Housing Finance and the Boom-Bust in the U.S. Housing Market*

Carlos Garriga† Aaron Hedlund‡

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Abstract

This paper analyzes the role of the housing finance during the 2000s housing boom-bust in the U.S. using a quantitative macroeconomic model with housing market search frictions and long-term mortgages with default option. In the model, the housing boom is fueled by easy credit conditions in the mortgage market that generate sizable increases in homeownership, refinancing activity, but modest effects on aggregate consumption. While the form of housing finance (adjustable rate vs. fixed rate mortgages) is not very important during the housing boom, it matters for the speed of the recovery. When borrowers use ARMs, their consumption during bust periods is more sensitive to changes in the interest rate. The model also rationalizes the asymmetric behavior of consumption—namely, that it is more sensitive to house price declines than increases.

Keywords: Housing; Consumption; Liquidity; Debt; Great Recession
JEL Classification Numbers: D31, D83, E21, E22, G11, G12, G21

1 Introduction

Between 2002 and 2009, real house prices in the United States soared over 50 percent before collapsing. The pattern of homeownership followed a very similar pattern, with a large number of households entering the housing market during the boom and exiting during the bust. This increase in participation was fueled by easy credit conditions in the mortgage market, those also allowed exiting homeowners to refinance their mortgage and extract home equity. As a result, credit conditions not only affected new homebuyers, but also existing

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*The views expressed are those of the authors and not necessarily of the Federal Reserve Bank of St. Louis or the Federal Reserve System.
†Federal Reserve Bank of St. Louis, carlos.garriga@stls.frb.org
‡University of Missouri, hedlunda@missouri.edu.
buyers as suggested by Greenspan and Kennedy (2007). From a macroeconomic perspective, the build-up of mortgage debt followed by the decline of house values might have been an important driver of the slow recovery of the U.S. economy, as employment declined and homeowners had to adjust their balance sheets. Some of these adjustments came via refinancing, but also mortgage default.

While there is still not clear what made this experience different from the traditional business cycle, it seems clear that housing markets and mortgage debt have been important contributors of the recent macroeconomic performance, not only in the United States, but in several countries in the European Union.

This paper explores the contribution of housing finance driving the dynamics of house prices and homeownership during the boom-bust episode. The importance of housing is evaluated using a two-sector economy general equilibrium where goods and consumption are produced. There is a continuum of individuals that in the tradition of models with incomplete markets face uninsurable income risk. Housing is provides service flows, but is an investment good that can be financed using a long-term mortgage loan with a default option. Households can refinance their mortgage and withdraw home equity but this is costly. The housing market is subject to a trading friction, and as a result, the liquidity properties of the housing stock are endogenously determined. This feature allows capturing extreme liquidity (or very low time in the market) during the peak of the housing market, and the illiquidity during the Great Recession generating an asymmetry between boom and bust.

The baseline version of the model is calibrated to replicate key features of the United States economy prior to the housing (1998). The calibration puts heavy emphasis on matching key housing moments related to sales, time on the market, and foreclosures, but also important dimensions of the joint distribution of assets, housing wealth, and mortgage debt. To simulate the boom and bust, the baseline model is exposed to two series of unanticipated shocks. The initial shock displays easing in credit conditions in the mortgage market. Agents perceive these conditions as permanent, but they are again surprise by a reversal in 2007. Afterwards, the agents face a perfect foresight path.

The model can rationalize the performance of the housing market during the boom and
the bust replicating the dynamics and magnitude of house prices, home ownership rates, housing defaults, and endogenous housing liquidity measured in terms of time-on-the-market (TOM). Analyzing this particular episode through the lens of the model provide some important lessons in terms of the quantitative importance of the various mechanism at play.

During the housing boom, the low mortgage rates, access to home equity and the ability to collateralize made homes a very attractive asset for many households that previously rented. Improvements in the mortgage market (i.e., lower mortgage rates and downpayment limits) drive all the income savings into housing as opposed to consumption. The collapse of the housing market wiped out the home equity of many homeowners, but also reduced the liquidity properties of the house. As a result, a significant number of households exited the owner-occupied housing market, via selling or defaulting, and had to adjust their consumption expenditures. Housing has favorable risk-sharing benefits in good times by allowing owners to extract equity through refinancing or selling, but it reverses when home equity and liquidity evaporate. This mechanism is the main driver of the asymmetric behavior of aggregate consumption dynamics, and it matches the consumption elasticity to house price movements as estimated by Mian, Rao and Sufi (2013).

1.1 Related Literature

There is a growing literature that emphasizes the connection between the housing market and the macroeconomy. Some examples include Iacoviello (2005), Davis and Heathcote (2005), Leamer (2007). An extensive summary of the literature is provided by Davis and Van Nieuwerburgh (2015) and Piazessi and Schneider (2016). While these papers measure the contribution of housing to the traditional business cycle, none of them specifically addresses the episode of the Great Recession.

One of the main challenges to understand this episode was the dramatic boom-bust in valuation of the housing stock and leverage cycle of mortgage debt. With this regard, traditional macroeconomic models of housing have serious challenges to replicate the observed patterns of prices and quantities during this episode. As a result, the majority of the research on the Great Recession is making advances by analyzing different aspects of this event.

To understand the dynamics of house prices during the boom and the bust Garriga,
Manuelli, and Peralta-Alva (2012) develop a stylized macroeconomic model of market segmentation that generates sizable movement in house values, about 50 percent, driven by changes in housing finance. In their economy, the collapse of house prices, inducing a large and persistent recession through the deleveraging process and decline in non-housing consumption. This paper shares similar features in the process of engineering a housing crisis as unanticipated set of events, but the mechanisms are different allow the intensive and extensive margin of homeownership are considered. In addition, homeowners can choose to deleverage by repaying the loan or default. The choice of deleverage has important implications for the path the consumption of the homeowners during the boom and the bust.

One can interpret the decline in house prices as a shock to households net worth. There is also an extensive literature that analyzes the response of consumption to negative shocks in the balance sheet or income. For example, Iacoviello and Pavan (2013) argue that a tightening of households budget, due to the drop in real estate wealth, can generate a sharp decline in aggregate consumption. Huo and Ros-Rull (2016) also analyze this issue in an economy with a continuum of agents and frictions on the goods market. In their economy goods are produced in a market with frictions and as a result, a negative wealth effects effectively reduces aggregate demand generating a significant decline in consumption and output. However, households can readjust their portfolios instantly without incurring a cost and the houses not subject to any form of transaction costs.

To amplify the response to shocks recently Kaplan and Violante (2014) have argued that in the presence of illiquid assets, the response of consumption to unanticipated shocks can be substantially larger. When households have a substantial fraction of their wealth tied up in an illiquid asset, they behave as wealthy hand-to-mouth agents with relatively high marginal propensities to consume. This sensitivity affects income shocks but also shocks to interest rate as discuss by Kaplan, Moll and Violante (2016). The notion of liquidity in these models is not tight to the macroeconomic performance, rather exogenous transaction costs. In this paper, a decline in the house price endogenously reduces the liquidity properties of some assets, in this case homes. This mechanism significantly amplifies the response of consumption to house price shocks.

There is an important literature that explores the increase in foreclosure dynamics during
the Great Recession. To simplify the problem a number of papers consider an exogenous change in house prices to analyze the dynamics of defaults (i.e. Such as Guler (2014), Corbae and Quintin (2014), Campbell and Cocco (2014), and Hatchondo et. al. (2014)). Other papers endogenize both Garriga and Schlagenghauf (2009), Chatterjee and Eyigungor (2014), Arsland, Guler, and Temel (2015), but housing liquidity is exogenous.

The heterogeneity in the model has clear testable data implications. The ability of the model to match the empirical counterparts as suggested by the works of Mian, Rao, and Sufi (2013), Mian and Sufi (2014), Petev, Pistaferri, and Eksten (2011), and Parker and Vissing-Jorgensen (2009) among other is discussed in the results section.

2 The Model

2.1 Households

Households are infinitely lived and have preferences over consumption $c$ and housing services $c_h$. Agents obtain housing services either as homeowners or apartment dwellers. Apartment dwellers, or “renters,” purchase apartment space $a \leq \bar{a}$ and consume $c_h = a$ each period at a cost of $r_a$ per unit. Agents become homeowners by purchasing a house $h \in H$ that generates $c_h = h$ housing services each period. The housing market is physically segmented, i.e. $\bar{a} < h$. In other words, large units are only available for purchase.\footnote{This segmentation is consistent with the empirical evidence in the U.S. showing that the average rental unit is approximately half the size of the average owner-occupied unit.} Owners are not permitted to possess multiple houses or to have tenants.

Households supply a stochastic labor endowment $\epsilon \cdot s$ to the labor market. The persistent component $s \in S$ follows a Markov chain $\pi_s(s'|s)$, and households draw the transitory $e \in E \subset \mathbb{R}_+$ from the distribution $F(e)$.

2.2 Technology

The economy has a production sector for consumption goods and for houses. In the consumption sector, goods are produced according to a linear technology using labor, $Y_c = A_c N_c$. 
A linear reversible technology converts consumption into apartment services at the rate $A_a$. Thus, apartment services have price $r_a = 1/A_a$.²

Builders construct new houses using land $L$, structures $S_h$, and labor $N_h$ using a constant returns to scale technology $Y_h = F_h(L, S_h, N_h)$. Builders purchase structures $S_h$ from the consumption sector, and as in Favilukis, Ludvigson and Van Nieuwerburgh (2016), the government supplies new permits $L > 0$ each period and consumes the revenues. Houses depreciate with probability $\delta_h$, and there are no construction delays. Thus, the end of period stock of housing $H$ follows

$$H' = (1 - \delta_h)H + Y'_h.$$  

### 2.3 Housing Market

Buyers and sellers of houses trade in a decentralized housing market and direct their search by house size and transaction price. Sellers of house $h \in H$ choose a list price $p_s$ and face an equilibrium trade-off between higher prices and longer expected time on the market. Buyers who direct their search to house $h$ and price $p_b$ face an equilibrium trade-off between lower prices and longer expected time searching. **Housing illiquidity** is reflected by the trade-off between price and trading probability and the presence of failures to trade.

In general, the presence of heterogeneous buyers and sellers (in terms of assets, income, and debt) with directed search creates an intractable dynamic sorting problem. To circumvent this issue, market makers, referred to here as real estate brokers, are introduced as a modeling device. These brokers intermediate trades by first matching with sellers, purchasing their houses, and then matching with buyers who purchase the houses. Brokers can frictionlessly trade houses with each other at cost $p(h) = ph$ and purchase newly built housing.³ Brokers do not have the ability to speculate against housing dynamics, as they are not permitted to hold onto housing inventories. The only inventories are houses that owners and banks fail to sell.

²Sommer, Sullivan and Verbrugge (2013) and Davis, Lehnert and Martin (2008) report that rents have remained flat over the past 30 years, independent of house price swings.

³Here, brokers trade discrete houses with buyers and sellers but divisible units of housing stock with each other. A generalized case would segment by $h$, in which case $p(h) = p_nh$. 

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2.3.1 Directed Search in the Housing Market

Buyers direct their search by choosing a submarket \((p_b, h) \in \mathbb{R}_+ \times H\). With probability \(\eta_b(\theta_b(p_b, h))\), the buyer matches with and purchases house \(h \in H\) from a broker at cost \(p_b\), where \(\theta_b(p_b, h)\) is the ratio of brokers to buyers, i.e. the market tightness. Each period, sellers of house \(h \in H\) choose a list price \(p_s \geq 0\) and enter selling submarket \((p_s, h)\). With probability \(\eta_s(\theta_s(p_s, h))\), the seller matches with and sells their house to a broker for \(p_s\), where \(\theta_s\) is the ratio of brokers to sellers. To prevent excessive time on the market, owners that try and fail to sell pay a small utility cost \(\xi\).

Brokers find buyers and sellers with probabilities \(\alpha_b\) and \(\alpha_s\), respectively, which are both decreasing functions of the market tightness. Brokers incur entry costs each period of \(\kappa_b h\) and \(\kappa_s h\) in the buying and selling submarkets, respectively. On both sides of the market, all participants take submarket tightnesses as given.

The profit maximization conditions of the real estate brokers (some of whom meet with sellers, and some of whom meet with buyers) are

\[
\begin{align*}
\kappa_b h &\geq \alpha_b(\theta_b(p_b, h)) \left( p_b - p(h) \right) \\
\kappa_s h &\geq \alpha_s(\theta_s(p_s, h)) \left( p(h) - p_s \right)
\end{align*}
\]

where the conditions hold with equality in active submarkets.

The revenue to a broker that purchases a house from a seller is \(p(h) - p_s\). Therefore, brokers continue to enter submarket \((p_s, h)\) until the cost \(\kappa_s h\) exceeds the expected revenue. An analogous process occurs for buyer-brokers.

2.3.2 Block Recursivity

In Menzio and Shi (2010), block recursivity completely eliminates the need to keep track of the cross-sectional distribution when solving for equilibrium labor market dynamics. However, in this framework with housing, the presence of brokers as market makers simplifies the dynamic sorting problem but still leaves some dependence of market tightnesses \(\theta_s\) and \(\theta_b\) on the distribution \(\Phi\) of income, assets, and debt, i.e. \(\theta_b(p_b, h; \Phi)\) and \(\theta_s(p_s, h; \Phi)\). With
brokers, however, market tightnesses only depends on the distribution through its impact on $p$, i.e. $p(h)(\Phi) = p(\Phi)h$.

$$\theta_b(p_b, h; \Phi) = \alpha_b^{-1}\left(\frac{\kappa_b h}{p_b - p(h)(\Phi)}\right)$$

$$\theta_s(p_s, h; \Phi) = \alpha_s^{-1}\left(\frac{\kappa_s h}{p(h)(\Phi) - p_s}\right)$$

Absent the brokers, market tightnesses would depend nonparametrically on $\Phi$, and households would need to forecast the evolution of each tightness independently. Thus, block recursivity simplifies the problem to solving for the dynamics of $p(h)(\Phi)$ and substituting into (3) – (4), all without altering the underlying economics of household buying and selling behavior.

## 2.4 Financial Markets

Households save using one period bonds which trade in open financial markets at an exogenous risk-free rate $r$. In addition, homeowners can borrow in the form of long term, fixed rate mortgage contracts with a default option where housing serves as collateral.\(^4\)

### 2.4.1 Mortgages

Banks price default risk into new mortgage contracts. As such, this economy features credit illiquidity. Specifically, when a borrower with bonds $b'$, house $h$, and persistent labor efficiency $s$ takes out a mortgage of size $m'$ at rate $r_m$, the bank delivers $q^0_m((r_m, m'), b', h, s)m'$ units of the composite consumption good to the borrower at origination, where $r_m$ remains fixed for the duration of the loan. Mortgages in the model stand in for all forms of mortgage debt (beyond 30-year first liens) by not having a predefined maturity date, and as a result, amortization is endogenous. Homeowners can prepay without penalty but must pay a cost to extract equity through refinancing.

Banks incur an origination cost $\zeta$ and servicing costs $\phi$ over the life of each mortgage. During repayment, banks have exposure to two risks. First, if the house depreciates with

\(^4\)Section 4.2.1 explores the implications of fixed vs. adjustable rate mortgages.
probability $\delta_h$, the bank must forgive the loan.\footnote{This assumption prevents the model from generating artificially high foreclosure rates.} Second, homeowners can default in a given period by not making a payment. In this situation, the lender forecloses on the borrower with probability $\varphi$ and repossesses the house. With probability $1 - \varphi$, the lender ignores the skipped payment until the next payment comes due.

Perfect competition assures zero ex-ante profits loan-by-loan. Banks price all individual default risk into $q_m^0$ at origination, but the fixed rate $r_m$ reflects depreciation risk, servicing costs, and long-term financing costs $r^*$, which depend on the future path $r_t$ of the short term rate. A borrower with contract $(\tau_m, m)$ that chooses a new balance of $m' > m$ pays off $m$ and refinances to a new, re-priced loan of balance $m'$. Otherwise, borrowers with debt $m$ choose a payment $l \geq \frac{r_m}{1 + r_m} m$, and their debt evolves according to $m' = (m - l)(1 + r_m)$. The fixed rate satisfies

$$1 + r_m = \left( \frac{1 + \phi}{1 - \delta_h} \right) \frac{1 + r^*}{\text{long term risk-free rate}}$$

Mortgage prices satisfy the following recursive relationship:

$$q_m^0((\tau_m, m'), b', h, s)m' = \frac{1 - \delta_h}{(1 + \zeta)(1 + \phi)(1 + r)} \mathbb{E} \left[ \eta_s(\theta_s(p_s', h))m' + \left[ 1 - \eta_s(\theta_s(p_s', h)) \right] \right]$$

$$\times \left\{ \begin{array}{ll}
\begin{array}{l}
\text{sell + repay} \\
\text{no sale (do not try/fail)}
\end{array}
\end{array} \right\}$$

$$\left\{ \begin{array}{ll}
\begin{array}{l}
\text{default + repossession} \\
\text{no repossession}
\end{array}
\end{array} \right\}$$

$$\times \left\{ \begin{array}{ll}
\begin{array}{l}
\text{continuation value of current } m' \\
\text{continuation value of new } m''
\end{array}
\end{array} \right\}$$

$$+ (1 - d') \begin{array}{l}
m' \mathbf{1}_{[\text{Refi}]} + \mathbf{1}_{[\text{No Refi}]}
\end{array}$$

$$\left\{ \begin{array}{ll}
\begin{array}{l}
l - \frac{\phi}{1 + r_m} m'' \\
payment - servicing costs
\end{array}
\end{array} \right\}$$

$$+ (1 + \zeta)(1 + \phi)q_m^0((\tau_m, m''), b'', h, s')m''$$

where $p_s', d', b'', l$, and $m''$ are the policies for list price, default, bonds, payment, and debt, respectively, and $J_{REO}$ is the value of repossessed housing.

The long term nature of the contract is apparent in the continuation values, although the refinance option shortens the effective duration. Default risk depresses mortgage prices to the extent that $J_{REO}(h)$ falls below $m'$ after foreclosure, and because delinquent borrowers are not immediately evicted. Lastly, illiquidity from selling delays increases the risk of default.
2.4.2 Foreclosure Process

Banks sell repossessed houses (REO properties) in the decentralized housing market and lose a fraction \( \chi \) of proceeds as the cost of selling foreclosed houses. Banks absorb losses but must pass profits to the borrower.

The value to a lender in repossessing a house \( h \) is

\[
J_{REO}(h) = R_{REO}(h) - \gamma p(h) + \frac{1 - \delta_h}{1 + r} J_{REO}(h) - \delta h
\]

where \( \gamma \) represents holding costs (maintenance, property taxes, etc.).

The forgiveness of debt from foreclosure entails other penalties besides the repossession of the house. Specifically, defaulters receive a flag \( f = 1 \) on their credit record that shuts them out of the mortgage market. Flags persist to the next period with probability \( \gamma_f \in (0, 1) \).

2.5 Household Problem

Each period contains three subperiods. First, households learn their labor efficiency \( e \cdot s \) and their flag \( f \in \{0, 1\} \). An owner’s state is cash at hand \( y \), mortgage rate \( r_m \) and balance \( m \), house \( h \), and labor shock \( s \). A renter’s state is \( (y, s, f) \). The household problem is solved backwards:

2.5.1 Subperiod 3: Consumption/Saving

End-of-period owner expenditures consist of consumption, holdings costs, bond purchases, and mortgage payments. Household resources come from labor income, savings, and equity extraction. Owners with good credit \( (f = 0) \) who refinance have value function
\[ V^R_{own}(y, (r_m, m), h, s, 0) = \max_{c', b', c \geq 0} \left[ u(c, h) + \beta \mathbb{E} \left[ (1 - \delta_h)(W_{own} + R_{sell})(y', (r_m, m'), h, s', 0) \right. \\
+ \delta_h(V_{rent} + R_{buy})(y', s', 0) \right] \]

subject to
\[ c + \gamma p(h) + q_b b' + m \leq y + q^0_m((r_m, m'), b', h, s)m' \]
\[ q^0_m((r_m, m'), b', h, s)m' \leq \varphi p(h) \]
\[ y' = we's' + b' \]

(8)

where \( \varphi \) is the collateral constraint for new loans, \( q^0_m \) reflects the mortgage re-pricing, and the updated rate is \( r_m \). The terms \( W_{own} + R_{sell} \) and \( V_{rent} + R_{buy} \) are subperiod 1 utilities for owners and renters, respectively.

Owners who make a payment \( l \) on their existing mortgage solve

\[ V^C_{own}(y, (r_m, m), h, s, 0) = \max_{l, b', c \geq 0} \left[ u(c, h) + \beta \mathbb{E} \left[ (1 - \delta_h)(W_{own} + R_{sell})(y', (r_m, m'), h, s', 0) \right. \\
+ \delta_h(V_{rent} + R_{buy})(y', s', 0) \right] \]

subject to
\[ c + \gamma p(h) + q_b b' + l \leq y \]
\[ l \geq \frac{\bar{r}_m m}{1 + \bar{r}_m} \]
\[ m' = (m - l)(1 + \bar{r}_m) \]
\[ y' = we's' + b' \]

(9)

Borrowers must make at least an interest payment, and any larger payment reduces principal \( m' \). Owners with bad credit solve a similar problem but lack access to mortgages. Renters face the following constraint: \( c + r_a a + q_b b' \leq y \). Appendix A gives their detailed optimization problem.
2.5.2 Subperiod 2: House Buying

Buyers direct their search by choosing a submarket \((p_b, h)\). Buyers with bad credit are bound by the constraint \(y - p_b \geq 0\), while buyers with good credit are bound by \(y - p_b \geq y(s, (h, 1))\), where \(y < 0\) captures their ability to take out a mortgage in subperiod 3. The option value \(R_{buy}\) of buying is as follows:

\[
R_{buy}(y, s, 0) = \max\{0, \max_{h \in H, p_b \leq y} \eta_b(\theta_b(p_b, h)) [V_{own}(y - p_b, 0, h, s, 0) - V_{rent}(y, s, 0)]\} 
\]

(10)

\[
R_{buy}(y, s, 1) = \max\{0, \max_{h \in H, p_b \leq y} \eta_b(\theta_b(p_b, h)) [V_{own}(y - p_b, 0, h, s, 1) - V_{rent}(y, s, 1)]\} 
\]

(11)

2.5.3 Subperiod 1: Selling and Default Decisions

An owner deciding whether to default, refinance, or make a payment has utility

\[
W(y, (\tau_m, m), h, s, 0) = \max \{\varphi(V_{rent} + R_{buy})(y + \max\{0, J_{REO}(h) - m\}, s, 1) + (1 - \varphi)V_{own}^d(y, (\tau_m, m), h, s, 0), V_{own}(y, (\tau_m, m), h, s, 0)\} 
\]

(12)

where the value associated with defaulting but not being foreclosed on is

\[
V_{own}^d(y, (\tau_m, m), h, s, 0) = \max_{b', c \geq 0} u(c, h) + \beta \mathbb{E}
\left[
(1 - \delta_h)(W_{own} + R_{sell})(y', (\tau_m, m), h, s', 0) + \delta_h(V_{rent} + R_{buy})(y', s', 0)\right]
\]

subject to

\[
c + \gamma p(h) + q_b b' \leq y \\
y' = w e' s' + b'
\]

(13)

Owners of house \(h\) who wish to sell choose a list price \(p_s\). The option value \(R_{sell}\) of selling for an owner with good credit is

\[
R_{sell}(y, (\tau_m, m), h, s, 0) = \max\{0, \max_{p_s} \eta_s(\theta_s(p_s, h)) [(V_{rent} + R_{buy})(y + p_s - m, s, 0) - W_{own}(y, (\tau_m, m), h, s, 0)] + [1 - \eta_s(\theta_s(p_s, h))] (-\xi)\} \text{ subject to } y + p_s \geq m
\]

(14)

Debt overhang emerges when highly leveraged owners are forced to set high prices to pay off
their debt, thereby resulting in long selling delays.

2.5.4 Equilibrium

A stationary equilibrium is value/policy functions for households and banks; market tightness functions $\theta_s$ and $\theta_b$; prices $w$, $p_h$, $q_m^0$, $q_b$, and $r_a$; and stationary distributions $\Phi$ of households and $H_{REO}$ of REO housing stock that solve the relevant optimization problems and clear the markets for housing and factor inputs. Appendix A provides the detailed equilibrium conditions.

3 Parametrizing the Model

The model is calibrated to replicate key features of the United States economy during 2003 – 2005, prior to the Great Recession. The calibration puts heavy emphasis on matching key housing moments related to sales, time on the market, and foreclosures, as well as important dimensions of the joint distribution of assets, housing wealth, and mortgage debt.

3.1 Independent Parameters

The first set of parameters come from the literature or other external sources. On the household side, the labor efficiency process is adapted from Storesletten, Telmer and Yaron (2004) in the same way as done in Garriga and Hedlund (2016). In addition, households have constant relative risk aversion preferences with $\sigma = 2$ and CES period utility with an intratemporal elasticity of substitution of $\nu = 0.13$. The discount factor $\beta$ and weight $\omega$ on non-housing consumption are determined jointly.

In terms of production, total factor productivity is set to normalize annual earnings to 1. Housing construction is Cobb-Douglas with a structures share of $\alpha_s = 0.3$ and a land share of $\alpha = 0.33$, consistent with evidence from the Lincoln Institute of Land Policy. Meanwhile, housing depreciates at an annual rate of 1.4%, and the apartment technology $A_h$ is set to generate an annual rent-price ratio of 5%, consistent with Sommer et al. (2013).

Matching is Cobb-Douglas in the frictional housing market, and the joint calibration determines the entry costs, Cobb Douglas parameters, and disutility of attempting to sell.
Holding costs (maintenance, property taxes, etc.) are \( \eta = 0.007 \).

Pertaining to financial markets, the real risk-free rate is set to 2\%, the mortgage origination cost is 0.4\%, and the mortgage servicing cost \( \phi \) is set to bring the real mortgage rate to 5\%. Furthermore, the exogenous LTV limit is \( \vartheta = 1.25 \) (125\%), which makes it non-binding initially.\(^6\) Lastly, the persistence of bad credit flags is \( \gamma_f = 0.95 \), and the REO discount \( \chi \) is determined in the joint calibration.

### 3.2 Joint Calibration

The joint calibration determines the remaining parameters to match key aggregates, such as the homeownership rate, the value of gross housing wealth to income, median liquid assets, and the foreclosure rate. In addition, it is important that the model reasonably approximate the distribution of mortgage leverage, particularly at the upper end, as these homeowners are the most borrowing constrained and susceptible to shocks. Table 1 shows that the model successfully matches the targets and replicates other untargeted portfolio statistics from the 1998 Survey of Consumer Finances.

### 4 Results

This section seeks to understand the housing boom and bust during the 2000’s and the role of different features of housing finance in the U.S. In particular, what impact do changing downpayment constraints have on house prices, and what are the consequences of households having fixed rate vs. adjustable rate mortgages? This section also looks at the spillover of housing market activity into aggregate consumption, and it investigates how the efficacy of mortgage interventions depends on whether households have FRMs or ARMs.

#### 4.1 Generating the Housing Boom and Bust

To generate the housing boom, two shocks to the initial steady state are sufficient: a 5\% increase in total factor productivity and a fall in the real risk-free rate from 2\% to \(-1\%\),

Table 1: Model Calibration

<table>
<thead>
<tr>
<th>Description</th>
<th>Parameter</th>
<th>Value</th>
<th>Target</th>
<th>Model</th>
<th>Source/Reason</th>
</tr>
</thead>
<tbody>
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<td><strong>Calibration: Independent Parameters</strong></td>
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<td></td>
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<tr>
<td>Autocorrelation</td>
<td>$\rho$</td>
<td>0.952</td>
<td></td>
<td></td>
<td>Storesletten et al. (2004)</td>
</tr>
<tr>
<td>SD of Persistent Shock</td>
<td>$\sigma_\epsilon$</td>
<td>0.17</td>
<td></td>
<td></td>
<td>Storesletten et al. (2004)</td>
</tr>
<tr>
<td>SD of Transitory Shock</td>
<td>$\sigma_\epsilon$</td>
<td>0.49</td>
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<td></td>
<td>Storesletten et al. (2004)</td>
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<tr>
<td>Intratemp. Elas. of Subst.</td>
<td>$\nu$</td>
<td>0.13</td>
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<td>Flavin and Nakagawa (2008)</td>
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<tr>
<td>Risk Aversion</td>
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<td>2</td>
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<td>Structure Share</td>
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<td>Land Share</td>
<td>$\alpha_L$</td>
<td>33%</td>
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<td>Holding Costs</td>
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<td>Depreciation (Annual)</td>
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<td>1.4%</td>
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<tr>
<td>Rent-Price Ratio (Annual)</td>
<td>$r_h$</td>
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<td></td>
<td></td>
<td>Sommer et al. (2013)</td>
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<td>Risk-Free Rate (Annual)</td>
<td>$r$</td>
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<td>Federal Reserve Board</td>
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<td>Servicing Cost (Annual)</td>
<td>$\phi$</td>
<td>3.1%</td>
<td></td>
<td></td>
<td>5.0% Real Mortgage Rate</td>
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<td>Mortgage Origination Cost</td>
<td>$\zeta$</td>
<td>0.4%</td>
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<td>Maximum LTV</td>
<td>$\theta$</td>
<td>125%</td>
<td></td>
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<td>Fannie Mae</td>
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<td>Prob. of Repossession</td>
<td>$\varphi$</td>
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<td>2008 OCC Mortgage Metrics</td>
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<td>Credit Flag Persistence</td>
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<td>Fannie Mae</td>
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<td><strong>Calibration: Jointly Determined Parameters</strong></td>
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<td>Homeownership Rate</td>
<td>$\pi$</td>
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<td>66.7%</td>
<td>66.7%</td>
<td>Census</td>
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<td>Starter House Value</td>
<td>$h_1$</td>
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<td>1.75</td>
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<td>Housing Wealth (Owners)</td>
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<td>Median LTV</td>
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<td>0.9657</td>
<td>62.90%</td>
<td>63.38%</td>
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<td>Months of Supply*</td>
<td>$\xi$</td>
<td>0.0016</td>
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<td>5.32</td>
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<td>Avg. Buyer Search (Weeks)</td>
<td>$\gamma_b$</td>
<td>0.0940</td>
<td>10.00</td>
<td>10.04</td>
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<tr>
<td>Maximum Bid Premium</td>
<td>$\kappa_b$</td>
<td>0.0171</td>
<td>2.5%</td>
<td>2.5%</td>
<td>Gruber and Martin (2003)</td>
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<td>Maximum List Discount</td>
<td>$\kappa_s$</td>
<td>0.1029</td>
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<td>Foreclosure Discount</td>
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<td>0.0980</td>
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<td>21%</td>
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<td>0.6550</td>
<td>1.60%</td>
<td>1.61%</td>
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<td><strong>Model Fit</strong></td>
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<td>Borrowers with $LTV \geq 70%$</td>
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<td>Borrowers with $LTV \geq 90%$</td>
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<td>1998 SCF</td>
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<tr>
<td>Borrowers with $LTV \geq 95%$</td>
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<td></td>
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<td>1998 SCF</td>
</tr>
<tr>
<td>Median Owner Liq. Assets</td>
<td></td>
<td>0.25</td>
<td>0.23</td>
<td>1.00%</td>
<td>1998 SCF</td>
</tr>
</tbody>
</table>

*Months of supply is inventories divided by the sales rate and proxies for time on the market.
both perceived to be permanent. Five years into the boom, the bust is replicated using the combination of shocks described in Garriga and Hedlund (2016). In particular, the minimum downpayment increases to 10%, households experience an increase in downside labor market risk via a change in the labor efficiency transition matrix, and there is both a temporary increase in the risk-free rate from $-1\%$ to 3% and a temporary 5% decline in productivity.

Figure 1 shows the dynamics of house prices, time on the market, the foreclosure rate, homeownership, non-housing consumption, and median borrower leverage.

In response to these shocks, house prices jump by 45% before partially reverting as new housing construction increases the stock of housing. Similarly, consumption jumps rapidly, while the homeownership rate gradually rises.

4.1.1 Assessing The Importance of Credit Constraints

There has been some debate recently regarding the role of downpayment constraints in explaining house price booms. To assess their importance in this model, a counterfactual is run where the initial steady state is shocked in the same way as in the baseline while at the
same time households are forced to make a 20% downpayment. Every other exogenous shock for both the boom and the bust is left the same. As evident in figure 2, the economy with a tighter downpayment constraint exhibits a much smaller house price boom, and equally importantly, the bust in house prices and consumption is far smaller.

4.1.2 Asymmetric Balance Sheet Effects in the Boom and Bust

The boom and bust also provide insight into the nature and asymmetry of balance sheet effects. As shown in figure 3, the sensitivity of non-housing consumption to house prices is much higher during the bust than during the boom.

4.2 The Role of Housing Finance

Many commentators have pointed to the proliferation of alternative mortgage contracts as a primary cause for the foreclosure crisis. This section first addresses the impact of mortgage type—namely, fixed rate vs. adjustable rate loans—on macroeconomic dynamics during the recession and recovery. Second, the impact of adjustable rate vs. fixed rate mortgages on the macroeconomic efficacy of mortgage interventions is assessed.
Figure 3
Figure 4: The Great Recession with fixed rate and adjustable rate mortgages.

4.2.1 Dynamics with Fixed Rate vs. Adjustable Rate Mortgages

The United States is unique in that 30-year, fixed-rate loans are the predominant form of mortgage contract. From the perspective of the borrower, fixed rate mortgages (FRMs) provide insurance against interest rate hikes. Figure 4 shows the recessionary dynamics of house prices, foreclosures, homeownership, and consumption depending on whether all borrowers have fixed rate mortgages (baseline) or all borrowers have adjustable rate mortgages (ARMs). Recall that interest rates jump during the first two years of the recession simulation, corresponding to the tightening of monetary policy in 2006 and 2007. In the economy with fixed rate mortgages, existing homeowners are shielded from the increase in rates. However, with adjustable rates, homeowners experience a sudden jump in mortgage financing costs. When combined with the tightening in borrowing constraints and the deterioration in the labor market, the increase in rates causes a surge in foreclosures that far exceeds that observed in the economy with fixed rate mortgages. As a result, homeownership declines more dramatically with adjustable rate mortgages, and the declines in house prices and consumption are both magnified. However, the drop in consumption is not spread evenly across all households.

Figure 5 shows panel simulations of consumption by housing tenure, leverage, and default status. Unsurprisingly, the consumption drop for renters does not depend on whether the economy features fixed rate mortgages or adjustable rate mortgages. Furthermore, when one looks at all homeowners and those with considerable equity, consumption does not vary much based on mortgage type.
However, the bottom left panel reveals a striking 32% amplification for highly leveraged homeowners in the world with ARMs. Specifically, borrowers with FRMs and 90%+ leverage experience a 16% drop, whereas with ARMs, such borrowers cut their consumption by 21%. Mechanically, the more debt borrowers have, the more of an impact changes in interest rates have on budget constraints and, thus, on consumption. However, this effect is compounded by the greater difficulty highly leveraged homeowners face in smoothing shocks by quickly selling or accessing additional credit.

Lastly, the middle and right bottom panels show the different responses of consumption for non-defaulters and defaulters. For borrowers who do not default, their consumption drops by an additional 2 percentage points in the economy with adjustable rate mortgages and takes one year longer to recover. By contrast, consumption for borrowers who default is, quite intuitively, invariant to mortgage type.

### 4.3 Mortgage Interventions with FRMs and ARMs

In response to the Great Recession and short term rates hitting the zero lower bound, the Federal Reserve undertook an unprecedented series of “quantitative easing” interventions in financial markets to drive down long term interest rates and stimulate economic activity.
This section seeks to understand the macroeconomic consequences of quantitative easing (QE) on the macroeconomic behavior of the U.S. economy. In particular, can such a policy mitigate the contraction of credit from higher housing illiquidity and default risk? Can quantitative easing mitigate the decline in house prices? How important is the timing of the announcement of the policy, and what are the distributional consequences of quantitative easing?

From 2009 to 2011, real 30-year mortgage interest rates fell from 3% to under 1.5%. While this drop may be attributable to multiple factors, Krishnamurthy and Vissing-Jorgensen (2011) provide evidence that QE contributed significantly to the decline in long term rates. For the purposes of this section, QE is analyzed by reducing the mortgage servicing premium $\phi$ for five years to engineer a temporary, exogenous 1.5% drop in the spread between mortgage rates and the short term rate. Because the actual implementation of QE did not occur until almost 2009, the policy simulation does not institute QE until two years after the onset of the housing downturn. Furthermore, multiple scenarios are considered. In the first scenario, QE is implemented by complete surprise, whereas in the second scenario, QE is announced at the
beginning of the recession but implemented with the aforementioned delay. The economic response is analyzed with both fixed rate and adjustable rate mortgages.

As shown in figure 5, QE has a pronounced effect on house prices. When pre-announced, QE immediately causes house prices to jump by 4.3% relative to their baseline trough, thereby mitigating 14% of the overall decline even before the actual policy implementation. In the case of surprise QE, house prices immediately jump by over 6% and remain elevated as they converge to pre-crisis levels. Note that the fixed rate and adjustable rate economies exhibit similar house price responses to QE.

The response of the homeownership rate to QE differs dramatically by mortgage type, however. In the fixed rate economy, surprise QE has a negligible impact on the path of homeownership, and the pre-announcement of QE only modestly slows the decline in ownership. In the adjustable rate economy, though, homeownership recovers at a much more rapid pace after QE is implemented. Furthermore, in the pre-announcement case, the trough of homeownership is 3 percentage points higher than without the intervention. Note that the pre-announcement of QE blunts over a third of the spike in foreclosures. However, because the spike in foreclosures is 4.3% in the fixed rate economy and over 12% in the adjustable rate economy, the absolute reduction in house repossessions is much greater in the latter case.

**QE, Consumption, and Mortgage Type** Quantitative easing also has a significant impact on consumption. Upon implementation, surprise QE causes consumption to jump 3.5% above its previous trajectory. However, this top line number masks considerable heterogeneity. As table 2 indicates, homeowner consumption jumps by 4.5% in the fixed rate economy and by 6% for highly leveraged borrowers. By contrast, owners with significant equity only increase consumption by 2.5%. Unsurprisingly, the gains in consumption are

<table>
<thead>
<tr>
<th></th>
<th>All Owners</th>
<th>0% &lt; LTV &lt; 50%</th>
<th>LTV &gt; 80%</th>
<th>Non-Defaulters</th>
<th>Defaulters</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRMs</td>
<td>4.5%</td>
<td>2.5%</td>
<td>6.0%</td>
<td>4.3%</td>
<td>0.7%</td>
</tr>
<tr>
<td>ARMs</td>
<td>5.7%</td>
<td>2.9%</td>
<td>7.9%</td>
<td>5.5%</td>
<td>0.7%</td>
</tr>
</tbody>
</table>

These numbers are the jump in consumption upon implementation of “surprise” QE.
confined almost entirely to non-defaulters. Figures 7 and 8 show additional details on the heterogeneous consumption dynamics.

Table 2 shows that mortgage type also plays a significant role in the transmission of QE. In the adjustable rate economy, all borrowers immediately benefit from lower mortgage rates without needing to pay the fixed cost to refinance. As such, the consumption response is anywhere from 20% – 35% stronger. Figure 6 also reveals different dynamics of the consumption response to QE in the two economies. In the economy with adjustable rates, consumption jumps upon QE implementation and remains elevated. However, in the fixed rate economy, consumption increases upon impact but then falls below its non-policy trajectory two years later. Inspection of leverage dynamics reveals the culprit. In the adjustable rate economy, leverage initially drops upon the implementation of QE due to the surge in house prices. After exhibiting a modest increase, leverage resumes its downward trend. However, in the fixed rate economy, homeowners can only take advantage of the lower rates from QE by refinancing, and because refinancing is costly, borrowers take the opportunity to increase their leverage when they refinance. This increased indebtedness depresses consumption growth down the road.

5 Conclusion

References


Flavin, Marjorie and Shinobu Nakagawa, “A Model of Housing in the Presence of Adjustment Costs: A Structural Interpretation of Habit Persistence,” American Economic
Figure 7: Consumption response to lower mortgages rates from the policy intervention by ownership status and leverage in an economy with fixed rate mortgages.
Figure 8: Consumption response to lower mortgages rates from the policy intervention by ownership status and leverage in an economy with adjustable rate mortgages.


A Summary of Equilibrium Conditions

This section gives the complete definition of equilibrium from section 2.5.4.

A.1 Household Value Functions

A.1.1 Subperiod 3 Value Functions

Homeowners with good credit who refinance:

\[
V_{own}^R(y, (\bar{r}_m, m), h, s, 0) = \max_{m', b', c \geq 0} u(c, h) + \beta E \left[ (1 - \delta_h)(W_{own} + R_{sell})(y', (r_m, m'), h, s', 0) + \delta_h(V_{rent} + R_{buy})(y', s', 0) \right] \\
\text{subject to} \\
c + \gamma p(h) + q_b b' + m \leq y + q_m^0((r_m, m'), b', h, s)m' \\
q_m^0((r_m, m'), b', h, s)m' \leq \varphi p(h) \\
y' = we's' + b' 
\]  

(15)

Homeowners with good credit who make a regular payment:

\[
V_{own}^C(y, (\bar{r}_m, m), h, s, 0) = \max_{l, b', c \geq 0} u(c, h) + \beta E \left[ (1 - \delta_h)(W_{own} + R_{sell})(y', (\bar{r}_m, m'), h, s', 0) + \delta_h(V_{rent} + R_{buy})(y', s', 0) \right] \\
\text{subject to} \\
c + \gamma p(h) + q_b b' + l \leq y \\
l \geq \frac{\bar{r}_m}{1 + \bar{r}_m}m \\
m' = (m - l)(1 + \bar{r}_m) \\
y' = we's' + b' 
\]  

(16)
Homeowners with bad credit:

$$V_{\text{own}}(y, 0, h, s, 1) = \max_{b', c \geq 0} u(c, h) + \beta \mathbb{E} \left[ (1 - \delta_h)(W_{\text{own}} + R_{\text{sell}})(y', 0, h, s', f') 
+ \delta_h(V_{\text{rent}} + R_{\text{buy}})(y', s', f') \right]$$

subject to

$$c + \gamma p(h) + q_b b' \leq y$$

$$y' = we's' + b'$$

Apartment-dwellers with good credit:

$$V_{\text{rent}}(y, s, 0) = \max_{b', c \geq 0, a \leq \pi} u(c, a) + \beta \mathbb{E} [(V_{\text{rent}} + R_{\text{buy}})(y', s', 0)]$$

subject to

$$c + q_b b' + r_a a \leq y$$

$$y' = we's' + b'$$

Apartment-dwellers with bad credit:

$$V_{\text{rent}}(y, s, 1) = \max_{b', c \geq 0, a \leq \pi} u(c, a) + \beta \mathbb{E} [(V_{\text{rent}} + R_{\text{buy}})(y', s', f')]$$

subject to

$$c + q_b b' + r_a a \leq y$$

$$y' = we's' + b'$$
A.1.2 Subperiod 2 Value Functions

The value of searching to buy a house:

\[
R_{buy}(y, s, 0) = \max \left\{ 0, \max_{h \in H, p_b \leq y \eta_b(\theta_b(p_b, h))} \left[ \chi \left( V_{own}(y - p_b, 0, h, s, 0) - V_{rent}(y, s, 0) \right) - V_{rent}(y, s, 0) \right] \right\}
\]

(20)

\[
R_{buy}(y, s, 1) = \max \left\{ 0, \max_{h \in H, p_b \leq y \eta_b(\theta_b(p_b, h))} \left[ \chi \left( V_{own}(y - p_b, 0, h, s, 1) - V_{rent}(y, s, 1) \right) - V_{rent}(y, s, 1) \right] \right\}
\]

(21)

A.1.3 Subperiod 1 Value Functions

The utility associated with the default/refinance/payment decision:

\[
W(y, (\tau_m, m), h, s, 0) = \max \{ \varphi(V_{rent} + R_{buy})(y + \max \{ 0, J_{REO}(h) - m \}, s, 1) \\
+ (1 - \varphi)V_{own}^d(y, (\tau_m, m), h, s, 0), V_{own}^R(y, (\tau_m, m), h, s, 0), V_{own}^C(y, (\tau_m, m), h, s, 0) \}
\]

(22)

Utility of default conditional on no repossession:

\[
V_{own}^d(y, (\tau_m, m), h, s, 0) = \max_{c, b' \geq 0} u(c, h) + \beta \mathbb{E} \left[ (1 - \delta_{h})(W_{own} + R_{sell})(y', (\tau_m, m), h, s', 0) + \delta_{h}(V_{rent} + R_{buy})(y', s', 0) \right] \\
\text{subject to} \\
c + \gamma p(h) + \eta_s h' \leq y' \\
y' = w c' s' + b'
\]

(23)

The value of attempting to sell a house for a (possibly indebted) owner:

\[
R_{sell}(y, (\tau_m, m), h, s, 0) = \max \{ 0, \max_{p_s} \eta_s(\theta_s(p_s, h)) \left[ (V_{rent} + R_{buy})(y + p_s - m, s, 0) \\
- W_{own}(y, (\tau_m, m), h, s, 0) \right] + [1 - \eta_s(\theta_s(p_s, h))](\xi) \} \text{ subject to } y + p_s \geq m
\]

(24)
The value of attempting to sell a house for an owner with bad credit:

\[
R_{sell}(y, 0, h, s, 1) = \max \{0, \max_{s} \eta_s(\theta_s(p_s, h)) [(V_{rent} + R_{buy}) (y + p_s, s, 1) - W_{own}(y, 0, h, s, 1)] + [1 - \eta_s(\theta_s(p_s, h))] (-\xi) \} \tag{25}
\]

### A.2 Firms

#### A.2.1 Composite Consumption

The profit maximization condition of the composite good firm is

\[
w = A_c \tag{26}
\]

#### A.2.2 Apartments

The profit maximization condition of landlords is

\[
r_a = \frac{1}{A_h} \tag{27}
\]

#### A.2.3 Housing Construction

The relevant profit maximization conditions of home builders are

\[
1 = p \frac{\partial F_h(\bar{L}, S_h, N_h)}{\partial S_h} \tag{28}
\]

\[
w = p \frac{\partial F_h(\bar{L}, S_h, N_h)}{\partial N_h} \tag{29}
\]

### A.3 Banks

Bond prices satisfy

\[
q_b = \frac{1}{1 + r} \tag{30}
\]
Mortgage rates satisfy
\[ 1 + r_m = \frac{(1 + \phi)(1 + r)}{1 - \delta_h} \] (31)

The value to the bank of repossessing a house \( h \) is
\[
J_{REO}(h) = R_{REO}(h) - \gamma p(h) + \frac{1 - \delta_h}{1 + r} J_{REO}(h)
\]
\[
R_{REO}(h) = \max\left\{ 0, \max_{p_s \geq 0} \lambda \eta_s(\theta_s(p_s, h)) \left[ (1 - \chi)p_s - \left( -\gamma p(h) + \frac{1 - \delta_h}{1 + r} J_{REO}(h) \right) \right] \right\}
\] (32)

Mortgage prices satisfy the following recursive relationship:
\[
q^0_m((r_m, m'), b', h, s)m' = \frac{1 - \delta_h}{(1 + \zeta)(1 + \phi)(1 + r)} \mathbb{E} \left[ \begin{array}{l}
\text{sell + repay} \\
\text{no sale (do not try/fail)}
\end{array} \right] \eta_s(\theta_s(p_s', h)) m' + \left[ 1 - \eta_s(\theta_s(p_s', h)) \right]
\]
\[
\times \left[ d' \varphi \min \left\{ J_{REO}(h), m' \right\} + d'(1 - \varphi) \left[ -\phi m' + (1 + \zeta)(1 + \phi) q^0_m((r_m, m'), b', h, s)m' \right] \right.
\]
\[+(1 - d') \left\{ m' 1_{[\text{Refi}]} + 1_{[\text{No Refi}]} \left[ \begin{array}{l}
\text{default + repossession} \\
\text{no repossession} \\
\text{continuation value of current } m' \\
\text{continuation value of new } m''
\end{array} \right] \right\} \]
\] (33)

A.4 Housing Market Equilibrium

A.4.1 Market Tightnesses

Market tightnesses satisfy
\[
\kappa_b h \geq \alpha_b(\theta_b(p_b, h))(p_b - p(h))
\] (34)
\[
\kappa_s h \geq \alpha_s(\theta_s(p_s, h))(p(h) - p_s)
\] (35)

with \( \theta_b(x_b, h) \geq 0, \theta_s(x_s, h) \geq 0 \), and complementary slackness.
A.4.2 Determining the Shadow Housing Price

Housing supply $S_h(p)$ equals the sum of new and existing sold housing,

$$S_h(p) = \sum_{\text{new housing}} Y_h(p) + \sum_{\text{REO housing}} S_{REO}(p) + \sum_{\text{sold by owner}} \int h \eta_s(\theta_s(x^*_s, h; p)) \Phi_{own}(dy, dm, dh, ds, df)$$  \hspace{1cm} (36)

The supply of REO housing is given by

$$S_{REO}(p) = \sum_{h \in H} h \lambda_s(\theta_s(x^*_{REO}, h; p)) \left[ H_{REO}(h) + \int [1 - \eta_s(\theta_s(x^*_s, h; p))] d^* \Phi_{own}(dy, dm, dh, ds, 0) \right]$$  \hspace{1cm} (37)

Housing demand $D_h(p)$ equals housing purchased by matched buyers,

$$D_h(p) = \int h^* \eta_b(\theta_b(x^*_b, h^*; p)) \Phi_{rent}(dy, ds, df)$$  \hspace{1cm} (38)

The per unit shadow housing price $p$ (recall that $p(h) = ph$) equates these Walrasian-like equations,

$$D_h(p) = S_h(p)$$  \hspace{1cm} (39)

A.5 Detailed Equilibrium Definition

**Definition 1** Given interest rate $r$ and permits $L$, a stationary recursive equilibrium is

1. Household value and policy functions
2. Intermediary value and policy functions $J_{REO}$ and $x^*_{REO}$
3. Market tightness functions $\theta_b$ and $\theta_s$
4. A mortgage pricing function $q^0_m$
5. Prices $w, q_b, q_m, r_h$, and $p$
6. Quantities $K_c$, $N_c$, $S_h$, and $N_h$

7. Stationary distributions $\{H_{REO}\}_{h \in H}$, $\Phi_{own}$, and $\Phi_{rent}$

such that

1. **Household Optimality:** The value/policy functions solve (15) – (25).

2. **Firm Optimality:** Condition (29) is satisfied.

3. **Bank Optimality:** Conditions (30) – (33) are satisfied.

4. **Market Tightnesses:** $\{\theta_b(x_b, h)\}$ and $\{\theta_s(x_s, h)\}$ satisfy (34) – (35).

5. **Labor Market Clears:** $N_c + N_h = \sum_{s \in S} \int_E e \cdot s F(de) \Pi_s(s)$.

6. **Shadow Housing Price:** $D_h(p) = S_h(p)$.

7. **Stationary Distributions:** the distributions are invariant with respect to the Markov process induced by the exogenous processes and all relevant policy functions.

## B Computation

The computational algorithm to find the stationary equilibrium is as follows:

1. Given $r$, calculate $q_b$ and $q_m$ using (30) – (31).

2. **Loop 1** – Make an initial guess for the shadow housing price $p$.
   
   (a) Solve for market tightnesses $\{\theta_b(x_b, h; p)\}$ and $\{\theta_s(x_s, h; p)\}$ using (34) – (35).
   
   (b) Calculate the wage $w$ and housing construction $Y_h$ using (26) – (29).
   
   (c) **Loop 2a** – Make an initial guess for the bank’s REO value function, $J_{REO}^0(h)$.
      
      i. Substitute $J_{REO}^0$ into the right hand side of (32) and solve for $J_{REO}(h)$.
      
      ii. If $\sup(|J_{REO} - J_{REO}^0|) < \epsilon_J$, exit the loop. Otherwise, set $J_{REO}^0 = J_{REO}$ and return to (i).

   (d) **Loop 2b** – Make an initial guess for mortgage prices $q_{m,n}^0(m', b', h, s)$ for $n = 0$. 

i. Calculate the lower bound of the budget set for homeowners with good credit entering subperiod 3, \( y(m, h, s) \), by solving

\[
y(m, h, s) = \min_{m', b'} [\gamma_p(h) + q_b' + m - \widetilde{q}_m(m', b', h, s)m'],
\]

where

\[
\widetilde{q}_m(m', b', h, s) = \begin{cases} 
q^0_m(m', b', h, s) & \text{if } m' > m \\
q_m & \text{if } m' \leq m 
\end{cases}
\]

ii. Loop 3 – Make an initial guess for \( V^0_{\text{rent}}(y, s, f) \) and \( V^0_{\text{own}}(y, m, h, s, f) \).

A. Substitute \( V^0_{\text{rent}} \) and \( V^0_{\text{own}} \) into the right hand side of (20) – (21) and solve for \( R_{\text{buy}} \).

B. Substitute \( V^0_{\text{rent}}, V^0_{\text{own}}, \) and \( R_{\text{buy}} \) into the right hand side of (22) and solve for \( W_{\text{own}} \).

C. Substitute \( W_{\text{own}}, V^0_{\text{rent}}, \) and \( R_{\text{buy}} \) into the right hand side of (24) – (25) and solve for \( R_{\text{sell}} \).

D. Substitute \( W_{\text{own}}, V^0_{\text{rent}}, R_{\text{sell}}, \) and \( R_{\text{buy}} \) into the right hand side of (15) – (19) and solve for \( V_{\text{rent}} \) and \( V_{\text{own}} \).

E. If \( \sup(|V_{\text{rent}} - V^0_{\text{rent}}|) + \sup(|V_{\text{own}} - V^0_{\text{own}}|) < \epsilon_V \), exit the loop. Otherwise, set \( V^0_{\text{rent}} = V_{\text{rent}} \) and \( V^0_{\text{own}} = V_{\text{own}} \) and return to A.

iii. Substitute \( q^0_{m, n}, J_{\text{REO}}, \) and the household’s policy functions for bonds, mortgage choice and selling and default decisions into the right hand side of (33) and solve for \( q^0_m \).

iv. If \( \sup(q^0_m - q^0_{m, n}) < \epsilon_q \), exit the loop. Otherwise, set \( q^0_{m, n+1} = (1 - \lambda_q)q^0_{m, n} + \lambda_q q^0_m \) and return to (i).

(e) Compute the invariate distribution of homeowners and renters, \( \Phi_{\text{own}} \) and \( \Phi_{\text{rent}}, \) and the stock of REO houses, \( \{ H_{\text{REO}} \}_{h \in H} \).

(f) Calculate the excess demand for housing using (36) – (39).

(g) If \( |D_h(p) - S_h(p)| < \epsilon_p \), exit the loop. Otherwise, update \( p \) using a modified bisection method and go back to (a).
The state space \((y,m,h,s)\) for homeowners is discretized using 275 values for \(y\), 131 values for \(m\), 3 values for \(h\), and 3 values for \(s\). Homeowners with bad credit standing \((f = 1)\) have state \((y,h,s)\), and renters have state \((y,s)\). To compute the equilibrium transition path, the algorithm starts with an initial guess for the path of shadow house prices, \(\{p_{h,t}\}_{t=1}^{T}\). The algorithm then does backward induction on the REO value function, mortgage price equation, and the household Bellman equations before forward iterating on the distribution of households and REO properties. Equilibrium house prices (which depend on the current guess for the house price trajectory) are calculated period by period during the forward iteration. The initial guess is then compared with these equilibrium prices, and a convex combination of these sequences is used for the next guess. The process continues until convergence.
C Calibrating Labor Efficiency

As explained in section 3, it is impossible to estimate quarterly income processes from the PSID because it is annual data. Instead, a labor process is specified like that in Storesletten et al. (2004), except without life cycle effects or a permanent shock at birth. Their values are adopted for the annual autocorrelation of the persistent shock and for the variances of the persistent and transitory shocks and transformed into quarterly values.

Persistent Shocks It is assumed that in each period households play a lottery in which, with probability 3/4, they receive the same persistent shock as they did in the previous period, and with probability 1/4, they draw a new shock from a transition matrix calibrated to the persistent process in Storesletten et al. (2004) (in which case they still might receive the same persistent labor shock). This is equivalent to choosing transition probabilities that match the expected amount of time that households expect to keep their current shock. Storesletten et al. (2004) report an annual autocorrelation coefficient of 0.952 and a frequency-weighted average standard deviation over expansions and recessions of 0.17. The Rouwenhorst method is used to calibrate this process, which gives the following transition matrix:

\[
\tilde{\pi}_s(\cdot, \cdot) = \begin{pmatrix}
0.9526 & 0.0234 & 0.0006 \\
0.0469 & 0.9532 & 0.0469 \\
0.0006 & 0.0234 & 0.9526
\end{pmatrix}
\]

As a result, the transition matrix is

\[
\pi_s(\cdot, \cdot) = 0.75I_3 + 0.25\tilde{\pi}_s(\cdot, \cdot) = \begin{pmatrix}
0.9881 & 0.0059 & 0.0001 \\
0.0171 & 0.9883 & 0.0171 \\
0.0001 & 0.0059 & 0.9881
\end{pmatrix}
\]

Transitory Shocks Storesletten et al. (2004) report a standard deviation of the transitory shock of 0.255. To replicate this, it is assumed that the annual transitory shock is actually the sum of four, independent quarterly transitory shocks. The same identifying assumption as in Storesletten et al. (2004) is used, namely, that all households receive the same initial
persistent shock. Any variance in initial labor income is then due to different draws of the transitory shock. Recall that the labor productivity process is given by

$$\ln(e \cdot s) = \ln(s) + \ln(e)$$

Therefore, total labor productivity (which, when multiplied by the wage $w$, is total wage income) over a year in which $s$ stays constant is

$$(e \cdot s)_{\text{year 1}} = \exp(s_0)[\exp(e_1) + \exp(e_2) + \exp(e_3) + \exp(e_4)]$$

For different variances of the transitory shock, total annual labor productivity is simulated for many individuals, logs are taken, and the variance of the annual transitory shock is computed. It turns out that quarterly transitory shocks with a standard deviation of 0.49 give the desired standard deviation of annual transitory shocks of 0.255.