is important to check that the model has realistic implications for the investment in structures. 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 $t = 0, 1, 2, ...$ 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 one unit of time per period which they supply inelastically to the market in order to receive a wage rate w_t.

They are also the owners of non-housing capital, K_t, which they rent to firms at rate r_t. The stock of non-housing capital evolves following the standard law of motion,

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

where $0 \leq \delta_k \leq 1$ is the depreciation rate and x_t is non-housing investment. Households own a stock of residential structures, S_t, which depreciates at rate δ_s, and land, L_t, which does not depreciate. 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 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 an 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

[14] One interpretation is that collateralized loans are traded internationally, 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).

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

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

where $0 \leq \triangle \leq 1$ is the fraction of the stock of debt that must be repaid/amortized every period. Traditionally, the literature assumes one-period mortgage loans ($\triangle = 1$) 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 ($\triangle = 0$) where agents only need to make interest payments. In the intermediate case with $\triangle \in (0, 1)$ each period there is some amortization, so the value of $\triangle$ can be used to approximate the duration of the mortgage.[15]

The interesting region of the parameter space is one where equilibria satisfies $r_t^d \geq r_t^*$; that is 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. 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

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

When the adjusted value of the housing stock exceeds the market value of outstanding mortgages net of repayments, $\phi_t V_t \geq (1 - \triangle)B_t$, this specification implies that the next period's stock of debt equals $B_{t+1} = \phi_t(p_t^s S_t + p_t^\ell L_t)$. The model implies that the private sector refinances its entire stock of mortgage debt to take advantage of interest rate differentials. This is, of course, an extreme implication but it appears consistent with the observed refinancing trends observed in the data. When the value of the housing stock drops below the value of the mortgage, $\phi_t V_t < (1 - \triangle)B_t$, the long-term nature of the contracts requires borrowers to repay at least $\triangle B_t$ of the existing stock of mortgages (this follows from the law of motion and $b_{t+1} = 0$).[16]

The representative agent solves

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

[15] This 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 aproximate the average maturity of mortgage loans.

[16] In some of our numerical experiments this is a binding constraint as deleverage matters.

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

and the standard non-negativity constraints.

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.

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

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 return to capital/interest rate is value 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

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

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

One can easily separate house values, V, from house prices, $p^h H$, combining the above expressions. The steady state resource constraint

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

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.[17]

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

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

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

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

[17] Details about the proof can be found in Appendix D.

long-run since a larger amount of resources needs to be devoted to mortgage payments. These two effects work in opposite directions and, for extreme values, the income effect dominates and relaxation of the financial constraint has a negative impact on housing variables. The results also show that, even in the steady state, the nonlinearity of the model implies that the impact of changes in a given variable must depend on the equilibrium values of all other variables. The quantitative section illustrates these trade-off, but also calculates the short-run dynamics as a response to the levels on the cost of borrowing and financial conditions.

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 and the aggregator of housing services 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 (1929-1999), 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 accounting 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 gross value added by industry allows to separate the housing sector, a component of the real estate and rental and leasing, 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, proprietors' 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 3.2 percent to be consistent with the data described in Section 3. In the model, mortgage are long-term contracts with a constant amortization rate, $\triangle = 0.09$, to match the number of loans originated relative to the outstanding stock. This number is in line with the average duration of loans in the U.S. market once you allow for refinancing (i.e. 8-11 years). The nature of long-term mortgages contracts distinguishes the flow of newly originated loans from the outstanding stock, $B_{t+1} = b_t + (1 - \triangle)B_t$. The condition for the baseline equilibrium imposes the restriction that new originations replace part of the stock that has been amortized, $b = \triangle B$. Under this assumption, 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 specifications 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. 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 $1/(1+\mu) = 0.25$.[18] 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 of the economy in terms of quantities and values. Table 1 summarizes all the calibrated parameters and shows that the model

[18] See McDonald (1981).

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 gap between market and mortgage rates, $r^d - r^*$, and financial conditions —as measured by the LTV ϕ— on house values. Our results show that in this model the effects are very nonlinear. The results are summarized in Figure 6. The left panel shows the impact of changes in the two variables on the level of house prices, while the right panel reports the corresponding elasticities. There are two important findings:

1. Increases in the difference $r^d - r^*$ unambiguously increase housing values. However, relaxing the financial constraint (i.e. increasing ϕ) has ambiguous effects: housing values increase when $r^d - r^*$ is large but the opposite happens when $r^d - r^*$ is small.

2. The responsiveness of house values to changes in financial conditions (ϕ) depends both on the size of the wedge $r^d - r^*$ and the level of the LTV. For example for high $r^d - r^*$ a 20 point increase in the LTV from a high (80 percent) level has a proportional impact that is twice as large than a similar 30 point increase from a more moderate level (40 percent).

The steady state results highlight that linear approximations can be subject to large errors.[19] The computational approach in the quantitative analysis deals with these nonlinearities under different information structures.[20]

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 numerical exercise. The right panel shows that the loan-to-value ratio on new loans starts in 1998 at a steady-state level of 65.2 percent, and then, it 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.[21] Since households use long-term mortgages, the adjustment of the stock of outstanding mortgage debt is endogenously

[19] In 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.

[20] In an Appendix available upon request, there are additional examples discussing the relative importance of endogenizing land, as well as introducing heteregeneity in income, credit conditions, and locations.

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

determined. The path of mortgage rates is taken directly from the data described in Section 3. The effective real rate starts at an initial level around 3.2 percent in 1998 and rapidly declines in the early part of the 2000s to reach 1.5 percent in 2007. The adjustment during this period is very important to determine the magnitude during the housing boom. After the collapse of the housing market, mortgage rates continued on a declining path at least until 2016. To solve the model it is important to determine the long-run path of interest rates, and since it is unclear the direction and the level of future rates it is convenient to consider three alternative paths. One path assumes that by 2027 mortgage rate will revert back to the initial level in 1998, the other path assumes that rates will converge back to 1.5 percent by 2023, and the third path long-run mortgage rates will converge around 2 percent (see left panel of Figure 7).[22]

We now discuss the dynamic response of the model to changes in financial conditions 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.[23]

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 depends on the value of r^*_L, the long run rate. When the long-run mortgage rate reverts back to the initial level of 3.2 percent house prices increase about 25 percent from the late 1990s to the mid-2000s. In the alternative case — $r^*_L = 0.015$— house prices increase about 45 percent. Since the data show that house prices increased about 50-60 percent with respect to 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 capital is capitalized in the value of land and house prices increase. Second, since the

[22]The data suggest there was an increase in short-term rates between 2005 and 2007, however, this tightening had small effects in 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.

[23]The computation searches for 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}.

value of collateral rises and households can borrow against the value of the housing stock at below-domestic-market rates, this is equivalent to an income shock—given by the present discounted value of the interest rate differentials—which results in higher consumption of both goods. This higher demand has a positive impact on prices.

The increase in values is driven by changes in the volume of structures and in the price of land. The data suggests that the contribution of land to house values increases during the housing boom from 35 percent to 43 percent, whereas the model predicts an increase that ranges between 42 to 48 percent depending 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 deleverage effect. The magnitude of the decline depends on the long-run mortgage rate. When rates converge to the baseline level around 3 percent, then all the 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 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, it is not possible to disinvest in structures and their depreciation rate is very low. Thus, in the bust, the price of structures adjusts but not the stock. The second factor is that the paths of the driving variables are asymmetric. While the increase is unanticipated, the decrease is anticipated by about 20 years; the tightening of credit conditions generates an 8-10 points decline in house prices.

Rents The right panel of Figure 8 shows the dynamics of rents during the housing boom. Rents initially decline, thus, the increase in house values in the model is driven by the collateral value of homes as opposed to an increase of rents, something that proves to be very challenging as suggested by Kiyotaki, Michealides, and Nikolov (2011) and Gelain, Lansing, and Natvik (2016). The reason why rents decline is that there is a decrease in the ratio of non-housing to housing consumption driven by the positive income effect associated with the improvement in financial conditions (this drives up the demand for both housing and non-housing goods) and the relatively fast response of housing supply (structures) in the short run. The decline of rents in the model is consistent with the measure of owner equivalent rent (OER) measured by the Bureau of Labor Statistics. This will be discussed in Section 5.6 in more detail.

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 are complements. This results depends on general equilibrium effects that we discuss in the next section.[24]

The Contribution of the Two Shocks Our results are driven by the simultaneous changes in interest rates and the loan to value ratios. The next set of experiments decomposes the relative contribution of each of the two factors in isolation. The left panels of Figure 9 measure the contribution of lower mortgage rates to the change in house values for the two extreme cases of long-run mortgage rates (1.5 percent and 3.2 percent) while the right panels measure the contribution of the relaxation of LTV constraints. We report two experiments depending on whether we hold the other variable constant or we assume that it follows the baseline path. [25]

Given the path of the forcing variables, changes in interest rates account for the majority of the swing in house values. The model implies that the decline in mortgage rates accounts over 20 percent of the increase in house values between 1998 and 2007. This number is in line with the estimates of Glaeser, Gottlieb, and Gyourko (2013).

In the absence of a tightening of the LTV constraints house values increase and then remain stable. In the case displayed in panel A of Figure 9, house values eventually converge to the initial level as housing finance conditions are reversed. This is not the case in panel C, as the long-run mortgage rates are lower than the baseline ones, as a result house values remain high. The large response to the decline in mortgage rates indicates that the role of collateral constraints is more limited.

The perfect foresight analysis provides a very useful benchmark to understand the dynamics of house values, but it endows agents with too much information about credit conditions reversals.[26] To understand the sensitivity of the results to alternative information structures we now extend the model to allow for shocks to expectations.

6.5 Shocks to Expectations

The next set of experiments allows for shocks to expectations at different points in time. To incorporate these shocks/surprises in the dynamics of the model, the households have some initial expectations about housing finance variables set by the initial values $r^*_{97,t} = r^*_{97}$

[24] Appendix B contains the changes the implications of the model for non-housing consumption and goods production.

[25] For example, in the case of ϕ_t, in one case we assume that mortgage rates remain at the baseline level of 3.2 percent and the sequence for LTV, ϕ_t, follows the path described in Figure 6. In this case the change in house values is $\triangle V_t = V_t(\phi_t, r^*_0) - V_t(\phi_0, r^*_0)$. In the second option —labeled $\phi_t + r^*_t$— the calculated contribution is $\triangle V_t = V_t(\phi_t, r^*_t) - V_t(\phi_0, r^*_t)$

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

and $\phi_{97,t} = \phi_{97}$ for all t.[27] Looking forward, they assume that the mortgage rates and the LTV limits will remain unchanged in the future. In 1998 households are surprised by an initial decline in mortgage rates and a loosening of credit market conditions 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, these two housing finance variables take on new values, $r^*_{j,t} = r^*_j < r_j - 1^*$ and $\phi_{j,t} = \phi_j > \phi_j - 1$, that are perceived as permanent. We assume that in 2007, there is a reversal of the credit conditions and the new loan to value ratio, $\phi_{08,t}$, reverts back to the original steady state, ϕ_{98}, while the path of real mortgage rates matches the data data from 2008 forward, $r^*_{j,t}$ After 2007, households will have perfect foresight about conditions in housing finance.[28] The important issue is that agents learn that credit constraints will become tighter in 2008, and that mortgage rates will increase after 2023.[29] Appendix C has a graphical representation of the paths of the forcing variables.

House Values Compared to the perfect foresight case, the slow arrival of news about the future cost of borrowing and leverage mitigates the immediate response of house values. Figure 10 compares the predictions of the model for two most relevant cases based on long-run mortgage rates and two different speeds of deleverage, $\Delta \in \{0.09, 0.15\}$.[30] During the boom, the improvement in conditions in housing finance has immediate effects on house values that capitalize 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.

The slow arrival of news about the changes in the mortgage rates and LTV constraints generates a path of house values, in terms of magnitude and timing, consistent with the one observed in the data. Since the reversal of credit conditions is not anticipated, house values increase vis-à-vis much more than in the perfect foresight case. Comparing the path

[27] The 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 of predicting 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 through second homes. Similarly, Davis and Quintin (2014) show that during the boom period and bust period households fail to anticipate changes in the value of their home relative to the market value.

[28] The Appendix 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.

[29] The 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.

[30] The 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 $r^*_t - r^d_t$ that are neutral to house values.

during the boom with the most conservative estimate from the perfect foresight simulations (long-run rates converge back to the baseline level around 3.2 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 the agents ability to anticipate future increases of mortgage rates. One interpretation for this case is that households had overly optimistic expectations about the future conditions of housing finance.[31]

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. This suggests that a slow arrival of news and borrowing constraints are important elements in understanding the asymmetry between the boom and bust.

Higher expected long-run mortgage rates and higher values of Δ are associated with larger declines in house values as households are forced to repay part of their mortgage debt and this has an additional negative impact on house prices.

Why do house values adjust very quickly during the boom and slowly during the bust? The relatively slow decline during the bust is due to the presence of irreversibility constraints as the stock of housing depreciates slowly. 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 one), $p_t^S < 1$. The resulting adjustment in house values is slow relative to the boom.

Macroeconomic Effects The behavior of key macroeconomic variables responds very asymmetrically to the dynamics of house prices. The movements in the housing sector during the boom were not associated with similarly sized changes in the rest of the economy. 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

[31] For instance, Case and Shiller (2004) found that up to 95% of home-buyers in the year 2003 thought that housing prices would appreciate by an astonishing annual average of 9% 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 2003-2006 they would also expect positive near term appreciation since house prices have not yet converged to the long-run equilibrium.

the data.[32] As can be seen in Figure 11, consumption does not respond on impact but slowly grows up to 4.5 percent as housing finance conditions ease. In the data counterpart depicted in the top right, detrended consumption also increased very little during 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 with 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 with the expectations show reduces the size of the initial income effect generating small responses of consumption and output.

As the credit reversal is not anticipated, the tightening of credit conditions generates a large decline in house prices and a mismatch in the household balance sheet (i.e. assets < liabilities). The collapse of house values trigger a portfolio rebalancing process driven by a decline in the demand of consumption goods and residential structures. The last one due to overbuilding, but also due to the fact that housing is not longer good collateral. The consumption decline predicted by the model with the most dramatic decline in house prices ranges between 12 and 17 percent, and the detrended data shows declines of a similar magnitude.[33] The magnitude of these declines depends on the length of the deleverage 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 in the economy 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 deleverage period the larger the macroeconomic slump.[34]

These findings are consistent with observed decline in consumption and output, but also with the decline in residential and non-residential investment. This feature is not present in the standard frictionless model, where shocks that reduce aggregate consumption generate

[32] The model assumes no TFP or financial shocks 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 in Garriga and Hedlund (2016) that use a more complex model that does not provide expression for the equilibrium house prices.

[33] For example, Garriga and Hedlund (2016), Huo and Ríos-Rull (2016), Kaplan, Mitman, and Violante (2017) 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.

[34] The connection of between housing markets and the output has also 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.

an 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.[35] The decline in residential investment comes from the need to reduce the current stock of housing (too large relative to the size of their mortgage debt counterpart), whereas capital investment falls due to a lesser need to produce houses.

Financial Variables It is instructive to analyze the implications of the model for mortgage debt. Figure 12 presents the implications for mortgage originations and the stocks of mortgage debt. The model predicts —consistent with the data— a hump-shaped pattern with originations increasing during the boom and collapsing as house prices decline.[36] Theoretically, the dynamics during the bust are entirely determined by the length of mortgage contracts implied by the amortization rate (Δ). With short-term 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. In the other extreme case loans are an infinite consol with no maturity or amortization, $\Delta = 0$. As such, the effect on consumption is mitigated as households never need to repay the debt, only service the interest payment. In the baseline case $\Delta = 0.09$, the model predicts no new mortgage originations between 2008 and 2014. During the recession period households are reducing the outstanding debt, and the deleverage period behaves as a persistent negative demand shock. Despite the simplicity, the model performs remarkably well to capture qualitatively and quantitatively the boom and bust in housing prices in the U.S.

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 our 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. We report the values in the bottom panel of Figure 12.

[35] Other 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 in 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 show that the consumption response to declining house prices was stronger in high leverage counties.

[36] In 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).

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 periods of fast appreciation. To formalize this point, recall that the value of the housing stock is given by $V_t^h = p_t^s S_t + p_t^\ell L$. A standard asset pricing calculation shows that

$$V_t^h = \hat{V}_t^h + \sum_{j=0}^{\infty} m_t(j)\eta_t(j)R^h(t+j)G(S_{t+j}, L), \quad (2)$$

where

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

is the appropriate discount factor j periods into the future, $R^h(t) = \frac{u_h(t)}{u_c(t)}$ is the rental price of one unit of housing, 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.[37]

Here, $\hat{V}_t^h = \sum_{j=0}^{\infty} m_t(j)R^h(t+j)G(S_{t+j}, L)$ is the frictionless value of the housing stock in an economy with a real interest rate similar to the domestic rate in the model. This frictionless value is given by the present discounted value of future rents using the domestic interest rate, which is the standard valuation approach.

In steady state, the model predicts that the fact that housing can be used as collateral adds approximately 14 percent to the value of the housing stock and about 22 percent to the house price relative to valuation that only prices discounted future rents. The top of Figure 13 summarizes the decomposition in equation (2) corresponding to the model with shocks to expectations with $r_L^* = 0.032$, and $\triangle = 0.09$, with the left panel measuring house values and the right panel house prices. During the boom, the composition changes because rents decline and the collateral value of homes increases. During the boom frictions account for over 50 percent of the total value of housing stock and over 70 percent of house prices.[38]

[37] The frictional component, $\eta_t(j)$, is given by

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

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

[38] Our result is consistent with the findings of Campbell et. al. (2010), who decompose movements in 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 house finance (non-fundamental component) rationalizes the dynamics of house values. Like in their analysis, the covariates dampen the fluctuations in the price-rent ratio and it has a comparable magnitude than the non-fundamental component. This finding seems to be robust to the horizon of the decomposition.

The other important component are the expectations that 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 will bind again.

As this 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 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, and it is tight to consumption growth, whereas mortgage rates r_t^* only appear in the non-fundamental component in the valuation equation.[39]

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 is useful to recall that 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 collateral. Since the second effect is larger and ρ is positive (goods are complements), rents decrease during the housing boom.[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 the bottom of Figure 13. These numbers are consistent with the detrended measure of owner equivalent rent (OER) measured by the Bureau of Economic Statistics. For

[39] In contrast, Hubbard and Mayer (2009) argue that the decline in mortgage rates has been an important driver in the housing boom.

[40] Conventional wisdom suggests that models with a fixed housing supply have a better chance to rationalize house price dynamics. This is the argument made by Glaeser, Gyourko, and Saiz (2008). However, as Gelain, Lansing, Natvik (2016) show a version of the model where 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.

the boom period, the model predicts about a 10 percent decline in measured rents associated to 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 they themselves are the result of different forces that are triggered by 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 or not) 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 aggregate 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 U.S. experience.

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.[42] 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.

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

[42] For evidence, see Himmelberg, Mayer, and Sinai (2005), Doms et al. (2007), and Mian and Sufi (2009) provide some evidence spatial heterogeneity in changes in financial conditions.

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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 (1975-2015)

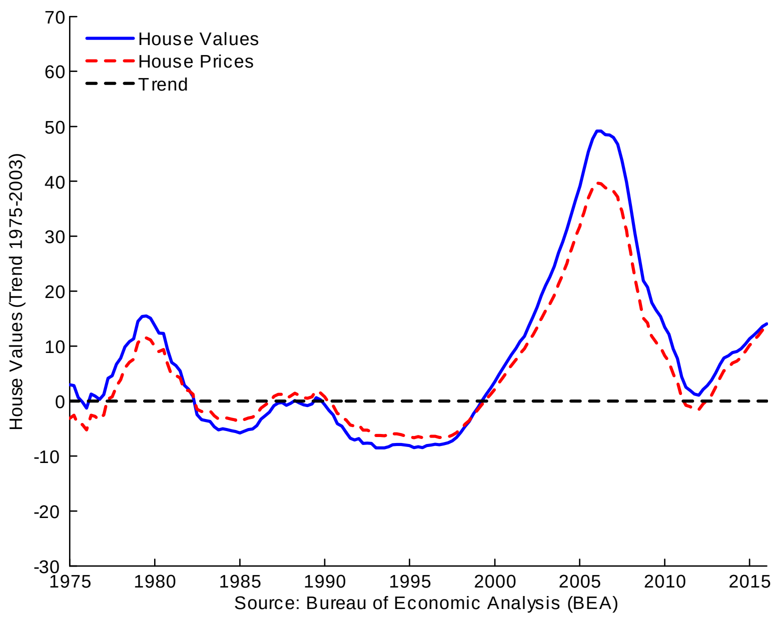
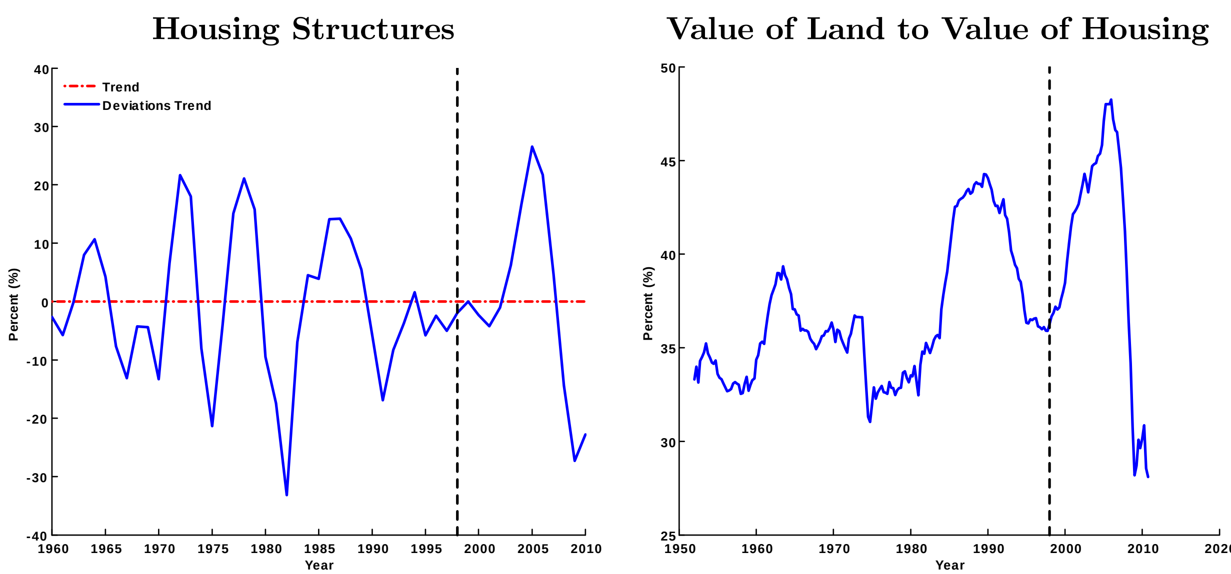
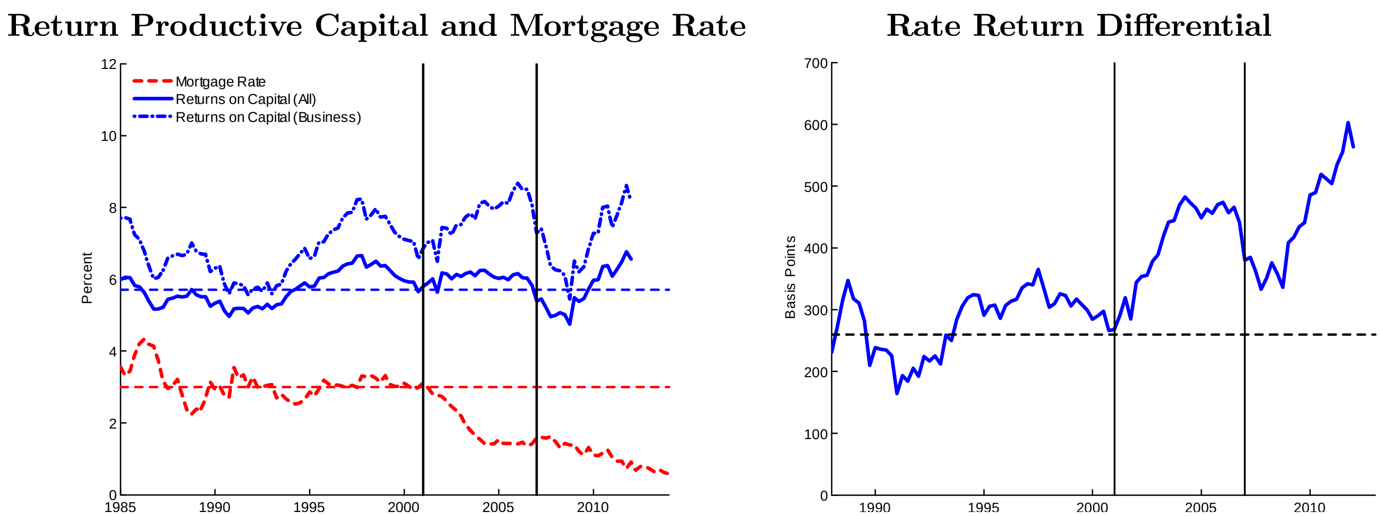


Figure 2: Housing Markets in the United States (1953-2011)



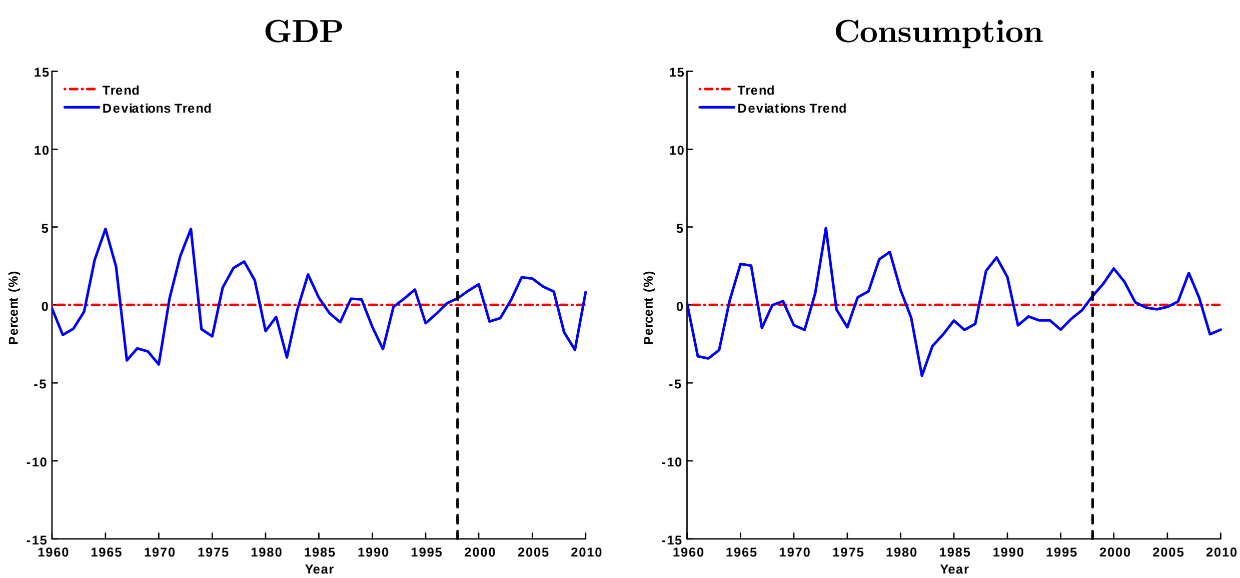
Source: NIPA index and land values from Davis and Heathcote (2007)

Figure 3: Aggregate Real Interest Rates in the United States



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

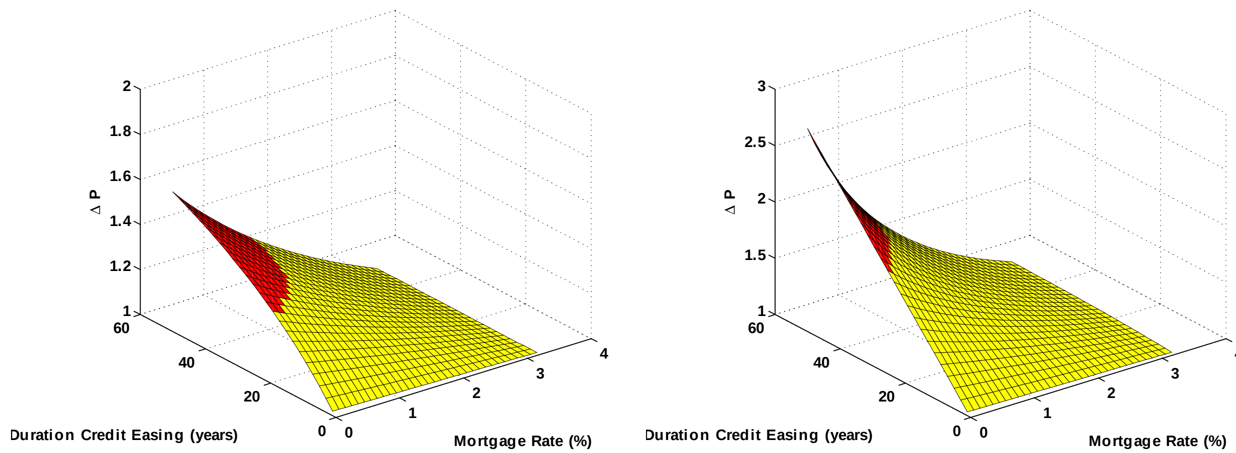
Figure 4: Macroeconomic Aggregates in the United States



Source: NIPA index and authors calculations of the trend.

Figure 5: House Prices and Credit Easings

LTV remains at 65% **LTV increases to 100%**



Source: NIPA index and authors calculations of the trend.

Figure 6: Steady State House Values and Housing Finance ($\varepsilon_{c,h} = 0.5$)

House Values **Elasticity of House Values to Credit Condition**

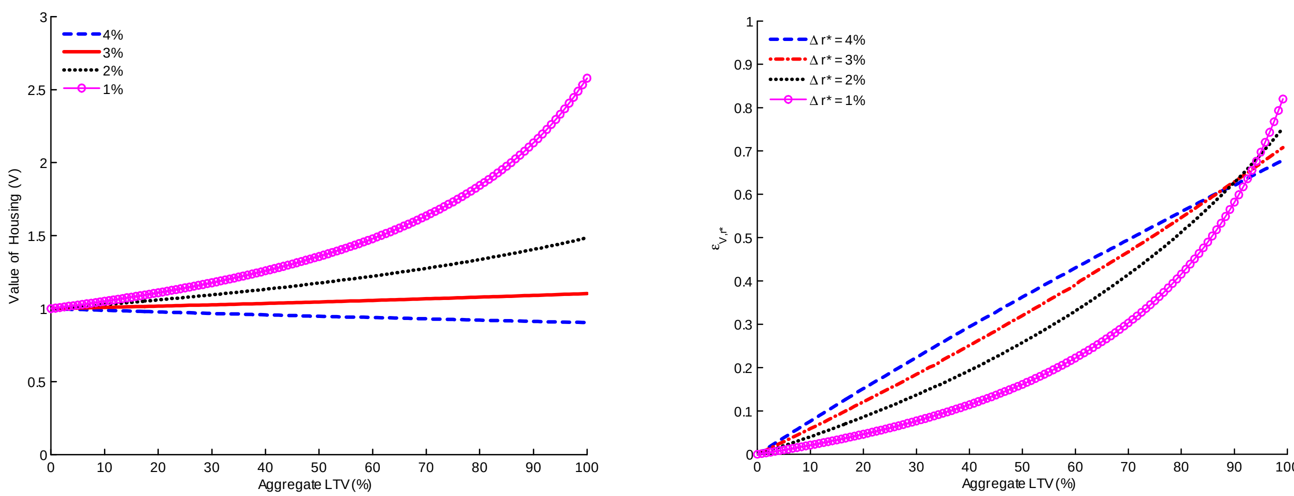
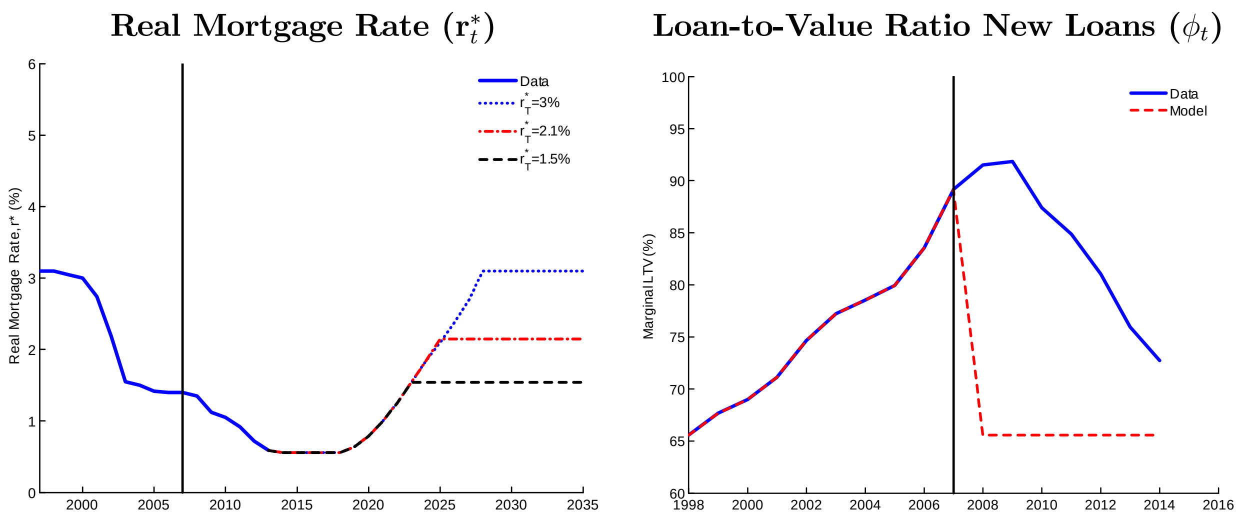
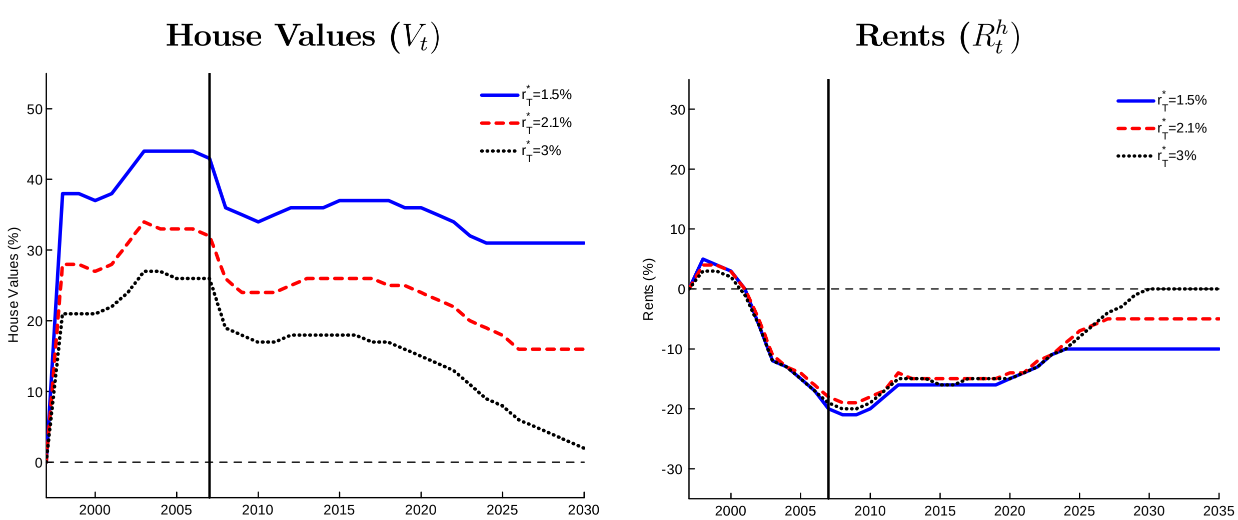


Figure 7: Exogenous Changes Housing Market



Source: Authors' calculations.

Figure 8: Housing Values Perfect Foresight

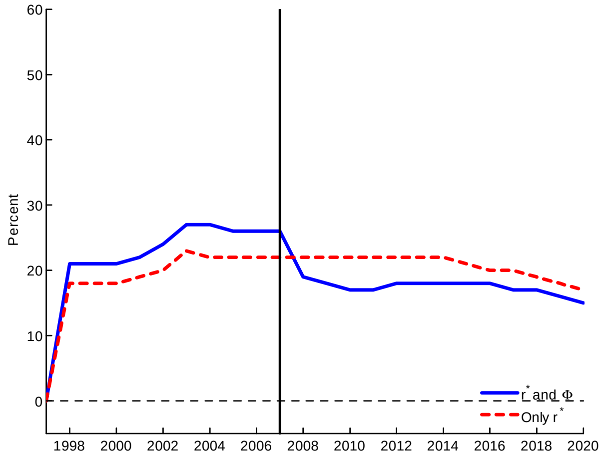


Source: Model-simulated data.

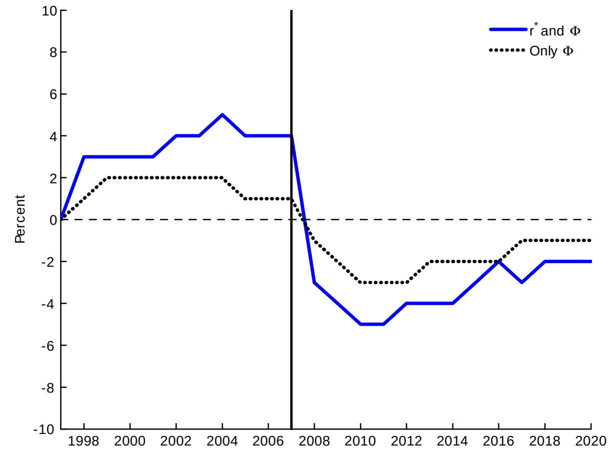
Figure 9: Decomposing Movements in Housing Values

Case $r_L^* = 3.2\%$

A. Mortgage Rates (r_t^*)

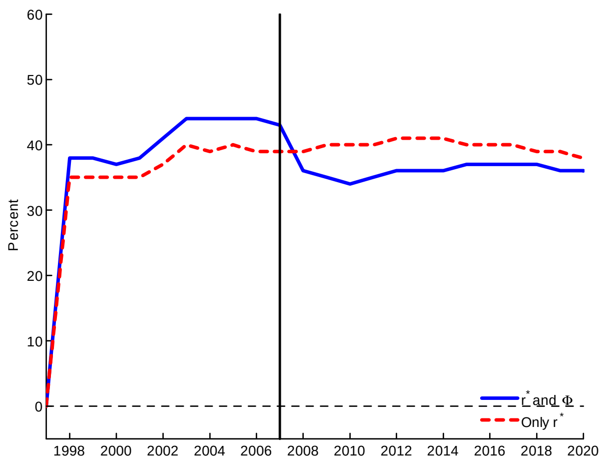


B. LTV (ϕ_t)

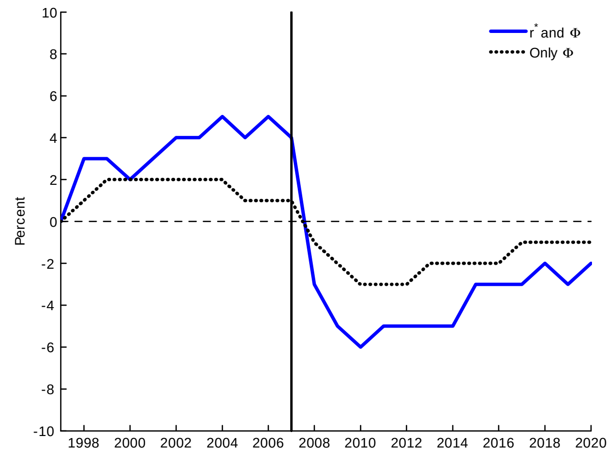


Case $r_T^* = 1.5\%$

C. Mortgage Rates (r_t^*)

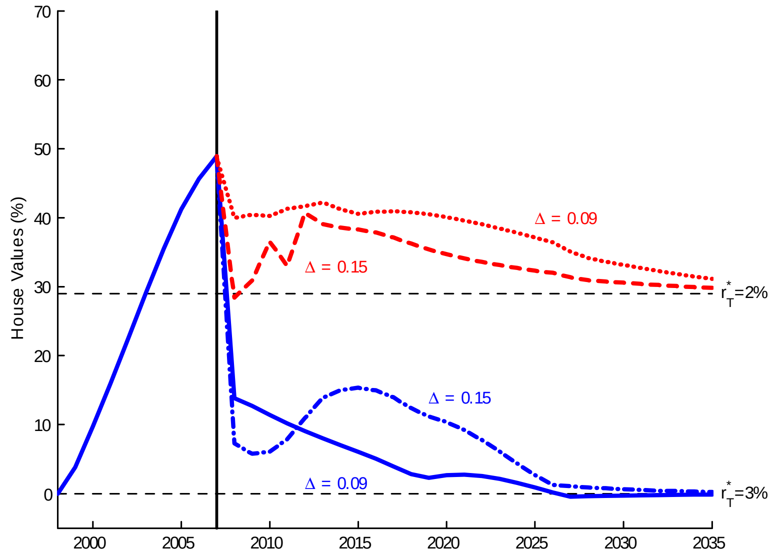


D. LTV (ϕ_t)



Source: Model-simulated data.

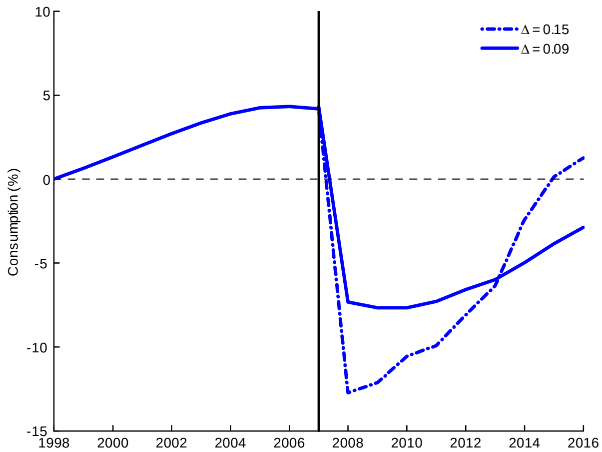
Figure 10: Housing Values with Shocks to Expectations



Source: Model-simulated data.

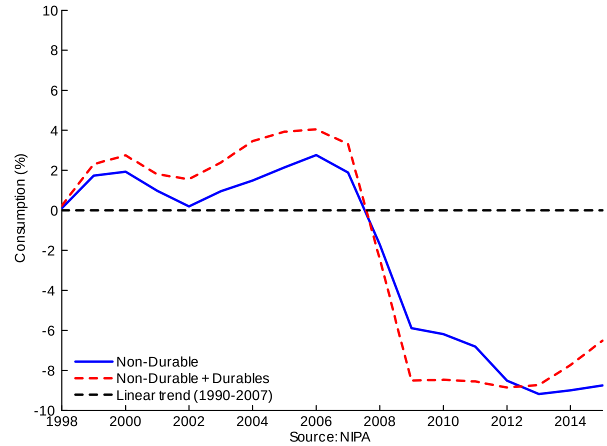
Figure 11: Macroeconomic Aggregates

Model: Consumption (C_t)



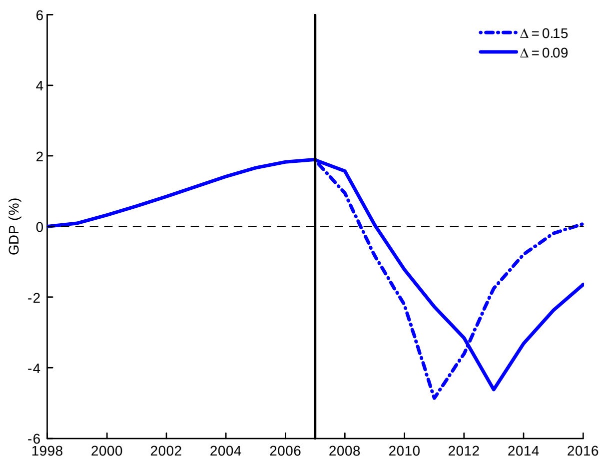
Source: Model-simulated data

Data: Consumption



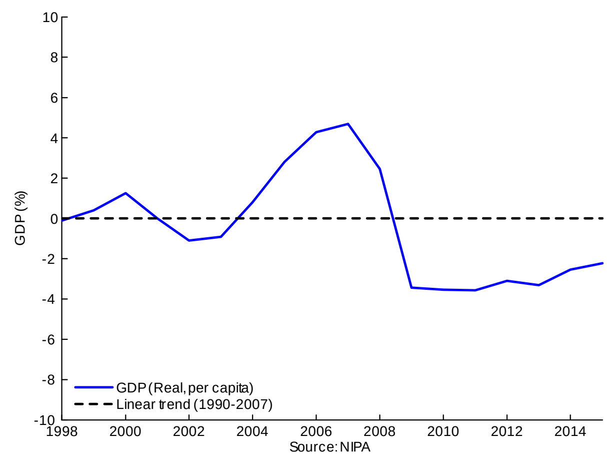
Source: BEA

Goods Production (Y_t)



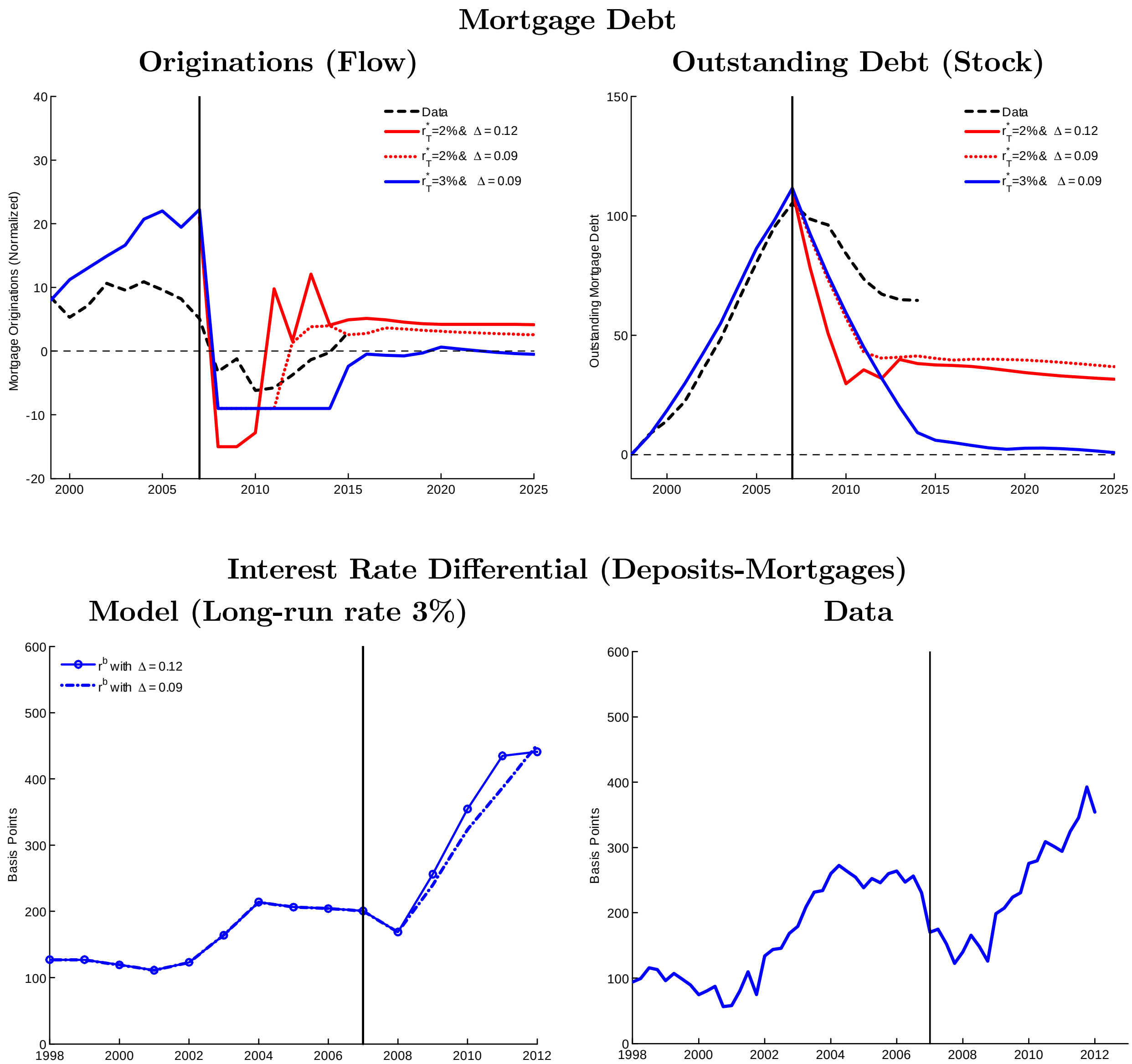
Source: Model-simulated data

Data: GDP



Source: BEA

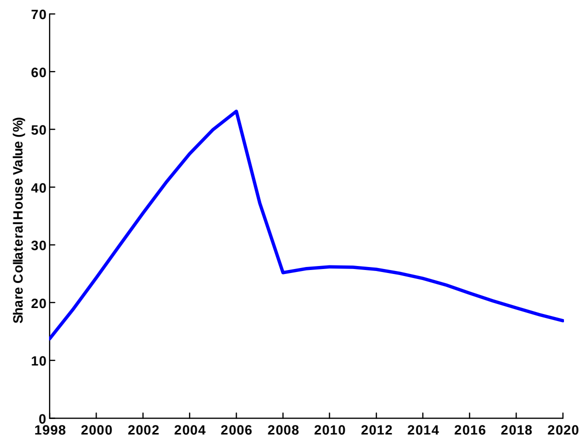
Figure 12: Housing Finance, Mortgage Debt and Interest Rates



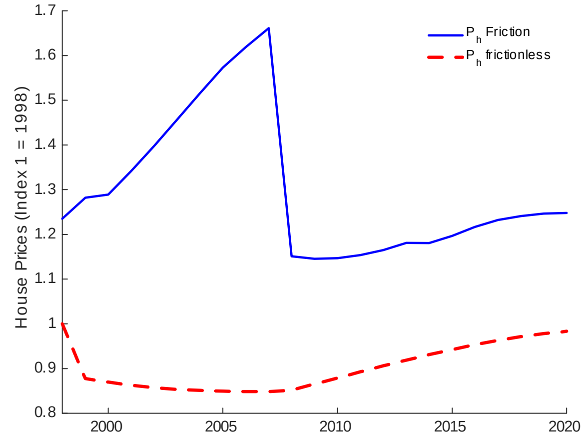
Source: Flow of Funds and authors' calculations.

Figure 13: House Prices, Rents, and Frictions

House Values



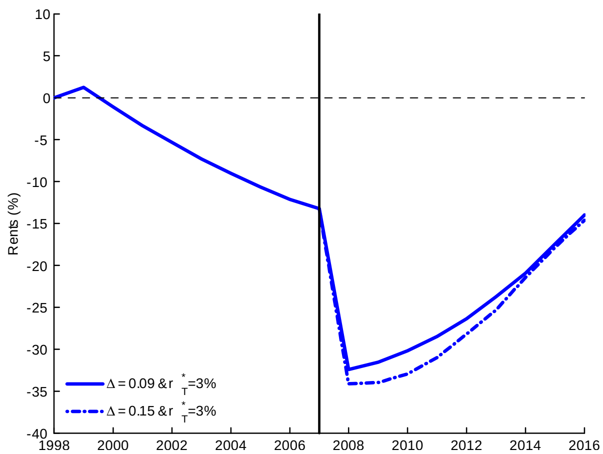
House Prices



Source: Authors' calculations.

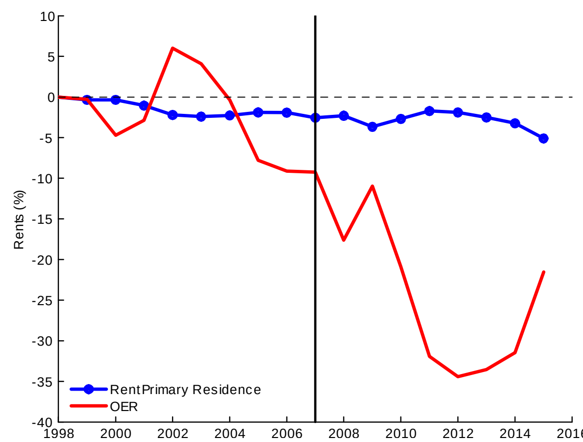
Rents (R_t^h)

Model



Source: Model-simulated data

Data



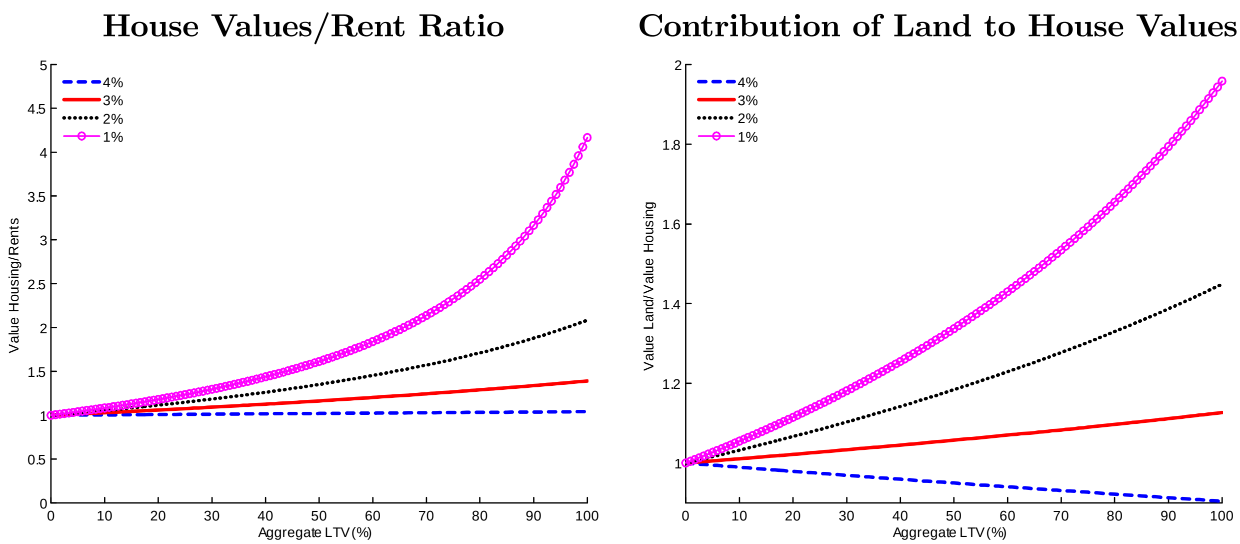
Source: Bureau of Labor Statistics (BLS)

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-to-rent ratio in the calibrated economy for different levels of leverage (LTV) 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 ($\varepsilon_{c,h} = 0.5$)



As discussed in the paper, the model generates an increase in house values relative to rents. However, for large values of the mortgage rate relative to $r^d - r^*$, the decline in house prices is entirely driven by the "income effect" that make consumption decrease. As a result, the price-to-rent ratio is constant. The "income effect" is mitigated as the mortgage rates decline relative to other assets.

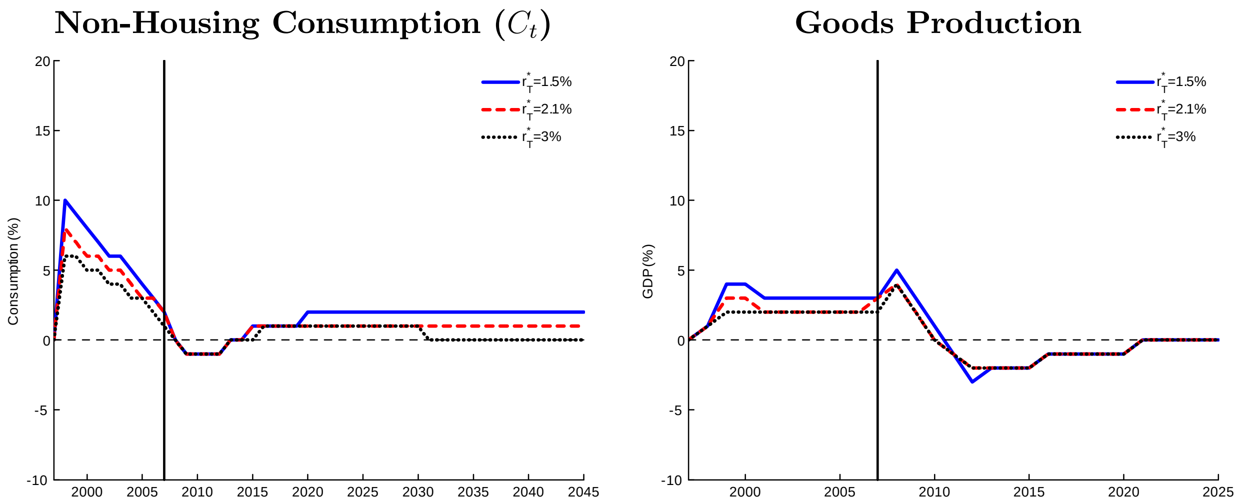
The model also captures the importance of land on house values. For the baseline calibration, the model suggests that with high mortgage rates the adjustment to a relaxation of collateral constraints comes from the quantity of structures, whereas in the case of low mortgage rates it comes from the value of land as suggested by Davis and Heatcote (2006).[43]

9.2 Appendix B: Perfect Foresight: Macroeconomic Aggregates

Here we report the level of macroeconomic aggregates in the perfect foresight case.

[43] The degree of complementarity between consumption and housing has important effects on the equilibrium composition of house values. Qualitatively the effects are similar for higher elastiticities of substitution, but quantitatively the effects are weaken. These different cases are analyzed in an Appendix available upon request.

Figure B.1: Macroeconomic Aggregates



Source: Model-simulated data.

Even though changes in house prices can potentially generate large income effects, the model implies that non-housing quantities do not move much because of the complementarity between housing and non-housing consumption implied by our calibration.[44] The dynamics of the macroeconomic variables is consistent with the evidence from Section 3.

Given the perfect foresight nature of the experiments, the magnitude of the initial increase in non-housing consumption depends on the size of the long-run income effect. In the case where housing finance conditions revert to the baseline case, consumption increases on impact 5 percent. The initial jump is responsible for the temporary increase in rental cost observed in Figure 8. As the quantity of services increases as collateral becomes more valuable and non-housing consumption declines resulting in a decrease of rents. The response on output is driven by non-residential investment and the desire to smooth the income effects associated to the change in housing finance. In the simulations, the housing boom generates very modest increase in economic activity, but the reversal generates a non-trivial decline in output. As shown in Section 5, the long-run properties of output are not determined by conditions in housing finance and the different simulations converge to the same level of production, $Y^* = C^* + \delta_s S^* + r_L^* \phi V^*$.

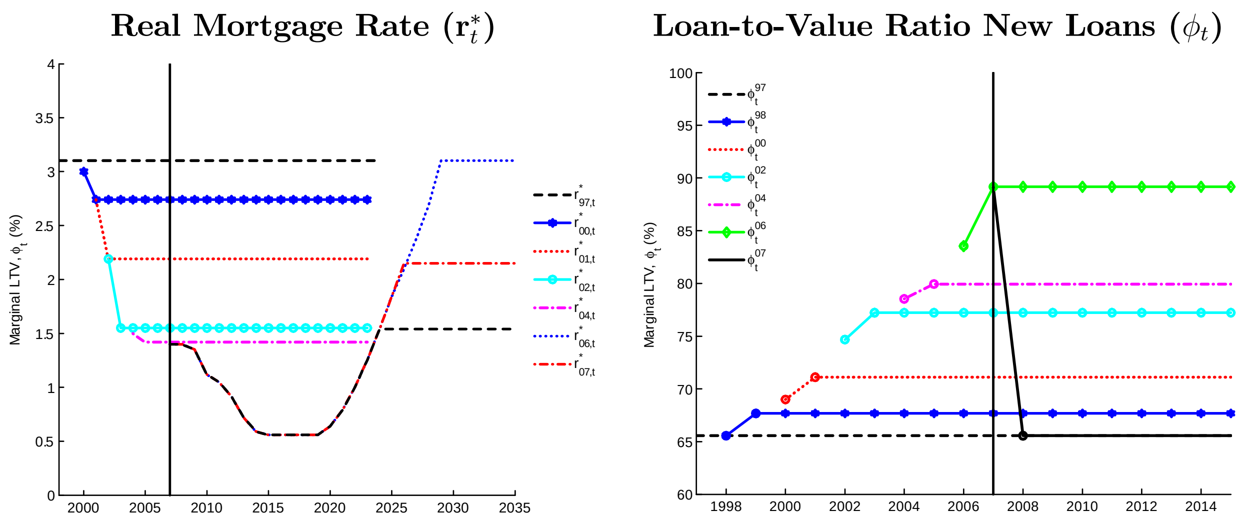
9.3 Appendix C: Shocks to Expectations

9.3.1 Timing of News about Financial Variables

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

[44] Decreasing the degree of complementarity between non-housing and housing consumption generates more movements on the quantities and less on the prices.

Figure C.1: Time Path of Financial Variables



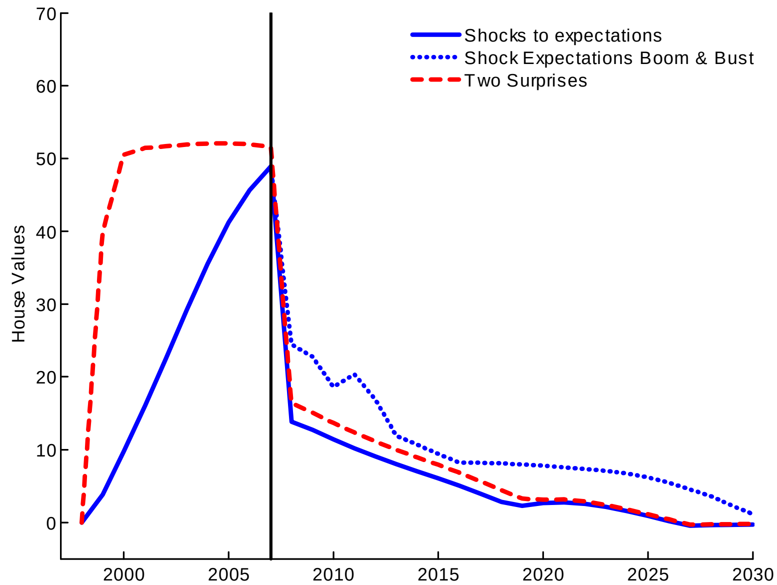
Source: Authors' calculations.

9.3.2 Sensitivity Analysis: The Timing of News about Financial Variables

This Appendix explores how sensitive are house values to the particular path of shocks to expectations. The next two experiments are designed to illustrate the relative importance of the timing of arrival of news (i.e. period of low mortgage rates and easy credit) from the regime switch (i.e., transition between relaxed to tight conditions in housing finance). In the experiments in Section 6.5., households face shocks to expectations during the boom, but face a perfect foresight adjustment after 2007. In the first experiment in this sensitivity section, the later assumption is relaxed and the information after 2007 arrives slowly. In the second sensitivity experiment, households receives two surprises or shocks to expectations. The first shock (the boom) arrives in 1998 and delivers a path of mortgage rates and LTV constraints consistent with the observed until 2007. Households assume that mortgage rates and LTV constraints from 2007 will be the new long-run level, $r^*_{07,t} = r^*_{07}$ and $\theta_{07,t} = \theta_{07}$ for all t. The second shock (the bust) arrives as a surprise and agents observe the new path as describe in Figure 10 after the year 2007. These two experiments are computed for the case that generates the large movement in house values ($r^*_L = 0.032$, and $\triangle = 0.09$). Figure C.2.

compares these two experiments with the baseline case in Section 6.5.

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



Source: Model-simulated data.

For the case of two surprises (boom and bust shocks), the size of the appreciation of house values depends on the expectations about how persistent is the easing of housing finance conditions. When households see that the reduction in mortgage rates and the relaxation of LTV constraints is permanent, house values respond on impact as in the perfect foresight case. The magnitude of the increase by 2007 is essentially the same as in the baseline case with continuous shocks to expectations. The experiment with two surprises shows that the slow arrival of news affects the timing of the increase, but does not affect the overall increase in house values. The key distinction relative to the perfect foresight case is whether agents can predict the reversal. When they cannot anticipate the reversal, house values increase about 50 percent whereas in the perfect foresight case, discussed in Figure 8, the increase is 25 percent.

Whether one uses multiple shocks to expectations or simply two surprises the model assigns to information around 50 percent of the contribution to the appreciation of house values.

In this model house values are comprised by land and physical structures, however, the dynamic adjustment of house values is relatively fast as agents can capitalize the gains by borrowing in the mortgage market. The predicted increase is roughly consistent with the steady state calculations presented in Figure 5a. A simultaneous relaxation of the LTV constraint and a decrease in the interest rate predicts a long-run increase in house values of 50 percent. This indicates that under the assumption that agents perceive the change in credit conditions to be permanent, the steady state calculations provide a good indication of the magnitude of increase in house values. However, if the agents predict that the change in credit conditions is temporary, then, the steady state calculations are too optimistic.

The other experiment that evaluates the perfect foresight assumption after 2007 shows that the decline in house values appears to be less sensitive to the arrival of information during the bust. The model indicates that when the reversal of credit conditions is slowly reveal to the agents, the tightening of collateral constraints has a less dramatic effect in house prices. In the baseline case with information shocks, households face a tightening of LTV constraints and the anticipation of future increases of mortgage rates after 2020. The anticipation of high mortgage rates in the future generates a decline in consumption that drives down house values. When households do not anticipate the future increase in mortgage rates, the decline in house values is less severe.

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:

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

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

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

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

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:

$$\lim_{S \to 0} V^1(S, \phi, r^*) = 0, \ \lim_{S \to \infty} V^1(S, \phi, r^*) = \infty, \ V^1_S > 0, \ V^1_{\phi} > 0, \ V^1_{r^*} < 0$$

$$\lim_{S \to 0} V^2(S, \phi, r^*) = \frac{Y}{\phi r^*}, \ \exists S^H(\phi, r^*), \text{ such that } V^1(S^H, \phi, r^*) = 0 \text{ and}$$

$$V^2_S < 0, \, V^2_{r^*} < 0.$$

Given the continuity of $V^1(S, \phi, r^*)$ and $V^2(S, \phi, r^*)$ and their monotonicity, there is a unique point in (V, S) at which they intersect, and this result holds even at the boundary when

$r^* = r^d$ and $\phi \in \{0, 1\}$. Given this point, there are unique values of c and p^ℓ that satisfy equations (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 $r^* \leq r^d$ and this, in turn, implies that

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

and, hence, that $\partial S / \partial r^* \leq 0$. 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

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

It follows that if 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.