Mortgage Debt, Consumption, and Illiquid Housing Markets in the Great Recession*

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Abstract

Using a model with housing search, endogenous credit constraints, and mortgage default, this paper quantitatively accounts for the housing crash from 2006 to 2011 and assesses its implications for aggregate and cross-sectional consumption during the Great Recession. Tighter downpayment requirements and higher downside labor market risk emerge as primary culprits. An endogenous decline in housing liquidity amplifies the recession by increasing foreclosures, contracting credit, and depressing consumption. Household balance sheets act as a transmission mechanism from housing to consumption that depends on gross portfolio positions and the leverage distribution. Low interest rate policies accelerate the recovery in housing and consumption.

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1 Introduction

Since 2006, both the housing market and macroeconomy in the U.S. have experienced their largest disruption in decades. Real house prices fell by 25% while housing liquidity evaporated with average time on the market increasing from under four months to almost a full year, as shown in figure 1. Meanwhile, aggregate consumption declined substantially and has yet to revert to pre-crisis trend. Some experts have even argued that the Great Recession occurred because of the housing collapse that fueled a foreclosure-induced credit contraction. According to the narrative, these twin collapses in credit and housing liquidity explain the pronounced decline in consumption through their impact on household deleveraging.

Whatever its merit, this narrative leaves the causes of the housing crash unresolved as well as the underlying mechanisms connecting the housing market to consumption, which is notable given the trouble that many workhorse models have producing significant transmission between the two. This paper reproduces the housing crash and quantifies its impact on aggregate and cross-sectional consumption. Furthermore, the paper highlights two important transmission mechanisms: the interaction of endogenous housing

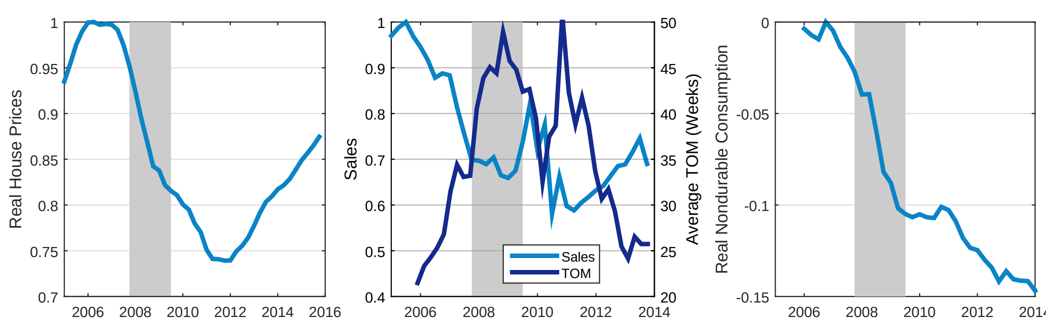


Figure 1: The dynamics of real house prices, sales, time on the market, and real nondurable consumption since 2006.

and credit liquidity as well as the impact of deteriorating household balance sheets. Importantly, these mechanisms are far more potent during periods of large house price declines and represent an important nonlinearity that distinguishes severe recessions from typical business cycles. The framework for analysis is a model with directed search for houses, endogenous credit constraints, and mortgage default. Households face uninsurable income risk that gives rise to heterogeneity in assets and liabilities. Agents make home tenure decisions, borrow using fixed-rate mortgages, and save in a risk-free asset. Owners can extract equity through refinancing, but **credit illiquidity** from default spreads affects credit access. Search frictions create **housing illiquidity** in the form of a trade-off between list price and time on the market.

Quantitatively, the model successfully reproduces the aggregate and cross-sectional behavior of the U.S. economy during the Great Recession. The model indicates that an increase in left tail labor income risk and a tightening of downpayment constraints act as the primary culprits. The left tail shock induces precautionary behavior that depresses house prices and consumption by approximately 10% and 5%, respectively. Furthermore, absent this decline in housing demand, falling house prices from the other shocks counterfactually boost homeownership. Tighter downpayments limit cash-out refinancing and force distressed borrowers to put their house on the market, which depresses house prices and consumption by 5% and increases selling delays by 10 weeks.

In general, when house prices fall, the difficulty of selling houses rises because it takes more time to find a buyer. Introducing this endogenous housing liquidity channel amplifies the drop in house prices and consumption by 27% and 32%, respectively, relative to an economy where houses always sell instantly but are subject to a fixed transaction cost. During booms, market tightness is high and houses sell quickly, and owners can easily extract equity through refinancing because of loose credit from low default risk.

However, during downturns, sellers face a deteriorating trade-off between list price and time on the market, and this evaporation of housing liquidity most keenly affects highly leveraged borrowers. The requirement to repay outstanding mortgage debt at closing limits the ability of sellers to drop the asking price. The resulting debt overhang causes long selling delays that push heavily indebted owners to either severely cut consumption or default on their mortgage. In the latter case, selling delays spill over into foreclosure risk, which explains why foreclosures peak at 4.3% in the baseline economy versus 1.3% with exogenous illiquidity. Importantly, this spillover feeds a credit channel from banks pricing higher default risk into new mortgages. This chain cascades as lower housing and credit liquidity depress house prices, which further erodes liquidity. The end result is a persistent macroeconomic slump marked by high foreclosure activity and deep declines in house prices and consumption. Importantly, the presence of long-term mortgages creates debt overhang that prolongs the crisis, whereas with one period loans, a tightening of collateral constraints forces owners to immediately deleverage.

Endogenous housing illiquidity is also necessary to generate the sales collapse and the positive correlation between prices and sales, which has proven challenging in the literature. In the standard model where houses sell instantly, buyers surge into the market to purchase cheap housing whenever prices fall. However, increased selling delays in the model with endogenous housing illiquidity depress the number of successful transactions, and the adverse interaction with credit liquidity blunts demand.

Through its impact on the assets side of household portfolios, the house price decline magnifies the fall in consumption by 63%. This balance sheet channel delivers an elasticity of consumption to house prices of 0.3, which comports with Mian, Rao and Sufi (2013) and others. However, this relationship is non-linear and depends on the underlying drivers of the house price decline. Notably, endogenous housing illiquidity increases the persistence of balance sheet effects by prolonging the time it takes for households to adjust their housing and consumption behavior.

Importantly, balance sheet effects exhibit significant cross-sectional heterogeneity that depends on gross rather than net portfolio positions. After controlling for net worth, households with larger houses *and* more debt experience stronger consumption declines than households with smaller houses and less debt. As a stark example, renters in the 4th net worth decile before the crisis see consumption fall by 3.7% versus 30.7% for owners in the same decile. In the aggregate, owners with leverage above 80% and renters both account for one-fifth of pre-crisis consumption, but these owners account for over 30% of the aggregate decline compared to only 5% for renters.

The severity of the crisis led to an unprecedented effort by policymakers to reduce long term interest rates. Empirical work finds that these interventions succeeded in bringing rates down, while this paper evaluates the resulting implications for the macroeconomy. Several findings emerge. First, lower mortgage rates fuel a 6.3% rise in house prices and a 3.5% rise in consumption. However, ignoring the house price response attenuates the consumption gain by 62%. In other words, balance sheet effects, not intertemporal substitution, account for most of the transmission. When prices rise, housing and credit liquidity both increase, and owners extract equity via refinancing. After a couple of years, however, the surge of debt weighs down consumption growth. Lastly, the impact of the policy strengthens with leverage. Whereas owners with leverage below 50% experience a 2.5% rise in consumption, owners with leverage above 80% witness a 6% jump, consistent with empirical evidence.

1.1 Related Literature

There is a growing literature that emphasizes the connection between housing and the macroeconomy, including prominent papers by Iacoviello (2005), Davis and Heathcote (2005), and Leamer (2007) that focus on the business cycle. Davis and Van Nieuwerburgh (2015) and Piazzesi and Schneider (2016) provide a more thorough summary of this literature.

The recent boom and bust in the U.S. housing market marks a particularly notable episode that was accompanied by the largest decline in economic activity since the Great Depression. Several papers have attempted to understand the determinants of these large house price movements. For example, Favilukis, Ludvigson and Van Nieuwerburgh (2016) explore the role of credit conditions and time-varying risk premia and find that a financial liberalization and reversal can generate a large boom and bust in the price-to-rent ratio. By contrast, Glaeser, Gottlieb and Gyourko (2013), Sommer, Sullivan and Verbrugge (2013), and Kiyotaki, Michaelides and Nikolov (2011) argue for small effects of borrowing costs on house prices, and Kaplan, Mitman and Violante (2016b) claim that belief shocks are essential to replicating the housing boom and bust. Garriga, Manuelli and Peralta-Alva (2014) provide a framework that reconciles these contrasting findings by showing that a relaxation of collateral constraints has an ambiguous effect that depends on the level of interest rates.

Relative to the previous literature, this paper emphasizes the joint role of credit conditions and labor market uncertainty in generating the housing crash and Great Recession. Changing credit conditions have a non-trivial impact by themselves, as does uncertainty, which is in keeping with recent work by Guvenen, Ozkan and Song (2014), Stock and Watson (2012), Bloom, Floetotto, Jaimovich, Saporta-Eksten and Terry (2014), and Kozeniauskas, Orlik and Veldkamp (2016). However, in conjunction they generate a decline in consumption that exceeds that of output, which is discussed in Krueger, Mitman and Perri (2016b) and Huo and Ríos-Rull (2016).

This paper also builds upon the literature by establishing some important amplification and propagation mechanisms that are more salient in crisis episodes than during traditional business cycles. One mechanism connects the housing market collapse to the sharp fall in consumption through shocks to household balance sheets. The response of consumption to changes in income and net worth has been explored in a broad range of papers, including empirical work that finds an elasticity of nondurable consumption to house price changes of 0.1 to 0.3 (see Carroll, Otsuka and Slacalek (2011), Case, Quigley and Shiller (2013), Mian et al. (2013), and Kaplan, Mitman and Violante (2016c)), but the response is sensitive to the age of the household, as discussed by Campbell and Cocco (2007) and Attanasio, Blow, Hamilton and Leicester (2009).

In the structural literature, it is common to consolidate the household balance sheet into a single financial asset. Berger, Guerrieri, Lorenzoni and Vavra (2016) use this approach to quantify the effect of house price declines on consumption in a partial equilibrium setting. However, by treating house prices and credit as exogenous, they ignore the feedback from consumption into house prices and from prices into the availability of credit. This omission substantially weakens the consumption response to a large house price bust.

Huo and Ríos-Rull (2016) endogenize house prices in a model with frictions in the goods market where shocks to household wealth generate a significant decline in consumption and output. However, they omit long-term contracts and default, which forces households to immediately deleverage when the collateral constraint tightens in response to a decline in house prices.

Furthermore, they ignore the crucial role of housing transaction costs by assuming households can costlessly readjust their portfolios.

Kaplan and Violante (2014) have argued that consumption responds more strongly to unanticipated shocks when a sizable fraction of household net worth is tied up in an illiquid asset. However, their formulation implicitly consolidates the house and mortgage into one net position and ignores house prices. By contrast, this paper establishes that households with similar net worth but different gross positions in housing and mortgage debt exhibit far different consumption behavior during the Great Recession (i.e. renters versus highly leveraged homeowners). Gorea and Midrigan (2015) also emphasize the importance of illiquid housing, but both of these papers treat liquidity as an exogenous transaction cost that does not vary with the state of the economy.

This paper uses search frictions to endogenize the illiquidity of housing, and as such, builds upon recent housing search papers including Ngai and Tenreyro (2014), Head, Lloyd-Ellis and Sun (2014), and Díaz and Jerez (2013), Burnside, Eichenbaum and Rebelo (2016), and Landvoigt, Piazzesi and Schneider (2011) by adding budget constraints tied to credit.[1] Endogenous housing illiquidity from selling delays creates an additional default region that corresponds to indebted homeowners who fail to sell and can no longer maintain mortgage payments—a region not present in Chatterjee and Eyigungor (2015), Corbae and Quintin (2015), Herkenhoff and Ohanian (2015), and Hatchondo, Martinez and Sanchez (2015). Hedlund (2016c) discusses the spillover of selling risk to foreclosure risk at a business cycle frequency, but this channel is highly nonlinear and more quantitatively relevant during periods with large declines in house prices. Lastly, Hedlund (2016a) studies the efficacy of inflating away mortgage debt for mitigating episodes like the Great Recession.

[1] Hedlund (2016b) provides a more thorough summary of the housing search literature.

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 $a \leq \overline{a}$ 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. $\overline{a} < \underline{h}$. In other words, large units are only available for purchase.[2] Owners are not permitted to possess multiple houses or to have tenants.

Households supply a stochastic labor endowment $e \cdot s$ 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 $r_a = 1/A_a$.[3]

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

[2]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.

[3]Sommer et al. (2013) and Davis, Lehnert and Martin (2008) report that rents have remained flat over the past 30 years, independent of house price swings.

purchase structures S_h from the consumption sector, and as in Favilukis et al. (2016), the government supplies new permits $\overline{L} > 0$ each period and consumes the revenues. Houses depreciate with probability δ_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.[4] 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.

[4] Here, 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 $p(h) = p_h h$.

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 θ_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 ξ.

Brokers find buyers and sellers with probabilities α_b and α_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

$$\kappa_b h \geq \overbrace{\alpha_b(\theta_b(p_b, h))}^{\text{prob of match}} \overbrace{(p_b - p(h))}^{\text{broker revenue}} \tag{1}$$

$$\kappa_s h \geq \underbrace{\alpha_s(\theta_s(p_s, h))}_{\text{prob of match}} \underbrace{(p(h) - p_s)}_{\text{broker revenue}} \tag{2}$$

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 θ_s and θ_b on the distribution Φ 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. $p(h)(\Phi) = p(\Phi)h$.

$$\theta_b(p_b, h; \Phi) = \alpha_b^{-1}\left(\frac{\kappa_b h}{p_b - p(h)(\Phi)}\right) \tag{3}$$

$$\theta_s(p_s, h; \Phi) = \alpha_s^{-1}\left(\frac{\kappa_s h}{p(h)(\Phi) - p_s}\right) \tag{4}$$

Absent the brokers, market tightnesses would depend nonparametrically on Φ, 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.[5]

[5] Garriga and Hedlund (2016) explore the implications of fixed vs. adjustable rate mortgages. The presence of floating rates has important macroeconomic consequences.

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 $q_m^0((r_m, m'), b', h, s)m'$ 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 ζ and servicing costs ϕ over the life of each mortgage. During repayment, banks have exposure to two risks. First, if the house depreciates with probability δ_h, the bank must forgive the loan.[6] Second, homeowners can default in a given period by not making a payment. In this situation, the lender forecloses on the borrower with probability φ 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 $\overline{r}_m$ 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 $(\overline{r}_m, m)$ 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 $l \geq \frac{\overline{r}_m}{1+\overline{r}_m} m$, and their debt evolves according to $m' = (m - l)(1 + \overline{r}_m)$.

[6]This assumption prevents the model from generating artificially high foreclosure rates.

The fixed rate satisfies

$$1 + r_m = \underbrace{\left(\frac{1+\phi}{1-\delta_h}\right)}_{\text{spread}} \underbrace{1 + r^*}_{\text{long term risk-free rate}}. \tag{5}$$

Mortgage prices satisfy the following recursive relationship:

$$\begin{aligned} q_m^0((\bar{r}_m, m'), b', h, s)m' = \frac{1-\delta_h}{(1+\zeta)(1+\phi)(1+r)} \mathbb{E} \Bigg\{ & \overbrace{\eta_s(\theta_s(p_s', h))m'}^{\text{sell + repay}} + \overbrace{[1 - \eta_s(\theta_s(p_s', h))]}^{\text{no sale (do not try/fail)}} \\ \times \Bigg[& \underbrace{d'\varphi \min\{J_{REO}(h), m'\}}_{\text{default + repossession}} + \underbrace{d'(1-\varphi)}_{\text{no repossession}} \left(-\phi m' + \underbrace{(1+\zeta)(1+\phi)q_m^0((\bar{r}_m, m'), b'', h, s')m'}_{\text{continuation value of current } m'} \right) \\ +(1-d') \Bigg\{ & m'\mathbf{1}_{[\text{Refi}]} + \mathbf{1}_{[\text{No Refi}]} \Bigg(\underbrace{l - \frac{\phi}{1+\bar{r}_m} m''}_{\text{payment} - \text{servicing costs}} + \underbrace{(1+\zeta)(1+\phi)q_m^0((\bar{r}_m, m''), b'', h, s')m''}_{\text{continuation value of new } m''} \Bigg) \Bigg\} \Bigg] \Bigg\} \end{aligned} \tag{6}$$

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 χ of proceeds as the cost of selling foreclosed houses. Banks absorb losses but must pass profits to the borrower.

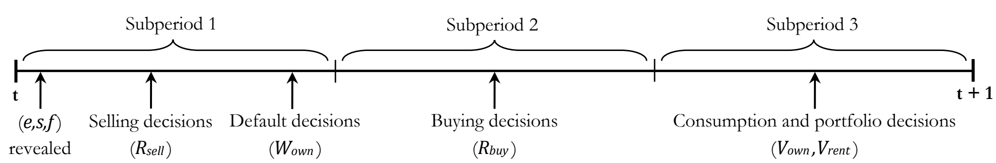
The value to a lender in repossessing a house h is

$$J_{REO}(h) = R_{REO}(h) - \gamma p(h) + \frac{1-\delta_h}{1+r} J_{REO}(h)$$
$$R_{REO}(h) = \max\left\{0, \max_{p_s \geq 0} \eta_s(\theta_s(p_s,h)) \left[(1-\chi)p_s - \left(-\gamma p(h) + \frac{1-\delta_h}{1+r} J_{REO}(h)\right)\right]\right\} \tag{7}$$

where γ 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 $\overline{r}_m$ 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

$$V_{own}^{R}(y,(\overline{r}_m,m),h,s,0)=\max_{m',b',c\geq 0} u(c,h)+\beta\mathbb{E}\left[\begin{array}{l}(1-\delta_h)(W_{own}+R_{sell})(y',(r_m,m'),h,s',0)\\ +\delta_h(V_{rent}+R_{buy})(y',s',0)\end{array}\right]$$

subject to

$$\begin{gathered} c+\gamma p(h)+q_b b'+m\leq y+q_m^0((r_m,m'),b',h,s)m' \\ q_m^0((r_m,m'),b',h,s)m'\leq \vartheta p(h) \\ y'=we's'+b' \end{gathered} \tag{8}$$

where ϑ is the collateral constraint for new loans, q_m^0 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

$$V_{own}^{C}(y,(\overline{r}_m,m),h,s,0)=\max_{l,b',c\geq 0} u(c,h)+\beta\mathbb{E}\left[\begin{array}{l}(1-\delta_h)(W_{own}+R_{sell})(y',(\overline{r}_m,m'),h,s',0)\\ +\delta_h(V_{rent}+R_{buy})(y',s',0)\end{array}\right]$$

subject to

$$\begin{gathered} c+\gamma p(h)+q_b b'+l\leq y \\ l\geq \frac{\overline{r}_m}{1+\overline{r}_m}m \\ m'=(m-l)(1+\overline{r}_m) \\ y'=we's'+b' \end{gathered} \tag{9}$$

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 B 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 $y - p_b \geq \underline{y}(s,(h,1))$, where $\underline{y} < 0$ captures their ability to take out a mortgage in subperiod 3. The option value R_{buy} of buying is as follows:

$$R_{buy}(y,s,0) = \max\{0, \max_{\substack{h\in H,\\ p_b \leq y-\underline{y}}} \eta_b(\theta_b(p_b,h))[V_{own}(y-p_b,0,h,s,0) - V_{rent}(y,s,0)]\} \tag{10}$$

$$R_{buy}(y,s,1) = \max\{0, \max_{\substack{h\in H,\\ p_b \leq y}} \eta_b(\theta_b(p_b,h))[V_{own}(y-p_b,0,h,s,1) - V_{rent}(y,s,1)]\} \tag{11}$$

2.5.3 Subperiod 1: Selling and Default Decisions

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

$$\begin{aligned} W(y,(\overline{r}_m,m),h,s,0) = \max\{&\varphi(V_{rent}+R_{buy})\,(y+\max\{0,J_{REO}(h)-m\},s,1) \\ &+(1-\varphi)V^d_{own}(y,(\overline{r}_m,m),h,s,0), V_{own}(y,(\overline{r}_m,m),h,s,0)\} \end{aligned} \tag{12}$$

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

$$V^d_{own}(y,(\overline{r}_m,m),h,s,0) = \max_{b',c\geq 0} u(c,h) + \beta\mathbb{E}\begin{bmatrix} (1-\delta_h)(W_{own}+R_{sell})(y',(\overline{r}_m,m),h,s',0) \\ +\delta_h(V_{rent}+R_{buy})(y',s',0) \end{bmatrix}$$

$$\text{subject to}$$

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

$$y' = we's' + b' \tag{13}$$

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

$$R_{sell}(y,(\overline{r}_m,m),h,s,0)=\max\{0,\max_{p_s}\eta_s(\theta_s(p_s,h))\left[(V_{rent}+R_{buy})(y+p_s-m,s,0)\right.$$
$$\left.-W_{own}(y,(\overline{r}_m,m),h,s,0)\right]+\left[1-\eta_s(\theta_s(p_s,h))\right](-\xi)\}\text{ subject to }y+p_s\geq m \tag{14}$$

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 θ_s and θ_b; prices w, p_h, q_m^0, q_b, and r_a; and stationary distributions Φ 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 B provides the detailed equilibrium conditions.

3 Model Parametrization

The model is parametrized to replicate key features of the United States economy during 2003 – 2005, prior to the Great Recession. Some parameters are identified from external sources, while the remaining parameters are set jointly to match key housing moments related to sales, time on the market, and foreclosures, as well as important household portfolio statistics.

Households Following Storesletten, Telmer and Yaron (2004), the log of the persistent component of labor efficiency follows an AR(1) process, while the transitory component is log-normal.[7] The persistent component is discretized

[7] The appendix explains the procedure to convert the annual estimates to quarterly values.

using a 3-state Markov chain using the Rouwenhorst method.

For preferences, households have CES period utility with an intratemporal elasticity of substitution of $\nu = 0.13$. Risk aversion is set to $\sigma = 2$, while the consumption share ω and discount factor β are determined jointly.

Technology Technology A_c in the consumption goods sector is set to normalize annual earnings to 1. Housing construction is a constant returns to scale Cobb-Douglas with a structures share of $\alpha_S = 0.3$ and a land share of $\alpha_L = 0.33$ from the Lincoln Institute of Land Policy. Housing depreciates at an annual rate of 1.4%. The apartment technology A_h is set to generate an annual rent-price ratio of 3.5%, consistent with Sommer et al. (2013).

Housing Market The matching technology is Cobb Douglas and implies trading probabilities of $\eta_s(\theta_s) = \min\{\theta^{\gamma_s}, 1\}$ and $\eta_b(\theta_b) = \min\{\theta^{\gamma_b}, 1\}$. Substituting in (3) and (4) gives

$$\eta_s(\theta_s) = \min\left\{1, \max\left\{0, \left(\frac{p(h)-p_s}{\kappa_s h}\right)^{\frac{\gamma_s}{1-\gamma_s}}\right\}\right\}, \quad \eta_b(\theta_b) = \min\left\{1, \max\left\{0, \left(\frac{p_b-p(h)}{\kappa_b h}\right)^{\frac{\gamma_b}{1-\gamma_b}}\right\}\right\}$$

The joint calibration determines κ_b, κ_s, γ_s, γ_b, and disutility ξ. Holding costs are $\gamma = 0.0075$ to match 3% annual property taxes/maintenance.

Financial Markets To match values in the U.S. during 2003 – 2005, the real risk-free rate is set to -1%, and the origination cost is 0.4%. The servicing cost ϕ is set to equate the real mortgage rate to 3.6%. Lastly, a non-binding LTV limit of $\vartheta = 1.25$ (125%) is used.[8] The persistence of credit flags is $\gamma_f = 0.95$, and the REO discount χ is determined in the joint calibration.

[8] See Herkenhoff and Ohanian (2015) for discussion of cash-out refinancing in the 2000s.

Table 1: Model Calibration

Description	Parameter	Value	Target	Model	Source/Reason
		Calibration: Independent Parameters			
Autocorrelation	ρ	0.952			Storesletten et al. (2004)
SD of Persistent Shock	σ_ϵ	0.17			Storesletten et al. (2004)
SD of Transitory Shock	σ_e	0.49			Storesletten et al. (2004)
Intratemp. Elas. of Subst.	ν	0.13			Flavin and Nakagawa (2008)
Risk Aversion	σ	2			Various
Structure Share	α_S	30%			Favilukis et al. (2016)
Land Share	α_L	33%			Lincoln Inst Land Policy
Holding Costs	γ	0.7%			Moody's
Depreciation (Annual)	δ_h	1.4%			BEA
Rent-Price Ratio (Annual)	r_h	3.5%			Sommer et al. (2013)
Risk-Free Rate (Annual)	r	-1.0%			Federal Reserve Board
Servicing Cost (Annual)	ϕ	3.6%			3.6% Real Mortgage Rate
Mortgage Origination Cost	ζ	0.4%			FHFA
Maximum LTV	ϑ	125%			Fannie Mae
Prob. of Repossession	φ	0.5			2008 OCC Mortgage Metrics
Credit Flag Persistence	λ_f	0.9500			Fannie Mae
		Calibration: Jointly Determined Parameters			
Homeownership Rate	$\overline{a}$	3.2840	69.0%	68.9%	Census
Starter House Value	h_1	2.7100	2.75	2.75	Corbae and Quintin (2015)
Housing Wealth (Owners)	ω	0.8159	3.99	3.99	2004 SCF
Borrowers with $LTV \geq 90\%$	β	0.9749	11.40%	11.28%	2004 SCF
Months of Supply*	ξ	0.0013	4.90	4.89	Nat'l Assoc of Realtors
Avg. Buyer Search (Weeks)	γ_b	0.0940	10.00	10.04	Nat'l Assoc of Realtors
Maximum Bid Premium	κ_b	0.0209	2.5%	2.5%	Gruber and Martin (2003)
Maximum List Discount	κ_s	0.1256	15%	15%	RealtyTrac
Foreclosure Discount	χ	0.1370	20%	20%	Pennington-Cross (2006)
Foreclosure Starts (Annual)	γ_s	0.6550	1.20%	1.29%	Nat'l Delinquency Survey
		Model Fit			
Borrowers with $LTV \geq 80\%$			21.90%	27.2%	2004 SCF
Borrowers with $LTV \geq 95\%$			7.10%	7.25%	2004 SCF
Median Owner Liq. Assets			0.19	0.22	2004 SCF

*Months of supply is inventories divided by the sales rate and proxies for time on the market.

Joint Parametrization The endogenously determined parameters are calculated to match specific moments from the data. The first set of moments targets select household portfolio statistics from the 2004 Survey of Consumer Finances (SCF). Specifically, the aim is to match average housing wealth and the distribution of leverage, especially at the higher end. These households are the ones who end up underwater and potentially in default during the simulated Great Recession.[9] Additional moments target key housing market variables such as sales volume, average search duration, and maximum price spreads. Lastly, the model seeks to match pre-crisis foreclosure starts and the average foreclosure discount.[10] Table 1 shows that the model matches the targets and replicates other untargeted statistics from the 2004 SCF, namely, median liquid assets the distribution of mortgage debt.

4 Results

This section undertakes four major tasks. The first task seeks to generate a housing bust and Great Recession of similar magnitude to those in the U.S. The second one is to explore the role of housing illiquidity as an amplification and propagation mechanism in the aggregate and for the cross section. The third task investigates the transmission from house prices, liquidity, and credit conditions to consumption through household balance sheets. Finally, the model is used to analyze the efficacy of interventions aimed at providing credit liquidity to the mortgage market.

[9] Only includes households in the bottom 95% of the earnings *and* net worth distributions.

[10] Appendix A.3 provides a brief overview of what happens if the economy is initialized to the late 1990s and the boom is simulated in addition to the bust. Importantly, the dynamics of the recession and recovery are nearly unchanged.

4.1 Replicating the Great Recession

To replicate the Great Recession, agents in the model are surprised by a combination of unanticipated shocks in 2006, and they have perfect foresight about the future path of economic variables from that point forward.[11]

An extensive literature has emerged that documents the importance of financial shocks during the boom and bust.[12] To capture the tightening of credit leading into the Great Recession documented by this literature, the minimum down payment in the model is increased effectively from 0% to 10% for three years, and origination costs rise from 0.4% to 1.2%.[13] In addition, the real risk free rate r rises to 3% for eight quarters—corresponding to the hike in the Federal Funds Rate in 2006 and 2007—before dropping back down. However, there is only modest pass-through into long term mortgage rates.

Lastly, to capture greater foreclosure delays and a higher propensity of banks to seek deficiency judgments during the Great Recession, the probability of repossession φ decreases from 50% to 20% and the probability of seeking a deficiency judgment increases from 0% to 50% for three years.[14]

[11] This approach follows Huo and Ríos-Rull (2016) and Krueger et al. (2016b), who also simulate the recession after initializing the economy in the 2000s. Garriga et al. (2014) provide useful discussion of alternative specifications for expectations and shock timing. Initializing the economy to the late 1990s and simulating the boom before the bust generates nearly identical dynamics for the recession and recovery. The appendix provides details.

[12] Favilukis et al. (2016) identifies the relaxation of credit and subsequent reversal as key drivers of recent house price dynamics in a model with exogenous illiquidity and no default. Gerardi, Lehnert, Sherlund and Willen (2008) document a rise from 2000 to 2006 in the use of secondary liens, or "piggyback loans," with high cumulative loan-to-value (CLTV) ratios above 90% or even 100%. By 2006, this type of lending accounted for approximately 50% of new originations and featured an average CLTV of 98.8%. However, Lee, Mayer and Tracy (2013) and Avery, Bhutta, Brevoort, Canner and Gibbs (2010) document that second lien originations dropped off precipitously from their mid-2006 market share of 24.3% to only 2.7% by 2008, and Garriga (2009) and Driscoll, Kay and Vojtech (2016) both report a large spike in loan denial rates. Leventis (2014) also shows a 15 percentage point drop in the average CLTV for these loans between 2006 and 2009 followed by a slow rebound.

[13] Source: FHFA Mortgage Interest Rate Survey.

[14] See Herkenhoff and Ohanian (2015) for evidence of increasing foreclosure delays.

Table 2: Empirical Validation of the Simulated Great Recession and Recovery*

	ΔHouse Prices	ΔConsumption	Max Foreclosures	Max TOM	Ownership
Model	−23.8%	−17.9%	4.3%	51.0 weeks	68.9%/64.3%
Data	−25.9%	−15.0%	5.2%	50.8 weeks	69.0%/64.0%

Sources: (House Prices) FHFA purchase index deflated by the core PCE. (Consumption) Detrended per-capita nondurable consumption deflated by the core PCE. (Foreclosures) Mortgage Bankers Association. (Time On Market) National Association of Realtors. (Ownership) US Census data from 2006 – 2014.

Part of the collapse in economic activity also comes from real shocks in the form of a temporary decline in productivity and an increase in downside labor market risk, consistent with evidence from Fernald (2014a,b), Guvenen et al. (2014), and Krueger et al. (2016b).[15] In the model, total factor productivity drops by 5% for three years. The increase in downside risk is engineered to generate the gradual 6.2% drop in hours observed from 2007 to 2010.[16]

4.1.1 Model Validation: Aggregates and Cross-Section

The model economy's response to the unanticipated shocks replicates the severity of the Great Recession and the slow recovery. As shown in table 2, the model closely mirrors the 25.9% drop in real house prices, the more than doubling of time on the market from 23 to 51 weeks, and the erosion of homeownership from 69% to 64%.[17] Beyond housing, the model captures the steep consumption decline that is also discussed in Pistaferri (2015), Berger et

[15]The left tail shock can also be viewed more generally as reflecting higher uncertainty, consistent with the pre-crisis deterioration in the University of Michigan Consumer Sentiment Survey and with evidence from Stock and Watson (2012), Bloom et al. (2014), and Kozeniauskas et al. (2016) regarding the role of uncertainty in generating the Great Recession.

[16]Specifically, the transition matrix π_s is replaced with new transitions $\widetilde{\pi}_s^{recession}(s'|s)$. Details: $\widetilde{\pi}_s^{recession}(s_2|s) = (1-0.026)\pi_s(s_2|s)$ for all s, $\widetilde{\pi}_s^{recession}(s_j|s) = \pi_s(s_j|s)$ for all s and j =2, 3, and $\widetilde{\pi}_s^{recession}(s_1|s)$ is increased until $\sum_{s'} \widetilde{\pi}_s^{recession}(s'|s) = 1$ for all s.

[17]Figure 9 in the appendix shows the model-generated series, and figure 1 plots the data.

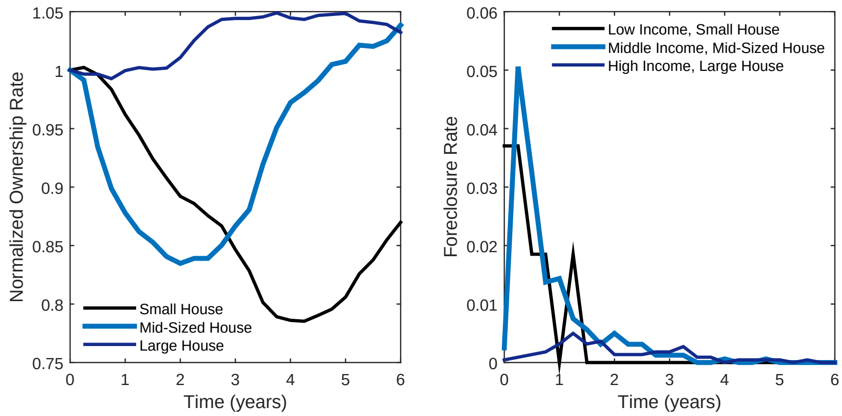


Figure 2: Ownership and foreclosure dynamics across different segments.

al. (2016), Huo and Ríos-Rull (2016), and Kaplan et al. (2016c).[18] Importantly, the model generates an immediate spike in leverage and foreclosures followed by slow endogenous deleveraging. As discussed in sections 4.2 and 4.3, the surge in foreclosures fuels an important credit channel into consumption. Lastly, the model successfully captures the nearly 50% collapse in housing sales that coincides with the price decline, which has puzzled the literature. The ensuing sections explore these successes in depth.

The model also lines up with recent cross-sectional findings about the crisis. Adelino, Schoar and Severino (2016), Foote, Loewenstein and Willen (2016), and Albanesi, DeGiorgi and Nosal (2016) establish a new narrative from that in Mian and Sufi (2009) by showing that credit growth during the boom and defaults during the bust were at least as prevalent in the middle of the income and credit score distributions as they were at the bottom. Figure 2 shows that, in the model, the drop in homeownership comes from owners leaving both small and mid-sized houses, and foreclosures are equally pronounced for

[18]In fact, the absence of the wealthiest households in the calibration causes the model to slightly exaggerate the consumption drop.

Table 3: Identifying the Main Culprits

	Baseline	Excluded	Alone	Bounds
Higher Left Tail Labor Risk				
House Price Trough	−23.8%	−14.8%	−11.6%	[9.0%,11.6%]
Consumption Trough	−17.9%	−12.2%	−4.6%	[4.6%,5.7%]
Peak Foreclosure Rate	4.3%	1.2%	1.5%	[0.9pp,3.1pp]
Peak TOM (Weeks)	51.0	38.8	32.8	[9.6,12.2]
Tighter Downpayment Constraint				
House Price Trough	−23.8%	−19.2%	−5.6%	[4.6%,5.6%]
Consumption Trough	−17.9%	−13.2%	−4.0%	[4.0%,4.7%]
Peak Foreclosure Rate	4.3%	2.4%	0.7%	[0.1pp,1.9pp]
Peak TOM (Weeks)	51.0	40.1	25.1	[1.9,10.9]

To quantify each shock, two differences are calculated: (1) excluded vs. baseline, and (2) alone vs. steady state (zero by construction, except for foreclosures).

middle income and low income borrowers.[19] Intuitively, pre-crisis leverage is actually higher among middle-income borrowers because their lower default risk gives them greater access to credit, as shown in figures 12 and 13. When the crisis hits, these middle-income borrowers are most exposed in terms of leverage, but low-income borrowers are more financially fragile. Overall, both groups default at similar frequencies during the crisis.

4.1.2 Identifying the Main Culprits

This empirical validation provides support for using the model to identify the main culprits behind the recession by unpacking the joint contribution of all the shocks. This decomposition is achieved by re-simulating the model in two ways: first, by removing one shock at a time from the baseline simulation, and next, by introducing one shock at a time to the no-shock equilibrium. These two decompositions then create bounds for the impact of each shock.

[19] In fact, lower house prices today plus future anticipated price growth during the recovery push up ownership of large houses. Consistent with this finding, Rappaport and Willen (2014) show that the median borrower since 2008 has had a higher credit score.

Higher Left Tail Labor Risk Higher left tail labor risk and tighter downpayment constraints have the largest impact.[20] Table 3 documents that isolating the left tail shock causes a 9.0% – 11.6% decline in house prices, an approximate 5% drop in consumption, and a 10+ week surge in time on the market. However, the foreclosure bounds are substantially wider. As discussed in section 4.2.1, foreclosures are highly *nonlinear* and depend on a complex interaction of income shocks and declines in house prices and liquidity. Importantly, even though the erosion of lower-end earnings is gradual, the left tail shock has an immediate impact by increasing precautionary behavior and reducing housing demand. Highly indebted, financially fragile owners rush to put their houses on the market, which causes prices to decline and selling delays to build up as housing liquidity evaporates. Lastly, labor market risk is a key determinant of housing tenure decisions. Households respond to higher labor risk, and with it greater foreclosure risk, by shifting into renter status. Absent the left tail shock, declining house prices from the other shocks produce a counterfactual *rise* in homeownership by increasing home affordability.

Tighter Downpayment Constraint As in Favilukis et al. (2016) and Garriga et al. (2014), evolving credit conditions have a substantial impact on the housing market. The tightening of the downpayment constraint causes house prices and consumption to both fall by approximately 5%, and in the presence of other shocks, tighter credit conditions contribute substantially to the elevated foreclosure rate and time on the market. The reduced ability during the downturn to extract equity through refinancing forces many

[20] The interest rate and TFP shocks have only modest effects, consistent with Arellano, Bai and Kehoe (2012), Kehoe, Midrigan and Pastorino (2016), and Midrigan and Philippon (2016), which suggests that hikes in the federal funds rate were not to blame for the crash. See table 7 and figure 10 in the appendix for more of the decomposition. Removing recourse and foreclosure delays exaggerates the decline in ownership to 60% at the trough.

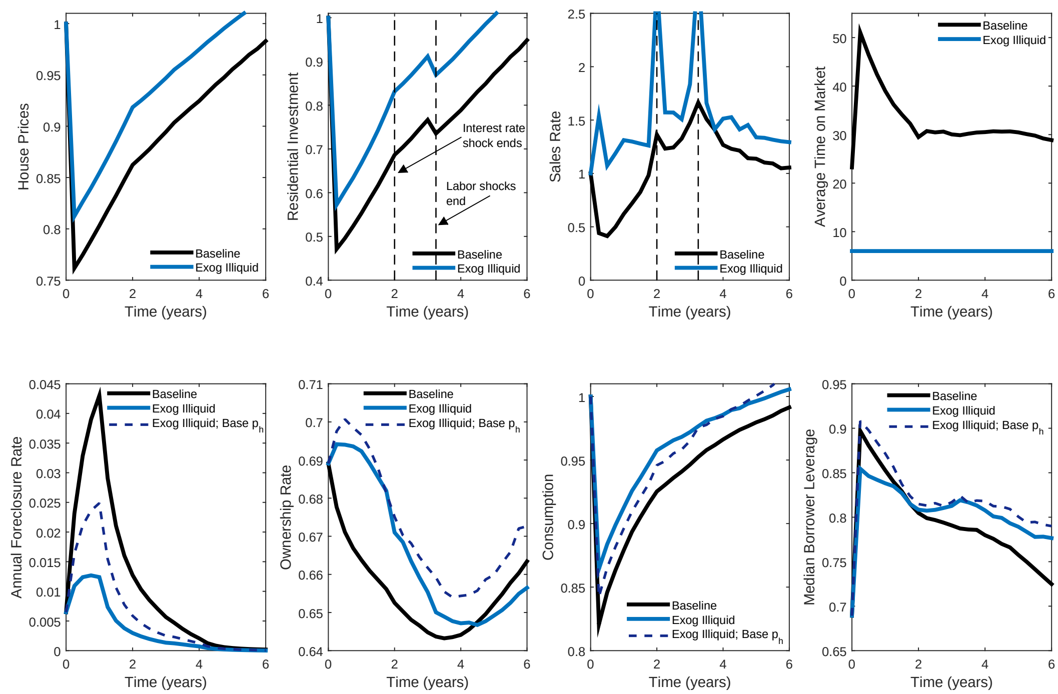


Figure 3: Baseline vs. exogenous illiquidity (no search; 6% transaction cost).

financially distressed homeowners to put their houses on the market, suffer long selling delays because of their small equity cushions (an issue discussed more thoroughly in section 4.2.1), and frequently end up in default.

4.2 The Role of Endogenous Housing Illiquidity

Recent work has highlighted the importance of illiquid assets on household balance sheets for consumption.[21] This section investigates how illiquidity in the housing market has influenced consumption during the Great Recession and recovery. Relative to the existing literature, this paper *endogenizes* housing illiquidity with search frictions. This departure provides novel

[21] Kaplan and Violante (2014) show that consumption is more sensitive to shocks when assets with transaction costs comprise a large fraction of household portfolios, and Kaplan, Moll and Violante (2016a) find that monetary policy transmission is noticeably altered.

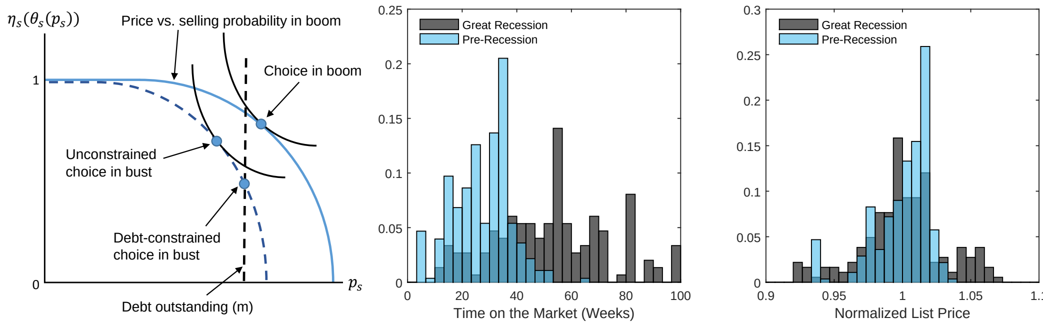


Figure 4: (Left) List prices and selling probabilities in booms and busts; dispersion of TOM (middle) and prices (right) before and during the crisis.

channels of transmission to consumption that amplify the magnitude and persistence of shocks.

To assess the role of endogenous illiquidity, the shocks from section 4.1 are fed into a version of the model with a Walrasian housing market where illiquidity arises only from an exogenous 6% transaction cost.[22] Figure 3 reveals three striking differences between the responses of these two economies. First, foreclosure activity is almost four times greater in the baseline than with exogenous illiquidity. Second, the drop in house prices, residential investment, and consumption are substantially amplified by endogenous illiquidity. Lastly, selling delays prove key to generating a large and protracted slump in housing sales and homeownership, whereas the economy with exogenous illiquidity generates a spike in sales and an initial rise in ownership.

4.2.1 Illiquidity, Debt Overhang, and Default

The enhanced foreclosure response in the baseline economy emerges from the interaction of debt overhang, endogenously tighter credit constraints, and search-induced illiquidity in the housing market.

[22]See Díaz and Luengo-Prado (2010), Bajari, Chan, Krueger and Miller (2013), Iacoviello and Pavan (2013), Berger et al. (2016), and Berger and Vavra (2015).

Debt Overhang In a Walrasian market, houses always sell without delay. However, with search frictions, sellers face a trade-off between list price and time on the market that moves with economic conditions. The left panel of figure 4 illustrates this trade-off during a housing boom and bust. In the boom, sellers sell quickly and at a high price. In the bust, the (p_s, η_s) locus shifts inward, and sellers prefer to adjust along both margins by setting a lower price and taking longer to sell. However, outstanding mortgage debt distorts the list price decision upward, $p_s \geq m - y$, and causes *debt overhang*. Highly leveraged sellers must set a higher price to ensure that they can pay off their loan upon selling, which leads to elevated time on the market. The middle and right panels of figure 4 show the distribution of time on the market and list prices, respectively. Seller heterogeneity creates dispersion, and this dispersion increases during the Great Recession. For time on the market, higher leverage resulting from the house price decline causes the distribution to fan to the right because debt-constrained sellers are forced to post high prices. These sellers account for the fatter right tail of the price distribution, while an increase in distressed sellers comprise the left tail.

Foreclosures and the "Double Trigger" Foreclosures peak at 4.3% in the baseline economy and only 1.3% with exogenous illiquidity. The larger house price drop in the baseline economy (discussed in section 4.2.2) provides a partial explanation, but in a counterfactual with the same house price path, the economy with exogenous illiquidity experiences only about half as many foreclosures. Debt-induced selling delays account for the bulk of the difference. Intuitively, if a homeowner experiences a large income drop and cannot afford to make mortgage payments, they may resort to putting their house up for sale. However, selling delays increase the probability of financial

Table 4: Amplification Due To Endogenous Housing Illiquidity

	Baseline	Exogenous Illiquidity	Amplification
House Price Trough	−23.8%	−18.8%	26.6%
Res. Investment Trough	−52.9%	−42.7%	23.9%
Consumption Trough	−17.9%	−13.6%	31.6%

Endogenous (baseline) vs. exogenous illiquidity (6% transaction cost).

insolvency and default after owners lose the ability to make payments while their house sits on the market. In short, the endogenous deterioration in housing liquidity spills over into higher foreclosure risk, *even for homeowners who have an equity cushion.* Of course, financially distressed owners can attempt to smooth consumption by extracting equity through refinancing, but the higher foreclosure risk causes credit supply to tighten.

These findings present a modified picture of foreclosure triggers. According to current wisdom encapsulated in Campbell and Cocco (2015), Gerardi, Herkenhoff, Ohanian and Willen (2015), and Schelkle (2015), a combination of negative equity and negative income shocks create a "double trigger" for foreclosure, where negative equity is strictly necessary. However, with endogenous illiquidity, even sellers with positive equity face non-trivial selling delays that could threaten them with future default. Thus, these results suggest complementing the deterministic double trigger with a region of stochastic illiquidity-induced default that reflects the role of probabilistic selling outcomes influenced by outstanding debt.

4.2.2 Amplification, Liquidity Spirals, and the Credit Channel

Besides fueling foreclosures, longer selling delays increase the severity of the recession. Quantitatively, table 4 shows that incorporating the endogenous decline in housing illiquidity magnifies the drop in house prices, residential investment, and consumption by 26.6%, 23.9%, and 31.6%, respectively, relative to the model with exogenous transaction costs.[23]

Deteriorating liquidity in the housing and mortgage markets drives this amplification. Conceptually, the value of housing V can be decomposed as

$$V = \text{User Cost (UC)} + \underbrace{\text{Housing Liquidity (HL)}}_{\text{low selling delays}} + \underbrace{\text{Credit Liquidity (CL)}}_{\text{low default premia}} \quad (15)$$

The user cost encapsulates the fundamental value of housing from implicit rents and the resale value of the house. The housing liquidity component captures the premium from ease of selling, and the credit liquidity component reflects the value associated with equity extraction through borrowing. During a housing bust, housing illiquidity makes selling more difficult, uncertain, and time-consuming, which increases the riskiness of homeownership and depresses housing demand. Furthermore, long delays force sellers to cut consumption to continue making mortgage payments while their house sits on the market. Credit illiquidity raises the cost of borrowing and reduces access to credit, which also depresses housing demand, house prices, and consumption.

Selling delays and default premia interact to create *liquidity spirals* ($\sigma_{HL,CL} > 0$ in equation 16) akin to Brunnermeier and Pedersen (2009).

$$\sigma_V^2 = \sigma_{UC}^2 + \sigma_{HL}^2 + \sigma_{CL}^2 + 2\sigma_{UC,HL} + 2\sigma_{UC,CL} + 2\sigma_{HL,CL} \quad (16)$$

As discussed in section 4.2.1, long selling delays spill over into higher foreclosure risk, which leads to elevated default premia in the mortgage market. In other words, reduced housing liquidity causes a drop in credit liquidity. Thus, by significantly enhancing foreclosure activity, endogenous housing

[23]For a 12% transaction cost, house prices fall 20.7% and consumption falls 17.0%.

illiquidity amplifies the familiar credit channel of macroeconomic transmission. In reaction to higher borrowing costs, many homeowners looking to extract equity switch from refinancing to selling, and the flood of houses—particularly from indebted sellers posting high prices—clogs up the market and reduces housing liquidity. The model with exogenous illiquidity omits these feedback loops ($\sigma_{UC,HL} = \sigma_{HL,CL} = 0$) and fails to replicate the volatility in the data.

4.2.3 Procyclical Sales and Homeownership

The endogenous decline in housing liquidity during the crisis also accounts for the sharp drop in sales and helps resolve the puzzle of positively correlated movements in prices and sales discussed by Ngai and Sheedy (2015) and Ríos-Rull and Sánchez-Marcos (2012). Figure 3 shows that, with only exogenous transaction costs, plummeting house prices spur a counterfactual *surge* in sales and ownership at the beginning of the crisis as buyers take advantage of greater affordability and expected future price growth. Endogenous housing illiquidity short circuits this response. First, it stymies sellers with long delays, and second, it stems the inflow of buyers by exacerbating credit costs. Long term mortgage debt moderates but prolongs the sales slump by allowing owners to "ride out" the crisis while their house sits on the market. With short term debt, owners need to roll over their debt each period, and many would fall into default when their equity evaporates.

4.3 Balance Sheet Effects: Aggregate and Cross Section

A bevy of empirical evidence identifies the house price crash and resulting deterioration in household balance sheets as key factors behind the severity of the Great Recession. One message that emerges from Mian et al. (2013),

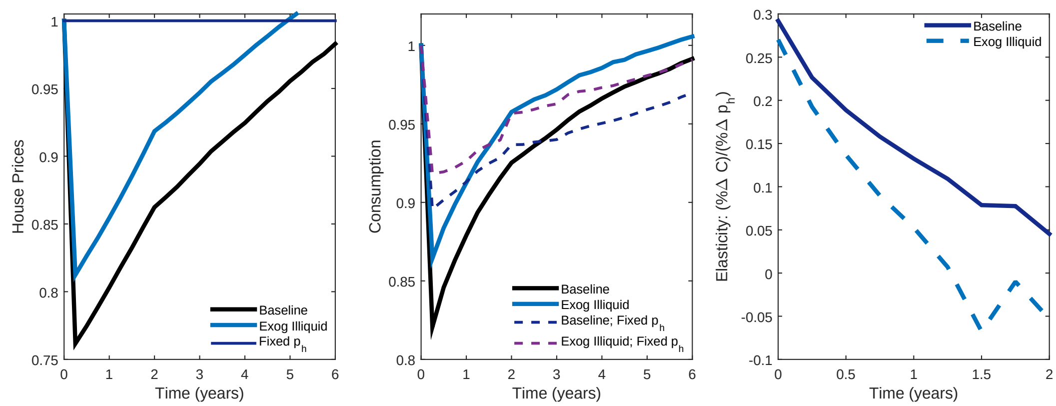


Figure 5: The sensitivity of consumption to house prices with and without endogenous illiquidity. The elasticity is % change in consumption between "baseline" and "fixed p_h" divided by % change in p_h.

Dynan (2012), Keys, Piskorski, Seru and Yao (2014), Midrigan and Philippon (2016), and others is that the cross-sectional distribution of mortgage leverage shapes aggregate consumption dynamics. However, as Berger et al. (2016) argue, standard representative agent models fail to replicate these large balance sheet effects. This section demonstrates that debt overhang, liquidity spirals, and the enhanced credit channel reconcile the theory with the data.

The decline in house prices represents an important driver of the fall in consumption. Absent the house price crash, the consumption decline attenuates by 39%. The implied elasticity of consumption to house prices of 0.29 comports with Mian et al. (2013) and Kaplan et al. (2016c), but it is *shock and time dependent.*[24] The elasticity falls to 0.05 two years into the recession, and the elasticity is only 0.12 with the left tail shock alone. In other words, consumption responds in a highly non-linear manner to house prices. Appendix figures 14 and 15 show the full decompositions.

Furthermore, **endogenous housing illiquidity** increases the persistence

[24] Kaplan et al. (2016b) also make this point about shock dependence.

Table 5: Decomposing the Consumption Decline

	Renters	Homeowners	LTV > 80%	0% < LTV < 50%
Pre-Crisis Share	19.1%	80.9%	20.3%	39.4%
Share of Decline	5.3%	94.7%	30.8%	15.3%

Consumption shares by housing tenure and borrower LTV.

of balance sheet effects. The right panel of figure 5 reveals that the elasticity upon impact is nearly identical, but after one year, the effect dissipates almost entirely with exogenous illiquidity. Intuitively, selling delays prolong households' response to economic shocks. Furthermore, the middle panel confirms the findings in section 4.2.2 that consumption falls further in the baseline economy. Selling delays curtail credit and force owners to cut consumption while their house sits on the market. Measuring the pure effect of debt overhang from selling delays, consumption falls by 10.4% with endogenous illiquidity and only 8.2% with exogenous transaction costs.

While significant, these aggregate results mask starker balance sheet effects in the cross-section. Table 5 demonstrates that owners account for almost 95% of the aggregate consumption decline, which exceeds their 80% share of consumption before the crisis. By contrast, renters contribute minimally to the aggregate decline despite accounting for nearly one-fifth of pre-crisis consumption.[25] Moreover, highly leveraged owners account for twice as much of the decline as do owners with significant equity, while the reverse holds true before the crisis. These results fit with empirical evidence at both the zip code and household level showing that the strongest consumption declines between 2006 and 2009 occurred where leverage was highest.[26]

Figure 6 further illustrates the heterogeneity in consumption responses. For

[25]Similar to Krueger, Mitman and Perri (2016a) for the bottom 40% of households.

[26]See Mian et al. (2013), Keys et al. (2014), Aladangady (2015), and Dynan (2012).

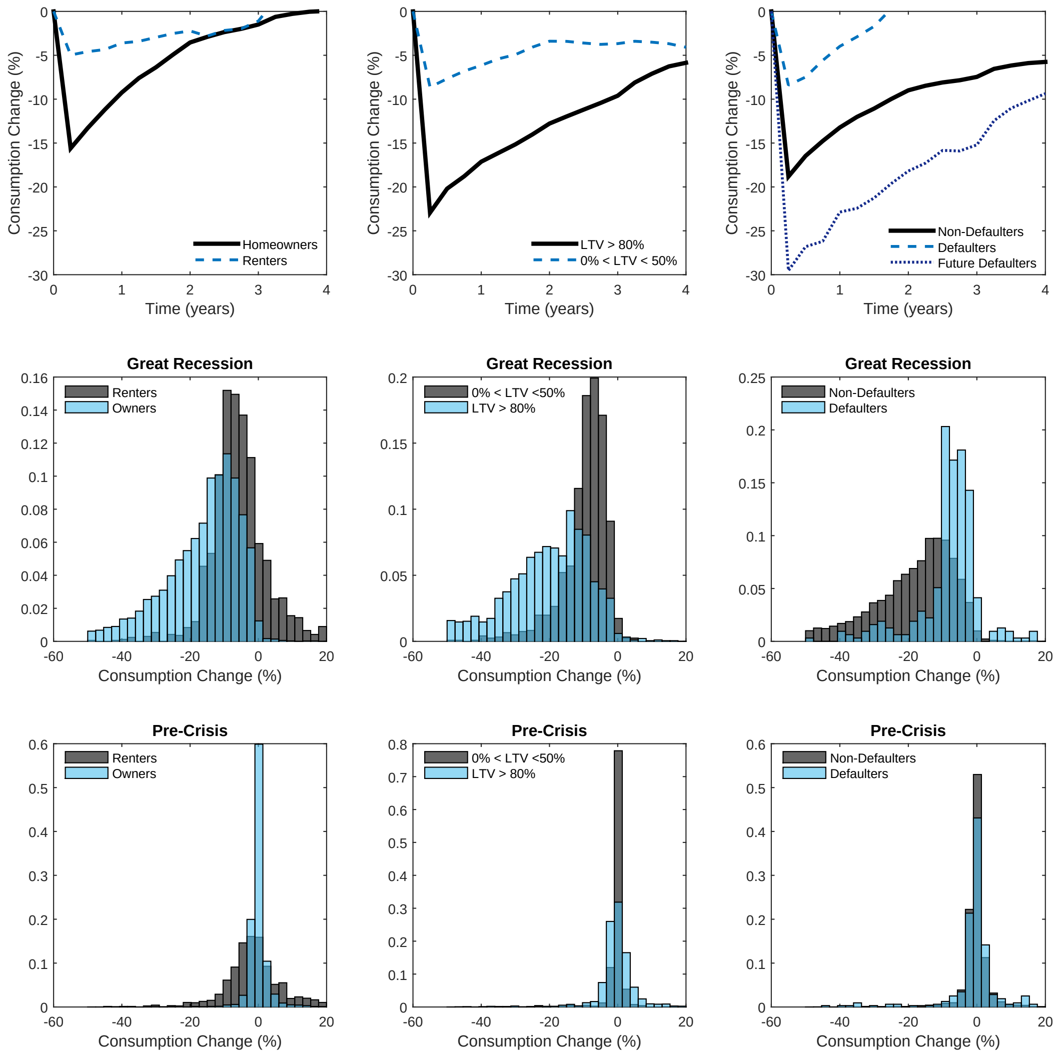


Figure 6: Consumption dynamics by ownership status, leverage, and default status. "Future defaulters" are those who default 1 year *after* the beginning of the Great Recession. The histogram represents the change in consumption between subsequent periods pre-crisis and at the onset of the Great Recession.

Table 6: Gross vs Net Positions of Household Portfolios

	NW Decile 4		NW Decile 6		NW Decile 8	
	Renter	Owner	$h = h_1$	$h = h_2$	$h = h_2$	$h = h_3$
Consumption Decline	−3.7%	−30.7%	−10.9%	−33.3%	−13.7%	−24.8%
Pre-Crisis Leverage	—	76.6%	62.0%	80.0%	64.3%	81.5%

Net worth (NW) = liquid assets + housing − mortgage debt.

example, not only do homeowners experience a larger *average* consumption decline during the crisis, but their consumption change histogram fans out noticeably to the left. By contrast, the distribution for renters remains almost symmetric and exhibits less dispersion. Typically, though, homeowners are the ones with less consumption variability, as shown in the bottom left panel. By way of explanation, wealthier households who can better self-insure tend to select into ownership, and access to mortgage credit provides another vehicle for consumption smoothing.

The decline in house prices and liquidity during the crisis reverses the risk-sharing advantages of ownership. However, the ability to default affords owners some downside protection. The top right and middle right panels show that defaulters experience much smaller declines in consumption, especially compared to financially distressed homeowners who delay default.

Table 6 and appendix figure 17 demonstrate the importance of decomposing net worth into **gross positions** for quantifying balance sheet effects. Notably, the consumption of renters in the 4th net worth decile falls by only 3.7%, whereas homeowners in the 4th decile see consumption drop by a staggering 30.7%. Given the 46.5% ownership rate of the 4th decile, consumption falls by 16.3% overall for this group, but this number masks divergent responses of owners and renters. Similarly, within a given net worth decile, owners who have higher housing wealth and larger mortgages experience sharper falloffs in consumption than those who have smaller houses and lower leverage.

Lastly, **endogenous housing illiquidity** enhances balance sheet effects differentially throughout the cross-section.[27] Whereas renters experience the same consumption drop in both economies, owners undergo a larger consumption drop with endogenous housing illiquidity. Effects increase with leverage, as seen by the consumption of owners with high loan-to-value fanning out more to the left in the baseline.

4.4 Interventions to Lower Mortgage Rates

Boldrin, Garriga, Peralta-Alva and Sanchez (2016) argue that, because of the irreversibility of construction, sizable declines in housing demand create a large surplus of unneeded residential structures that cannot be repurposed for other economic activities. Furthermore, the low depreciation rate of residential structures drags out the recovery of house prices and, by extension aggregate consumption, because of the feedback between housing liquidity, credit liquidity, and household balance sheets. Given that widespread policies to shrink the stock of housing inventories are often infeasible, a viable alternative is to pursue policies aimed at reducing the cost of borrowing.

Between 2009 and 2011, policymakers undertook several interventions to reduce long-term interest rates, and real 30-year mortgage rates indeed fell from 3% to under 1.5%. However, did the interventions *cause* the lower rates? Krishnamurthy and Vissing-Jorgensen (2011) and Joyce, Miles, Scott and Vayanos (2014) provide empirical evidence that suggests an affirmative answer. This section looks instead at the *consequences* of this decline in interest rates for consumption and at the role of transmission through the housing market.

[27] Figure 16 in the appendix plots cross-sectional consumption with exogenous illiquidity.

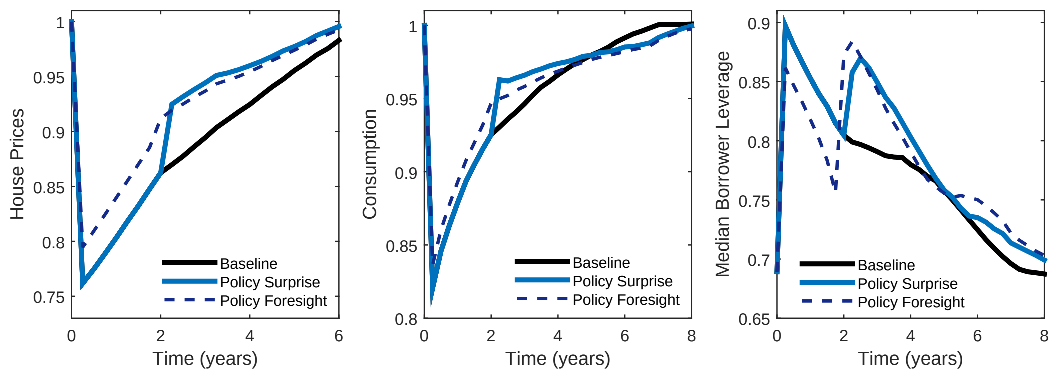


Figure 7: The effects of lower mortgage rates from the policy intervention.

The decrease in mortgage rates is engineered in the model via lower servicing costs. When implemented by surprise, the decline in mortgage rates causes house prices and consumption to jump by 6.3% and 3.5%, respectively, as shown in figure 7. When announced ahead of time, the policy causes an *immediate* but muted response of 4.3% for house prices and 1.9% for consumption. In both cases, owners extract equity when they refinance. Empirically, Di Maggio, Kermani and Palmer (2016) ascribe \$600 billion in refinancing and \$76 billion in higher consumption to the interventions. However, while this equity extraction fuels higher consumption initially, consumption subsequently slows from the effects of higher debt.

Multiple channels account for the increase in consumption from lower mortgage rates. First, intertemporal substitution slows the process of deleveraging. Second, the increase in house prices from cheaper borrowing creates balance sheet effects that fuel consumption gains as in section 4.3. To quantify the role of balance sheet effects, figure 8 plots the path of consumption with and without the house price response to the decline in rates.

The left panel shows that, when the rate decline is announced in advance, the entire initial increase and almost half of the post-implementation increase

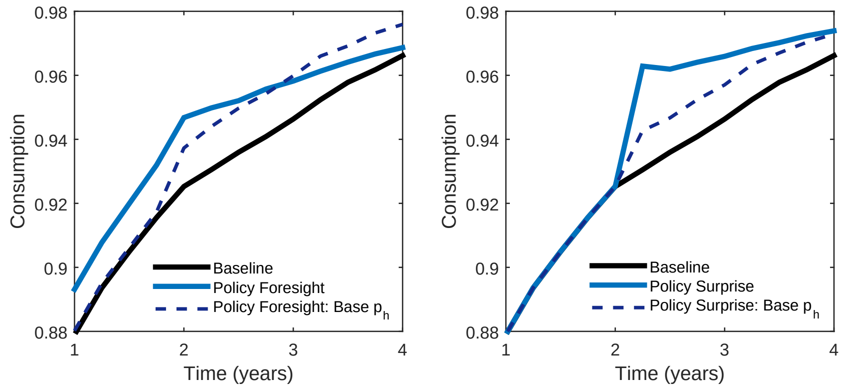


Figure 8: (Left) Balance sheet effects when the rate decline is announced in advance; (right) balance sheet effects in the event of a surprise decline in rates.

in consumption evaporate when the endogenous house price response is shut down. In the policy surprise case, shutting down the endogenous response of house prices attenuates over 62% of the aggregate consumption gain.

Much of the effectiveness of pushing down long term rates dissipates when balance sheet effects and the endogenous response of house prices are ignored. As in section 4.3, house prices are a powerful transmission channel that amplify shocks and policy interventions via household balance sheets.

Balance sheet effects also explain the substantial heterogeneity in consumption shown in appendix figure 18. Whereas renter consumption is naturally unresponsive to lower mortgage rates, homeowner consumption rises by 4.5% upon impact. Furthermore, these gains are more pronounced among highly leveraged borrowers. While homeowners with less than 50% leverage see only a 2.5% rise in consumption, homeowners with more than 80% leverage experience a 6.0% jump. Thus, the *aggregate* consequences of lower mortgage rates depend on the *distribution* of leverage in the economy.

5 Conclusion

The causes of the housing market collapse and its connection to the sharp decline in consumption during the Great Recession are explored using a model with housing search frictions, endogenous credit constraints, and mortgage default. Several key insights emerge to guide thinking about the relationship between housing and consumption. First, endogenous housing illiquidity amplifies the response of the housing market to economic shocks by creating a feedback loop between debt overhang, default, and house prices. Second, house prices and liquidity have large effects on consumption via changes in household balance sheets. These effects vary in magnitude throughout the cross-section, including among households with similar net worth but different gross portfolio positions. Furthermore, endogenous housing illiquidity increases the persistence of this balance sheet transmission from house prices to consumption. Importantly, these mechanisms are far more potent during periods of large house price declines and represent an important nonlinearity that distinguishes severe recessions from typical business cycles. Lastly, policy interventions to reduce the cost of borrowing have powerful effects on aggregate consumption through balance sheet effects from endogenously higher house prices. Exploring regional heterogeneity, segmentation, and the link between housing and labor dynamics is left to future work.

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A Supplementary Tables and Figures

This appendix provides companion material to the tables and figures presented in the main text.

A.1 Replicating the Great Recession

Table 2 in the main text presents the quantitative response of key housing and macroeconomic variables during the simulated Great Recession, and figure 9 below presents the full time series. Importantly, these baseline series also appear in figure 3 from the main text alongside the response of the economy with exogenous transaction costs.

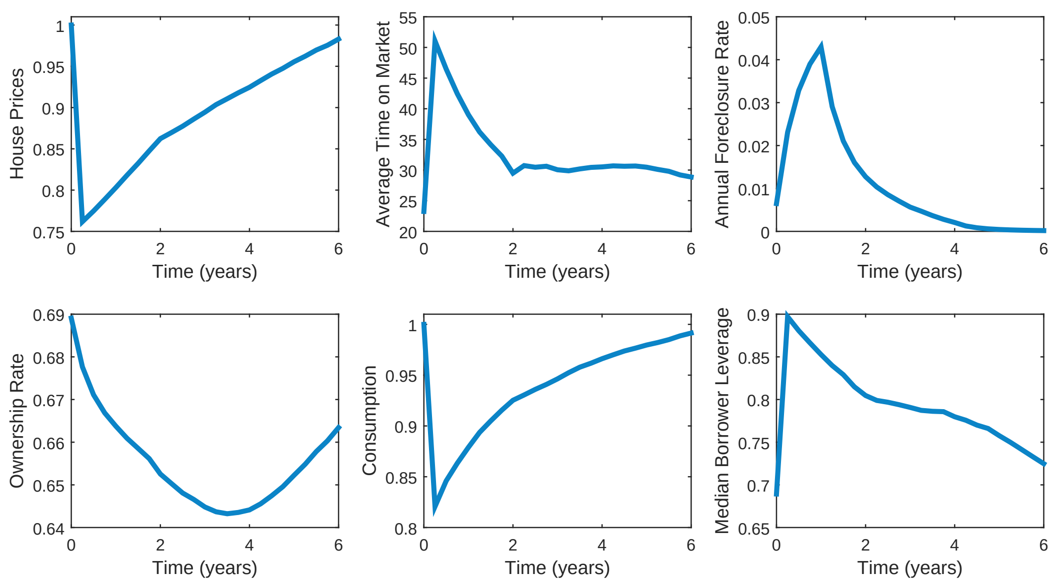

Figure 9: The simulated recession/recovery: (TL) house prices, (TM) time on market, (TR) foreclosures, (BL) ownership, (BM) consumption, (BR) leverage.

A.2 Decomposing the Great Recession

Section 4.1.2 in the main text highlights the importance of higher left tail labor risk and tighter downpayment requirements for generating the Great Recession. The role of the TFP and interest rate shocks is also briefly discussed in a footnote. Figure 10 and table 7 below present the full decomposition.

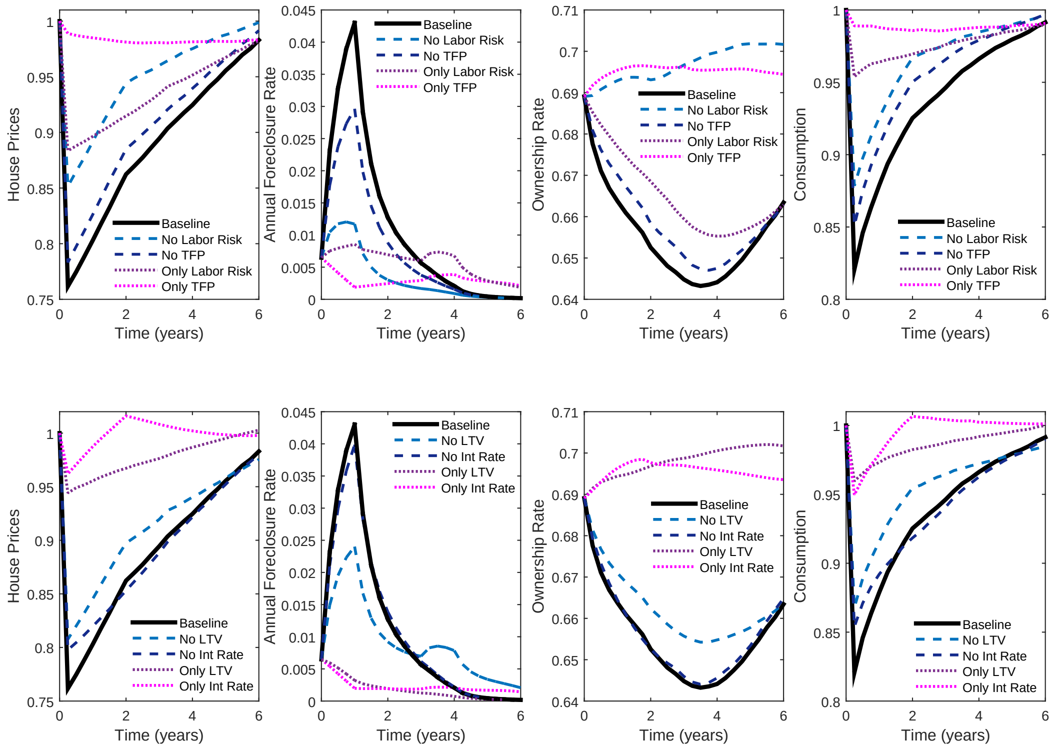

Figure 10: Top: disentangling the effects of real shocks (lower TFP and left tail labor market risk shock). Bottom: disentangling the effects of financial shocks (tighter downpayment constraint and higher interest rates).

Table 7: Measuring the Impact of Real and Financial Shocks

	Baseline	Excluded	Alone	Bounds
Real Shocks				
Higher Left Tail Labor Risk				
House Price Trough	−23.8%	−14.8%	−11.6%	[9.0%,11.6%]
Consumption Trough	−17.9%	−12.2%	−4.6%	[4.6%,5.7%]
Peak Foreclosure Rate	4.3%	1.2%	1.5%	[0.9pp,3.1pp]
Peak TOM (Weeks)	51.0	38.8	32.8	[9.6,12.2]
TFP Drop				
House Price Trough	−23.8%	−21.7%	−2.0%	[2.0%,2.1%]
Consumption Trough	−17.9%	−14.9%	−1.5%	[1.5%,3.0%]
Peak Foreclosure Rate	4.3%	3.0%	1.7%	[1.1pp,1.3pp]
Peak TOM (Weeks)	51.0	47.3	25.7	[2.5,3.7]
Financial Shocks				
Tighter Downpayment Constraint				
House Price Trough	−23.8%	−19.2%	−5.6%	[4.6%,5.6%]
Consumption Trough	−17.9%	−13.2%	−4.0%	[4.0%,4.7%]
Peak Foreclosure Rate	4.3%	2.4%	0.7%	[0.1pp,1.9pp]
Peak TOM (Weeks)	51.0	40.1	25.1	[1.9,10.9]
Interest Rate Increase				
House Price Trough	−23.8%	−20.2%	−3.8%	[3.6%,3.8%]
Consumption Trough	−17.9%	−14.6%	−5.0%	[3.3%,5.0%]
Peak Foreclosure Rate	4.3%	4.0%	1.2%	[0.3pp,0.6pp]
Peak TOM (Weeks)	51.0	44.2	27.2	[4.0,6.8]

To quantify each shock, two differences are calculated: (1) excluded vs. baseline, and (2) alone vs. steady state (zero by construction, except for foreclosures).

A.3 The Full Boom, Bust, and Recovery

The housing crash from 2006 – 2011 was preceded by a boom in house prices. However, under the premise that the crash was completely unforeseen, this paper (along with Huo and Ríos-Rull (2016), Krueger et al. (2016a), and others) studies only the Great Recession and recovery. Nevertheless, Garriga and Hedlund (2016) generate the housing boom by initializing the economy in the late 1990s and shocking it with lower interest rates and higher TFP that are perceived to be permanent.[28] Importantly, simulating the bust after the boom does not noticeably alter the dynamics of the recession and recovery. Figure 11 below shows the full boom-bust-recovery episode.

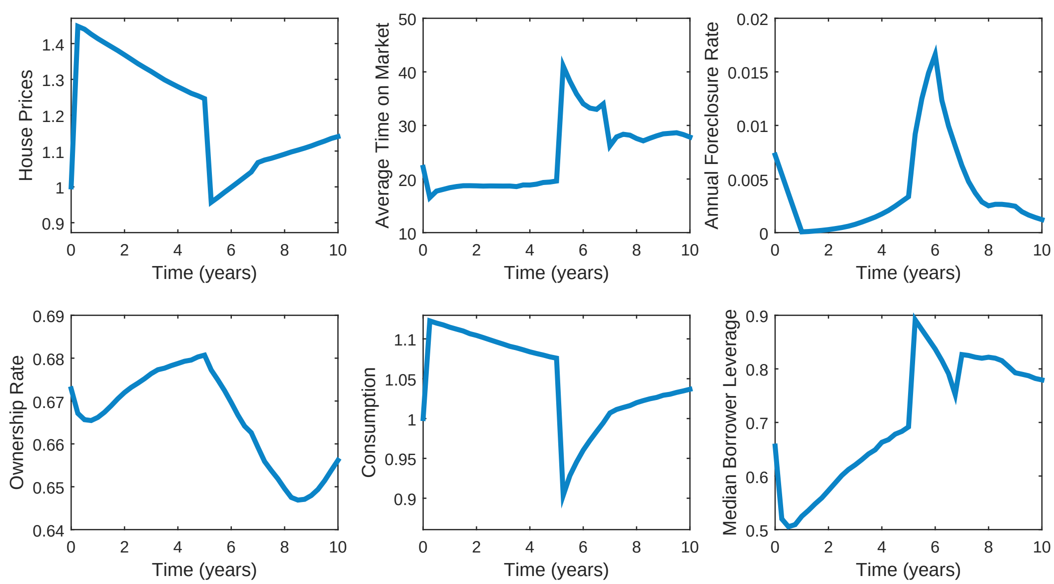

Figure 11: The simulated boom/bust/recovery: (TL) house prices, (TM) TOM, (TR) foreclosures, (BL) ownership, (BM) consumption, (BR) leverage.

[28]Other papers generate the boom-bust episode as well but often miss the recovery.

A.4 Cross-Sectional Validation

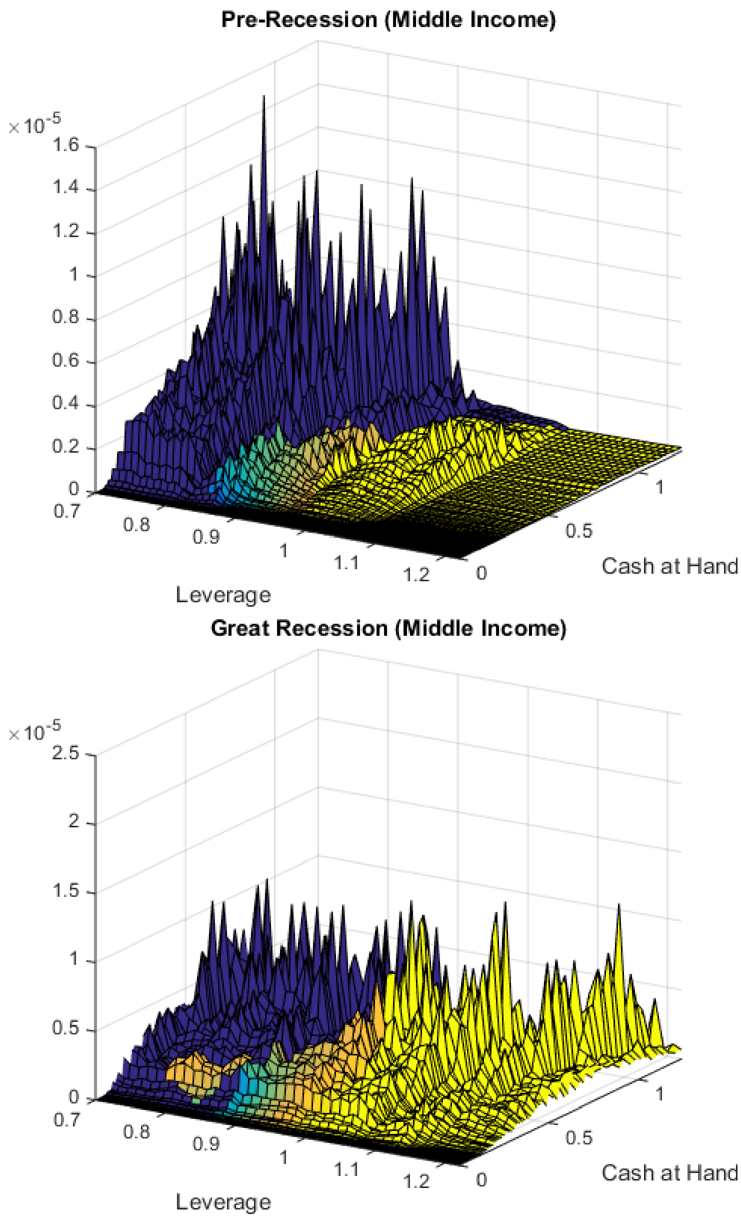

Figure 12: Distribution of *middle income households* over mortgage debt and liquid assets with shaded default probabilities: (top) pre-recession, (bottom) Great Recession. Lighter shading represents more likely default.

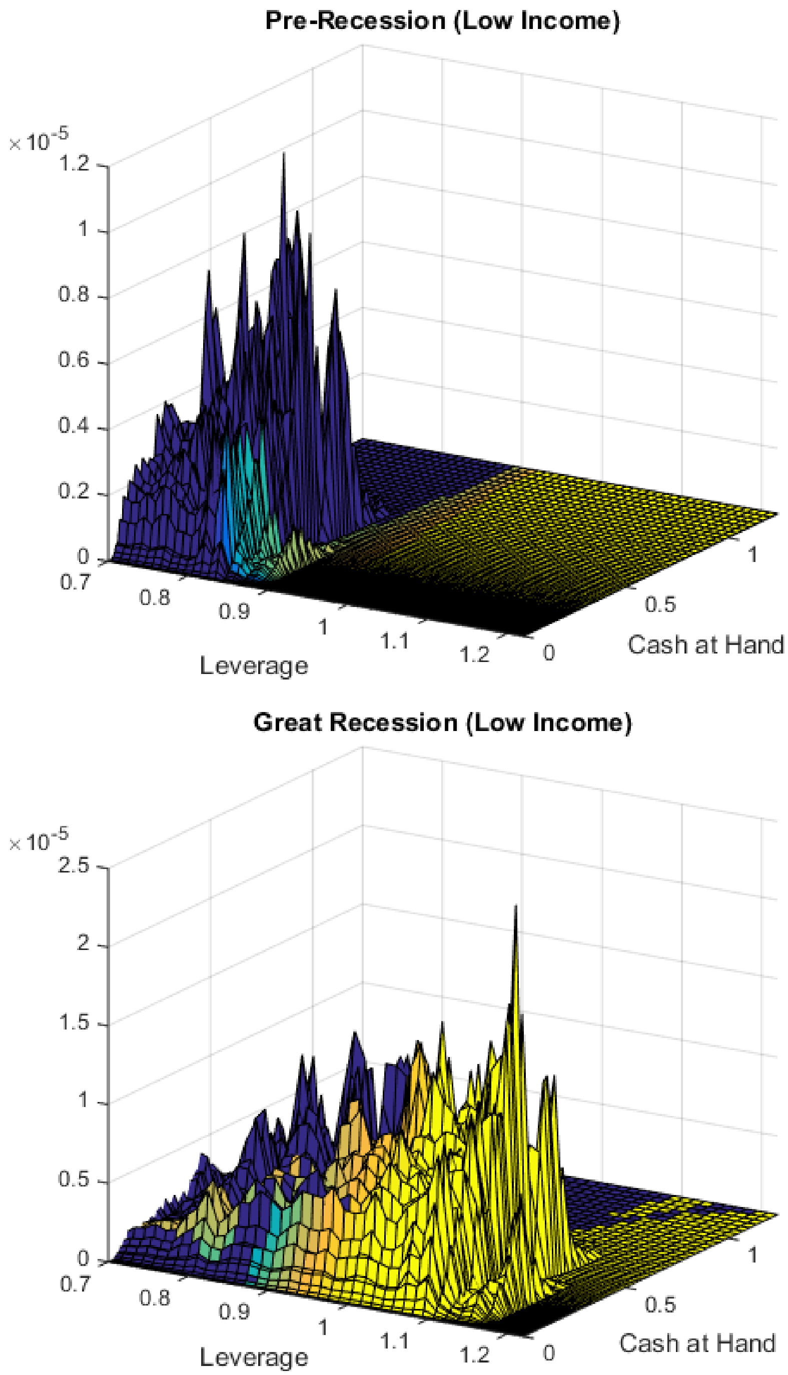

Figure 13: Distribution of *low income households* over mortgage debt and liquid assets with shaded default probabilities: (top) pre-recession, (bottom) Great Recession. Lighter shading represents more likely default.

A.5 Quantifying Balance Sheet Effects

Section 4.3 makes the point that the elasticity of consumption to house price movements is nonlinear and depends on the underlying shocks generating the price decline. Figures 14 and 15 below visually demonstrate these points.

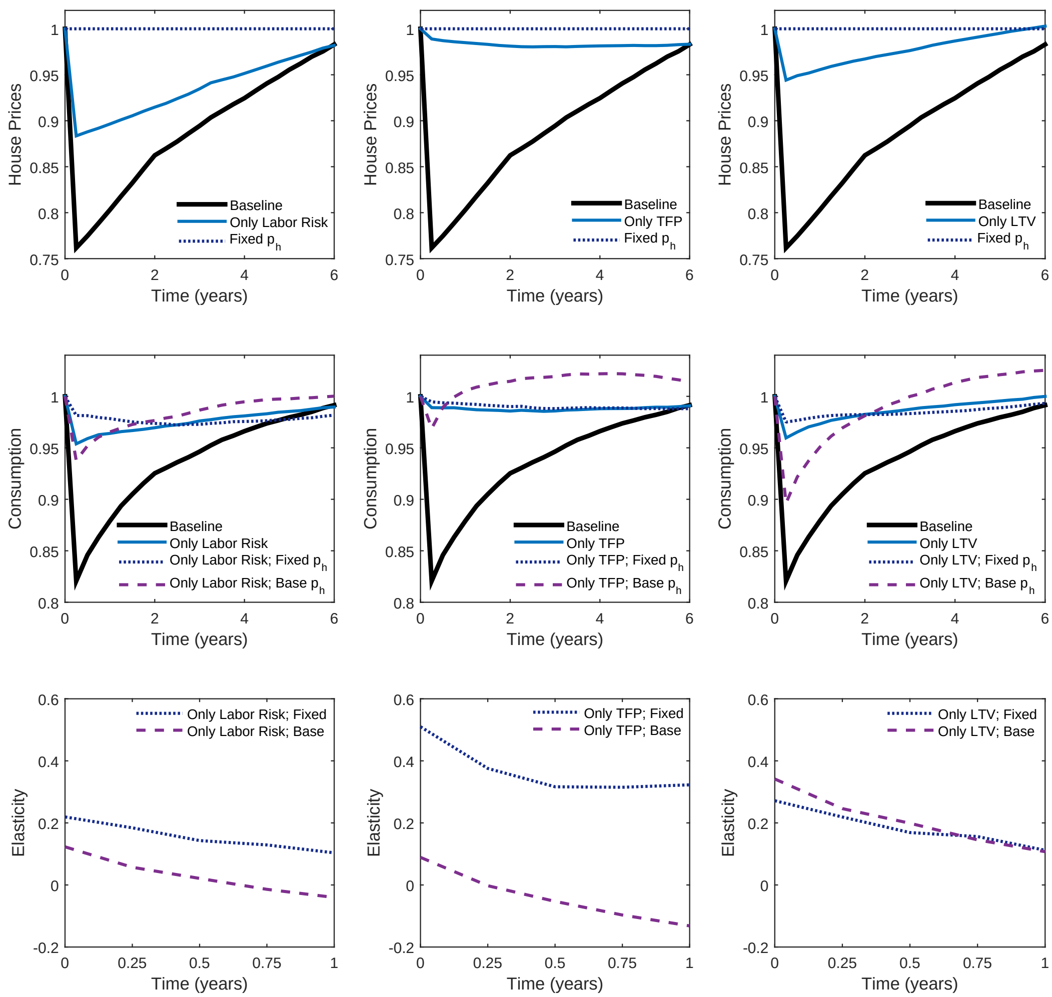

Figure 14: Consumption response to house price movements conditional on *only one* shock hitting the economy. Top: house prices; middle: consumption; bottom: elasticity of consumption to house prices. The "fixed" elasticity uses the "fixed $p(h)$" house price trajectory as the reference, whereas the "baseline" elasticity uses the "baseline $p(h)$" house price trajectory as the reference.

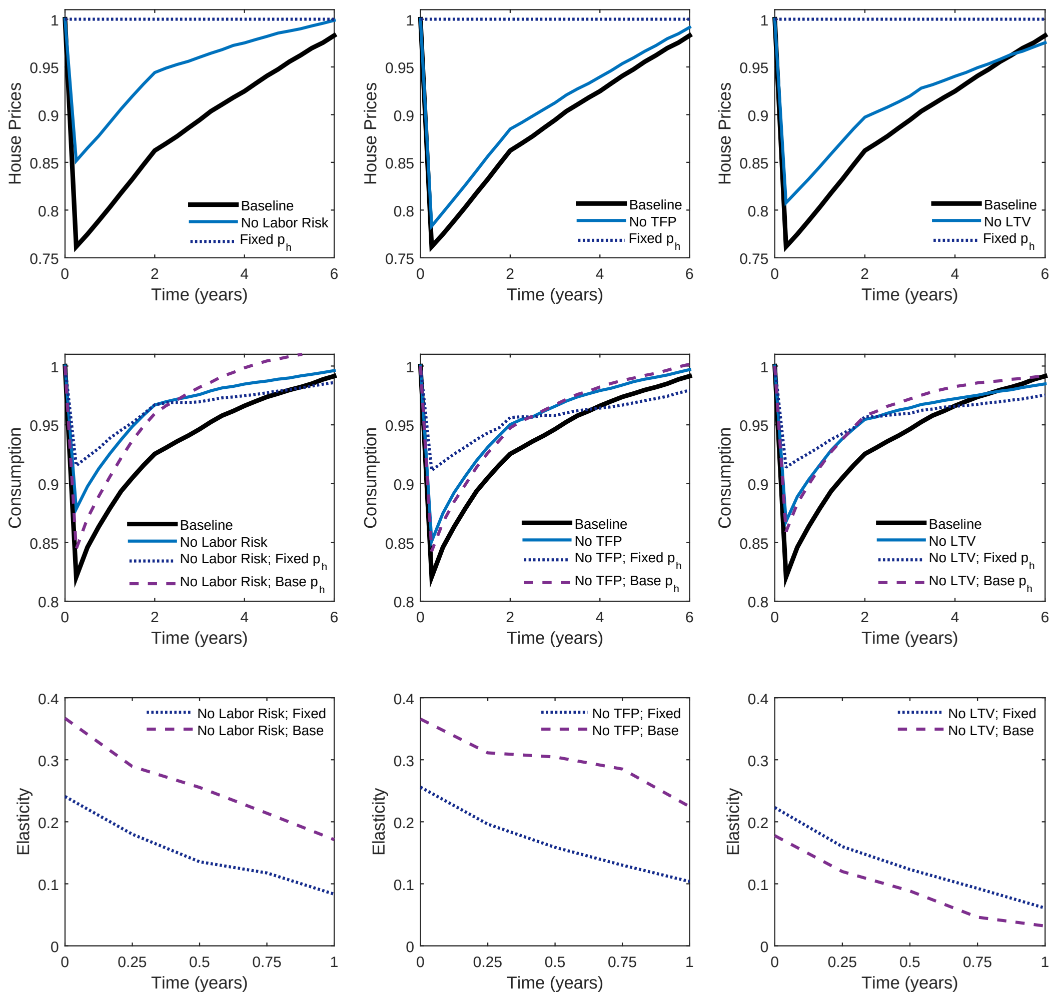

Figure 15: Consumption response to house price movements conditional on *all but one* shock hitting the economy. Top: house prices; middle: consumption; bottom: elasticity of consumption to house prices. The "fixed" elasticity uses the "fixed $p(h)$" house price trajectory as the reference, whereas the "baseline" elasticity uses the "baseline $p(h)$" house price trajectory as the reference.

The main text points out that endogenous illiquidity enhances balance sheet effects differentially throughout the cross-section. In particular, selling delays increase the mass of the left tail of the consumption decline histogram for indebted homeowners, as shown in figure 16.

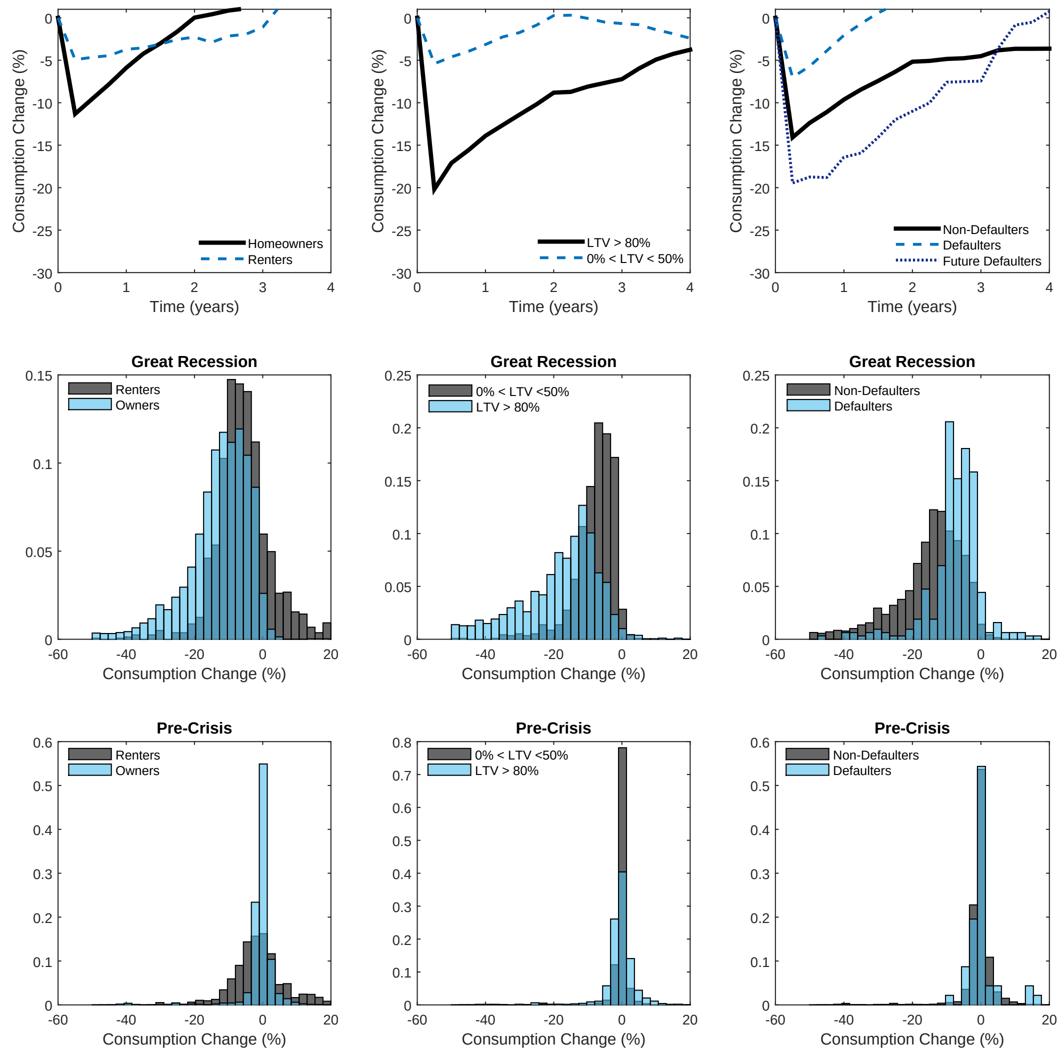

Figure 16: Consumption dynamics by ownership status, leverage, and default status in the economy with **exogenous housing illiquidity**. The histogram represents the change in consumption between subsequent periods pre-crisis and at the onset of the Great Recession.

Table 6 in the main text establishes the importance of gross portfolio positions for the behavior of consumption during the Great Recession. Figure 17 below demonstrates that gross portfolio positions matter not just for the mean consumption decline, but also for the distribution. In particular, households with larger houses and higher mortgage debt experience more dramatic consumption declines than households with similar net worth but smaller houses and less debt.

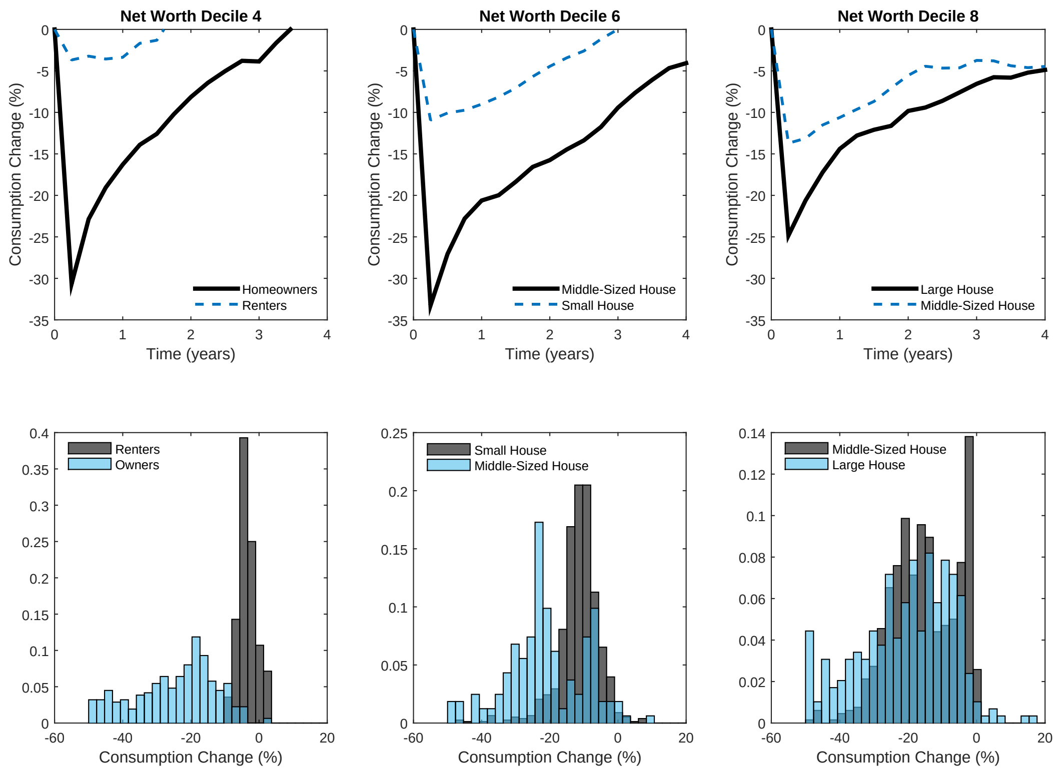

Figure 17: Consumption dynamics within net worth deciles for households with different gross portfolio positions.

A.6 Interventions to Lower Mortgage Interest Rates

Section 4.4 establishes the efficacy of policies aimed at reducing the cost of borrowing for stimulating aggregate consumption. Furthermore, the transmission from the endogenous rise in house prices to consumption through balance sheet effects is the dominant mechanism. Figure 18 below shows that the potency of this channel increases with household leverage.

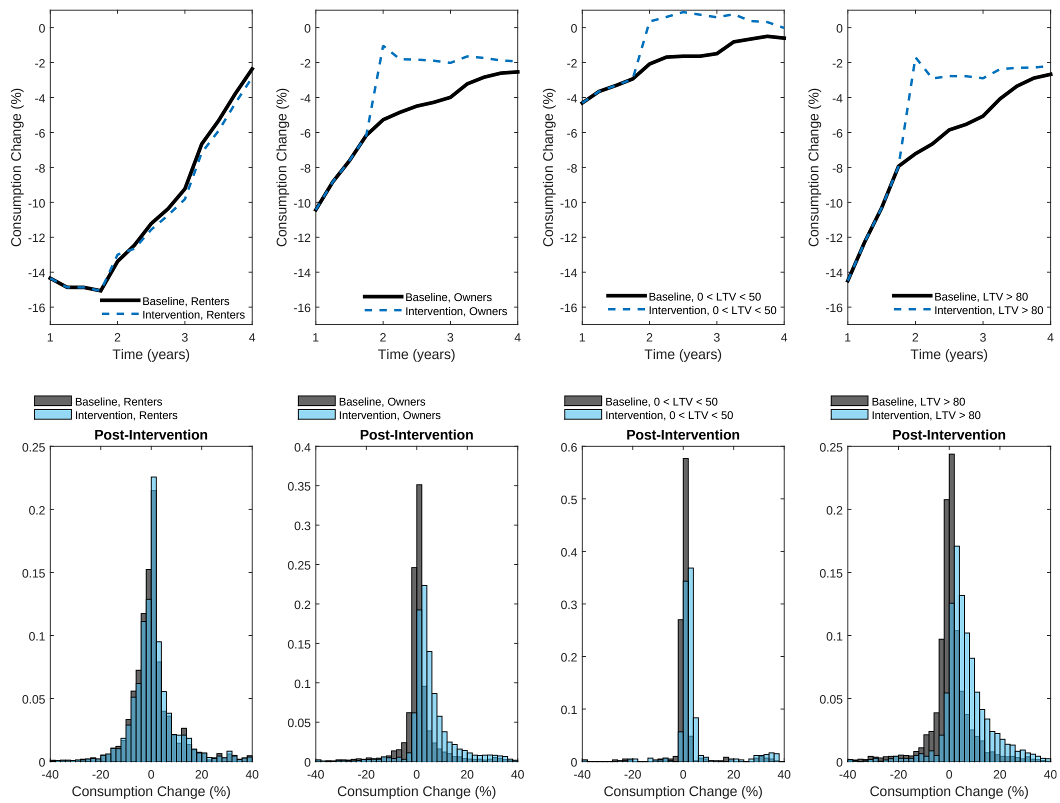

Figure 18: Consumption response to lower mortgages rates from the policy intervention by ownership status and leverage.

B Summary of Equilibrium Conditions

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

B.1 Household Value Functions

B.1.1 Subperiod 3 Value Functions

Homeowners with good credit who refinance:

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

$$\text{subject to}$$

$$c + \gamma p(h) + q_b b' + m \leq y + q_m^0((r_m,m'),b',h,s)m'$$

$$q_m^0((r_m,m'),b',h,s)m' \leq \vartheta p(h)$$

$$y' = we's' + b' \tag{17}$$

Homeowners with good credit who make a regular payment:

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

$$\text{subject to}$$

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

$$l \geq \frac{\overline{r_m}}{1+\overline{r_m}} m$$

$$m' = (m-l)(1+\overline{r_m})$$

$$y' = we's' + b' \tag{18}$$

Homeowners with bad credit:

$$V_{own}(y,0,h,s,1) = \max_{b',c\geq 0} u(c,h) + \beta\mathbb{E}\left[\begin{array}{l}(1-\delta_h)(W_{own}+R_{sell})(y',0,h,s',f') \\ +\delta_h(V_{rent}+R_{buy})(y',s',f')\end{array}\right]$$
$$\text{subject to}$$
$$c+\gamma p(h)+q_b b' \leq y$$
$$y' = we's'+b' \tag{19}$$

Apartment-dwellers with good credit:

$$V_{rent}(y,s,0) = \max_{b',c\geq 0,a\leq \overline{a}} u(c,a) + \beta\mathbb{E}\left[(V_{rent}+R_{buy})(y',s',0)\right]$$
$$\text{subject to} \tag{20}$$
$$c+q_b b'+r_a a \leq y$$
$$y' = we's'+b'$$

Apartment-dwellers with bad credit:

$$V_{rent}(y,s,1) = \max_{b',c\geq 0,a\leq \overline{a}} u(c,a) + \beta\mathbb{E}\left[(V_{rent}+R_{buy})(y',s',f')\right]$$
$$\text{subject to} \tag{21}$$
$$c+q_b b'+r_a a \leq y$$
$$y' = we's'+b'$$

B.1.2 Subperiod 2 Value Functions

The value of searching to buy a house:

$$R_{buy}(y, s, 0) = \max\{0, \max_{\substack{h \in H, \\ p_b \leq y - \underline{y}}} \eta_b(\theta_b(p_b, h))[V_{own}(y - p_b, 0, h, s, 0) - V_{rent}(y, s, 0)]\} \tag{22}$$

$$R_{buy}(y, s, 1) = \max\{0, \max_{\substack{h \in H, \\ p_b \leq y}} \eta_b(\theta_b(p_b, h))[V_{own}(y - p_b, 0, h, s, 1) - V_{rent}(y, s, 1)]\} \tag{23}$$

B.1.3 Subperiod 1 Value Functions

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

$$\begin{aligned} W(y, (\overline{r_m}, m), h, s, 0) &= \max \{\varphi(V_{rent} + R_{buy})\,(y + \max\{0, J_{REO}(h) - m\}\,, s, 1) \\ &+(1-\varphi)V^d_{own}(y, (\overline{r_m}, m), h, s, 0), V^R_{own}(y, (\overline{r_m}, m), h, s, 0), V^C_{own}(y, (\overline{r_m}, m), h, s, 0)\} \end{aligned} \tag{24}$$

Utility of default conditional on no repossession:

$$V^d_{own}(y, (\overline{r_m}, m), h, s, 0) = \max_{b', c \geq 0} u(c, h) + \beta \mathbb{E} \begin{bmatrix} (1-\delta_h)(W_{own} + R_{sell})(y', (\overline{r_m}, m), h, s', 0) \\ +\delta_h(V_{rent} + R_{buy})(y', s', 0) \end{bmatrix}$$

$$\text{subject to}$$

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

$$y' = we's' + b' \tag{25}$$

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

$$R_{sell}(y, (\overline{r_m}, m), h, s, 0) = \max\{0, \max_{p_s} \eta_s(\theta_s(p_s, h)) \left[(V_{rent} + R_{buy}) (y + p_s - m, s, 0) \right.$$
$$\left. -W_{own}(y, (\overline{r_m}, m), h, s, 0) \right] + [1 - \eta_s(\theta_s(p_s, h))] (-\xi)\} \text{ subject to } y + p_s \geq m \tag{26}$$

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

$$R_{sell}(y, 0, h, s, 1) = \max\{0, \max_{x_s} \eta_s(\theta_s(p_s, h)) \left[(V_{rent} + R_{buy}) (y + p_s, s, 1) \right.$$
$$\left. -W_{own}(y, 0, h, s, 1) \right] + [1 - \eta_s(\theta_s(p_s, h))] (-\xi)\} \tag{27}$$

B.2 Firms

B.2.1 Composite Consumption

The profit maximization condition of the composite good firm is

$$w = A_c \tag{28}$$

B.2.2 Apartments

The profit maximization condition of landlords is

$$r_a = \frac{1}{A_h} \tag{29}$$

B.2.3 Housing Construction

The relevant profit maximization conditions of home builders are

$$1 = p\frac{\partial F_h(\overline{L}, S_h, N_h)}{\partial S_h} \tag{30}$$

$$w = p\frac{\partial F_h(\overline{L}, S_h, N_h)}{\partial N_h} \tag{31}$$

B.3 Banks

Bond prices satisfy

$$q_b = \frac{1}{1+r} \tag{32}$$

Mortgage rates satisfy

$$1 + r_m = \frac{(1+\phi)(1+r)}{1-\delta_h} \tag{33}$$

The value to the bank of repossessing a house h is

$$\begin{aligned} J_{REO}(h) &= R_{REO}(h) - \gamma p(h) + \frac{1-\delta_h}{1+r} J_{REO}(h) \\ R_{REO}(h) &= \max\left\{0, \max_{p_s \geq 0} \lambda \eta_s(\theta_s(p_s, h)) \left[(1-\chi)p_s - \left(-\gamma p(h) + \frac{1-\delta_h}{1+r} J_{REO}(h)\right)\right]\right\} \end{aligned} \tag{34}$$

Mortgage prices satisfy the following recursive relationship:

$$q_m^0((\overline{r_m}, m'), b', h, s)m' = \frac{1-\delta_h}{(1+\zeta)(1+\phi)(1+r)}\mathbb{E}\left\{\overbrace{\eta_s(\theta_s(p_s', h))m'}^{\text{sell + repay}} + \overbrace{[1-\eta_s(\theta_s(p_s', h))]}^{\text{no sale (do not try/fail)}}\right.$$

$$\times\left[\underbrace{d'\varphi\min\{J_{REO}(h), m'\}}_{\text{default + repossession}} + \underbrace{d'(1-\varphi)}_{\text{no repossession}}\left(-\phi m' + \underbrace{(1+\zeta)(1+\phi)q_m^0((\overline{r_m}, m'), b'', h, s')m'}_{\text{continuation value of current } m'}\right)\right.$$

$$\left.\left.+(1-d')\left\{m'\mathbf{1}_{[\text{Refi}]} + \mathbf{1}_{[\text{No Refi}]}\left(\underbrace{l - \frac{\phi}{1+\overline{r_m}}m''}_{\text{payment} - \text{servicing costs}} + \underbrace{(1+\zeta)(1+\phi)q_m^0((\overline{r_m}, m''), b'', h, s')m''}_{\text{continuation value of new } m''}\right)\right\}\right]\right\} \tag{35}$$

B.4 Housing Market Equilibrium

B.4.1 Market Tightnesses

Market tightnesses satisfy

$$\kappa_b h \geq \overbrace{\alpha_b(\theta_b(p_b, h))}^{\text{prob of match}}\overbrace{(p_b - p(h))}^{\text{broker revenue}} \tag{36}$$

$$\kappa_s h \geq \underbrace{\alpha_s(\theta_s(p_s, h))}_{\text{prob of match}}\underbrace{(p(h) - p_s)}_{\text{broker revenue}} \tag{37}$$

with $\theta_b(x_b, h) \geq 0$, $\theta_s(x_s, h) \geq 0$, and complementary slackness.

B.4.2 Determining the Shadow Housing Price

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

$$S_h(p) = \overbrace{Y_h(p)}^{\text{new housing}} + \overbrace{S_{REO}(p)}^{\text{REO housing}} + \overbrace{\int h\eta_s(\theta_s(x_s^*, h; p))\Phi_{own}(dy, dm, dh, ds, df)}^{\text{sold by owner}} \tag{38}$$

The supply of REO housing is given by

$$S_{REO}(p) = \sum_{h \in H} h\lambda\eta_s(\theta_s(x_s^{*REO}, h; p)) \left[\underbrace{H_{REO}(h)}_{\text{existing REOs}} + \underbrace{\int [1 - \eta_s(\theta_s(x_s^*, h; p))] d^* \Phi_{own}(dy, dm, dh, ds, 0)}_{\text{new foreclosures from failing to sell and then defaulting}} \right] \tag{39}$$

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

$$D_h(p) = \int h^* \eta_b(\theta_b(x_b^*, h^*; p)) \Phi_{rent}(dy, ds, df) \tag{40}$$

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

$$D_h(p) = S_h(p) \tag{41}$$

B.5 Detailed Equilibrium Definition

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

1. *Household value and policy functions*
2. *Intermediary value and policy functions J_{REO} and x_s^{REO}*
3. *Market tightness functions θ_b and θ_s*
4. *A mortgage pricing function q_m^0*
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* $\{H_{REO}\}_{h\in H}$, Φ_{own}, *and* Φ_{rent}

such that

1. ***Household Optimality:*** *The value/policy functions solve (17) – (27).*

2. ***Firm Optimality:*** *Condition (31) is satisfied.*

3. ***Bank Optimality:*** *Conditions (32) – (35) are satisfied.*

4. ***Market Tightnesses:*** $\{\theta_b(x_b, h)\}$ *and* $\{\theta_s(x_s, h)\}$ *satisfy (36) – (37).*

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

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.*

C Computation

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

1. Given r, calculate q_b and q_m using (32) – (33).

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 (36) – (37).

   (b) Calculate the wage w and housing construction Y_h using (28) – (31).

   (c) **Loop 2a** – Make an initial guess for the bank's REO value function, $J^0_{REO}(h)$.

i. Substitute J^0_{REO} into the right hand side of (34) and solve for $J_{REO}(h)$.

ii. If $\sup(|J_{REO} - J^0_{REO}|) < \epsilon_J$, exit the loop. Otherwise, set $J^0_{REO} = J_{REO}$ and return to (i).

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

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

$$\underline{y}(m, h, s) = \min_{m', b'}[\gamma p(h) + q_b b' + m - \widetilde{q_m}(m', b', h, s)m'], \text{ where}$$

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

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

A. Substitute V^0_{rent} and V^0_{own} into the right hand side of (22) – (23) and solve for R_{buy}.

B. Substitute V^0_{rent}, V^0_{own}, and R_{buy} into the right hand side of (24) and solve for W_{own}.

C. Substitute W_{own}, V^0_{rent}, and R_{buy} into the right hand side of (26) – (27) and solve for R_{sell}.

D. Substitute W_{own}, V^0_{rent}, R_{sell}, and R_{buy} into the right hand side of (17) – (21) and solve for V_{rent} and V_{own}.

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

iii. Substitute $q_m^{0,n}$, J_{REO}, and the household's policy functions for bonds, mortgage choice and selling and default decisions into the right hand side of (35) and solve for q_m^0.

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

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

(f) Calculate the excess demand for housing using (38) – (41).

(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.

D 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

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

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.