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

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Abstract

This paper analyzes the role of the housing collapse in explaining U.S. macroeconomic performance since 2006. Using a heterogeneous agent model with endogenous credit constraints, housing market search frictions, and equilibrium mortgage default, it is shown that an increase in downside labor market risk and a tightening of down payment constraints are key to replicating the steep drop in house prices and consumption. Importantly, the endogenous deterioration of housing illiquidity greatly amplifies the severity of the recession by increasing foreclosures, raising default premia, and tightening credit. Furthermore, house prices and endogenous liquidity have a pronounced effect on the dynamics of consumption that varies across the leverage distribution. Lastly, quantitative easing is shown to substantially accelerate the recovery in house prices and consumption, particularly among highly indebted borrowers and homeowners with adjustable rate mortgages.

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

Between 2006 and 2011, real house prices in the United States fell by 25% while the macroeconomy experienced its most severe recession in decades. Since then, house prices have recovered significantly and the U.S. economy has experienced steady but tepid growth. From a macroeconomic perspective, the contribution of the housing market to the deterioration and recovery in broader economic activity and the availability of credit remains an open question. In traditional macroeconomic models, shocks to household balance sheets have only modest effects on household and aggregate economic behavior. However, in widely read work, Mian and Sufi (2011) and Mian, Rao and Sufi (2013) present empirical evidence of a housing-induced build up of debt that, upon the collapse of house prices, led to a spike in foreclosure rates, a severe contraction in credit and consumption, and a slow process of deleveraging that hampered the economic recovery. At the same time that prices were declining, a lesser reported but equally notable phenomenon was occurring in the housing market: a dramatic increase in selling delays. Prior to the collapse, houses put up for sale typically sat on the market for around four months. However, by 2008, this measure of housing illiquidity skyrocketed as time on the market reached almost a full year. In response to these events and the hitting of the zero lower bound, the Federal Reserve intervened in financial markets with quantitative easing in an attempt to drive down long term rates, stimulate housing, and resuscitate the economy.

The broad goal of this paper is to understand the relationship between housing, debt, and consumption during the Great Recession and subsequent recovery. Specifically, four questions are addressed:

1. What accounts for the pronounced drop in house prices and consumption and the surge in foreclosures during the Great Recession?

2. What are the macroeconomic implications of the spike in selling delays?

3. How do housing and debt influence the dynamics of consumption?

4. What are the macroeconomic effects of quantitative easing and how sensitive are they to the nature of mortgage contracts?

To address these questions, a macroeconomic model is constructed with search frictions in the housing market, endogenous credit constraints, and equilibrium mortgage default. Households face idiosyncratic income risk and incomplete insurance markets, which gives rise to endogenous heterogeneity by income, assets, and debt. Households make housing tenure decisions and

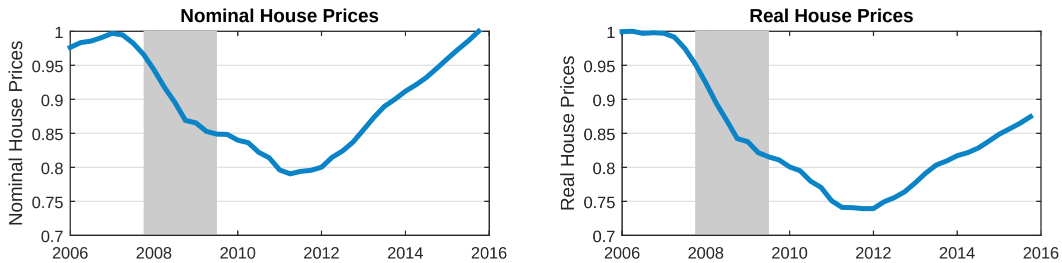


Figure 1: Nominal house prices fell by 20% from 2006 – 2011 and have completely recovered. Real prices declined by 25% and have recovered half-way.

finance purchases with long-term mortgages. Apartment rentals are available for individuals who choose not to purchase a house. The ability to default on mortgage debt causes banks to price mortgages based on the individual default risk of each borrower. Borrowers are also permitted to extract equity through refinancing, but default spreads affect access to credit and act as a form of endogenous *credit illiquidity*. Crucially, mortgages are long-term, fixed-rate contracts that shield borrowers from re-pricing of default risk and from fluctuations in interest rates. The model also features *housing illiquidity* in the form of search-induced endogenous selling delays. Unlike in price-taking Walrasian models of the housing market, sellers here choose their own list price and face an endogenous trade-off between price and time on the market. The quantitative version of the model captures selected micro and macro features of the U.S. economy in 2004.

Before delving into the implications of illiquidity, the paper simulates the Great Recession using a combination of observed labor market and financial shocks and successfully reproduces the large drop in house prices. Furthermore, the model also generates a steep drop in consumption and matches the observed surge in time on the market and foreclosures as well as the gradual decline in homeownership. The increase in downside labor market risk and the tightening of loan-to-value constraints at origination emerge as the most salient shocks. In fact, without the contribution of labor market risk, homeownership counterfactually *increases* in response to declining house prices.

In this economy, housing illiquidity generates an endogenous and asymmetric amplification mechanism. Intuitively, during booms, houses sell quickly and abundant credit allows owners to easily extract equity through refinancing. However, during downturns, sellers face a deteriorating trade-off between list price and time on the market, and this adverse change in housing liquidity affects highly leveraged borrowers most keenly. The need to pay off outstanding debt imposes a lower bound on list price that prevents these sellers from pricing their houses competitively. As a result, debt overhang causes long selling delays and forces homeowners who fail to quickly unload their house to either severely cut consumption or go into default. In the latter case, heightened selling delays spill over into greater foreclosure risk from homeowners who are unable to maintain mortgage payments while their house sits on the market. A credit channel emerges from this increase in foreclosure risk as banks price higher default risk into new mortgages, thereby reducing credit liquidity and increasing the cost of refinancing. This chain of events cascades as depressed housing and credit liquidity push down house prices, which further pushes down both forms of liquidity. The end result is a persistent slump marked by high foreclosure activity and deep declines in house prices and consumption.

Quantitatively, endogenous illiquidity in the housing and mortgage markets amplifies the drop in house prices and consumption by 27% and 32%, respectively, relative to a version of the model with Walrasian housing markets and exogenous transaction costs. Absent endogenous housing illiquidity and its impact on prices, the foreclosure rate only reaches 1.3% instead of the 4.3% peak in the baseline. As a result, endogenous illiquidity represents a key ingredient for researchers interested in the credit channel transmission of housing behavior to consumption.

The link between selling delays and foreclosure risk also revises the conventional wisdom on mortgage default behavior. According to the prevailing view, negative equity and some form of negative shock to household finances are necessary and sufficient to cause foreclosure. This paper proposes a modification called the Stochastic Liquidity-Adjusted Double Trigger (SLADT). Under SLADT, highly-leveraged homeowners who know they have a zero probability of selling their house at a price that allows for debt repayment behave according to the standard double trigger hypothesis. However, with SLADT, positive equity is no longer ironclad protection against default, because what matters is not equity on paper, but rather the ability to sell *in a timely manner*. As a result, financially vulnerable sellers with small equity cushions may default in the event that their houses take too long to sell.

In addition to the amplification it generates, endogenous housing illiquidity proves necessary to replicate the reduction in homeownership and the positive co-movement of house prices and sales (both decline). By contrast, house prices and sales are negatively correlated in many models, including the version here with Walrasian housing and exogenous transaction costs. When house prices fall in standard models, buyers surge into the market to purchase cheap housing. However, for two distinct reasons, endogenous housing illiquidity works against this dynamic and realigns the model with the data. First, selling delays increase as prices fall, particularly in a debt-laden economy. As a result, holding fixed the willingness to sell of homeowners, the volume of transactions decreases mechanically from a reduction in *successful* sales. Second, credit liquidity contracts more strongly in response to deteriorating housing illiquidity, which blunts the ability of new buyers to flood into the market.

The adjustment of household balance sheets generates sizable effects from housing into consumption behavior, and a growing cottage industry of empirical papers has recently arisen to investigate this connection. This paper, in turn, makes major advances in understanding the underlying mechanisms that operate between house price movements and consumption. Before addressing these economic channels, the model is first shown to successfully replicate the consumption elasticity to house price movements of 0.3 established empirically by Mian et al. (2013). Next, this elasticity is shown to vary over time and be nonlinear and shock-dependent. Furthermore, the interaction of endogenous housing and credit illiquidity magnifies the response of consumption to shocks and prolongs the sensitivity of consumption to house prices. Looking deeper into consumption dynamics by household type during the Great Recession, this paper finds that indebted homeowners who opt not to default experience the most drastic consumption declines. By contrast, renters, homeowners with substantial equity, and defaulters all face only modest cuts to consumption. A key lesson emerges: while housing has favorable risk-sharing benefits in good times by allowing owners to extract equity through refinancing or selling, fortunes reverse in a housing collapse when equity and liquidity evaporate.

Some commentators have suggested that the structure of mortgage finance is an important source of fragility in the credit market. However, the baseline economy takes an extreme view by considering only fixed rate mortgages (FRMs), which provide insurance to borrowers against interest rate fluctuations. To test the effects of this insurance, a comparison economy with only adjustable rate mortgages (ARMs) is constructed that exposes borrowers to mortgage rate resets. In response to the same economic shocks, foreclosures in the ARM economy spike all the way to 12% compared to just 4.3% in the FRM economy. As a result, homeownership plummets to below 61% with ARMs, rather than the more modest decline to 65% with FRMs.

The increased exposure of borrowers to risk from the removal of interest rate insurance amplifies the connection between endogenous housing illiquidity and the credit channel. At an aggregate level, house prices and consumption both fall approximately 2 percentage points further in the ARM economy. This top line consumption response masks substantial heterogeneity, however. Unsurprisingly, the modest drops in *renter* consumption in the two economies mirror each other. The same goes for the consumption of homeowners with substantial equity and for owners who default. However, highly leveraged borrowers cut their consumption by over *30%* more with ARMs than with FRMs in response to the recessionary shocks.

The severity of the Great Recession led to an unprecedented response from the monetary authority with the goal of providing credit and reestablishing the liquidity properties of homes. Motivated by the literature's inconclusive findings on the magnitudes and channels through which these interventions work, this paper evaluates quantitative easing in the context of the model for both the FRM and ARM economies and based on whether the policy is implemented immediately as a surprise or whether it is announced ahead of time. Several lessons emerge. First, expectations matter for the efficacy of QE. In the case where QE is announced and implemented by surprise two years after the beginning of the housing collapse (i.e. late 2008 vs. 2006), house prices and consumption both jump by approximately 5 percentage points. However, had QE been announced immediately upon signs of deterioration in the housing market, QE would have partially arrested the drop in house prices and would have reduced the peak in foreclosures by one third. Secondly, the dynamic economic response to QE depends on the prevalence of mortgage type. In the FRM economy, QE has a minimal impact on the trajectory of homeownership. Furthermore, even though consumption jumps upon implementation, this surge is accompanied by a build up of debt from borrowers refinancing to take advantage of lower rates, which leads to lower consumption growth in the medium run. However, in the ARM economy, QE significantly buttresses homeownership and pushes up consumption in both the short run and medium run because borrowers do not need to refinance to take advantage of lower rates. As with many of the results in this paper, the overall response of consumption to QE also covers over substantial heterogeneity. In the FRM economy, average homeowner consumption increases by 4.5% in response to QE, with a 2.5% increase for owners with substantial equity and 6.0% for highly indebted owners. In the ARM economy, these numbers are all larger: 5.7%, 2.9%, and 7.9%, respectively. Lastly, it is shown that the consumption response to QE depends heavily on the positive endogenous response of house prices. Holding fixed the trajectory of house prices dampens the increase in consumption by more than half.

1.1 Related Literature

There is a growing literature that relates aspects of financial crises with the Great Recession. While there are some important connections with this paper, the main objective of this section is to relate our research with different strands of the macro-housing literature.

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

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

To understand the dynamics of house prices during the boom and the bust Garriga, Manuelli, and Peralta-Alva (2012) develop a stylized macroeconomic model of market segmentation that generates sizable movement in house values, about 50 percent, driven by changes in housing finance. In their economy, the collapse of house prices induces a large and persistent recession through the deleveraging process and decline in non-housing consumption. This paper shares similar features in the process of engineering a housing crisis as unanticipated set of events, but the mechanisms are different. The most important is the presence of search frictions in the housing market that endogeneizes the liquidity of homes, thereby introducing an amplification mechanism relative to a framework with exogenous transaction costs. In addition, the presence of household heterogeneity and tenure choice allows for exploring the differential response of homeowners and renters. In addition, homeowners can choose to deleverage by repaying the loan or defaulting. The choice to deleverage has important implications for the path of consumption of the home owners.

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

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

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

The heterogeneity in the model has clear testable data implications. The ability of the model to match the empirical counterparts as suggested by the works of Mian, Rao, and Sufi (2013), Mian and Sufi (2014), Petev, Pistaferri, and Eksten (2011), and Parker and Vissing-Jorgensen (2009) among other is discussed in the results section. It is worth mentioning that there is also an extensive literature that explores the role of financial conditions as drivers of the Great Recession using quantitative dynamic macroeconomic models (i.e., Black (1995); Bloom (2009); Christiano et al. (2010); Arellano et al. (2010); Gertler and Karadi (2011); Hall (2011); Kocherlakota (2012); Jermann and Quadrini (2012); Brunnermeier and Sannikov (2013); He and Krishnamurthy (2014); Gertler and Kiyotaki (2015), Navarro (2015), among others). However, most of this research focuses on firms investment and private employment, but the literature makes no attempt to measure the specific role of housing and construction and in the Great Recession.

2 The Model

2.1 Households

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

Preferences Households 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_h per unit. Agents become homeowners by purchasing a house $h \in H = \{\underline{h}, h_2, h_3\}$ that generates $c_h = h$ housing services each period. Owners are not permitted to possess multiple houses or to have tenants. They all occupy their residence because $\overline{a} \leq \underline{h}$.

2.2 Technology

Composite Consumption A representative firm hires labor N_c at unit cost w to produce the consumption good: $Y_c = A_c N_c$.

Apartments Landlords operate a reversible technology that converts one unit of consumption into A_h units of apartment space to be sold at price r_h.[1]

Housing Construction Home builders construct new houses using a constant returns to scale production function with land L, structures S_h, and labor N_h: $Y_h = F_h(L, S_h, N_h)$. Builders purchase structures S_h from the consumption good sector, and as in Favilukis, Ludvigson and Van Nieuwerburgh (2016), the government supplies a fixed amount $\overline{L} > 0$ of new land permits each period, with all revenues going to government consumption. Individual houses face complete stochastic depreciation with probability δ_h.[2] The aggregate housing stock evolves according to

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

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

[2] As discussed in section 2.4.1, there is mortgage forgiveness if a house depreciates. Complete depreciation avoids artificial foreclosures from somebody losing part of their house.

2.3 Housing Market

Real estate brokers intermediate all trades in the decentralized housing market. First, owners (owner-occupiers or banks with foreclosed properties) choose a list price x_s to attract seller-brokers willing to purchase their house at that price. Subsequently, buyers choose a desired house type $h \in H$ and purchase price x_b and direct their search for a buyer-broker willing to sell said house at said price. The market "clears" as seller-brokers, buyer-brokers, and home builders trade housing frictionlessly with each other at the *shadow housing price* p_h. Brokers are not permitted to carry housing inventories into future periods, but inventories *do* arise in equilibrium from the portion of the housing stock that owners put on the market but fail to sell. **Housing illiquidity** is reflected by the fact that both sides of the market feature a trade-off between price and trade probability and frequently exhibit a failure to trade.

2.3.1 Directed Search in the Housing Market

Buyers Prospective buyers direct their search for houses by choosing a desired price $x_b \geq 0$ and a house size $h \in H$. Formally, buyers enter submarket $(x_b, h) \in \mathbb{R}_+ \times H$. With probability $p_b(\theta_b(x_b, h))$, a buyer matches with and purchases a house from a buyer-broker, where $\theta_b(x_b, h)$ is the ratio of brokers to buyers, i.e. the market tightness of submarket (x_b, h). The probability that a broker finds a buyer is $\alpha_b(\theta_b(x_b, h)) = \frac{p_b(\theta_b(x_b,h))}{\theta_b(x_b,h)}$. The function $p_b : \mathbb{R}_+ \to [0, 1]$ is continuous and strictly increasing with $p_b(0) = 0$; α_b is strictly decreasing. It is possible that $\alpha_b > 1$, in which case the same broker finds multiple buyers, to which the broker sells one house each. Successful buyers immediately move into their house. Unsuccessful buyers remain as renters until the next period.

Sellers Sellers of existing houses, which includes homeowners and lenders selling foreclosed properties, simply choose a list price $x_s \geq 0$ *each period* that they commit to honoring if they match with a seller-broker. In the parlance of directed search, sellers enter submarket (x_s, h), where h is the size of house they are selling. With probability $p_s(\theta_s(x_s, h))$, a seller successfully matches and sells the house, *provided that they have the ability to pay off any outstanding mortgage debt.* Brokers find sellers with probability α_s, where p_s and α_s are analogous to p_b and α_b, respectively. Each broker incurs an entry cost $\kappa_s h$, and owners that try and fail to sell pay a small utility cost ξ. On both sides of the market, all participants take submarket tightnesses parametrically.

The profit maximization conditions of the real estate brokers are

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

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

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

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

2.3.2 Block Recursivity

As the above analysis shows, the menu of market tightnesses does not depend directly on the distribution of households over income, assets, and debt. Instead, $\theta_s(x_s, h)$ and $\theta_b(x_b, h)$ depend only on p_h:

$$\theta_b(x_b, h) = \alpha_b^{-1}\left(\frac{\kappa_b h}{x_b - p_h h}\right) \tag{3}$$

$$\theta_s(x_s, h) = \alpha_s^{-1}\left(\frac{\kappa_s h}{p_h h - x_s}\right) \tag{4}$$

Block recursivity greatly simplifies and speeds up the computation without altering the substance of the frictional buying and selling problems of the households. As a result, solving for the dynamics of the market tightnesses reduces to finding the equilibrium path of p_h and substituting into (3) – (4).

2.4 Financial Markets

Households save through the use of one period real bonds that trade at price $q_b = \frac{1}{1+r}$, where r is the (exogenous) risk-free rate. In addition, homeowners can borrow in the form of long term, fixed rate mortgage contracts.

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 $q_m^0((q_m, m'), b', h, s)m'$ units of the composite consumption good to the borrower at origination, where $q_m \equiv \frac{1}{1+r_m}$ remains fixed for the duration of the loan. Perfect competition assures zero ex-ante profits loan-by-loan. For the duration of the paper, q_m denotes the current market (inverse) fixed rate for new mortgages while $\overline{q_m}$ denotes the rate for an individual existing borrower. No distinction exists in the steady state.

Mortgages in this paper have no predefined maturity date, which allows them to act as a stand-in for all forms of mortgage debt (i.e. not just a 30-year first lien). As a result, homeowners gradually accumulate equity at their own pace. However, homeowners that want to tap into their equity must refinance.

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, the bank must forgive the loan.[3] 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.

Banks front-load all borrower-specific default risk into the price q_m^0 borrowers receive at origination, but the fixed rate $\overline{q_m}$ reflects depreciation risk. To summarize, a borrower with contract $(\overline{q_m}, m)$ that chooses a new balance of m' owes $m - \overline{q_m}m'$ if $m' \leq m$, or else $m - q_m^0((q_m, m'), b', h, s)m'$ if $m' > m$.

The fixed rate r_m set at origination satisfies $1+r_m = \underbrace{\left(\frac{1+\phi}{1-\delta_h}\right)}_{\text{spread}} \underbrace{1+r^*}_{\text{long-run risk-free rate}}.$

Mortgage prices satisfy the following recursive relationship:

$$q_m^0((\overline{q_m}, m'), b', h, s)m' = \frac{1-\delta_h}{(1+\zeta)(1+\phi)(1+r)}\mathbb{E}\left\{\overbrace{p_s(\theta_s(x_s', h))m'}^{\text{sell + repay}} + \overbrace{[1-p_s(\theta_s(x_s', h))]}^{\text{no sale (do not try/fail)}}\right.$$
$$\times\left[\underbrace{d'\varphi\min\left\{J_{REO}(h), m'\right\}}_{\text{default + repossession}} + \underbrace{d'(1-\varphi)}_{\text{no repossession}}\left(-\phi m' + \underbrace{(1+\zeta)(1+\phi)q_m^0((\overline{q_m}, m'), b'', h, s')m'}_{\text{continuation value of current } m'}\right)\right.$$
$$\left.\left.+(1-d')\left(\underbrace{m' - (1+\phi)\overline{q_m}m''\mathbf{1}_{[m''\leq m']}}_{\text{borrower payment net of servicing costs}} + \underbrace{(1+\zeta)(1+\phi)q_m^0((\overline{q_m}, m''), b'', h, s')m''\mathbf{1}_{[m''\leq m']}}_{\text{continuation value of new } m''}\right)\right]\right\} \tag{5}$$

where x_s', d', b'', and M'' are the policies for list price, default, bonds, and new debt, respectively, and J_{REO} is the value of repossessed housing.

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

2.4.2 Foreclosure Process

In the event of foreclosure, borrowers lose their house, have their debt erased, and receive a flag $f = 1$ on their credit record. Borrowers with a credit flag lose access to the mortgage market. Flags persist to next period with probability $\gamma_f \in (0, 1)$.

Banks sell repossessed houses (REO properties) in the decentralized housing market. Banks lose a proportion χ of sales revenue to the various costs of selling foreclosed houses. The bank absorbs all losses but must pass along profits to the borrower in the unlikely event that sales revenues exceed the remaining mortgage balance.

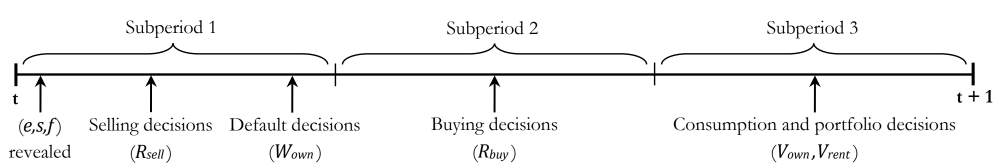
The value to a lender in repossessing a house h is

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

$$R_{REO}(h) = \max\left\{0, \max_{x_s \geq 0} p_s(\theta_s(x_s, h)) \left[(1-\chi)x_s - \left(-\eta h + \frac{1-\delta_h}{1+r} J_{REO}(h)\right)\right]\right\} \tag{6}$$

where η is the cost of holding onto the house (maintenance, property taxes, etc.) and $R_{REO}(h)$ is the option value of trying to sell the house.

2.5 Household Problem



Each period contains three subperiods. At the beginning of subperiod 1, households learn their labor efficiency components, e and s, and their credit score $f \in \{0, 1\}$. The individual state of a homeowner is cash at hand y, inverse mortgage rate $\overline{q_m}$ and balance m, house h, and persistent labor component s. The individual state of a renter is simply (y, s, f). Working backwards, the household problem is as follows:

2.5.1 Consumption/Saving

End-of-period homeowner expenditures consist of the consumption good, bond purchases, and mortgage payments. Homeowners face the following constraint:

$$c + \eta h + q_b b' + m - \widetilde{q_m} m' \leq y$$

where $\widetilde{q_m} = \overline{q_m} \mathbf{1}_{[m' \leq m]} + q_m^0((q_m, m'), b', h, s)\mathbf{1}_{[m' > m]}$.

In the stationary environment, owners with good credit have value function

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

$$\begin{gathered} \text{subject to} \\ c + \eta h + q_b b' + m - \widetilde{q_m} m' \leq y \\ q_m^0((q_m, m'), b', h, s) m' \mathbf{1}_{[m' > m]} \leq \vartheta p_h \\ y' = w e' s' + b' \end{gathered} \tag{7}$$

where ϑ is the loan-to-value limit for new loans. The terms $W_{own} + R_{sell}$ and $V_{rent} + R_{buy}$ are subperiod 1 utilities for homeowners and apartment-dwellers, respectively.

The problem for homeowners with bad credit is analogous, except that they lack access to the mortgage market. Apartment-dwellers replace mortgage payments with period-by-period purchases of apartment space $a \leq \overline{a}$. Therefore, apartment-dwellers face the following constraint:

$$c + r_h a + q_b b' \leq y.$$

2.5.2 House Buying

Prospective buyers (including successful home sellers from subperiod 1) direct their search to a submarket (x_b, h) of their choice. Buyers with bad credit are bound by the constraint $y - x_b \geq 0$, while buyers with good credit are bound by the constraint $y - x_b \geq \underline{y}(s, (h, 1))$, where $\underline{y} < 0$ captures the ability of new buyers to take out a mortgage in subperiod 3. The option value R_{buy} of attempting to buy is as follows:

$$R_{buy}(y,s,0) = \max\{0, \max_{\substack{h\in H,\\ x_b \leq y-\underline{y}}} p_b(\theta_b(x_b,h))[V_{own}(y-x_b,0,h,s,0) - V_{rent}(y,s,0)]\} \tag{8}$$

$$R_{buy}(y,s,1) = \max\{0, \max_{\substack{h\in H,\\ x_b \leq y}} p_b(\theta_b(x_b,h))[V_{own}(y-x_b,0,h,s,1) - V_{rent}(y,s,1)]\} \tag{9}$$

2.5.3 Mortgage Default

The value function for a homeowner deciding whether to default is

$$\begin{aligned} W(y,(\overline{q_m},m),h,s,0) = \max\{&\varphi(V_{rent}+R_{buy})\left(y+\max\{0, J_{REO}(h)-m\}, s, 1\right) \\ &+(1-\varphi)V^d_{own}(y,(\overline{q_m},m),h,s,0), V_{own}(y,(\overline{q_m},m),h,s,0)\} \end{aligned} \tag{10}$$

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

$$\begin{gathered} V^d_{own}(y,(\overline{q_m},m),h,s,0) = \max_{b',c\geq 0} u(c,h) + \beta\mathbb{E}\left[\begin{array}{l} (1-\delta_h)(W_{own}+R_{sell})(y',(\overline{q_m},m),h,s',0) \\ +\delta_h(V_{rent}+R_{buy})(y',s',0) \end{array}\right] \\ \text{subject to} \\ c+\eta h + q_b b' \leq y \\ y' = we's'+b' \end{gathered} \tag{11}$$

2.5.4 House Selling

Owners of house size h who want to sell choose a list price x_s and direct their search to submarket (x_s, h). The option value R_{sell} for a homeowner with good credit is

$$\begin{aligned} R_{sell}(y,(\overline{q_m},m),h,s,0) = \max\{0, \max_{x_s} p_s(\theta_s(x_s,h))\,&[(V_{rent}+R_{buy})\,(y+x_s-m,s,0) \\ -W_{own}(y,(\overline{q_m},m),h,s,0)] + [1-p_s(\theta_s(x_s,h))]\,(-\xi)\}&\text{ subject to } y+x_s \geq m \end{aligned} \tag{12}$$

where the constraint reflects the mortgage repayment requirement. Debt overhang emerges when highly leveraged homeowners are forced to set high prices that lead to long selling delays.

3 Model Parametrization

The model is calibrated to replicate key features of the United States economy during 2003 – 2005, prior to the Great Recession. The calibration puts heavy emphasis on matching key housing moments related to sales, time on the market, and foreclosures, as well as important dimensions of the joint distribution of assets, housing wealth, and mortgage debt. Some parameters are drawn from the literature or from external sources, but the remainder are determined jointly within the model.

3.1 Independent Parameters

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.[4] The persistent component is discretized using a 3-state Markov chain.

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 in the joint calibration.

Technology TFP in the consumption good sector is set to normalize mean quarterly earnings to 0.25. Meanwhile, housing construction is Cobb-Douglas with a structures share of $\alpha_S = 0.3$ and a land share of $\alpha_L = 0.33$, based on data from the Lincoln Institute of Land Policy. Housing depreciates at an annual rate of 1.4%. Lastly, 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 Matching is Cobb Douglas, i.e. $p_s(\theta_s) = \min\{\theta^{\gamma_s}, 1\}$ and $p_b(\theta_b) = \min\{\theta^{\gamma_b}, 1\}$. Substituting in (3) and (4) gives

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

The joint calibration determines the parameters κ_b, κ_s, γ_s, γ_b, and disutility ξ. Holding costs (maintenance, property taxes, etc.) are $\eta = 0.007$.

[4]The appendix explains the procedure to convert the annual estimates from Storesletten et al. (2004) to quarterly values.

Financial Markets To match values in the U.S. during 2003 – 2005, the real risk-free rate is set to -1%, and the mortgage origination cost is 0.4%. The mortgage servicing cost ϕ is set to equate the real mortgage rate to 3.6%. Lastly, the exogenous LTV limit is $\vartheta = 1.25$ (125%), which makes it *non-binding* initially.[5] Lastly, the persistence of bad credit flags is $\gamma_f = 0.95$, and the REO discount χ is determined in the joint calibration.

3.2 Joint Calibration and Model Fit

The joint calibration determines the remaining parameters. First, the calibration targets select household portfolio moments calculated from the 2004 Survey of Consumer Finances (SCF). Specifically, the calibration aims to match average housing wealth and the distribution of leverage—especially at the higher end—to generate the correct fraction of underwater borrowers during the Great Recession.[6] The calibration also targets certain key housing market variables such as sales volume, average search duration for buyers and sellers, and maximum price spreads. Lastly, the model is calibrated to match foreclosure starts and the average foreclosure discount.[7]

Table 1 shows that the model successfully matches the targets and nearly replicates other untargeted portfolio statistics from the 2004 SCF. Notably, the model matches median liquid assets and reasonably approximates the distribution of mortgage debt.

4 Results

This section undertakes four major tasks. First, the relative importance of each determinant of the Great Recession is quantified. Second, results are presented that highlight the importance of *endogenous housing liquidity* in explaining macroeconomic dynamics during the Great Recession. Next, the transmission of house price movements into consumption is analyzed. The last task evaluates the Federal Reserve's quantitative easing interventions and the role of fixed rate vs. adjustable rate mortgages in the transmission of shocks.

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

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

[7]Garriga and Hedlund (2016) use a version of this model calibrated to match U.S. economic conditions in the late 1990s to analyze the boom-bust episode of 2001 – 2011. The post-boom recession in that paper generates almost identical drops in house prices, consumption, and homeownership to those generated here. Like this paper, Ríos-Rull and Huo (2016) also focus on the recession and recovery but not the boom. By contrast, Kaplan, Mitman and Violante (2015) simulate the boom and bust but not the subsequent recovery.

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	η	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	3.2%			3.2% 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.

4.1 Replicating and Decomposing the Great Recession

To simulate the Great Recession, the model is hit with a combination of shocks starting in 2006, and the perfect foresight transition path is calculated. In other words, agents are surprised by the onset of the recession but have rational expectations about the progression of the recession and recovery. Because of the open economy assumption, the rest of the world directly bears all unexpected foreclosure losses.

Labor Market Conditions The first set of shocks used to simulate the Great Recession affects the labor market. First, total factor productivity (TFP) drops by 5% and remains at that level for 3 years before reverting. Although the Great Recession did not officially begin until the end of 2007, evidence from Fernald (2014) indicates that TFP started dropping beforehand. In the model, this drop in TFP translates directly into a 5% cut in wages for all households.

Second, a temporary increase in labor market risk is engineered to generate a gradual 6.2% drop in aggregate labor consistent with the deterioration in employment from 2007 to 2010. Specifically, the labor efficiency transition matrix π_s is replaced with new transition probabilities $\widetilde{\pi}_s^{recession}(s'|s)$.[8]

Financial Conditions Many analysts have also pointed to the importance of credit market disruptions in creating and exacerbating the Great Recession. This tightening of credit is captured in two ways for the simulation. First, the real risk free rate r jumps from -1% to 3% for eight quarters, corresponding to the hike in the Federal Funds Rate in 2006 and 2007. However, given the long horizon of mortgages, the adjustment in the mortgage market takes place through changes in mortgage prices $q_m^0((q_m, m'), b', h, s)$ rather than in the continuation q_m. Furthermore, existing borrowers in fixed rate contracts do not experience any change in rates. Second, the loan-to-value constraint on new mortgages is tightened from 125% to 90%, and the origination cost is increased from 0.4% to 1.2%[9]

Lastly, two temporary changes in bank behavior are implemented to reflect increased delays in foreclosure processing and the heightened propensity of banks to seek deficiency judgments: the probability of repossession φ decreases from 50% to 20%, and the probability of seeking a deficiency judgment increases from 0% to 50%.

[8]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.

[9]Source: Monthly Interest Rate Survey.

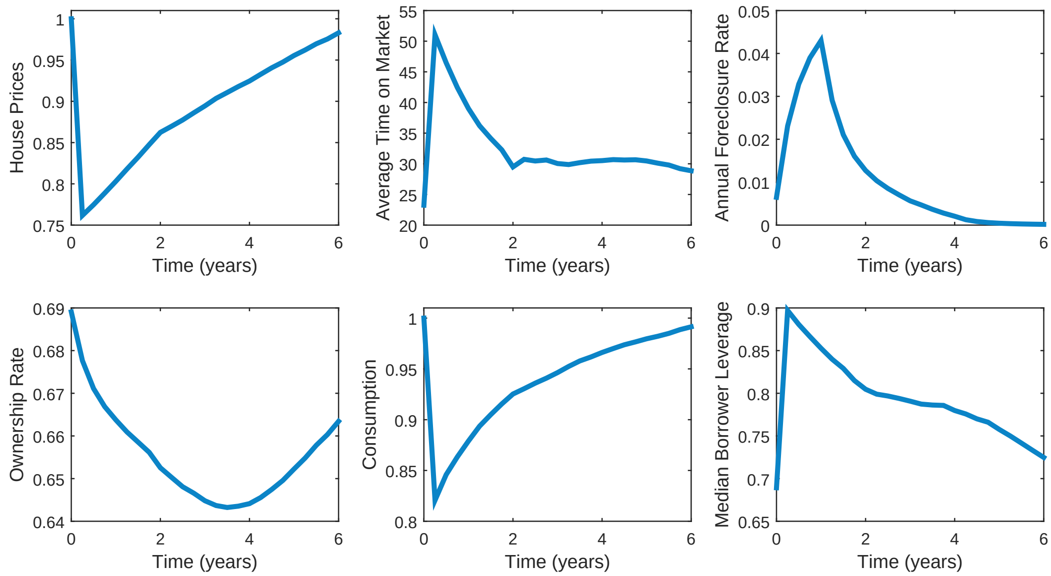


Figure 2: The simulated recession/recovery: (TL) house prices, (TM) time on market, (TR) foreclosures, (BL) ownership, (BM) consumption, (BR) leverage.

4.1.1 The Simulated Great Recession and Recovery

The simulated recession replicates the empirical changes in leverage, consumption, and key housing variables during the Great Recession and recovery, thereby validating the model as a tool to evaluate the role of housing and debt in the recent crisis.[10] Quantitatively, the precipitous 24% drop in house prices and surge in time on the market from 23 to 51 weeks shown in figure 2 match the data almost perfectly. Furthermore, the rise in the foreclosure rate to 4.3% mirrors the 5.2% peak reported in 2009 by the Mortgage Bankers Association. Beyond matching the mortgage default data itself, generating sufficient foreclosure activity also proves critical to explaining the dynamics of consumption and other housing variables. Furthermore, foreclosures generate an important household-side credit channel that complements the emphasis on firm-side credit frictions in Gertler and Kiyotaki (2011). Notably, the increase in foreclosures does *not* come about from *forced* deleveraging that occurs mechanically in models with short-term debt and collateral constraints. In such models, lenders demand an injection of equity from borrowers in response to

[10] Garriga and Hedlund (2016) use an alternative calibration of the model to generate the preceding boom in addition to the bust and recovery. However, doing so has little impact on the simulated dynamics of the recession and recovery relative to this paper, which initializes the economy in the mid-2000s.

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%	−16.0%	5.2%	50.8 weeks	69.0%/64.0%

Sources: (House Prices) FHFA purchase index deflated by the core PCE. (Consumption) Ríos-Rull and Huo (2016). (Foreclosures) Mortgage Bankers Association. (TOM) National Association of Realtors. (Ownership) US Census data from 2006 – 2014.

a reduction in the value of collateral, and borrowers default when they are unable to do so. By contrast, long-term debt in this paper causes the collateral constraint to only operate in the period of loan origination. As a result, leverage initially *spikes* when prices fall, and the gradual *endogenous* deleveraging shown in the last panel of figure 2—and confirmed empirically by Mian et al. (2013)—arises from recovering house prices, higher loan repayment, higher foreclosures, and decreased originations.

Generating the large house price decline represents a particular success of the model, given the difficulty many others have had in doing so without resorting to irrational expectations or other bubble phenomena. Sections 4.1.2 and 4.1.3 describe the role of each shock in achieving this outcome, and 4.2 explains the crucial importance of endogenous housing illiquidity and its interaction with credit illiquidity. Absent the positive reinforcement of both types of illiquidity, the model fails to explain the depth of the recession and the slow recovery. Beyond matching the house price decline, the model also achieves three other feats proven elusive in the literature: it replicates the gradual drop in homeownership from 69% to 64%, it reproduces a steep decline in consumption consistent with evidence presented by Ríos-Rull and Huo (2016), Kaplan et al. (2015), Berger, Guerrieri, Lorenzoni and Vavra (2015), and Pistaferri (2015), and it rationalizes the steep $\approx$ 50% *decline* in housing sales when many other models generate a counterfactual surge in sales. These successes and the underlying mechanisms are discussed in the ensuing sections.

4.1.2 Measuring the Impact of Labor Market Shocks

This section and the next disentangle the role of each shock in generating the Great Recession and explain the key underlying economic mechanisms. Two counterfactuals are simulated to bound the impact of labor market shocks. First, the recession is re-computed with one shock *removed* at a time. Next, the recession is re-computed with one shock *introduced* at a time.

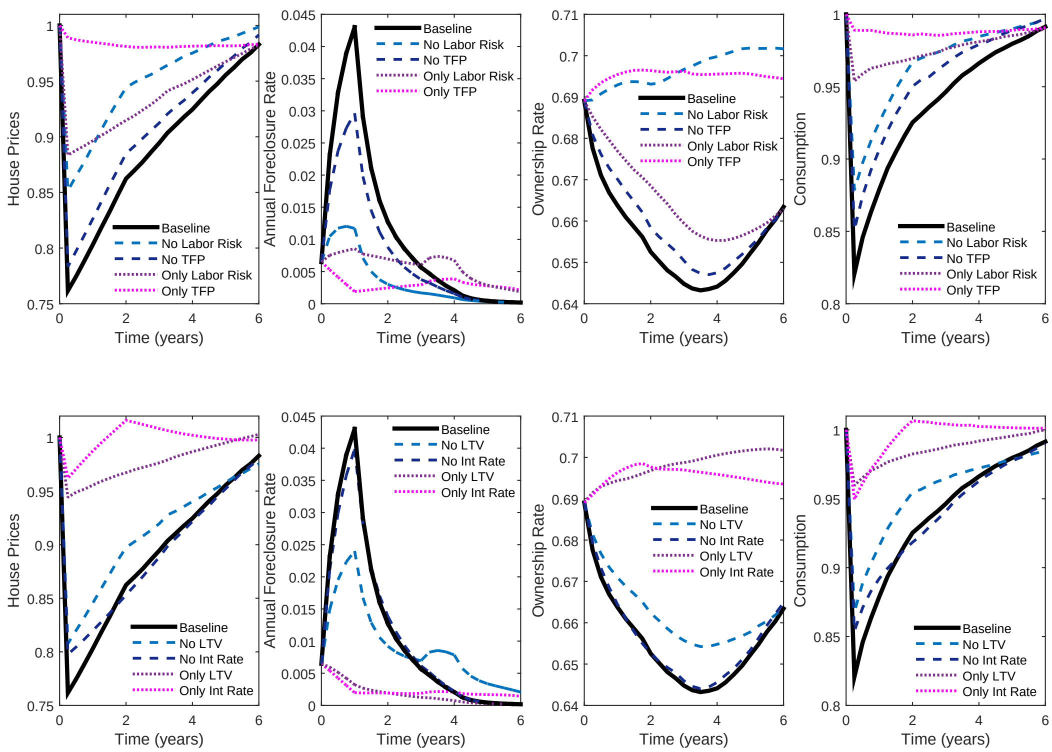


Figure 3: Top: disentangling the effects of labor market shocks. Bottom: disentangling the effects of financial shocks.

Higher Downside Labor Risk Although its direct effect on earnings is gradual, the uptick in downside labor risk immediately impacts the economy in several key ways. As shown in figure 3, ignoring this heightened risk substantially blunts the drop in house prices and consumption, almost entirely attenuates the jump in foreclosures, and produces a counterfactual *increase* in homeownership. Approaching the problem from the other side, introducing *only* the increase in labor risk causes a sizable drop in house prices and a moderate consumption decline, but foreclosure activity barely budges. Table 3 quantifies bounds on the effects of labor market risk and underscores its significance.

Three important lessons emerge from these results. First, the response of the foreclosure rate to shocks is highly **non-linear.** A 10% drop in house prices from their initial level has a minimal effect on foreclosures, but an *additional* 10% drop in house prices from −15% to −25% causes a surge in foreclosures. Secondly, foreclosure decisions depend on the **double trigger** of reduced house prices and a drop in income. Even with other shocks depressing household income, higher labor risk proves essential to inducing a sufficiently deep drop in house prices to stimulate a surge in foreclosures. In fact, causality also runs in the opposite direction. A muted foreclosure response greatly weakens the house price and consumption decline caused by the interaction of deteriorating credit and housing illiquidity—a channel that is discussed in section 4.2. In fact, table 3 shows that increased labor market risk accounts for a significant fraction of the increase in housing illiquidity indicated by higher time on the market. Lastly, labor market risk is a key determinant behind housing tenure decisions. Households respond to higher labor risk, and with it the higher likelihood of at some point activating the mortgage default double trigger, by shifting into renter status. Absent higher labor market uncertainty, the sharp drop in house prices increases affordability and *encourages* homeownership, which is inconsistent with the data.

The Drop in TFP/Wages Isolating the effect of the drop in TFP (and, thus, wages) reveals much more modest effects on all but foreclosures, which is consistent with the de-emphasis of TFP in Kehoe, Midrigan and Pastorino (2014). Table 3 shows an approximate 2% effect on house prices and 1.5% – 3.0% effect on consumption. However, absent the TFP drop, the peak foreclosure rate only reaches 3% instead of 4.3%, even with more or less the same fall in house prices. This result reinforces the importance of non-linearity and the double trigger in explaining foreclosure activity. However, contrary to the standard explanation of the double trigger, *negative* equity is not required for

Table 3: Measuring the Impact of Labor Market and Financial Shocks

	Baseline	Excluded	Alone	Bounds
Labor Market Shocks				
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 Credit Access				
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).

default. Instead, equity and endogenous housing illiquidity interact in a rich manner that sheds light on the default decision. Section 4.2 expounds.

4.1.3 Measuring the Impact of Financial Shocks

Tighter Credit Access The tightening of the loan-to-value constraint from 125% to 90% and the increase in origination costs both curtail access to credit. However, given the small 11% share of borrowers with more than 90% leverage in the calibration, these changes should have small long-run effects.

However, when house prices fall steeply in the Great Recession, the tighter borrowing constraint and the reduced value of housing collateral make refinancing impossible for many homeowners. While this change leaves many borrowers unaffected because of the long term nature of mortgage contracts, it shuts off a means of smoothing shocks for financially distressed homeowners and forces them to either sell or default. To see the magnitude of this channel, note that the peak foreclosure rate falls from 4.3% to 2.4% when the tightening of borrowing constraints is removed, and time on the market falls by over *two and a half months* from 51 weeks to 40 weeks. Without access to additional credit, highly indebted homeowners who put their house on the market face long selling delays and a higher likelihood of foreclosure from a failure to sell. By contrast, the ability to refinance mitigates this debt overhang and default.

The surge of owner-occupied and foreclosure properties that hit the market from the tightening of credit causes house prices to fall by 5 percentage points more than they would have otherwise. Furthermore, in the simulation with *only* the tighter LTV constraint, prices fall by almost 6%. These two experiments place relatively tight bounds of 5 – 6% on the negative impact of tighter LTV constraints on house prices. Inspection of 3 reveals a similar impact of approximately 4 – 5% on consumption.

Temporary Increase in Interest Rates Many commentators have pointed to the tightening of monetary policy in 2006 and 2007 as a significant contributing factor to the Great Recession. However, the model simulation suggests that the temporary increase in interest rates has far more modest effects relative to the tightening in the LTV constraint. The jump in interest rates pushes house prices down by 4%, accounts for 0.3 – 0.6 percentage points of the higher foreclosure rate, and affects consumption by anywhere from 3.3% – 5.0% using the two methods of decomposition. Section 4.4 explores in much greater detail the effects of interest rates on consumption and touches upon the asymmetry between rate increases and decreases, the effects of quantitative easing, and the role of fixed rate vs. adjustable rate mortgages.

4.2 The Importance of Endogenous Housing Illiquidity

In many standard models, shocks to household balance sheets have little impact on macroeconomic dynamics because households have access to a large stock of buffer savings from which they can costlessly draw. By contrast, when a substantial fraction of assets are illiquid, households—including wealthy ones—exhibit a greater sensitivity to shocks. Kaplan and Violante (2014) illustrate this principle vis-a-vis the consumption response to fiscal stimulus payments, and recently, Kaplan, Moll and Violante (2016) analyze the role of illiquid assets in the transmission of monetary policy.

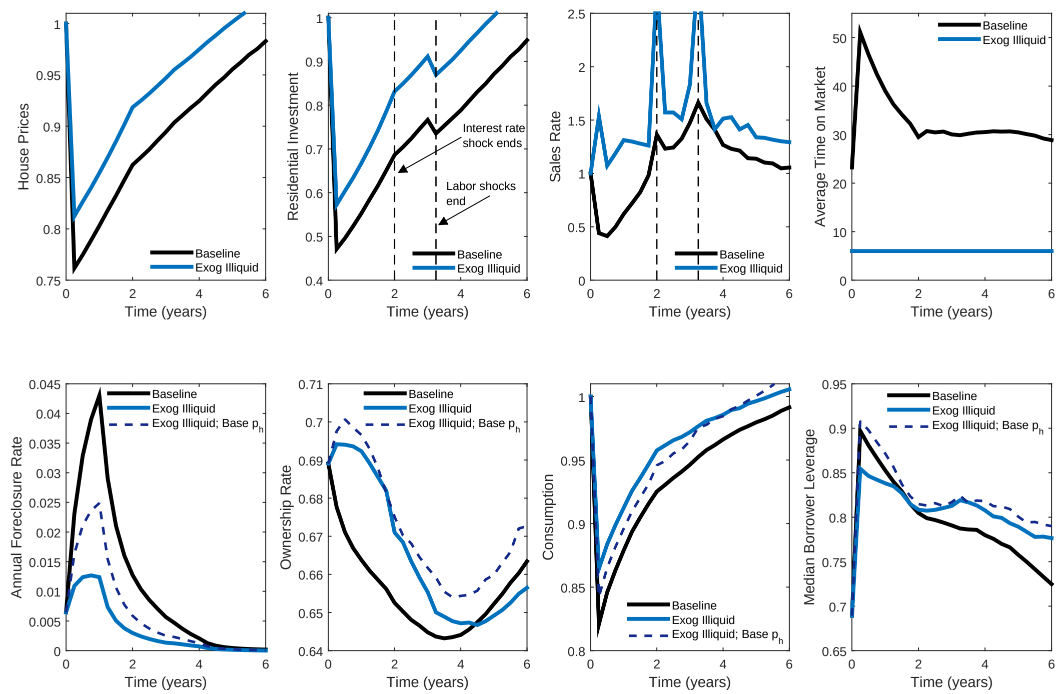


Figure 4: Baseline vs. exogenous illiquidity (no search; transaction costs only) with and without recomputing the path of equilibrium house prices

However, whereas they focus on net financial positions, treat housing implicitly, and view illiquidity as an exogenous characteristic, this paper takes a different view. By incorporating housing explicitly and introducing search frictions, housing illiquidity arises endogenously and reacts to changes in economic conditions. Far from a mere mental exercise, this endogenous housing illiquidity reflects convincing evidence from the Great Recession and beforehand of considerable cyclicality in time on the market.

Figure 4 compares the Great Recession in the baseline model to that in a model with Walrasian housing markets and an exogenous 6% selling transaction cost. Both economies are initialized at the same distribution to control for the effect of wealth and debt on economic dynamics. Three striking differences emerge. First, foreclosure activity is much greater in the model with endogenous housing illiquidity. Second, endogenous housing illiquidity magnifies the drop in house prices, residential investment, and consumption. Lastly, the model with exogenous housing illiquidity displays counterfactual behavior of sales transactions and the ownership rate.

The first two differences are linked by a chain reaction that causes endogenous housing illiquidity and credit illiquidity to positively reinforce each other.

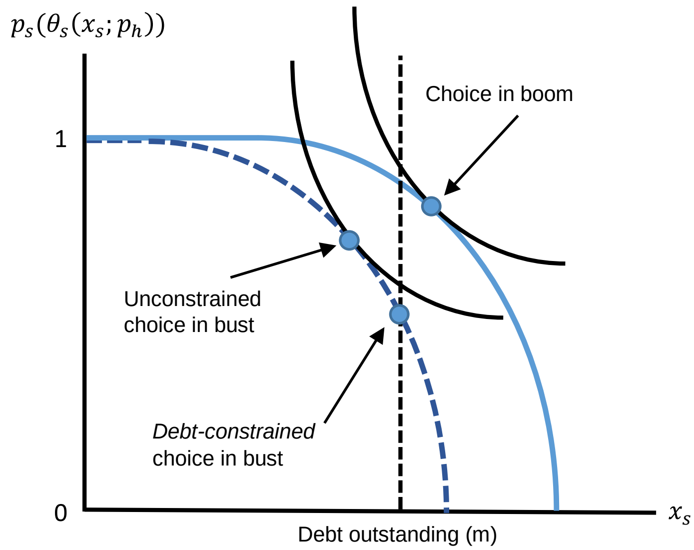


Figure 5: Optimal choice of list price x_s and selling probability p_s in boom and bust housing markets, with and without outstanding debt.

Conceptually, suppose that the value of housing V satisfies

$$V = \text{User Cost (UC)} + \text{Credit Liquidity (CL)} + \text{Housing Liquidity (HL)} \quad (13)$$

Its variance is then

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

By treating both housing and credit liquidity as endogenous, not only are the second two direct terms added, but they are joined by several covariances. The rest of this section addresses the macroeconomic importance of endogenous housing illiquidity and the role of these interaction terms.

4.2.1 Illiquidity, Debt Overhang, and Default

Debt Overhang Absent search frictions, houses always sell without delay in the period of listing, which corresponds to 6 weeks time on the market. This selling time is invariant to housing market conditions and the equity position of the homeowner, as long as the homeowner is able to pay off the mortgage upon selling. However, search frictions cause time on the market, and thus housing illiquidity, to be *endogenous* and sensitive to market *and* individual conditions. Figure 5 gives insight into the relationship between the housing market, debt, and individual selling experiences.

During "boom" times, the shadow price of housing is high, and sellers face a favorable schedule of list price and selling probabilities $\{p_s(\theta_s(x_s; p_h))\}$ from which to choose. However, in a bust, the shadow price of housing falls, and homeowners face a worse price-probability schedule. Absent intervening constraints, homeowners prefer to adjust along *both* the price and selling time margins. Therefore, houses tend to sell for less *and* sit on the market longer in busts, which reflects an *increase* in housing illiquidity. Conventional models of exogenously illiquid housing miss this dynamic.

However, the story does not end there. Figure 5 also shows how excessive mortgage debt distorts the list price decision. Because homeowners must pay off their mortgage upon selling, they face a lower bound to their price choice x_s: $x_s \geq m - y$, where m is outstanding debt and y is cash at hand. During booms, this constraint is unlikely to bind. However, during busts, highly indebted homeowners are forced to post a higher price than they would otherwise post, which leads to even longer selling delays.[11] The increase in time on the market from 23 to 51 weeks in figure 4 underscores the magnitude of the deterioration in housing liquidity. Such homeowners, if they fail to sell, still have to deal with mortgage payments. Depending on the circumstances of the homeowner, this **debt overhang** either results in a dramatic drop in consumption—which 4.3 explores further—or in mortgage default.

Mortgage Default The top right panel of figure 4 shows that removing endogenous housing illiquidity causes the peak in the foreclosure rate to fall from 4.3% to 1.3%. Undoubtedly, part of the attenuated response comes from the muted decline in house prices. However, even when the path of house prices is held at its baseline trajectory, the peak in the foreclosure rate still only reaches 2.5%. Clearly, endogenous housing illiquidity has a sizable effect on the spike in foreclosure activity during deep recessions.

Consistent with findings in Gerardi, Herkenhoff, Ohanian and Willen (2015) and Schelkle (2015), negative equity is not a sufficient condition to generate foreclosures. Instead, the standard "double trigger" hypothesis states that both negative equity *and* a negative income shock are necessary for default. This paper proposes a modified version: the *stochastic liquidity-adjusted double trigger (SLADT).* Under the basic double trigger hypothesis, homeowners know with probability 1 the price they can instantly receive by selling their

[11] Hedlund (2015) contains an extended discussion of this relationship.

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%
Peak Foreclosure Rate	4.3%	1.3%	428.6%

Comparing the severity of the recession with endogenous (baseline) vs. exogenous illiquidity (no search; transaction costs only).

house and, conditional on not being able to pay off their debt with the proceeds, they default if their cash at hand is sufficiently low.

Under SLADT, if highly-leveraged homeowners know they have a zero probability of selling at a price high enough to pay off their debt, their decision to default is the same as in the basic double trigger case. However, there is a wide range of *positive* equity (in many cases, up to 20% equity) where outstanding debt can distort the selling price and cause increased selling delays. In this case, homeowners first post a price and learn the stochastic selling outcome. Then, if they fail to sell, they decide whether to default based on their cash at hand and expectations of future liquidity.

In short, the basic double trigger hypothesis assumes that equity on paper translates immediately to realized selling outcomes. However, endogenous housing illiquidity replaces this deterministic relationship with stochastic selling outcomes that are influenced by the magnitude of outstanding debt.

4.2.2 Illiquidity and Amplification

The effect of endogenous housing illiquidity on mortgage default behavior partially accounts for the magnified baseline response of house prices, foreclosures, and consumption illustrated by figure 4 and quantified in table 4. In the exogenous illiquidity economy, house prices fall by 18.8%, whereas they fall by 23.8% in the baseline economy. The additional 5 percentage point drop represents an amplification of almost 27% in the house price decline. This magnified drop in house prices has a ripple effect on residential investment, which falls by an additional 10 percentage points in the economy with endogenous housing illiquidity, representing a 23.9% amplification. Note that the 53% drop in the baseline model comes much closer to matching the 57% observed in the data.

Endogenous housing illiquidity also magnifies the decline in consumption. Specifically, consumption falls by 17.9% in the baseline compared to only 13.6% in the economy without search—an amplification of almost 32%. Also, note that even when the path of house prices is fixed at the baseline trajectory, consumption falls more with endogenous illiquidity than in the model where illiquidity comes only from exogenous transaction costs. In other words, consumption responds more strongly with endogenous housing illiquidity for both direct *and* general equilibrium reasons. Section 4.3 discusses this decomposition in more detail.

Two mechanisms cause the amplification in house prices and consumption. First, falling house prices depress *housing liquidity* and cause extended selling delays, which increase foreclosures and induce banks to curtail lending. This reduced *credit liquidity*, in turn, puts further downward pressure on house prices. These **liquidity spirals** have been shown in Hedlund (2016) to generate substantial amplification in house price dynamics. Also, note that this channel has sufficient quantitative bite *without* resorting to the addition of housing preference shocks that reduce the threshold for default and amplify foreclosures during downturns. Secondly, endogenous housing illiquidity magnifies house price and consumption dynamics even in the absence of default. From a pure asset pricing perspective, equation 13 shows that house prices are influenced positively by the future ability to sell quickly. When house prices decline, selling probabilities $\{p_s(\theta_s(x_s; p_h))\}$ deteriorate, which makes housing less appealing and further depresses prices.

4.2.3 Sales and Homeownership Dynamics

As discussed in section 4.1.2, the increase in labor risk is necessary to generate the large decline in homeownership during the Great Recession. However, even with the increase in labor risk, the model with Walrasian housing and exogenous illiquidity generates counterfactual homeownership dynamics. In the Walrasian model, the steep drop in house prices makes purchasing a house more appealing, both because of greater affordability and because of higher expected appreciation as prices rebound. As a result, in opposition to the data, homeownership *increases* early in the recession before falling as rising prices and worse labor risk take hold. However, in the baseline model, a sharp increase in housing illiquidity that accompanies the decline in house prices induces a shift from ownership to renting that comports with the data.

The inclusion of endogenous housing illiquidity also helps explain the decline in housing *sales* in the Great Recession. As such, it provides insight into the puzzle of positively correlated house prices and sales discussed by Ngai and Sheedy (2015) and Ríos-Rull and Sánchez-Marcos (2012). Figure 4 shows that sales in the model with exogenous illiquidity depart from the data and *spike* by 50% at the onset of the recession as owners immediately dump their houses and buyers rush in to purchase cheap housing. Similarly, sales spike each time one of the shocks reverts. By contrast, the model with endogenous housing illiquidity exhibits smoother sales behavior and correctly replicates the protracted *decline* in sales at the beginning of the recession.

Two factors account for the flip in the correlation between house prices and sales in the two models. In the Walrasian economy, all homeowners with any equity are able to immediately sell. By contrast, the endogenous collapse of housing liquidity in the baseline model leads to markedly longer selling delays and reduced transactions. Second, credit liquidity deteriorates more in the baseline model because of the spillover of house selling risk into foreclosure risk. This credit contraction, combined with the reduced desirability of housing, limits the flow of buyers into the market and the share of owners looking to move up the housing ladder à la Stein (1995) and Ortalo-Magné and Rady (2006). To explain why sales stay low for so long, observe that long term debt prolongs the sales slump by allowing owners to ride out shocks longer before they potentially find themselves forced to sell. Lastly, it is important to note that an alternative approach for reducing the negative correlation of prices and sales in the Walrasian model by tightly tying rents to house price movements is at odds with the price-rent ratio data.

4.3 Consumption and Housing

In influential work, Mian et al. (2013) assert that the housing decline contributed substantially to the large decline in consumption during the Great Recession. They estimate a large elasticity of consumption to house price changes and present evidence that consumption responded most strongly among poorer and more levered households. This section undertakes two tasks. First, new insights are presented pertaining to how house price movements impact consumption. Second, panel data is simulated to analyze how consumption dynamics vary by housing tenure, indebtedness, and foreclosure status.

4.3.1 The Sensitivity of Consumption to House Price Movements

Figure 6 shows that the model delivers empirically consistent results regarding the consumption response to house price movements. Consumption falls by over 17% in the baseline simulation, whereas it only falls by 10% in a counterfactual with fixed house prices. Because the same shocks are present in both cases, the divergent consumption responses reflect only the effect of house prices. The third panel of figure 6 plots the elasticity of consumption to house prices during the first two years of the recession. Upon impact, this

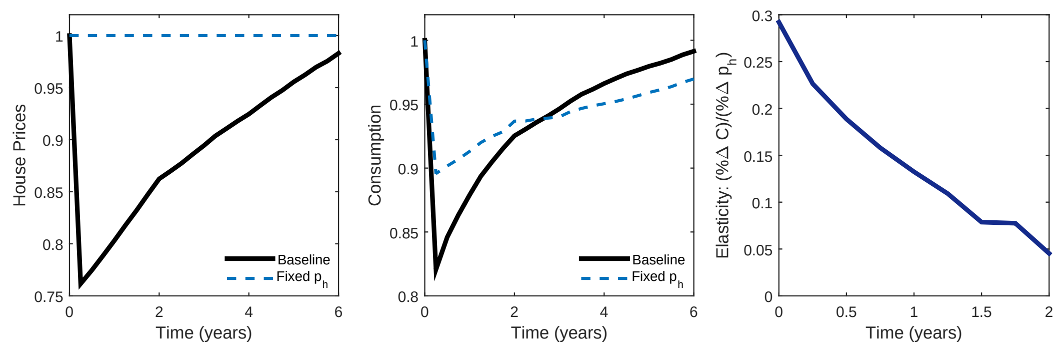


Figure 6: Consumption sensitivity to house prices. The elasticity is % change in consumption between "baseline" and "fixed p_h" divided by % change in p_h.

elasticity is approximately 0.3, which closely matches estimates reported by Mian et al. (2013), Berger et al. (2015), and Kaplan et al. (2015). However, the sensitivity of consumption to house prices *varies over time*, is *nonlinear*, and is *shock-dependent*.

Regarding its time profile, the elasticity peaks at 0.3 at the onset of the recession but gradually falls as consumption responds more to the underlying shocks and less to house prices. Furthermore, a compositional effect arises because of the decrease in the homeownership rate. In the baseline simulation, homeownership falls from 69% to 64%, and in the fixed price economy, it falls even further to 56%. As will be shown momentarily, renter consumption is insensitive to house prices.

Figures 13 and 14 in the appendix show the sensitivity of consumption to house prices depending on which shocks hit the economy. For each experiment, consumption is simulated with the new equilibrium house price path and then again with the baseline price trajectory and again assuming fixed house prices. Figure 13 shows that when only the labor risk shock hits the economy, the consumption elasticity to house price movements is only between 0.12 and 0.21, depending on whether one uses the fixed house price simulation as the reference point or the simulation which feeds in the baseline trajectory of house prices. In other words, the elasticity is **nonlinear**. When only the TFP shock hits the economy, the elasticity changes dramatically and ranges anywhere from 0.08 to over 0.5. Lastly, when only the credit constraints tighten, the elasticity of consumption to house price changes falls between 0.25 and 0.35. In summary, the responsiveness of consumption to house prices is **shock-dependent**.

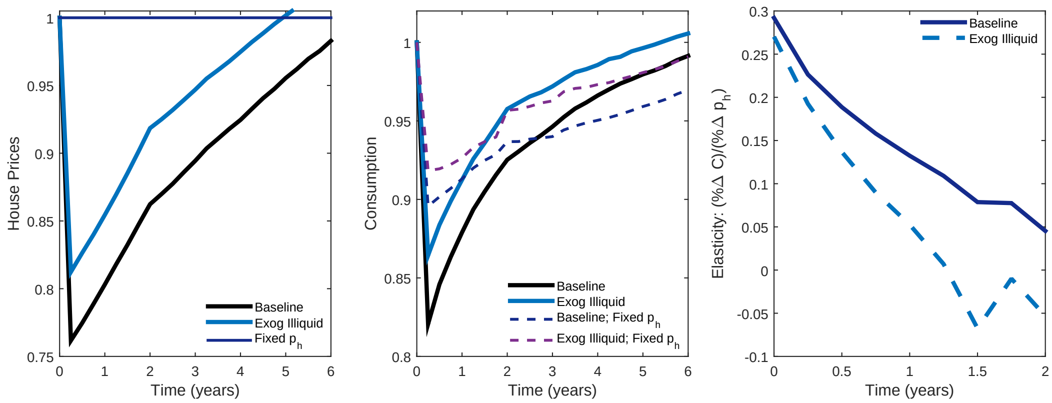


Figure 7: The effect of endogenous illiquidity on the sensitivity of consumption to house prices.

4.3.2 Consumption, House Prices, and Endogenous Illiquidity

Several economic mechanisms account for the impact of housing on consumption, such as the endowment and collateral effects articulated by Berger et al. (2015). However, this paper highlights the novel and quantitatively important effects of endogenous housing liquidity on consumption. First, as the second panel of figure 7 shows, consumption falls further in the baseline economy, *even when house prices are held fixed*. Consumption drops by 11.5% in the baseline economy and by only 8% in the Walrasian economy.

With exogenous housing illiquidity, homeowners with sufficient equity to cover the 6% transaction cost have the ability to immediately sell and escape the burden of their debt. By contrast, selling delays in the economy with endogenous housing illiquidity force indebted homeowners to either default or significantly reduce consumption to keep making mortgage payments while their house sits on the market. In short: debt overhang occurs. Compounding matters, credit liquidity also dries up in response to the elevated foreclosure risk from long selling delays. Both the increased difficulty of selling and cost of refinancing interfere with consumption smoothing. The endogenous decline in house prices and evaporation of equity magnify these consumption smoothing difficulties. Furthermore, as described earlier, the liquidity spirals that arise from the positive reinforcement of housing and credit illiquidity amplify the drop in house prices and, thus, the fall in consumption.

Looking specifically at the sensitivity of consumption to house prices, figure 7 shows that the economies deliver the same elasticity of consumption to house prices at the beginning of the recession. However, the economy with endogenous housing illiquidity exhibits greater *persistence* in the sensitivity of consumption to house prices. One year into the recession, the consumption elasticity in the baseline model is still approximately 0.15, whereas it falls below 0.05 with exogenous housing illiquidity. Intuitively, selling delays, along with long term debt, prolong households' response to economic shocks.

4.3.3 The Effect of Housing and Debt on Consumption Dynamics

Recall that Mian et al. (2013) emphasize the role of the housing bust in explaining the consumption decline during the Great Recession, and they assert that consumption dropped the most for heavily indebted homeowners. To test these findings within the model, a panel of 10,000 households is simulated that allows for consumption dynamics to be disaggregated by ownership status, indebtedness, and default status.

The left column of panels in figure 8 shows consumption dynamics for renters and homeowners based on ownership status upon the onset of the recession. The top left panel shows that homeowners experience a steep drop in consumption of over 15% followed by a slow recovery. By contrast, renter consumption only falls by 5% and rapidly recovers. The two panels below plot the distribution of consumption changes between two periods. In the steady state, the consumption change distributions are symmetric, but renter consumption has wider variance. In other words, during normal times, homeowners are better able to insure shocks. Part of this insurance is likely a selection effect—homeowners have more buffer savings and better income realizations—but in addition, homeowners can extract equity out of their houses to smooth shocks. However, the middle left panel shows how fortunes change in the Great Recession. Upon impact of the recession, the consumption change distribution for renters has a mean below zero but is symmetric and has moderate variance. However, the consumption change distribution for homeowners exhibits a strong left skew with some homeowners experiencing more than a 40% drop in consumption.

The second column of panels compares homeowner consumption dynamics by degree of indebtedness. Consistent with Mian et al. (2013), consumption falls much more for homeowners with high leverage. It is precisely these homeowners who are shut out from refinancing and who have the greatest difficulty selling their houses. Note that indebted homeowners exhibit higher consumption variance, even in the steady state, as shown in the bottom middle panel.

The third column shows consumption behavior for *borrowers* who default at the beginning of the recession compared to those who do not. Even though defaulters are more likely to have the highest amount of debt and the lowest

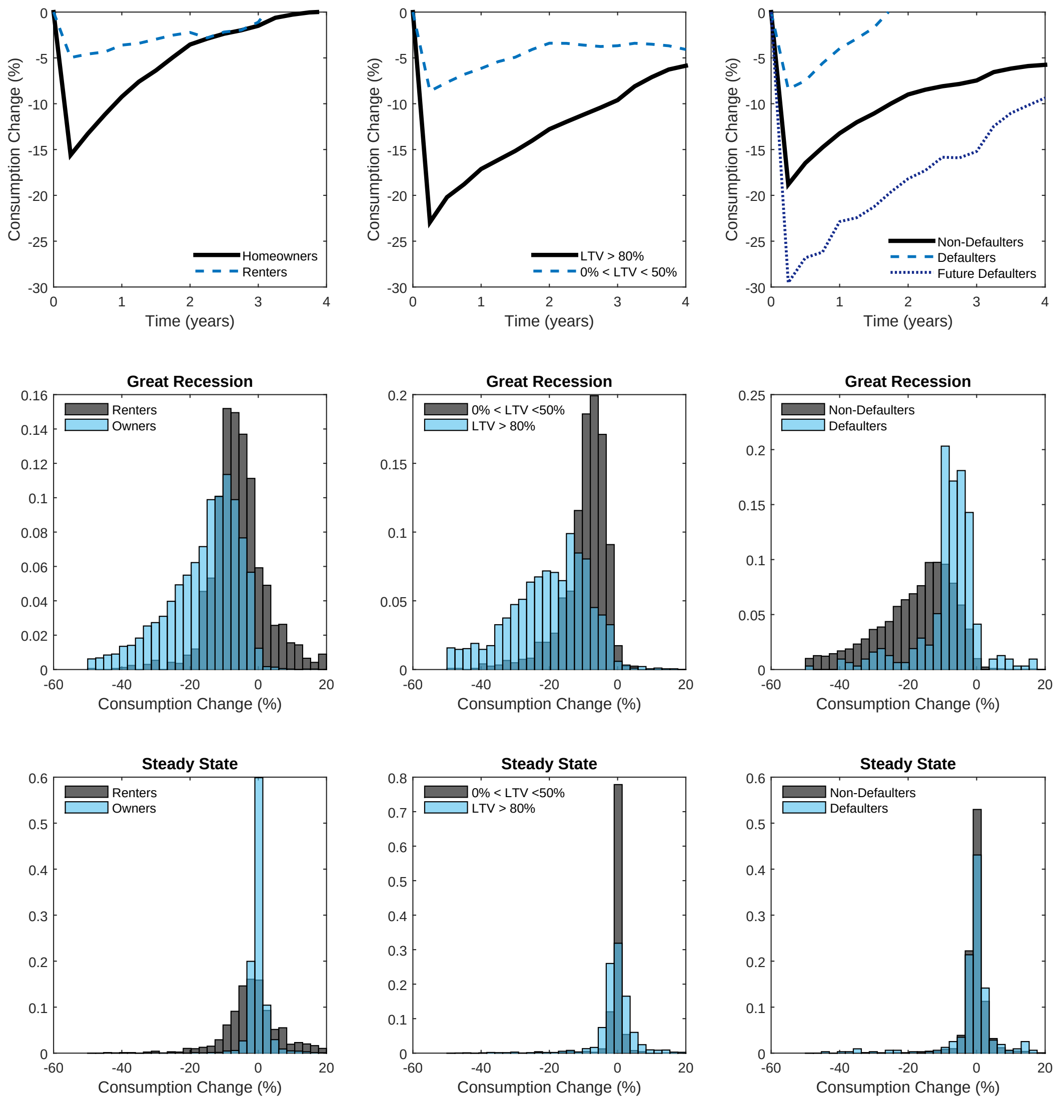


Figure 8: Consumption dynamics by ownership status, leverage, and default status. "Future defaulters" are those who default 1 year *after* the beginning of the Great Recession.

income, default acts as a form of insurance against bad shocks that mediates the drop in consumption (at the expense of house repossession and a temporary exclusion from credit markets). Observe that consumption for "future defaulters"— namely, households who default one year into the recession rather than immediately— falls the most dramatically. These households look similar to defaulters, but they are able to cut consumption and continue making mortgage payments while they hope for their house to sell.

Lastly, comparison of figure 15 in the appendix with figure 8 reveals that the magnification of the consumption drop due to endogenous illiquidity is greatest for the most indebted and financially unstable households. In particular, for those households temporarily forestalling default, consumption drops by *50%* more in the baseline economy. This enhanced response comes because *both forms* of illiquidity contract more in the baseline economy— selling probabilities *and* mortgage prices from higher default risk.

4.4 Housing Finance and Quantitative Easing

Although the model replicates much of the Great Recession quite well, it somewhat undershoots the peak in foreclosures. Keep in mind, however, that all households have standard, fixed rate mortgages in the baseline economy. By contrast, many commentators have pointed to the proliferation of alternative mortgage contracts as a primary cause for the foreclosure crisis. This section first addresses the impact of mortgage type—namely, fixed rate vs. adjustable rate loans—on macroeconomic dynamics during the recession and recovery. Second, the Federal Reserve's policy of quantitative easing is evaluated, and important lessons emerge for future interventions.

4.4.1 Dynamics with Fixed Rate vs. Adjustable Rate Mortgages

The United States is unique in that 30-year, fixed-rate loans are the predominant form of mortgage contract. From the perspective of the borrower, fixed rate mortgages (FRMs) provide insurance against interest rate hikes. Figure 9 shows the recessionary dynamics of house prices, foreclosures, homeownership, and consumption depending on whether all borrowers have fixed rate mortgages (baseline) or all borrowers have adjustable rate mortgages (ARMs). Recall that interest rates jump during the first two years of the recession simulation, corresponding to the tightening of monetary policy in 2006 and 2007. In the economy with fixed rate mortgages, existing homeowners are shielded from the increase in rates. However, with adjustable rates, homeowners experience a sudden jump in mortgage financing costs. When combined with the

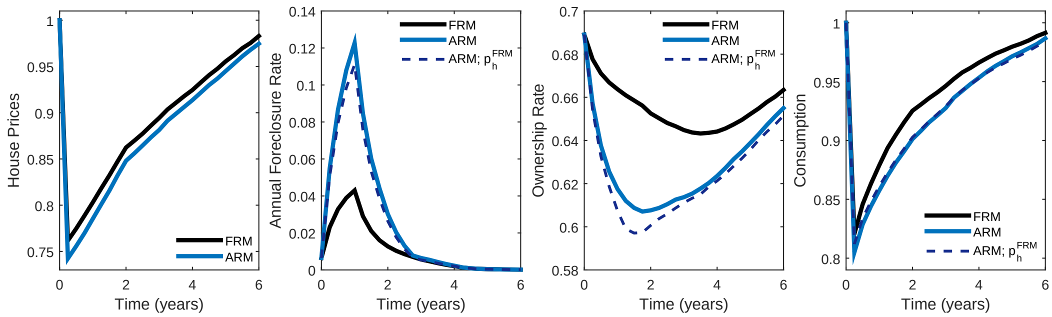


Figure 9: The Great Recession with fixed rate and adjustable rate mortgages.

tightening in borrowing constraints and the deterioration in the labor market, the increase in rates causes a surge in foreclosures that far exceeds that observed in the economy with fixed rate mortgages. As a result, homeownership declines more dramatically with adjustable rate mortgages, and the declines in house prices and consumption are both magnified. However, the drop in consumption is not spread evenly across all households.

Consumption Figure 10 shows panel simulations of consumption by housing tenure, leverage, and default status. Unsurprisingly, the consumption drop for renters does not depend on whether the economy features fixed rate mortgages or adjustable rate mortgages. Furthermore, when one looks at *all* homeowners and those with considerable equity, consumption does not vary much based on mortgage type.

However, the bottom left panel reveals a striking 32% amplification for highly leveraged homeowners in the world with ARMs. Specifically, borrowers with FRMs and 90%+ leverage experience a 16% drop, whereas with ARMs, such borrowers cut their consumption by 21%. Mechanically, the more debt borrowers have, the more of an impact changes in interest rates have on budget constraints and, thus, on consumption. However, this effect is compounded by the greater difficulty highly leveraged homeowners face in smoothing shocks by quickly selling or accessing additional credit.

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

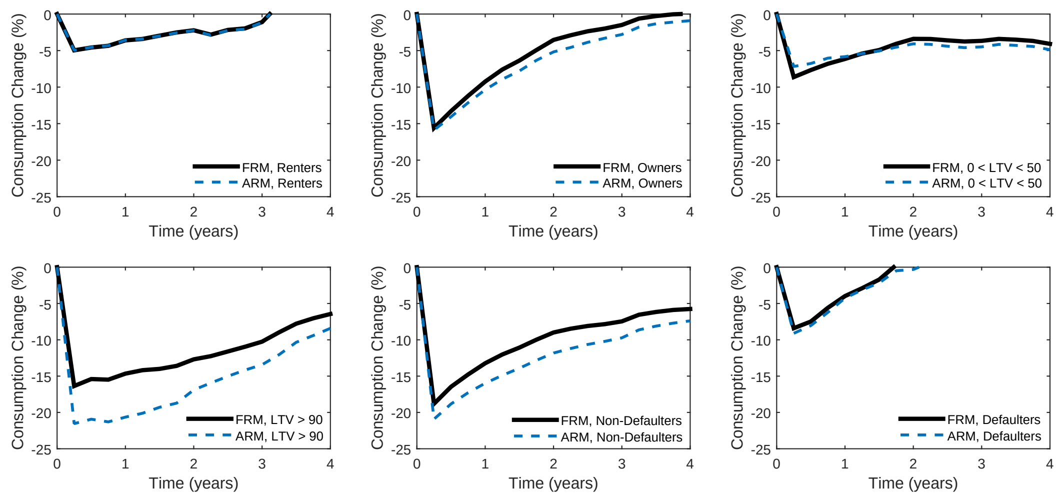


Figure 10: Consumption dynamics by housing tenure, leverage, default status, and mortgage type.

4.4.2 Quantitative Easing

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

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

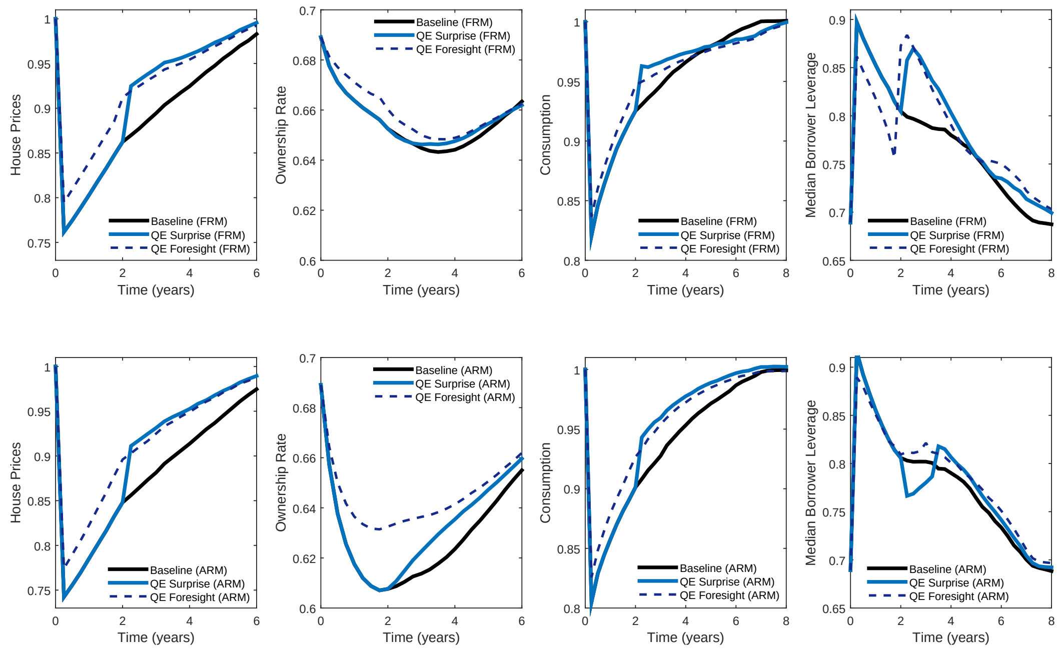


Figure 11: The effects of QE by mortgage type.

the recession but implemented with the aforementioned delay. The economic response is analyzed with both fixed rate and adjustable rate mortgages.

As shown in figure 10, QE has a pronounced effect on house prices. When pre-announced, QE immediately causes house prices to jump by 4.3% relative to their baseline trough, thereby mitigating 14% of the overall decline even *before* the actual policy implementation. In the case of surprise QE, house prices immediately jump by over 6% and remain elevated as they converge to pre-crisis levels. Note that the fixed rate and adjustable rate economies exhibit similar house price responses to QE.

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

Table 5: The Effects of Quantitative Easing on Consumption

	All Owners	$0\% < LTV < 50\%$	$LTV > 80\%$	Non-Defaulters	Defaulters
FRMs	4.5%	2.5%	6.0%	4.3%	0.7%
ARMs	5.7%	2.9%	7.9%	5.5%	0.7%

These numbers are the jump in consumption upon implementation of "surprise" QE.

QE, Consumption, and Mortgage Type Quantitative easing also has a significant impact on consumption. Upon implementation, surprise QE causes consumption to jump 3.5% above its previous trajectory. However, this top line number masks considerable heterogeneity. As table 5 indicates, homeowner consumption jumps by 4.5% in the fixed rate economy and by 6% for highly leveraged borrowers. By contrast, owners with significant equity only increase consumption by 2.5%. Unsurprisingly, the gains in consumption are confined almost entirely to non-defaulters. Figures 16 and 17 show additional details on the heterogeneous consumption dynamics.

Table 5 shows that mortgage type also plays a significant role in the transmission of QE. In the adjustable rate economy, all borrowers immediately benefit from lower mortgage rates without needing to pay the fixed cost to refinance. As such, the consumption response is anywhere from 20% – 35% stronger. Figure 11 also reveals different *dynamics* of the consumption response to QE in the two economies. In the economy with adjustable rates, consumption jumps upon QE implementation and remains elevated. However, in the fixed rate economy, consumption increases upon impact but then falls *below* its non-policy trajectory two years later. Inspection of leverage dynamics reveals the culprit. In the adjustable rate economy, leverage initially drops upon the implementation of QE due to the surge in house prices. After exhibiting a modest increase, leverage resumes its downward trend. However, in the fixed rate economy, homeowners can only take advantage of the lower rates from QE by refinancing, and because refinancing is costly, borrowers take the opportunity to increase their leverage when they refinance. This increased indebtedness depresses consumption growth down the road.

QE, Consumption, and the Role of House Prices Figure 12 reveals the importance of endogenous house prices to the consumption response. In the first panel, consumption jumps after the mere *announcement* of QE, but only because house prices rise. In the counterfactual where house prices follow their non-QE path, consumption only rises upon actual policy implementation. The second panel plots the sensitivity of consumption to house prices.

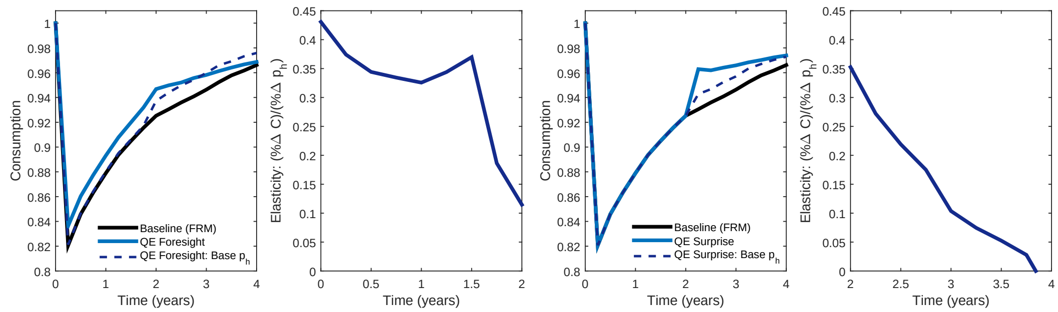


Figure 12: Consumption, QE, and house prices.

Note that consumption becomes much less sensitive to house price differences once rates actually fall. Similarly, the latter two panels show the dynamics of consumption for surprise QE, with and without the endogenous response of house prices. Absent the increase in house prices, the consumption surge from QE is blunted by more than half.

5 Conclusion

This paper draws several big picture conclusions to guide thinking about housing and the macroeconomy. First, housing matters for consumption. House price movements induce large and heterogeneous consumption responses by owners based on their indebtedness. Second, endogenous housing illiquidity plays a central role in generating large house price and consumption movements, in driving strong foreclosure swings, and in explaining the positive co-movement between prices, sales, and homeownership. Third, the design of mortgage contracts impacts economic dynamics. Fixed rate mortgages provide insurance against interest rate movements and mitigate house price and consumption declines during recessionary episodes. Lastly, quantitative easing proves to be a potent weapon to mitigate foreclosures and drops in house prices and consumption. The impact of quantitative easing on consumption is stronger with adjustable rate mortgages and among the most indebted households, and importantly, its efficacy depends strongly on taking into account the endogenous response of house prices. Exploring regional heterogeneity, the link between housing and labor dynamics, and the role of other policy interventions is left to future work.

References

Berger, David, Veronica Guerrieri, Guido Lorenzoni, and Joseph Vavra, "House Prices and Consumer Spending," 2015. Working Paper.

Corbae, Dean and Erwan Quintin, "Leverage and the Foreclosure Crisis," *Journal of Political Economy*, 2015, *123*, 1–65.

Davis, Morris A., Andreas Lehnert, and Robert F. Martin, "The Rent-Price Ratio for the Aggregate Stock of Owner-Occupied Housing," *Review of Income and Wealth*, 2008, *54* (2), 279–284.

Favilukis, Jack, Sydney C. Ludvigson, and Stijn Van Nieuwerburgh, "The Macroeconomic Effects of Housing Wealth, Housing Finance, and Limited Risk-Sharing in General Equilibrium," *Journal of Political Economy*, Forthcoming 2016.

Fernald, John, "Productivity and Potential Output Before, During, and After the Great Recession," June 2014. NBER Working Paper 20248.

Flavin, Marjorie and Shinobu Nakagawa, "A Model of Housing in the Presence of Adjustment Costs: A Structural Interpretation of Habit Persistence," *American Economic Review*, Mar. 2008, *98* (1), 474–495.

Garriga, Carlos and Aaron Hedlund, "Credit, Illiquidity, and the Boom and Bust of U.S. Housing Markets," 2016. Working Paper.

Gerardi, Kristopher, Kyle F. Herkenhoff, Lee E. Ohanian, and Paul S. Willen, "Can't Pay or Won't Pay? Unemployment, Negative Equity, and Strategic Default," 2015. Working Paper.

Gertler, Mark and Nobuhiro Kiyotaki, "Financial Intermediation and Credit Policy in Business Cycle Analysis," in Benjamin Friedman and Michael Woodford, eds., *Handbook of Monetary Economics*, 2011.

Gruber, Joseph and Robert F. Martin, "The Role of Durable Goods in the Distribution of Wealth: Does Housing Make Us Less Equal?," 2003. Working Paper.

Hedlund, Aaron, "Illiquidity and its Discontents: Trading Delays and Foreclosures in the Housing Market," June 2015. Working Paper.

_ , "The Cyclical Dynamics of Illiquid Housing, Debt, and Foreclosures," *Quantitative Economics*, Mar. 2016, *7* (1), 289–328.

Herkenhoff, Kyle and Lee Ohanian, "Foreclosure Delay and U.S. Unemployment," 2015. Working Paper.

Kaplan, Greg and Giovanni L. Violante, "A Model of the Consumption Response to Fiscal Stimulus Payments," *Econometrica*, 2014, *82* (4), 1199–1239.

_ , Benjamin Moll, and Giovanni L. Violante, "Monetary Policy According to HANK," 2016. Working Paper.

_ , Kurt Mitman, and Giovanni L. Violante, "Consumption and House Prices in the Great Recession: Model Meets Evidence," 2015. Working Paper.

Kehoe, Patrick, Virgiliu Midrigan, and Elena Pastorino, "Debt Constraints and Employment," 2014. Working Paper.

Krishnamurthy, Arvind and Annette Vissing-Jorgensen, "The Effects of Quantitative Easing on Interest Rates: Channels and Implications for Policy," *Brookings Papers on Economic Activity*, Fall 2011, pp. 215–288.

Mian, Atif and Amir Sufi, "House Prices, Home Equity-Based Borrowing, and the US Household Leverage Crisis," *American Economic Review*, 2011, *101* (5), 2132–2156.

_ , Kamalesh Rao, and Amir Sufi, "Household Balance Sheets, Consumption, and the Economic Slump," *Quarterly Journal of Economics*, 2013, *128* (4), 1687–1726.

Ngai, L. Rachel and Kevin D. Sheedy, "The Ins and Outs of Selling Houses," 2015. Working Paper.

Ortalo-Magné, François and Sven Rady, "Housing Market Dynamics: On the Contribution of Income Shocks and Credit Constraints," *The Review of Economic Studies*, Apr. 2006, *73* (2), 459–485.

Pennington-Cross, Anthony, "The Value of Foreclosed Property," *JRER*, 2006, *28* (2), 193–214.

Pistaferri, Luigi, "Household Consumption: Research Questions, Measurement Issues, and Data Collection Strategies," *Journal of Economic and Social Measurement*, 2015.

Ríos-Rull, José-Víctor and Virginia Sánchez-Marcos, "Aggregate Shocks and House Price Fluctuations," 2012. mimeo.

_ **and Zhen Huo**, "Financial Frictions, Asset Prices, and the Great Recession," 2016. Working Paper.

Schelkle, Thomas, "Mortgage Default during the U.S. Mortgage Crisis," 2015. Working Paper.

Sommer, Kamila, Paul Sullivan, and Randal Verbrugge, "The Equilibrium Effect of Fundamentals on House Prices and Rents," *Journal of Monetary Economics*, 2013, *60* (7), 854–870.

Stein, Jeremy C., "Prices and Trading Volume in the Housing Market: A Model with Down-Payment Effects," *The Quarterly Journal of Economics*, May 1995, *110* (2), 379–406.

Storesletten, Kjetil, Chris I. Telmer, and Amir Yaron, "Cyclical Dynamics in Idiosyncratic Labor Market Risk," *Journal of Political Economy*, June 2004, *112* (3), 695–717.

A Supplementary Figures

A.1 Consumption Response to House Price Movements

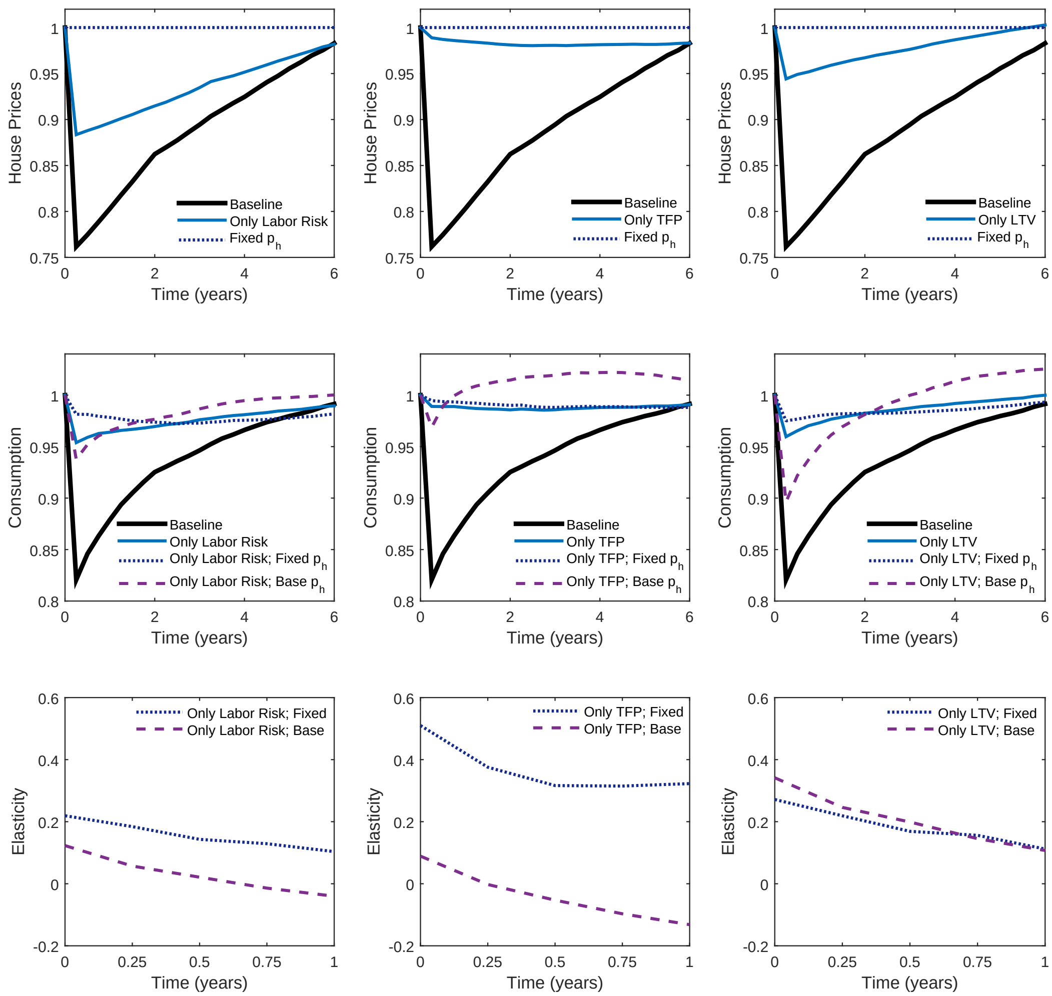


Figure 13: Consumption response to house price movements conditional on only one shock hitting the economy. Top: house prices; middle: consumption; bottom: elasticity of consumption to house prices. The "fixed" elasticity uses the "fixed p_h" house price trajectory as the reference, whereas the "baseline" elasticity uses the "baseline p_h" house price trajectory as the reference.

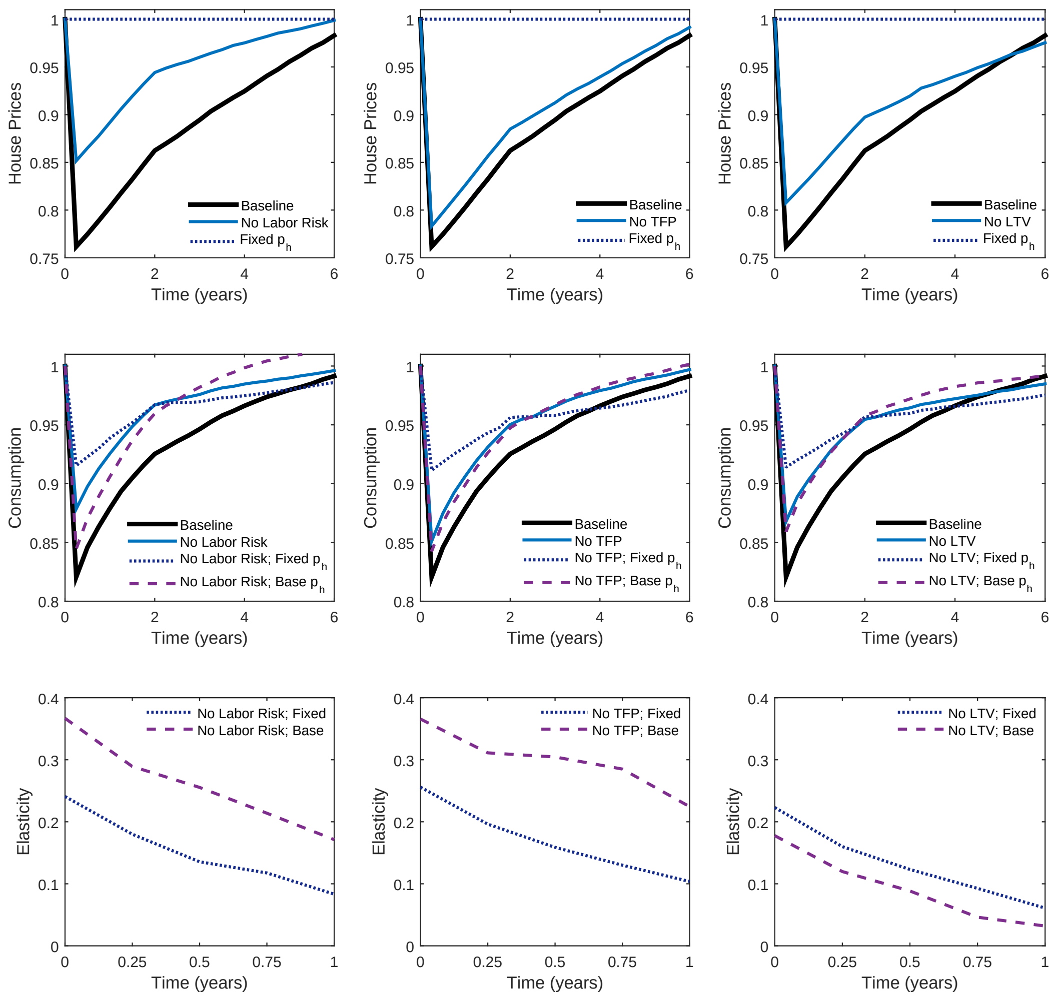


Figure 14: Consumption response to house price movements conditional on all but one shock hitting the economy. Top: house prices; middle: consumption; bottom: elasticity of consumption to house prices. The "fixed" elasticity uses the "fixed p_h" house price trajectory as the reference, whereas the "baseline" elasticity uses the "baseline p_h" house price trajectory as the reference.

A.2 Consumption Dynamics with Exogenous Illiquidity

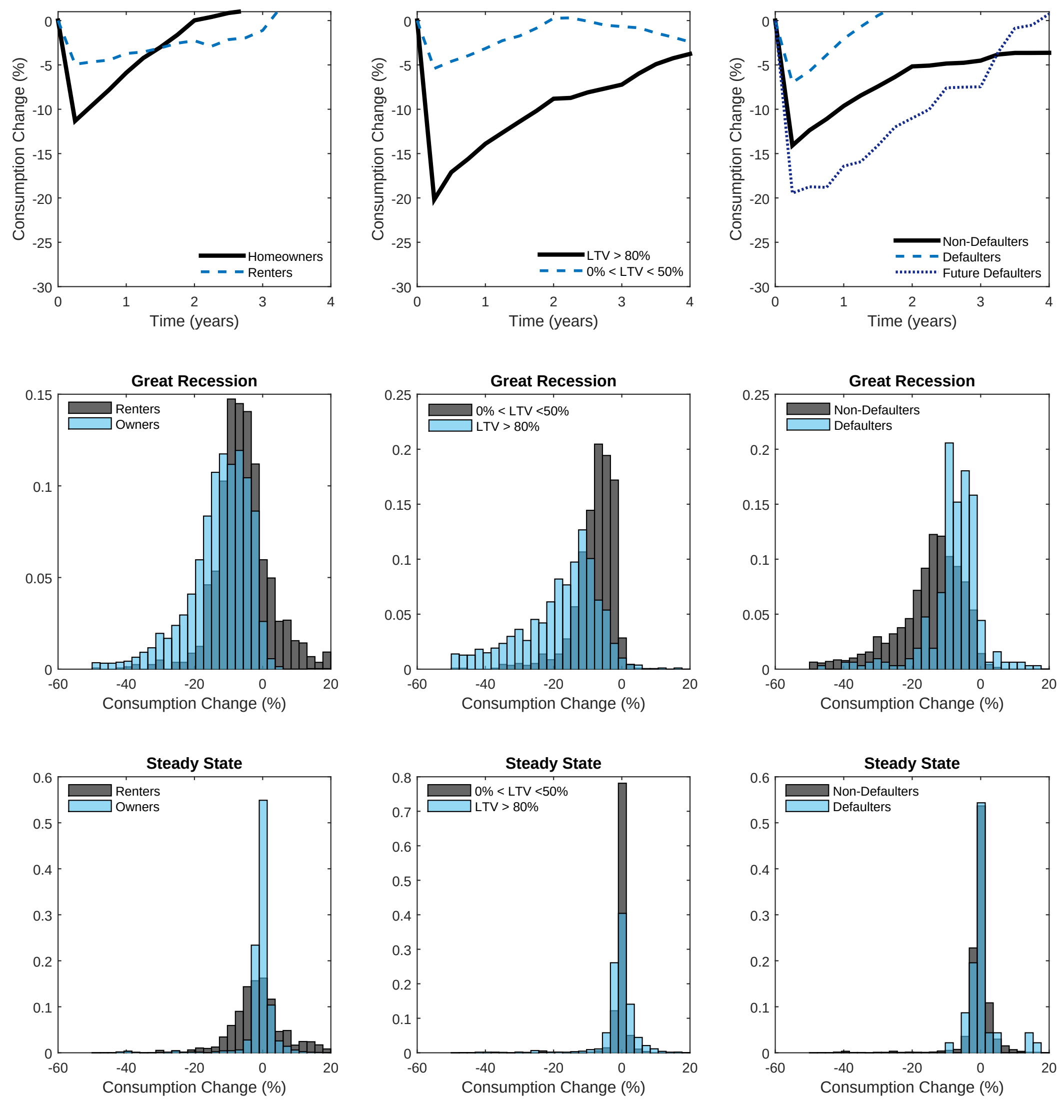


Figure 15: Consumption dynamics by ownership status, leverage, and default status in the economy with exogenous housing illiquidity.

A.3 Consumption Response to Quantitative Easing

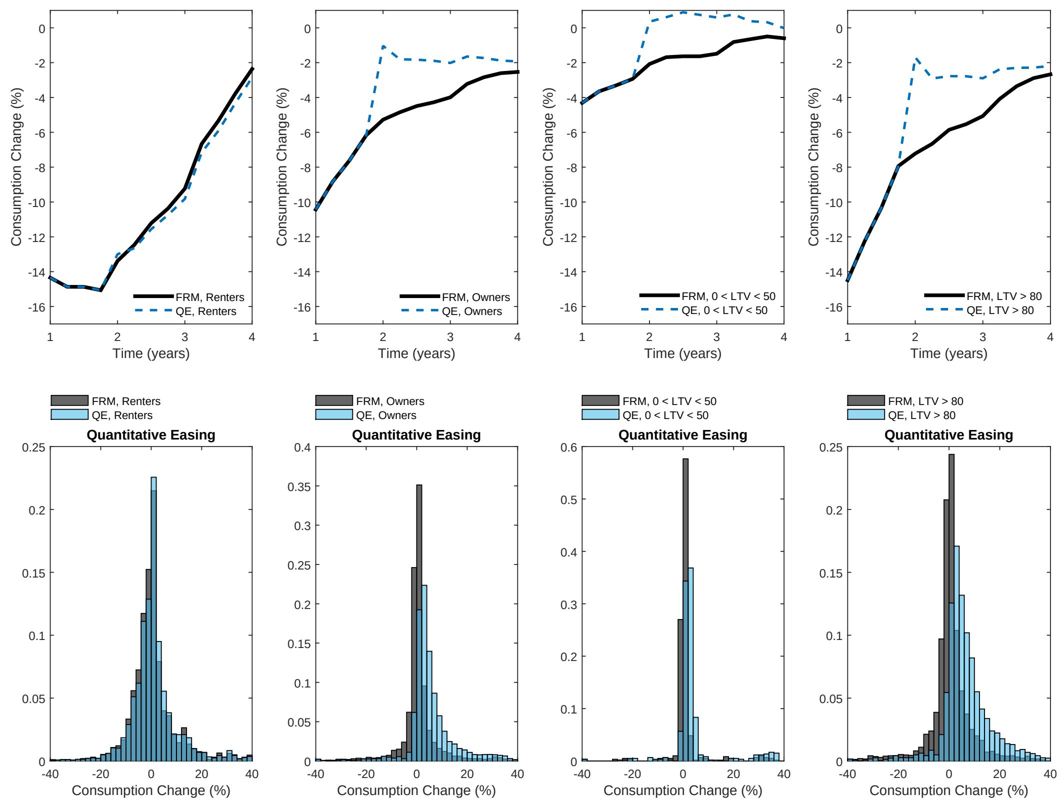


Figure 16: Consumption response to QE by ownership status and leverage in an economy with fixed rate mortgages.

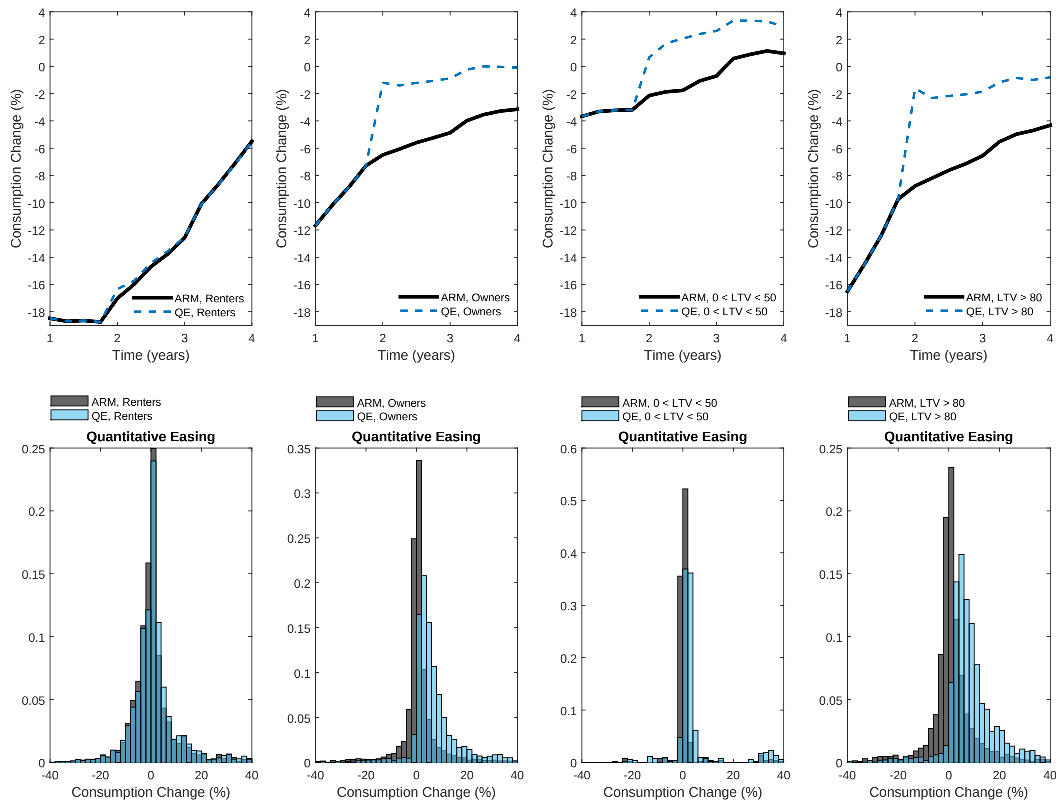


Figure 17: Consumption response to QE by ownership status and leverage in an economy with adjustable rate mortgages.

B Calibrating Labor Efficiency

As explained in the calibration section, it is not possible to estimate quarterly income processes from PSID data because the PSID is only conducted annually. 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.

C Summary of Equilibrium Conditions

C.1 Household Value Functions

C.1.1 Subperiod 3 Value Functions

Homeowners with good credit:

$$V_{own}(y, (\overline{q_m}, m), h, s, 0) = \max_{m', b', c \geq 0} u(c, h) + \beta \mathbb{E} \begin{bmatrix} (1 - \delta_h)(W_{own} + R_{sell})(y', (\overline{q_m}, m'), h, s', 0) \\ +\delta_h (V_{rent} + R_{buy})(y', s', 0) \end{bmatrix}$$
$$\text{subject to}$$
$$c + \eta h + q_b b' + m - \widetilde{q_m} m' \leq y$$
$$q_m^0((q_m, m'), b', h, s) m' \mathbf{1}_{[m' > m]} \leq \vartheta p_h$$
$$y' = we's' + b' \tag{14}$$

Homeowners with bad credit:

$$V_{own}(y, 0, h, s, 1) = \max_{b', c \geq 0} u(c, h) + \beta \mathbb{E} \begin{bmatrix} (1 - \delta_h)(W_{own} + R_{sell})(y', 0, h, s', f') \\ +\delta_h (V_{rent} + R_{buy})(y', s', f') \end{bmatrix}$$
$$\text{subject to}$$
$$c + \eta h + q_b b' \leq y$$
$$y' = we's' + b' \tag{15}$$

Apartment-dwellers with good credit:

$$\begin{aligned} V_{rent}(y,s,0) = \max_{b',c\geq 0,a\leq \overline{a}} & u(c,a) + \beta \mathbb{E}\left[(V_{rent}+R_{buy})(y',s',0)\right] \\ & \text{subject to} \\ & c + q_b b' + r_h a \leq y \\ & y' = we's' + b' \end{aligned} \tag{16}$$

Apartment-dwellers with bad credit:

$$\begin{aligned} V_{rent}(y,s,1) = \max_{b',c\geq 0,a\leq \overline{a}} & u(c,a) + \beta \mathbb{E}\left[(V_{rent}+R_{buy})(y',s',f')\right] \\ & \text{subject to} \\ & c + q_b b' + r_h a \leq y \\ & y' = we's' + b' \end{aligned} \tag{17}$$

C.1.2 Subperiod 2 Value Functions

The value of searching to buy a house:

$$R_{buy}(y,s,0) = \max\{0, \max_{\substack{h\in H,\\ x_b\leq y-\underline{y}}} p_b(\theta_b(x_b,h))[V_{own}(y-x_b,0,h,s,0) - V_{rent}(y,s,0)]\} \tag{18}$$

$$R_{buy}(y,s,1) = \max\{0, \max_{\substack{h\in H,\\ x_b\leq y}} p_b(\theta_b(x_b,h))[V_{own}(y-x_b,0,h,s,1) - V_{rent}(y,s,1)]\} \tag{19}$$

C.1.3 Subperiod 1 Value Functions

The utility associated with the default decision:

$$\begin{aligned} W(y,(\overline{q_m},m),h,s,0) = \max\{&\varphi(V_{rent}+R_{buy})\left(y+\max\{0,J_{REO}(h)-m\},s,1\right) \\ &+(1-\varphi)V^d_{own}(y,(\overline{q_m},m),h,s,0), V_{own}(y,(\overline{q_m},m),h,s,0)\} \end{aligned} \tag{20}$$

Utility of default conditional on no repossession:

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

$$\text{subject to}$$

$$c + \eta h + q_b b' \leq y$$

$$y' = we's' + b' \tag{21}$$

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

$$R_{sell}(y,(\overline{q_m},m),h,s,0) = \max\{0, \max_{x_s} p_s(\theta_s(x_s,h))\left[(V_{rent}+R_{buy})(y+x_s-m,s,0)\right.$$
$$\left.-W_{own}(y,(\overline{q_m},m),h,s,0)\right] + \left[1-p_s(\theta_s(x_s,h))\right](-\xi)\} \text{ subject to } y+x_s \geq m \tag{22}$$

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

$$R_{sell}(y,0,h,s,1) = \max\{0, \max_{x_s} p_s(\theta_s(x_s,h))\left[(V_{rent}+R_{buy})(y+x_s,s,1)\right.$$
$$\left.-W_{own}(y,0,h,s,1)\right] + \left[1-p_s(\theta_s(x_s,h))\right](-\xi)\} \tag{23}$$

C.2 Firms

C.2.1 Composite Consumption

The profit maximization condition of the composite good firm is

$$w = z_c \tag{24}$$

C.2.2 Apartments

The profit maximization condition of landlords is

$$r_h = \frac{1}{A_h} \tag{25}$$

C.2.3 Housing Construction

The relevant profit maximization conditions of home builders are

$$1 = p_h \frac{\partial F_h(\overline{L}, S_h, N_h)}{\partial S_h} \tag{26}$$

$$w = p_h \frac{\partial F_h(\overline{L}, S_h, N_h)}{\partial N_h} \tag{27}$$

C.3 Banks

Bond prices satisfy

$$q_b = \frac{1}{1+r} \tag{28}$$

Mortgage rates satisfy

$$q_m \equiv \frac{1}{1+r_m} = \frac{1-\delta_h}{(1+\phi)(1+r)} \tag{29}$$

The value to the bank of repossessing a house h is

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

$$R_{REO}(h) = \max\left\{0, \max_{x_s \geq 0} \lambda p_s(\theta_s(x_s, h)) \left[(1-\chi)x_s - \left(-\eta h + \frac{1-\delta_h}{1+r} J_{REO}(h)\right)\right]\right\} \tag{30}$$

Mortgage prices satisfy the following recursive relationship:

$$q_m^0((\overline{q_m}, m'), b', h, s)m' = \frac{1-\delta_h}{(1+\zeta)(1+\phi)(1+r)} \mathbb{E}\left\{\overbrace{p_s(\theta_s(x_s', h))m'}^{\text{sell + repay}} + \overbrace{[1 - p_s(\theta_s(x_s', h))]}^{\text{no sale (do not try/fail)}}\right.$$
$$\times \left[\underbrace{d'\varphi \min\left\{J_{REO}(h), m'\right\}}_{\text{default + repossession}} + \underbrace{d'(1-\varphi)}_{\text{no repossession}} \left(-\phi m' + \underbrace{(1+\zeta)(1+\phi)q_m^0((\overline{q_m}, m'), b'', h, s')m'}_{\text{continuation value of current } m'}\right)\right.$$
$$\left.\left. +(1-d')\left(\underbrace{m' - (1+\phi)\overline{q_m}m''\mathbf{1}_{[m'' \leq m']}}_{\text{borrower payment net of servicing costs}} + \underbrace{(1+\zeta)(1+\phi)q_m^0((\overline{q_m}, m''), b'', h, s')m''\mathbf{1}_{[m'' \leq m']}}_{\text{continuation value of new } m''}\right)\right]\right\} \tag{31}$$

C.4 Housing Market Equilibrium

C.4.1 Market Tightnesses

Market tightnesses satisfy

$$\kappa_b h \geq \overbrace{\alpha_b(\theta_b(x_b, h))}^{\text{prob of match}} \overbrace{(x_b - p_h h)}^{\text{broker revenue}} \tag{32}$$

$$\kappa_s h \geq \underbrace{\alpha_s(\theta_s(x_s, h))}_{\text{prob of match}} \underbrace{(p_h h - x_s)}_{\text{broker revenue}} \tag{33}$$

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

C.4.2 Determining the Shadow Housing Price

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

$$S_h(p_h) = \overbrace{Y_h(p_h)}^{\text{new housing}} + \overbrace{S_{REO}(p_h)}^{\text{REO housing}} + \overbrace{\int hp_s(\theta_s(x_s^*, h; p_h))\Phi_{own}(dy, dm, dg, ds, df)}^{\text{sold by owner}} \tag{34}$$

The supply of REO housing is given by

$$S_{REO}(p_h) = \sum_{h \in H} h\lambda p_s(\theta_s(x_s^{*REO}, h; p_h)) \left[\underbrace{H_{REO}(h)}_{\text{existing REOs}} + \underbrace{\int [1 - p_s(\theta_s(x_s^*, h; p_h))] d^* \Phi_{own}(dy, dm, dg, ds, 0)}_{\text{new foreclosures from failing to sell and then defaulting}} \right] \tag{35}$$

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

$$D_h(p_h) = \int h^* p_b(\theta_b(x_b^*, h^*; p_h))\Phi_{rent}(dy, ds, df) \tag{36}$$

The shadow housing price p_h equates these Walrasian-like equations,

$$D_h(p_h) = S_h(p_h) \tag{37}$$

C.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_h*
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 (14) – (23).*
2. ***Firm Optimality:*** *Condition (27) is satisfied.*
3. ***Bank Optimality:*** *Conditions (28) – (31) are satisfied.*
4. ***Market Tightnesses:*** *$\{\theta_b(x_b, h)\}$ and $\{\theta_s(x_s, h)\}$ satisfy (32) – (33).*
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:*** *$D_h(p_h) = S_h(p_h)$.*
7. ***Stationary Distributions:*** *the distributions are invariant with respect to the Markov process induced by the exogenous processes and all relevant policy functions.*

D Computation

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

1. Given r, calculate q_b and q_m using (28) – (29).
2. **Loop 1** – Make an initial guess for the shadow housing price p_h.

(a) Solve for market tightnesses $\{\theta_b(x_b, h; p_h)\}$ and $\{\theta_s(x_s, h; p_h)\}$ using (32) – (33).

(b) Calculate the wage w and housing construction Y_h using (24) – (27).

(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 (30) 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 $q^{0,n}_m(m', b', g, s)$ for $n = 0$.

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

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

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

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

      A. Substitute V^0_{rent} and V^0_{own} into the right hand side of (18) – (19) and solve for R_{buy}.

      B. Substitute V^0_{rent}, V^0_{own}, and R_{buy} into the right hand side of (20) and solve for W_{own}.

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

      D. Substitute W_{own}, V^0_{rent}, R_{sell}, and R_{buy} into the right hand side of (14) – (17) 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 $q^{0,n}_m$, J_{REO}, and the household's policy functions for bonds, mortgage choice and selling and default decisions into the right hand side of (31) and solve for q^0_m.

   iv. If $\sup(q^0_m - q^{0,n}_m) < \epsilon_q$, exit the loop. Otherwise, set $q^{0,n+1}_m = (1 - \lambda_q)q^{0,n}_m + \lambda_q q^0_m$ 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 (34) – (37).

(g) If $|D_h(s_h) - S_h(p_h)| < \epsilon_{p_h}$, exit the loop. Otherwise, update p_h using a modified bisection method and go back to (a).

The state space (y, m, h, s) for homeowners with good credit standing is discretized using 275 values for y, 131 values for m, 3 values for h, and 3 values for s (the calibration of labor efficiency is described in the previous section). 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 two sequences is used for the next guess. This process continues until convergence.