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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 accounts for the housing crash from 2006 to 2011 and its implications for aggregate and cross-sectional consumption during the Great Recession. Left tail shocks to labor market uncertainty and tighter downpayment requirements emerge as the key drivers. An endogenous decline in housing liquidity amplifies the recession by increasing foreclosures, contracting credit, and depressing consumption. 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.

Keywords: Housing; Consumption; Liquidity; Debt; Great Recession
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1 Introduction

The decade since the 2000s debt-driven boom in house prices has witnessed the largest disruption in the U.S. housing market since the Great Depression, with real prices falling by 25% between 2006 and 2011 alongside a five-fold surge in foreclosures and three-fold increase in the inventory of unsold houses. This paper argues that the deterioration in the value and liquidity of homes coupled with elevated default risk in the mortgage market is closely tied with the large and persistent decline in consumption during the Great Recession. However, one of the main challenges in evaluating this connection during crisis episodes is the inability of traditional business cycle models to generate sizable house price and consumption declines.[1]

Against this backdrop, the research in this paper uses a quantitative model to study the origins of the housing crash and the key channels of transmission between the housing market, credit market, and consumption. By identifying the drivers of the housing bust and quantifying its impact on aggregate and cross-sectional consumption, the model also serves as a useful laboratory to evaluate the unprecedented mortgage rate interventions employed to reverse the crisis and accelerate the recovery. According to the model, higher left tail labor income risk and tightening credit constraints act as the main drivers of the housing crash. By contrast, productivity shocks have only a modest impact on house prices, consistent with the literature. As sources of macroeconomic transmission, the decline in house prices and overhang of mortgage debt trigger an increase in selling delays that reduces the liquidity of homes, increases the risk of foreclosure, and dries up the availability of credit. This interaction generates substantial amplification and propagation

[1] For example, see Iacoviello (2005) and Davis and Heathcote (2005).

of house prices and foreclosures, and the failure to account for endogenous fluctuations in housing illiquidity produces sales and ownership rate dynamics that are opposite the data. With regard to consumption, the decline in house prices creates an imbalance between assets and liabilities that pushes many homeowners to deleverage and sharply curtail spending. Lastly, policies to reduce mortgage rates successfully boost house prices and consumption, and balance sheet effects operate as the most important transmission channel.

The quantitative framework includes 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 price and time on the market. *Ceteris paribus*, higher list prices produce longer selling delays.

Regarding the origins of the crash, the model ascribes half of the decline in house prices to elevated labor market uncertainty and one quarter of the decline to tighter credit constraints.[2] The left-tail uncertainty shock undermines homeowners' ability to smooth consumption through equity withdrawals, and the resulting drop in housing demand causes prices and ownership to plummet as foreclosures spike. Absent this uncertainty, other forces that depress house prices fuel a counterfactual rise in homeownership driven by increased affordability. Tighter credit constraints simultaneously restrict funding to new buyers and prevent equity extraction by owners. As prices decline, this inability to refinance leaves distressed owners with no option but to list their

[2] Declining productivity, a temporary hike in short-term rates consistent with Federal Reserve actions in 2005 and 2006, and joint interaction terms account for the residual.

house on the market and default in the event of failure to sell.

Overall, the model explains nearly the entire decline in real house prices, consumption, and ownership along with the spike in foreclosures and time on the market. Importantly, the model's success comes not from reverse engineering the shocks, but rather from capturing key sources of macroeconomic transmission absent in existing analyses of the Great Recession, namely, the interaction of endogenous housing and credit illiquidity and the asymmetric balance sheet response to falling house prices. Although these mechanisms operate qualitatively even in typical productivity-driven business cycles, strong nonlinearities produced during crisis episodes drastically enhance their potency.

Quantitatively, endogenous housing illiquidity amplifies the drop in house prices and consumption by 27% and 32%, respectively, compared to an economy where houses transact without delay subject only to exogenous illiquidity from transaction costs. Furthermore, replicating the same house price decline with exogenous housing illiquidity requires implausibly large shocks at the further expense of producing counterfactual foreclosure, sales, and ownership dynamics. To understand the transmission from endogenous housing liquidity, note that during booms, market tightnesses rise alongside prices as sellers face shorter wait times for buyers. At the same time, lower default risk gives rise to loose credit conditions. Together, reduced trading delays and inexpensive mortgages facilitate homeowner equity extraction both through quick selling and cheap refinancing. However, during downturns, sellers face a deteriorating trade-off between list price and time on the market. Furthermore, this evaporation of housing liquidity most severely affects highly leveraged borrowers, who are restricted in their ability to set lower asking prices because of the need to pay off outstanding mortgage debt at closing. The resulting debt overhang causes long selling delays that push heavily indebted owners to either severely cut consumption or default on their mortgage. Quantitatively, the spilling over of selling risk into default risk explains why foreclosures peak at 4.3% in the baseline economy versus only 1.3% with exogenous illiquidity. To worsen matters for households, banks respond by demanding a higher default premium that mortgages more expensive, which further weakens the housing market and precipitates a downward spiral.

Aside from acting as an amplification and propagation mechanism, endogenous housing illiquidity rationalizes the simultaneous decline in sales and homeownership with prices during the bust—a positive co-movement that has previously eluded the literature. Without this channel, buyers surge into the market to purchase cheap housing whenever prices fall. However, rising selling delays from the endogenous decline in housing liquidity reverse this dynamic by depressing the number of successful transactions. Furthermore, the previously mentioned adverse impact of rising selling delays on credit conditions blunts the inflow of buyers pursuing lower prices.

The last channel involves the transmission of house price movements to consumption through balance sheet effects. Quantitatively, the model finds that the large house price decline magnifies the fall in consumption by 63% relative to a world with fixed house prices, which delivers an elasticity of consumption to house prices of 0.3 that comports with Mian, Rao and Sufi (2013) and Kaplan, Mitman and Violante (2016). However, this relationship in the model is non-linear and shock-dependent. 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.

A deeper cross-sectional analysis reveals significant heterogeneity across housing tenure status, wealth, and indebtedness that points to the importance of gross portfolio positions for balance sheet effects. Controlling for net worth, households with larger houses *and* debt experience stronger consumption declines than households with less of each, which is consistent with the data. As a stark example, renters in the 4th net worth decile 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 with similar net worth both account for one-fifth of pre-crisis consumption, but these owners account for over 30% of the decline compared to only 5% by the renters. In short, net worth alone is insufficient to study balance sheet effects.

Finally, this paper uses the model to quantify the impact of policies oriented toward lowering mortgage rates to revitalize house prices and consumption. The model indicates that lower rates fuel a 6.3% rise in house prices and a 3.5% rise in consumption relative to the alternative recovery path. Furthermore, ignoring the endogenous house price response attenuates the gain in consumption by 62%, which underscores the importance of general equilibrium effects. Thus, lower rates boost consumption primarily through their impact on household balance sheets rather than through the traditional channel of intertemporal substitution. Lastly, these interventions have a larger impact on households suffering from debt overhang, with owners above 80% loan-to-value (LTV) experiencing twice the gain as owners below 50% LTV.

1.1 Related Literature

Davis and Van Nieuwerburgh (2015) and Piazzesi and Schneider (2016) summarize a growing literature on housing and the macroeconomy that includes seminal business cycle studies by Davis and Heathcote (2005), and Leamer (2007). Current wisdom suggests only a modest impact of traditional productivity fluctuations on house prices, which has pushed some authors to shift their attention to preference shocks, notably Iacoviello (2005). However, the actual *realization* of preference shocks generates an incorrect co-movement between house prices and consumption. As an alternative, Burnside, Eichenbaum and Rebelo (2017) and Kaplan, Mitman and Violante (2017) argue for shocks to expectations, with Kaplan et al. (2017) downplaying the contribution of credit constraints to house prices—an assessment shared by Glaeser, Gottlieb and Gyourko (2013), Sommer, Sullivan and Verbrugge (2013), and Kiyotaki, Michaelides and Nikolov (2011). By contrast, Favilukis, Ludvigson and Van Nieuwerburgh (2016) attribute the boom and bust to a financial liberalization and reversal characterized by time-varying credit constraints and risk premia. Similarly, Garriga, Manuelli and Peralta-Alva (2014) underscore the *joint* importance of changing credit constraints and interest rate movements driving house prices and rents.

This paper finds that credit constraints matter for the crisis but not overwhelmingly so, with higher downside labor market uncertainty emerging as an even more potent force. In its absence, other shocks that depress house prices produce a counterfactual rise in homeownership. Furthermore, elevated uncertainty proves necessary to replicate the outsized decline in consumption relative to income discussed by Krueger, Mitman and Perri (2016b) and Huo and Ríos-Rull (2016). 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) further establishes the broader macroeconomic significance of uncertainty shocks.

As mentioned previously, the success of this paper in replicating the housing crash comes from incorporating features absent from existing analyses of the Great Recession, not by engaging in reverse engineering. In particular, *endogenous housing illiquidity* and the operation of balance sheet effects through *gross portfolio positions* stand out quantitatively as transmission channels. With regard to illiquidity, Kaplan and Violante (2014) argue that consumption responds more strongly to shocks when households hold much of their net worth in an illiquid asset. However, they abstract from explicitly formulating the housing and mortgage markets and treat exogenous transaction costs as the sole source of illiquidity. Gorea and Midrigan (2015) also emphasize the importance of illiquidity in a model which includes housing, though they, too, employ fixed transaction costs. These abstractions ignore the dependence of illiquidity on economic conditions and ignore an intrinsic risk of homeownership. By contrast, endogenous search-induced housing illiquidity produces selling delays that increase foreclosure risk and default premia to amplify the dynamics of house prices, foreclosures, and consumption. Furthermore, endogenous housing illiquidity creates substantial propagation from house prices to consumption and is necessary to replicate the positive co-movement between house prices and sales.

Other papers, such as Ngai and Tenreyro (2014), Head, Lloyd-Ellis and Sun (2014), Díaz and Jerez (2013), and Landvoigt, Piazzesi and Schneider (2011), have also studied search in the housing market, but only by abstracting from borrowing and credit constraints. Hedlund (2016a) marks an exception by studying the steady state relationship between housing and credit illiquidity, and Hedlund (2016b) studies the implications for typical productivity-driven business cycles. Relative to those papers, the analysis here takes a large step forward by revealing the unique interaction between movements in housing illiquidity and downside uncertainty during crisis episodes—further enriched by deteriorating credit conditions—that produces strong nonlinear responses of house prices, foreclosures, and consumption through household balance sheets.

The analysis of balance sheet effects serves as another important distinction between this paper and much of the recent structural literature that consolidates assets and liabilities into one net position, such as Kaplan and Violante (2014) and Krueger et al. (2016b). This paper shows that the sensitivity of consumption to house prices depends strongly on *gross* rather than net household portfolio positions. Specifically, households with greater levels of housing wealth and mortgage debt respond more than households with smaller houses and less debt. The magnitude of the heterogeneity is such that shifts in portfolio composition have large effects on aggregate consumption. The endogeneity of house prices increases the contribution of balance sheet effects relative to other work that employs a partial equilibrium setting, such as Berger, Guerrieri, Lorenzoni and Vavra (2016). In this paper as in Kaplan et al. (2017), endogenizing house prices allows the model to match the aggregate empirical evidence described by Carroll, Otsuka and Slacalek (2011), Case, Quigley and Shiller (2013), Mian et al. (2013), and Kaplan et al. (2016).

2 The Model

The model consists of a continuum of households, a production sector for the numeraire good, a construction sector, a market for trading homes, and a mortgage market situated within a discrete time, open economy environment.

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.[3] 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 $r_a = 1/A_a$.[4]

Builders construct new houses using land L, structures S_h, and labor N_h using a constant returns to scale technology $Y_h = F_h(L, S_h, N_h)$. Builders purchase structures S_h from the consumption sector, and as in Favilukis 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

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

[3] 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.

[4] 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.

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.[5] 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.

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

[5] 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 $p(h) = p_h h$.

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.[6]

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

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

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.[7] 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 $m' = (m-l)(1+\overline{r}_m)$. The fixed rate satisfies

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

[7]Stochastic depreciation can be thought of as akin to a catastrophic fire that completely destroys the house. In this event, owners lose any equity they may have accumulated in the house, but to prevent the model from generating artificially high foreclosure rates, it is assumed that the bank forgives all outstanding mortgage debt. Naturally, this insurance provided by the bank increases the cost of borrowing, although the actual probability of stochastic depreciation is quite low.

Mortgage prices satisfy the following recursive relationship:

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

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

$$\left.\left.+(1-d')\left\{m'\mathbf{1}_{[\text{Refi}]} + \mathbf{1}_{[\text{No Refi}]}\left(\underbrace{l}_{\text{payment}} + \underbrace{(1+\zeta)q_m^0((\overline{r}_m, m''), b'', h, s')m''}_{\text{continuation with } m''=(m'-l)(1+\overline{r}_m)}\right)\right\}\right]\right\} \tag{6}$$

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

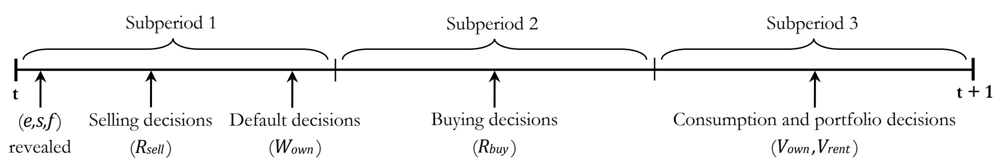
$$J_{REO}(h) = R_{REO}(h) - \gamma p(h) + \frac{1-\delta_h}{1+r}J_{REO}(h)$$

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

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 $\bar{r}_m$ and balance m, house h, and labor shock s. A renter's state is (y, s, f). The household problem is solved backwards:

2.5.1 Subperiod 3: Consumption/Saving

End-of-period owner expenditures consist of consumption, holdings costs, bond purchases, and mortgage payments. Household resources come from labor income, savings, and equity extraction. Owners with good credit ($f = 0$) who refinance have value function

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

subject to

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

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

$$y' = we's'+b' \tag{8}$$

where ϑ is the collateral constraint for new loans. The terms W_{own} and V_{rent} are the subperiod 1 utilities of owning and renting, respectively, while R_{sell} and R_{buy} represent the respective option values of selling and buying.

Owners who make a payment l on their existing mortgage solve

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

subject to

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

$$l \geq \frac{\overline{r}_m}{1+\overline{r}_m}m$$

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

$$y' = we's'+b' \tag{9}$$

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 $y - p_b \geq \underline{y}(h, s)$, where $\underline{y}(h, s) = \min_{m',b'}[\gamma p(h) + q_b b' - q_m^0((r_m, m'), b', h, s)m'] < 0$ 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

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

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

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

$$\text{subject to}$$

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

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

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

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

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 in the years 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.[8] The persistent component is discretized 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.[9] The persistence of credit flags is $\gamma_f = 0.95$, and the REO discount χ is determined in the joint calibration.

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

[9] 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	$\overline{a}$	2.7240	69.0%	68.9%	Census
Starter House Value	h_1	3.2800	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.[10] 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. 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

The analysis in this section delivers several major insights into the sources and broader economic implications of the housing crash as well as the efficacy of mortgage rate interventions implemented to address the crisis:

1. Productivity shocks cannot reproduce the Great Recession. Downside labor uncertainty and tighter credit constraints are the dominant factors.

2. Endogenous movements in search-induced housing illiquidity amplify the economy's response and prove necessary for the collapse in housing sales.

3. Falling house prices cause nearly 40% of the consumption decline through balance sheet effects that depend on gross portfolio positions.

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

4. Reduced mortgage rates accelerate the recovery. General equilibrium and balance sheet effects are the dominant transmission channels.

4.1 Drivers of the Housing Bust and Great Recession

Business cycle models regularly feature productivity shocks as the principal driver of economic fluctuations. This fact, combined with evidence of declining productivity documented by Fernald (2014), makes them a natural starting point for investigating the origins of the crisis. The model implementation consists of an unexpected 5% decline in goods sector productivity that reverts after three years. Although the onset comes as a surprise, agents fully anticipate its duration and the response of all endogenous variables. Productivity shocks in this context prove utterly insufficient to replicate the crisis by generating only a short-lived 2% fall in house prices and 1.5% drop in consumption. This result shows that housing does little to change the findings in Krueger, Mitman and Perri (2016a) that large productivity shocks cannot generate significant consumption declines.

Besides productivity, an alternative narrative blames the Federal Reserve for raising short-term interest rates prior to 2007 and kicking off a wave of mortgage defaults. To test this hypothesis in the model, a four percentage point exogenous rise in short-term interest rates is implemented for two years. This channel in isolation produces a 3.8% fall in house prices that completely dissipates once interest rates return to their original levels.

4.1.1 Uncertainty and Financial Shocks

An emerging but extensive literature documents two additional economic disturbances during the Great Recession: a rise in uncertainty from higher downside labor market risk and a tightening of minimum downpayment requirements.[11,12] To capture these features in the model, a left tail labor shock is constructed to replicate the gradual decline in labor hours from 2007 to 2010, and the minimum downpayment constraint increases to 10% to capture the tightening of credit. These two shocks and the previous ones are all unanticipated.[13,14]

The addition of uncertainty and financial shocks causes the model economy to closely mimic the severity of the Great Recession. As shown in table 2, the model mirrors the 25.9% drop in real house prices, the erosion of homeownership from 69% to 64%, and the more than doubling of time on the market from 23 to 51 weeks, which represents the swell of unsold housing

[11] See Guvenen et al. (2014) and Krueger et al. (2016b) about the rise in downside labor risk. The left tail shock can also be viewed as reflecting more general higher uncertainty consistent with the pre-crisis deterioration in the University of Michigan Consumer Sentiment Survey and evidence from Arellano, Bai and Kehoe (2016), Stock and Watson (2012), Bloom et al. (2014), and Kozeniauskas et al. (2016) regarding the role of uncertainty in the Great Recession.

[12] Favilukis et al. (2016) identify the relaxation of credit and subsequent reversal as key drivers of the housing boom and bust. Empirically, 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] 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.

[14] Consistent with FHFA Mortgage Interest Rate Survey data, origination costs also rise from 0.4% to 1.2%. Furthermore, 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. See Herkenhoff and Ohanian (2015) for evidence of these foreclosure delays.

Table 2: The Housing Bust and Great Recession: Model vs. Data

	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.

inventories.[15] Beyond housing, the model captures the steep consumption decline that is also discussed in Pistaferri (2015), Berger et al. (2016), Huo and Ríos-Rull (2016), and Kaplan et al. (2016).[16] Importantly, the model generates an immediate spike in leverage and foreclosures followed by slow endogenous deleveraging. The surge in foreclosures fuels an important credit channel into consumption, as will be discussed in sections 4.2 and 4.3. 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.

Table 3 measures the contribution of higher downside uncertainty and tighter credit constraints, while table 7 and figure 9 in the appendix present the full decomposition. The measurements come by first removing one shock at a time and then by introducing each shock in isolation.

Higher Left Tail Labor Risk Isolating the left tail labor 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 will be discussed in section 4.2.1, foreclosures

[15] Figure 8 in the appendix shows the full model-generated series.

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

Table 3: Measuring the Impact of Uncertainty and Financial Shocks

	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).

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 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.

4.1.2 Cross-Sectional Validation

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 1 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 middle income and low income borrowers.[17] 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 10 and 11. 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.

[17] 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.

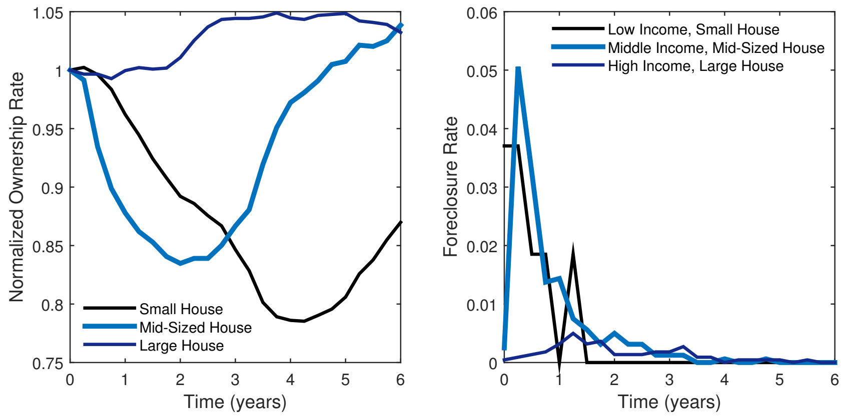


Figure 1: Ownership and foreclosure dynamics across different segments.

4.2 The Role of Endogenous Housing Illiquidity

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.[18] Figure 2 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, by ignoring selling delays, the economy with exogenous illiquidity generates a counterfactual spike in sales and homeownership.

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.

[18] 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).

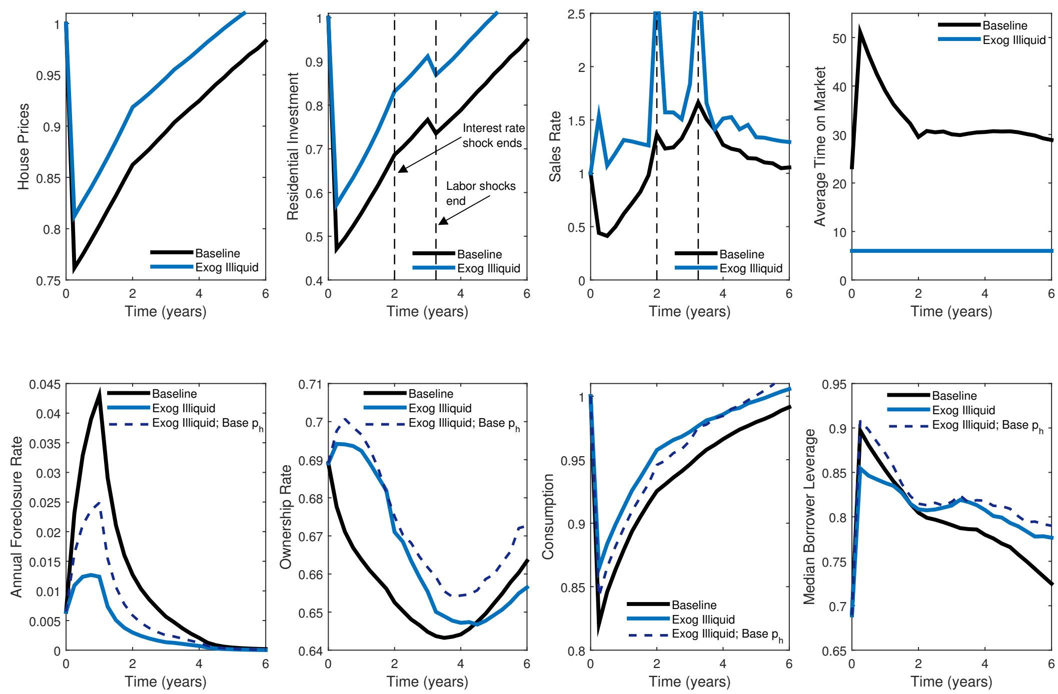


Figure 2: Baseline vs. exogenous illiquidity (no search; 6% transaction cost).

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 3 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 3 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

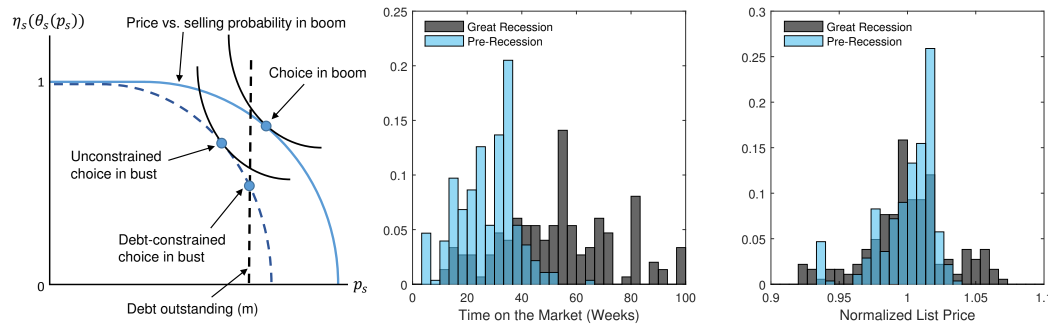


Figure 3: (Left) List prices and selling probabilities in booms and busts; dispersion of TOM (middle) and prices (right) before and during the crisis.

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 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

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).

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

The larger foreclosure spike with endogenous housing illiquidity causes a deterioration in credit that magnifies the drop in house prices, residential investment, and consumption by 26.6%, 23.9%, and 31.6%, respectively.[19]

Conceptually, the value of housing V can be decomposed as

$$V = \text{User Cost (UC)} + \text{Housing Liquidity (HL)} + \text{Credit Liquidity (CL)} \quad (15)$$

[19] Increasing the transaction cost from 6% to 12% in the model with exogenous illiquidity causes house prices to fall by 20.7%, which is still insufficient relative to the data.

The user cost encapsulates the implicit rents and resale value of the house. Housing liquidity captures the premium from ease of selling, and credit liquidity reflects the value of 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).

$$\sigma_V^2 = \sigma_{UC}^2 + \sigma_{HL}^2 + \sigma_{CL}^2 + 2\sigma_{UC,HL} + 2\sigma_{UC,CL} + 2\sigma_{HL,CL} \tag{16}$$

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, which enhances 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 this feedback loop ($\sigma_{HL,CL} = 0$) and fails to replicate the volatility in the data.

4.2.3 Resolving the Sales and Homeownership Puzzles

Endogenous housing illiquidity, if accompanied by the rise in downside labor risk, also resolves the positive co-movement puzzle between house prices, sales, and ownership. In the Walrasian model with exogenous illiquidity, plummeting house prices spur a counterfactual *surge* in sales and ownership as buyers take advantage of greater affordability and expected future price growth during the recovery (see figure 2).[20] Search frictions alone improve the correlation, but without the nonlinearities created by higher uncertainty, homeownership continues to move in the wrong direction.[21] To resolve this puzzle, endogenous housing illiquidity stymies sellers with long selling delays, which mechanically reduces the number of successful transactions. In addition, liquidity spirals and higher uncertainty both stem the inflow of buyers by exacerbating credit costs and reducing the risk-sharing properties of homeownership.

4.3 Consumption and Balance Sheet Effects

Several recent studies establish an empirical relationship between initial household leverage, the magnitude of house price declines during the bust, and the drop in consumption.[22] These findings hint at a causal relationship between prices and consumption through household balance sheets, but standard representative agent models have not been able to replicate the empirical findings. By contrast, in this model, a large decline in house prices creates an imbalance between assets and liabilities that drives homeowners to deleverage and substantially reduce consumption.

Quantitatively, holding house prices fixed while preserving all the shocks attenuates the drop in consumption by 39% compared to the baseline.

[20]Exogenous transaction costs in Ngai and Sheedy (2015) and Ríos-Rull and Sánchez-Marcos (2012) also create a negative co-movement between house prices and sales.

[21]These nonlinearities are absent in Hedlund (2016b), which only studies productivity-driven business cycles.

[22]For example, Mian et al. (2013), Dynan (2012), Keys, Piskorski, Seru and Yao (2014), Midrigan and Philippon (2016).

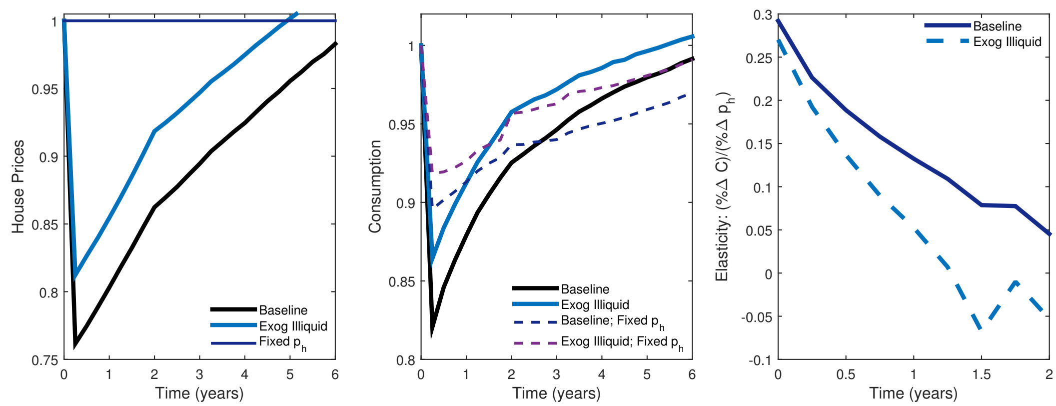


Figure 4: The sensitivity of consumption to house prices with and without endogenous illiquidity. The elasticity is % change in consumption between "baseline" and "fixed p_h" divided by % change in p_h.

Furthermore, the implied elasticity of consumption to house prices upon impact is 0.29, which is compatible with Mian et al. (2013) and Kaplan et al. (2016), and it is highly persistent. However, the elasticity is *shock dependent*—falling to 0.12 with only the left tail shock.[23,24]

Importantly, endogenous housing illiquidity doubles the persistence of balance sheet effects relative to the Walrasian model. The right panel of figure 4 reveals that the elasticity is nearly identical between the two upon impact but completely dissipates after only one year 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. Holding house prices fixed, the pure debt overhang effect from selling delays magnifies the consumption decline by 27% relative to the model with exogenous illiquidity.

While significant, these aggregate results mask starker balance sheet effects

[23] Kaplan et al. (2017) also make this point about shock dependence.

[24] Appendix figures 12 and 13 show the elasticity under each of the shocks.

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.

in the cross-section. Table 5 demonstrates that homeowners 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 5 further illustrates the heterogeneity in consumption responses. For example, not only do homeowners experience a larger *average* consumption decline during the crisis, but the distribution of consumption growth fans out noticeably to the left. By contrast, the distribution for renters remains almost symmetric and exhibits less dispersion. However, prior to the crisis, homeowners are the ones with less consumption variability. Self-selection into homeownership by wealthier households with the ability to self-insure provides a partial explanation, and homeownership also provides direct risk-sharing benefits through the ability to extract equity in the mortgage market.

The decline in house prices and liquidity during the crisis reverses the risk-sharing advantages of homeownership. However, the ability to default

[25] Similar to Krueger et al. (2016a) for the bottom 40% of households.

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

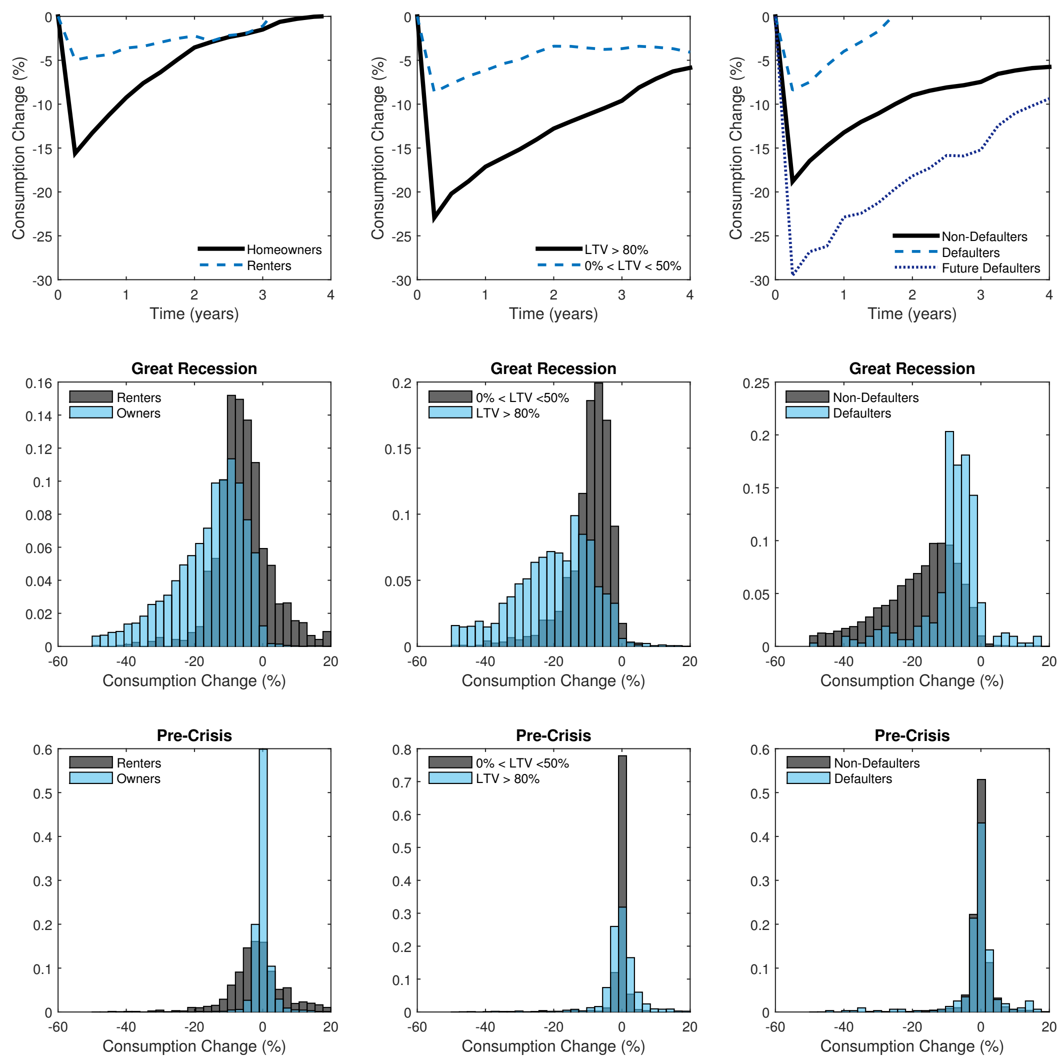


Figure 5: Consumption dynamics by ownership status, leverage, and default status. "Future defaulters" are those who default 1 year *after* the beginning of the Great Recession. The histogram represents the change in consumption between subsequent periods pre-crisis and at the onset of the Great Recession.

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.

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.

By shocking the assets side of the household balance sheet without altering liabilities, the collapse in house prices generates balance sheet effects that depend critically on the decomposition of net worth into **gross positions**, as shown by table 6 and figure 15 in the appendix. For example, the consumption of renters in the 4th net worth decile falls by only 3.7%, whereas homeowners with similar net worth experience a staggering 30.7% drop in consumption. 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. These asymmetric balance sheet effects are missing in models that only formalize net positions, as in Krueger et al. (2016a) and Kaplan and Violante (2014).

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.

[27]Figure 14 in the appendix plots cross-sectional consumption with exogenous illiquidity.

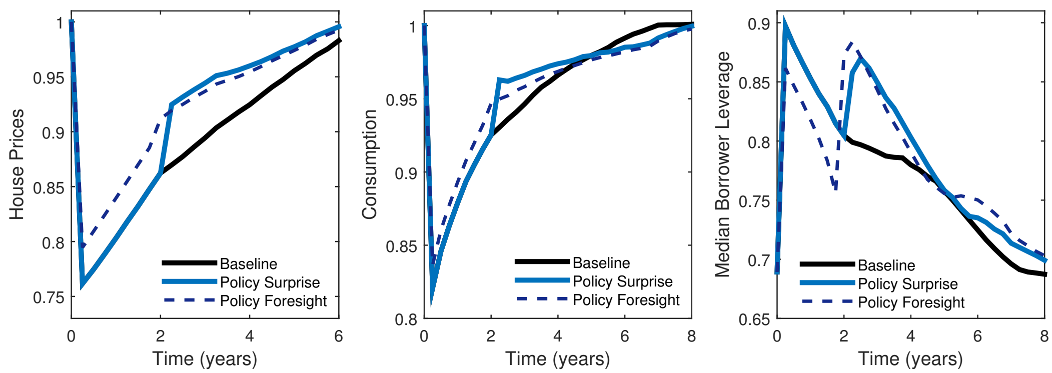


Figure 6: The effects of lower mortgage rates from the policy intervention.

4.4 Interventions to Lower Mortgage Rates

Between 2009 and 2011, policymakers undertook several interventions to reduce long-term interest rates in hopes of resuscitating the economy, and real 30-year mortgage rates indeed fell from 3% to under 1.5%. In terms of causality, Engen, Laubach and Reifschneider (2015) ascribe a 120 basis point to the interventions themselves, which is consistent with the findings in Krishnamurthy and Vissing-Jorgensen (2011) and Joyce, Miles, Scott and Vayanos (2014). This paper takes a different tack by instead assessing the *consequences* of this decline in interest rates for consumption and by evaluating the role of transmission through the housing market.

The decrease in mortgage rates is engineered in the model via lower servicing costs. When implemented by surprise two years after the crash, the decline in mortgage rates causes house prices and consumption to jump by 6.3% and 3.5%, respectively, as shown in figure 6. When announced ahead of time, the policy causes an *immediate* response, but the disconnect between the announcement and implementation dates reduces the magnitudes to 4.3% for house prices and 1.9% for consumption.

Multiple channels account for the increase in consumption from lower

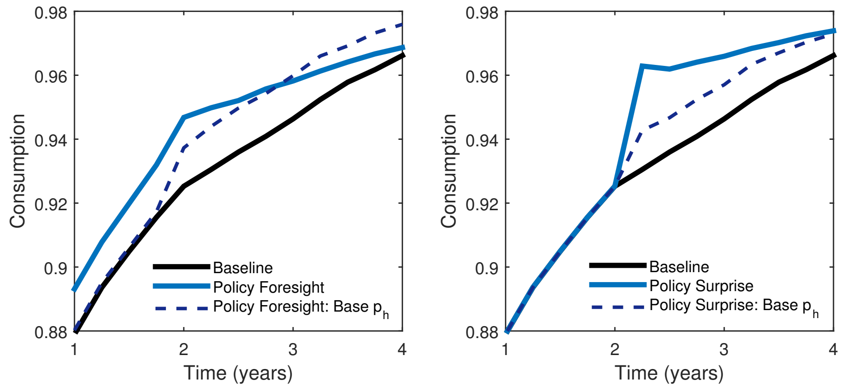


Figure 7: (Left) Balance sheet effects when the rate decline is announced in advance; (right) balance sheet effects in the event of a surprise decline in rates.

rates. First, intertemporal substitution slows the process of deleveraging by increasing the value of present consumption relative to future consumption. Second, the increase in house prices from cheaper borrowing creates balance sheet effects that fuel consumption gains in the manner of section 4.3.

To quantify the role of balance sheet effects, figure 7 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 jump and half of the post-implementation jump 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 reducing long term rates dissipates when the endogenous response of house prices is ignored. By restoring equity on the asset side of the household balance sheet, the upward adjustment of house prices proves a potent channel through which lower interest rates stimulate consumption. Furthermore, these policy interventions have heterogeneous effects across the leverage distribution. For example, 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. Naturally, renter consumption is almost completely unresponsive to lower mortgage rates. Thus, the *aggregate* consequences of lower mortgage rates depend on the *distribution* of housing tenure status and 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 driven by higher uncertainty and tighter credit, thus representing an important nonlinearity that distinguishes severe recessions from typical productivity-driven business cycles. Lastly, interventions to reduce borrowing costs have powerful effects on consumption through balance sheet effects caused by endogenously higher house prices.

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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 Accounting for 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 8 below presents the full time series. Importantly, these baseline series also appear in figure 2 from the main text alongside the response of the economy with exogenous transaction costs.

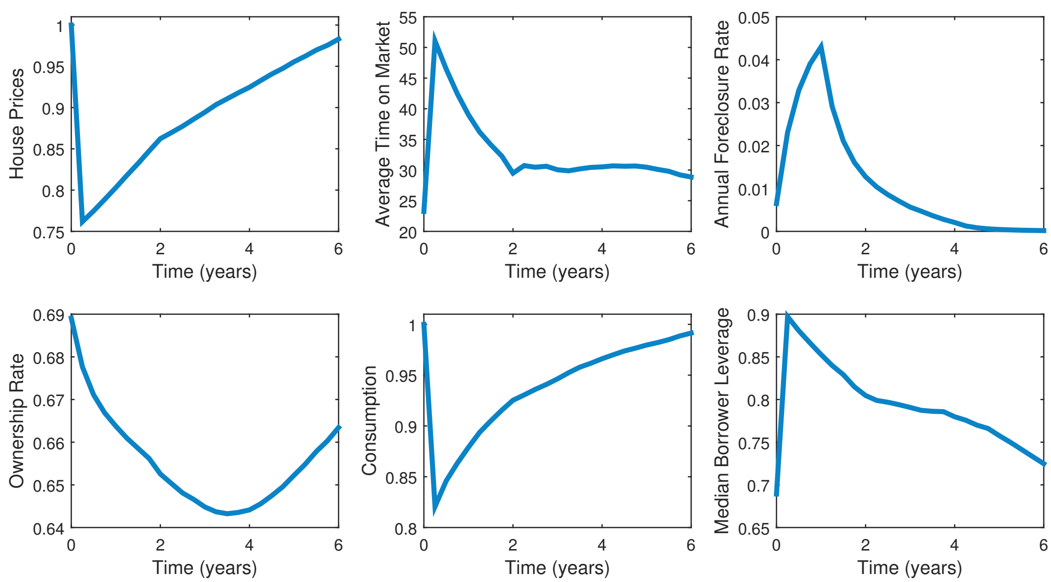

Figure 8: The simulated recession/recovery: (TL) house prices, (TM) time on market, (TR) foreclosures, (BL) ownership, (BM) consumption, (BR) leverage.

A.2 Decomposing the Great Recession

Section 4.1 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 9 and table 7 below present the full decomposition.

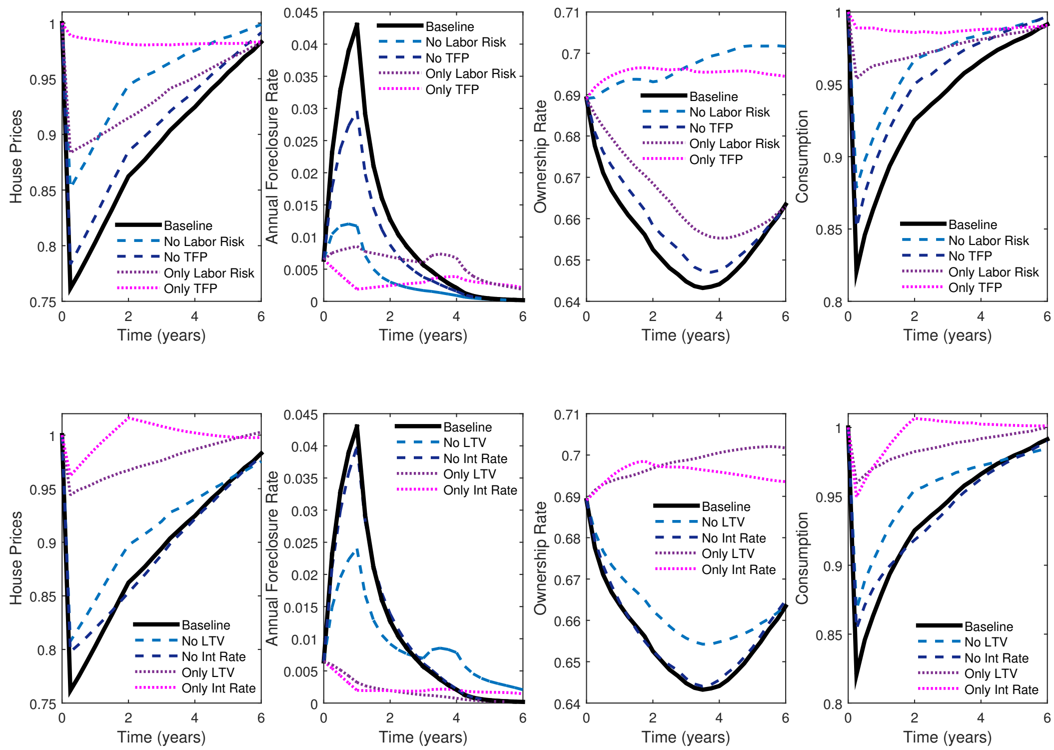

Figure 9: Top: disentangling the effects of real shocks (lower TFP and left tail labor market risk shock). Bottom: disentangling the effects of financial shocks (tighter downpayment constraint and higher interest rates).

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 Cross-Sectional Validation

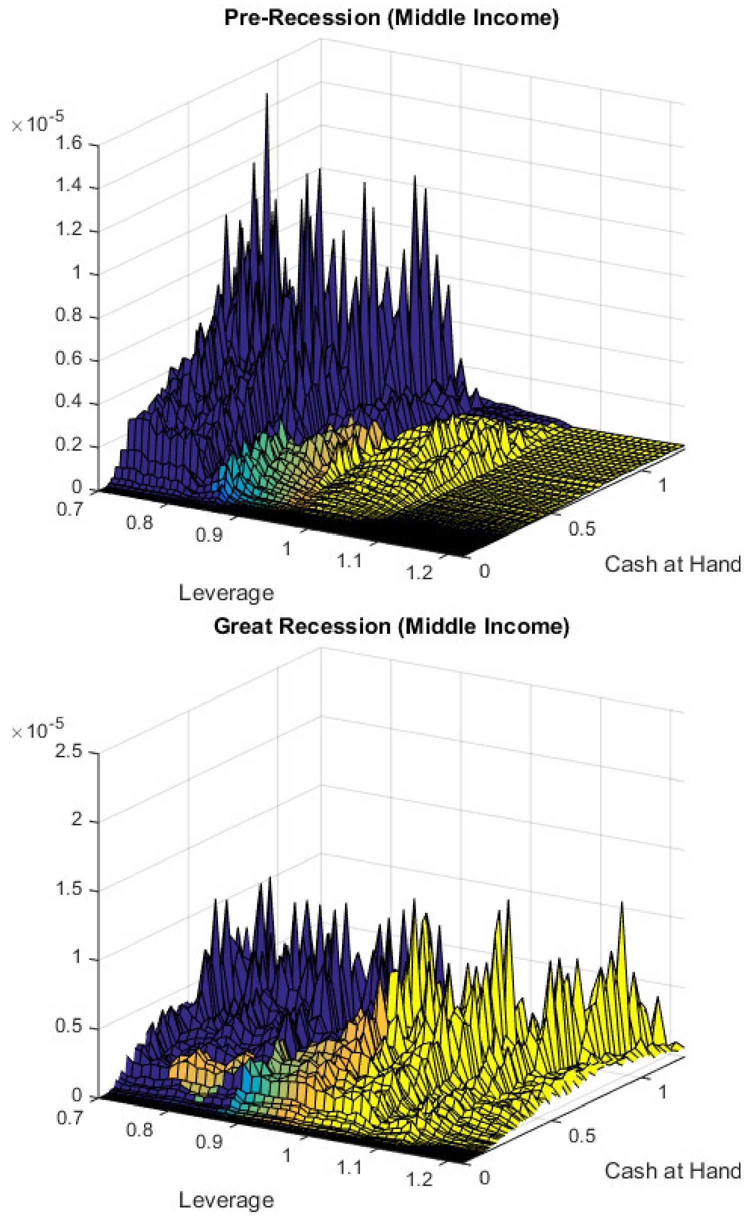

Figure 10: Distribution of *middle income households* over mortgage debt and liquid assets with shaded default probabilities: (top) pre-recession, (bottom) Great Recession. Lighter shading represents more likely default.

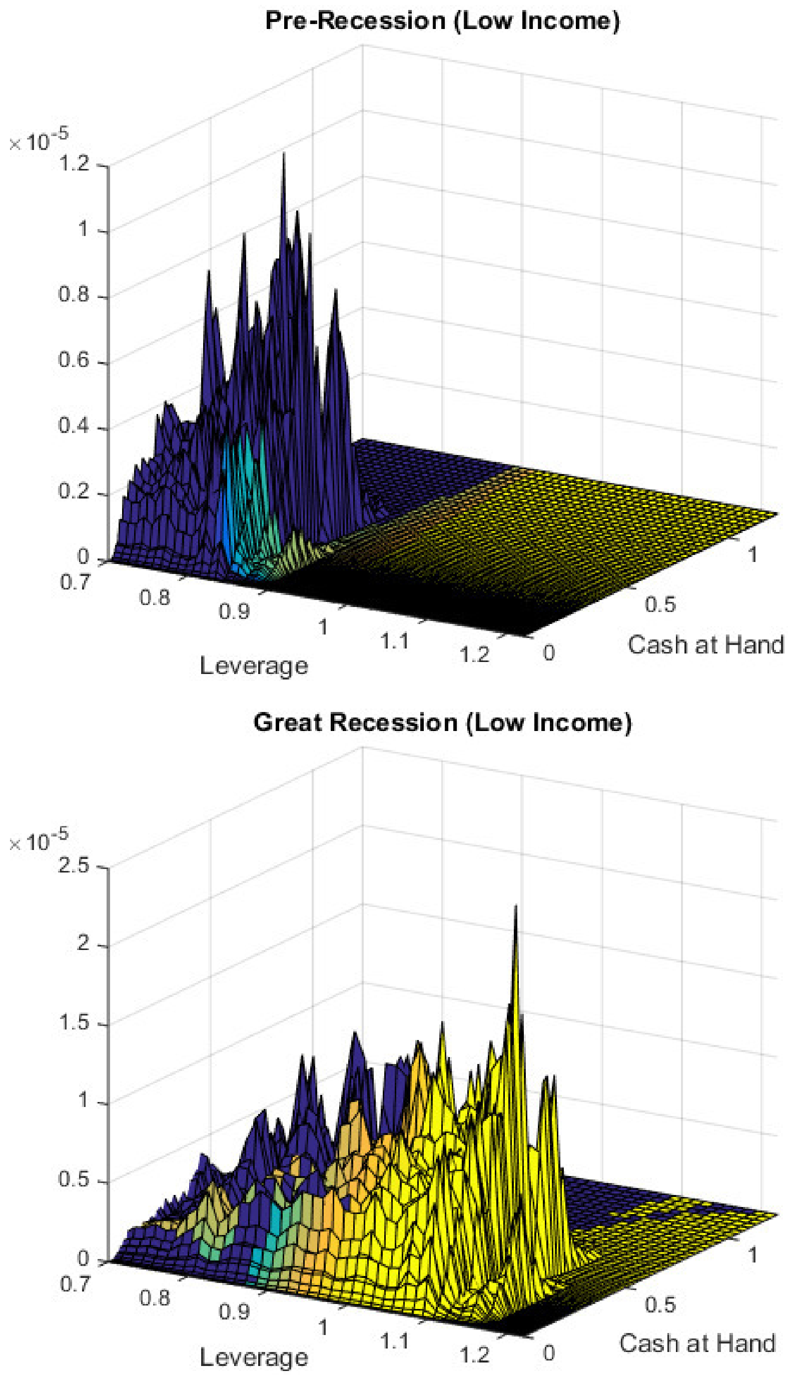

Figure 11: Distribution of *low income households* over mortgage debt and liquid assets with shaded default probabilities: (top) pre-recession, (bottom) Great Recession. Lighter shading represents more likely default.

A.4 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 12 and 13 below visually demonstrate these points.

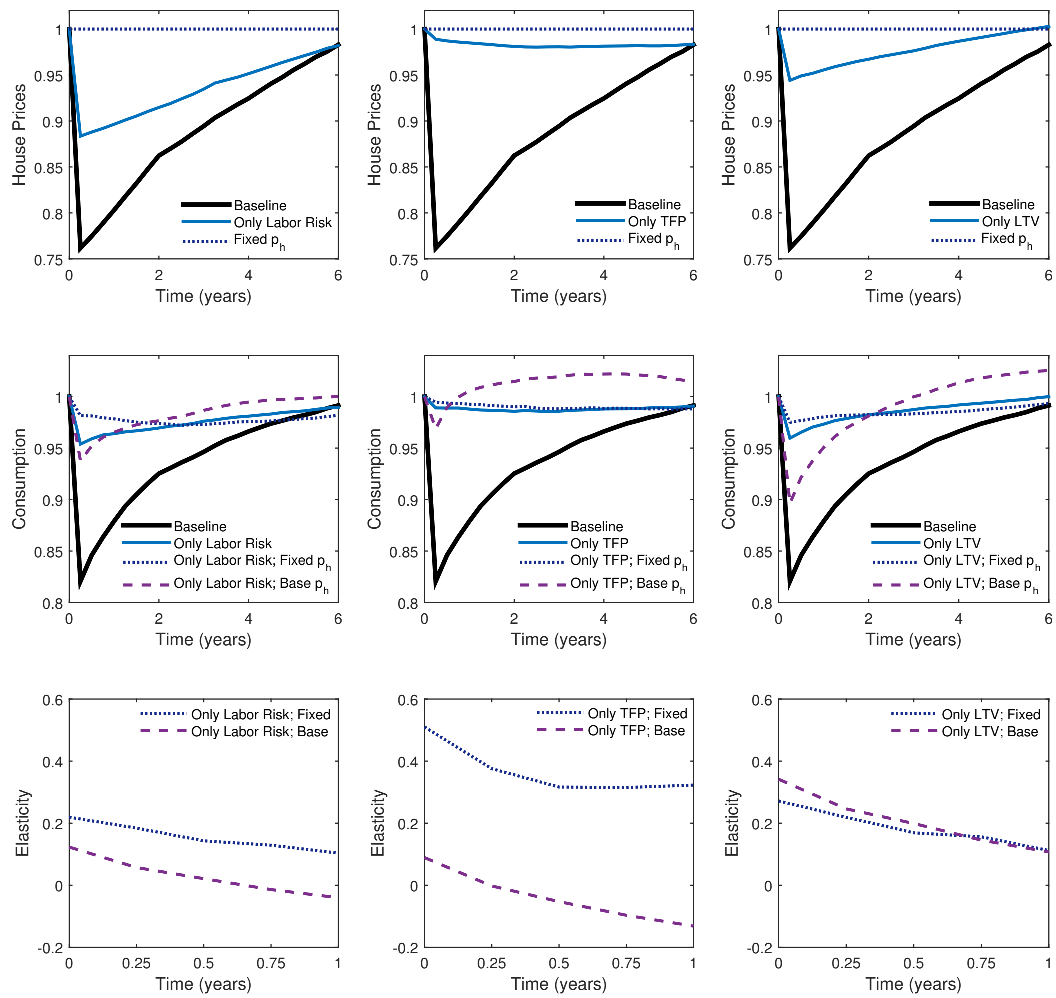

Figure 12: Consumption response to house price movements conditional on *only one* shock hitting the economy. Top: house prices; middle: consumption; bottom: elasticity of consumption to house prices. The "fixed" elasticity uses the "fixed $p(h)$" house price trajectory as the reference, whereas the "baseline" elasticity uses the "baseline $p(h)$" house price trajectory as the reference.

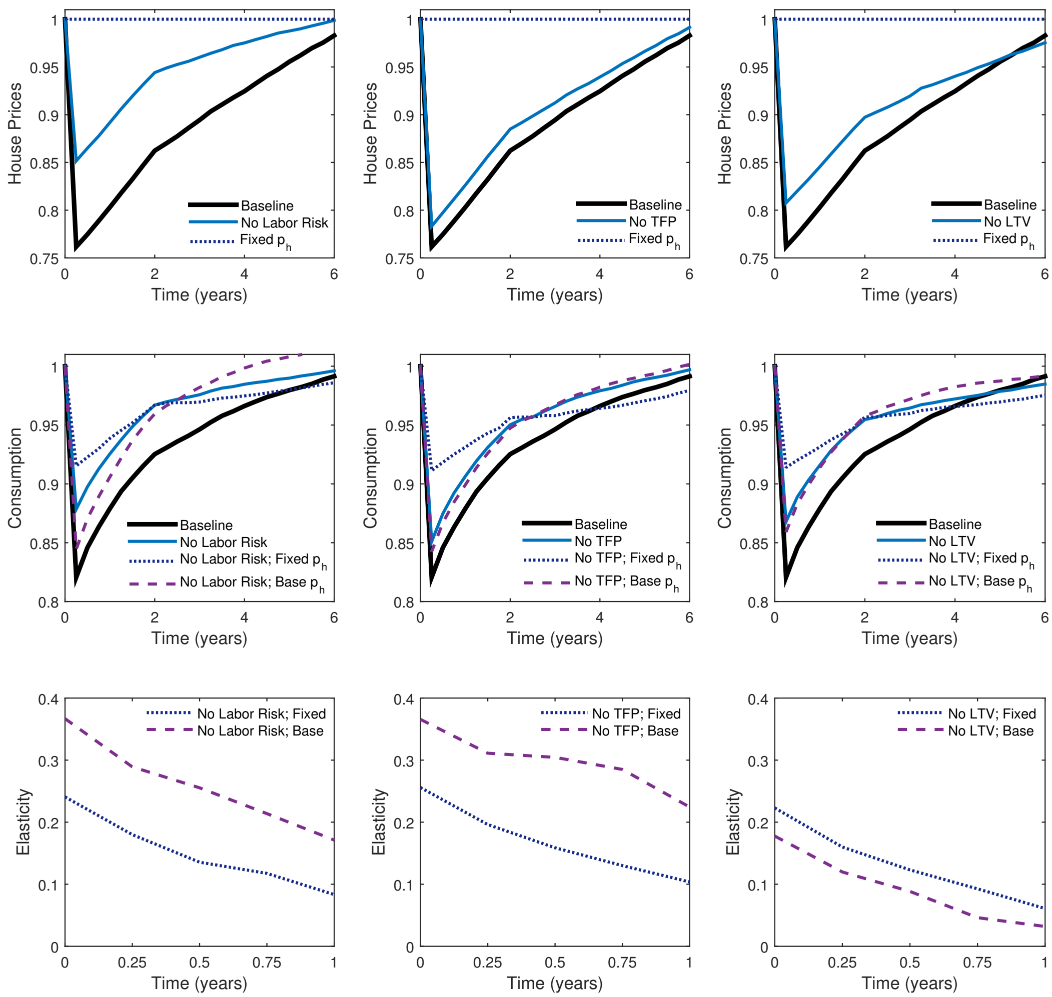

Figure 13: Consumption response to house price movements conditional on *all but one* shock hitting the economy. Top: house prices; middle: consumption; bottom: elasticity of consumption to house prices. The “fixed” elasticity uses the “fixed $p(h)$” house price trajectory as the reference, whereas the “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 14.

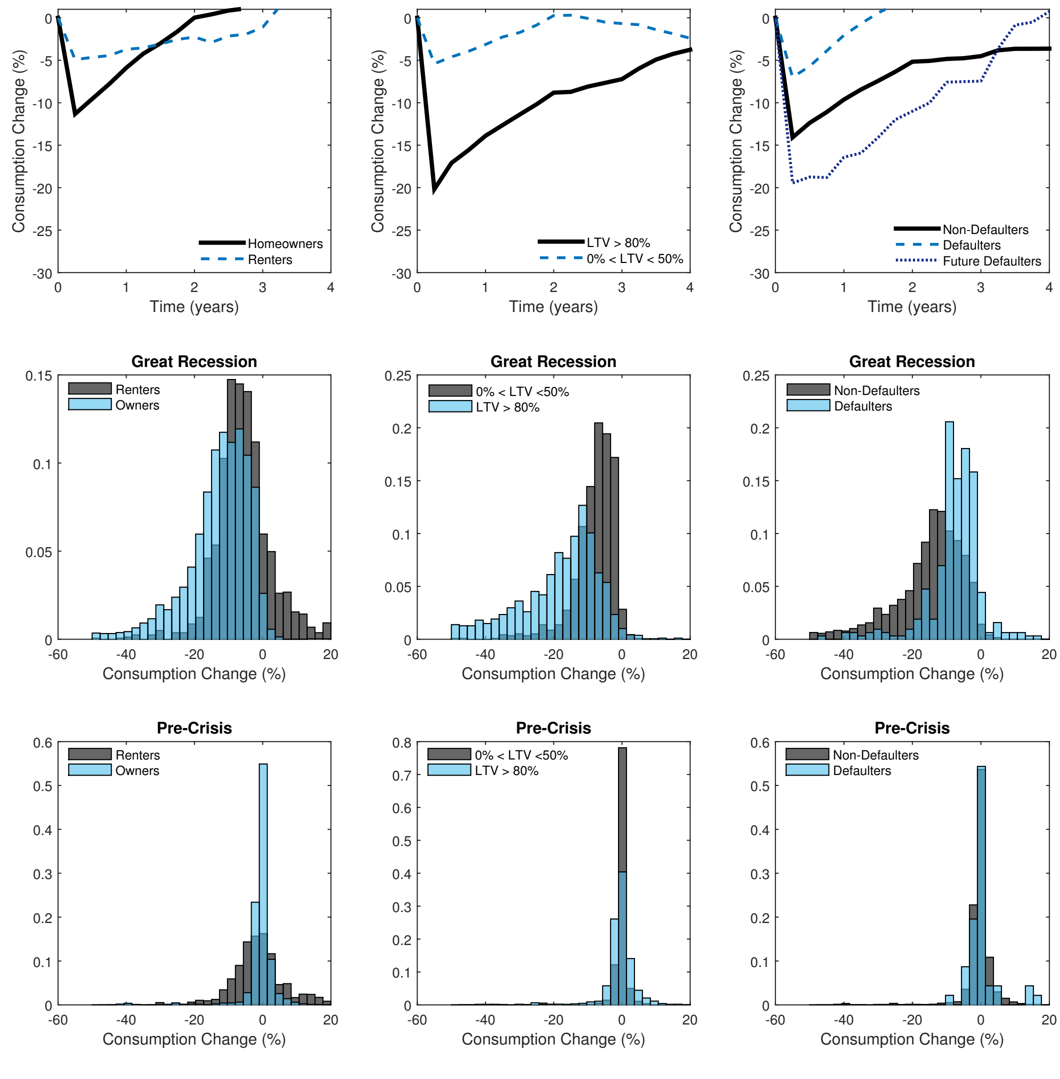

Figure 14: Consumption dynamics by ownership status, leverage, and default status in the economy with **exogenous housing illiquidity**. The histogram represents the change in consumption between subsequent periods pre-crisis and at the onset of the Great Recession.

Table 6 in the main text establishes the importance of gross portfolio positions for the behavior of consumption during the Great Recession. Figure 15 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.

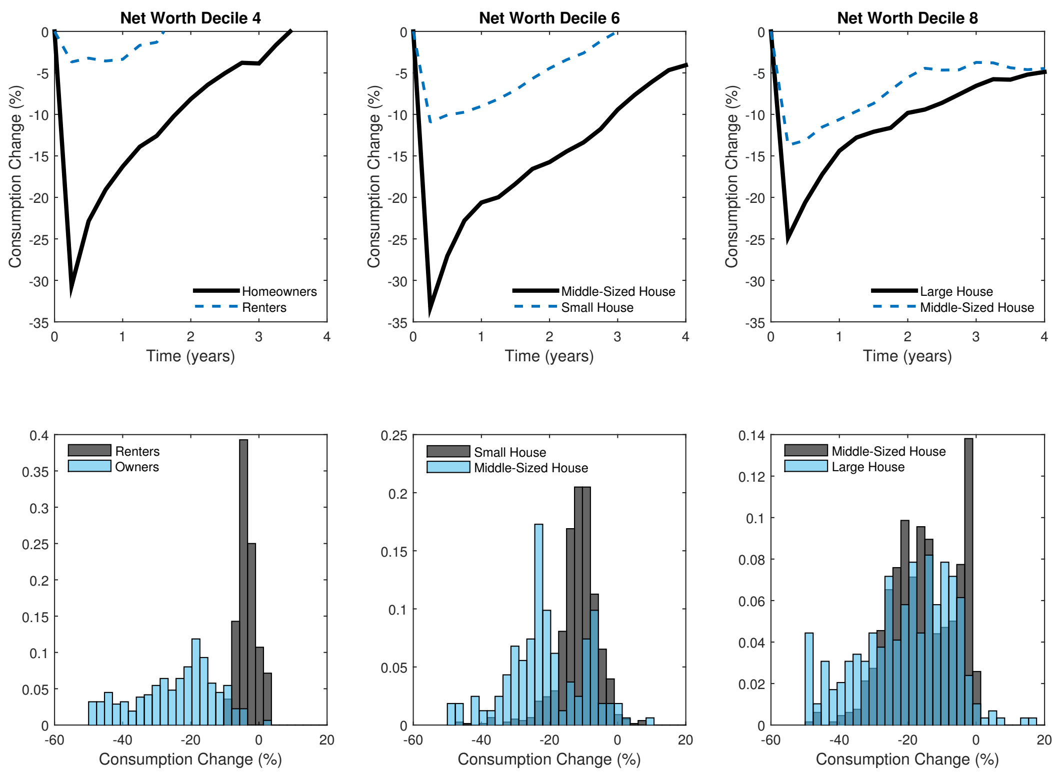

Figure 15: Consumption dynamics within net worth deciles for households with different gross portfolio positions.

A.5 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 16 below shows that the potency of this channel increases with household leverage.

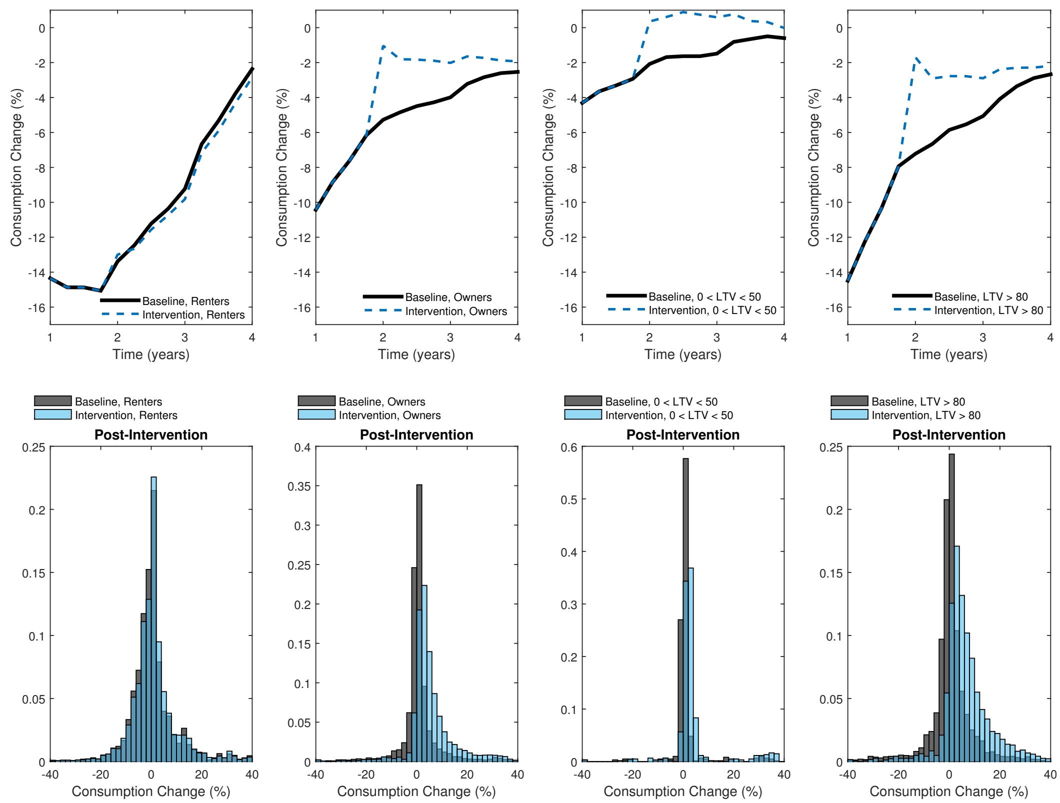

Figure 16: Consumption response to lower mortgages rates from the policy intervention by ownership status and leverage.

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:

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

subject to

$$\begin{gathered} c + \gamma p(h) + q_b b' + m \leq y + q^0_m((r_m, m'), b', h, s) m' \\ q^0_m((r_m, m'), b', h, s) m' \leq \vartheta p(h) \\ y' = w e' s' + b' \end{gathered} \tag{17}$$

Homeowners with good credit who make a regular payment:

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

subject to

$$\begin{gathered} c + \gamma p(h) + q_b b' + l \leq y \\ l \geq \frac{\overline{r}_m}{1 + \overline{r}_m} m \\ m' = (m - l)(1 + \overline{r}_m) \\ y' = w e' s' + b' \end{gathered} \tag{18}$$

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:

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

Apartment-dwellers with bad credit:

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

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:

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

Utility of default conditional on no repossession:

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

$$\text{subject to}$$

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

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

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

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

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

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

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:

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

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

$$\left.\left. +(1-d')\left\{m'\mathbf{1}_{[\text{Refi}]} + \mathbf{1}_{[\text{No Refi}]}\left(\underbrace{l}_{\text{payment}} + \underbrace{(1+\zeta)q_m^0((\bar{r}_m, m''), b'', h, s')m''}_{\text{continuation with } m''=(m'-l)(1+\bar{r}_m)}\right)\right\}\right]\right\} \tag{35}$$

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 $q^{0,n}_m(m', b', h, s)$ 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

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

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

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