Liquidity Constraints in the U.S. Housing Market*

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Abstract

We study the severity of liquidity constraints in the U.S. housing market using a heterogeneous-agent model in which houses are illiquid but agents have the option to refinance their long-term mortgages. We parameterize the model to match the distribution of individual-level holdings of housing, mortgage debt and liquid assets, as well as the amount of housing turnover and mortgage refinancing in the 2001 data. Our model implies sizable welfare losses from liquidity constraints: one-third of homeowners are willing to give up in excess of 5% of every dollar transferred from home equity to a liquid account. Interestingly, we find that liquidity constraints are more severe during a boom rather than a bust in house prices, and are more severe for retirees despite their lower marginal propensities to consume out of liquidity injections. The wave of mortgage refinancing observed in the data accounts for about one-third of the rise and fall in household spending during the 2001-2011 period.

Keywords: Great Recession, Housing, Liquidity Constraints, Mortgage Refinancing.

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1 Introduction

Housing is an important savings instrument for a large fraction of U.S. households. According to the Survey of Consumer Finances (SCF), about two-thirds of U.S. households own a home. Importantly, homeowners' asset allocations are heavily tilted towards housing equity: the median homeowner has about 80% of his wealth in housing.[1] Housing, however, is a special asset because selling or buying a home involves substantial transaction costs. This raises the possibility that many wealthy agents are *liquidity constrained*: although they are rich, they have relatively little holdings of liquid wealth that would allow them to smooth fluctuations in consumption. Indeed, Kaplan and Violante (2014) and Kaplan et al. (2014) show that a sizable fraction of rich households have very small holdings of liquid wealth.

In this paper we ask: how severe are liquidity constraints in the U.S. housing market? A number of economists, for example Bernanke (2012a), Bernanke (2012b), Dynan (2012) and Mian et al. (2013) have conjectured that the decline in housing prices following 2007 has considerably reduced household's financial flexibility, by preventing homeowners from tapping home equity to pay for emergency expenses or to respond to job losses or reduced income. These concerns led to the introduction of a number of programs, such as the Home Affordable Refinance Program (HARP) and the Home Affordable Modification Program (HAMP), whose goal was to allow homeowners to refinance their mortgages and reduce monthly mortgage payments. As Eberly and Krishnamurthy (2014) point out, the view that liquidity constraints are particularly severe during periods of declining house prices has important implications for policy. In particular, reductions in mortgage payments that are concentrated in periods of house price collapses and thus restore homeowners' liquidity would be more effective than debt write-downs that reduce mortgage payments over the entire duration of mortgage contracts.

As we argue below, measuring the severity of liquidity constraints using data alone, by comparing households' consumption to their liquid assets or by studying marginal propensities to consume out of tax rebates, is challenging. Risk-averse homeowners may choose to keep their consumption low compared to their liquid assets in order to finance future mortgage payments and guard against the possibility of negative income shocks. Alternatively, some homeowners may choose to pay costly transaction or refinancing costs in order to replenish their stock of liquid assets. Such behavior is indicative of strongly binding liquidity constraints and yet would not be captured by the ratio of one's consumption or income to

[1]See Panel C of Table 1 below which reports data from the 2001 SCF.

liquid assets or by the marginal propensity to consume. Indeed, as we show below, some of the most liquidity constrained agents in our economy have negative marginal propensities to consume out of a transfer.

Given these challenges, we use both theory and data to measure the severity of liquidity constraints. The model we study is an overlapping generations small open economy model in which agents are subject to idiosyncratic income shocks. Agents can save in a liquid asset at an exogenously fixed interest rate or by purchasing housing which entails non-convex transaction costs. Our modeling choices are designed to mimic, in a simple and thus computationally tractable way, the main institutional details of the U.S. housing market. Agents can borrow against the value of their home. Doing so is costly, however, so not all agents do so: only about two-thirds of U.S. homeowners have a mortgage in the 2001 SCF data. Mortgages are long-term securities: their average maturity is 25 years. A mortgage contract requires payment of both interest and principal, thus forcing owners to save over time by building home equity. Agents can cash-out refinance their mortgage[2] in order to tap into their rising home equity, but doing so entails substantial costs, which we choose so that the model matches the share of cash-out refinanced mortgages.

We pin down the parameters of the model by matching key moments of the cross-sectional distribution of income, liquid and housing wealth, as well as mortgage debt in the U.S. We also require the model to match the frequency with which households transact houses and the share of cash-out refinanced mortgages. By assuming heterogeneity in the discount rates of households, we allow the model to reproduce the dispersion and skewness of the wealth, liquid asset and housing distributions in the 2001 U.S. data. Moreover, the model matches well all the deciles in the distribution of the ratio of liquid assets to income and the fraction of housing equity in homeowners' total wealth. As we show below, these ratios are critical in determining the extent to which agents are liquidity constrained in the model.

We measure the severity of liquidity constraints by conducting a series of experiments which we refer to as *liquidity injections.* In these experiments we allow all homeowners to partially refinance their mortgage debt at no cost by cashing in some of their home equity. We study the effect such transfers have on agents' decision rules, their marginal propensities to consume out of them, as well as the discount agents are willing to pay for a transfer, which

[2]We use the term *cash-out refinancing* to denote refinance activities in which the face value of a homeowner's mortgage increases so that the homeowner converts some of its housing equity into liquid assets. Rate refinances, in contrast, only entail a change in the interest rate and do not involve home equity extraction. Since the interest rate is constant in our model, all refinancing activity is cash-out refinancing.

we denote the *liquidity premium*. We find that about one-third of homeowners are severely constrained and would be willing to give up in excess of 5% of every dollar transferred from the home equity to the liquid account. Although the average marginal propensity to consume out of such transfers is indeed positive, we find that about 20% of homeowners *reduce* consumption in response to the transfers. They do so because a liquidity injection increases the option value of waiting both for agents that would have upgraded their homes (and thus would have reduced consumption) as well as for those agents that would have refinanced or downsized (and thus would have increased their consumption). Not surprisingly, liquidity constraints are strongly correlated with the share of housing equity in homeowners' total wealth, as well as their age. Older households have built up large amounts of home equity and face the highest liquidity premium. Interestingly, these agents have the *lowest* marginal propensity to consume out of a transfer, owing to the effect a transfer has on their option value of waiting before refinancing or downsizing.

Having described the steady-state predictions of our model, we then turn to studying how the severity of liquidity constraints varies over time in periods of large swings in house prices, of the type the U.S. has experienced in the decade starting in 2001. We do so by feeding our model a series of unanticipated permanent shocks to housing preferences. These shocks are chosen so as to ensure that the equilibrium price of houses in the model reproduces exactly the 2001-2011 path for house prices in the U.S. (upper-left panel of Figure 1). We show that the model accounts well for (i) the rise and fall in mortgage debt in the data (upper-right panel of Figure 1), (ii) the fact that about 40% of the increase in mortgage debt in the data was due to cash-out refinancing (lower-left panel of Figure 1),[3] and (iii) the rise and fall in the aggregate consumption to income ratio in the data (lower-right panel of Figure 1).

Interestingly, we find that liquidity constraints are *most severe* during periods of *rising* house prices and *least severe* when house prices *decline*. To see why this is the case, note that liquidity constraints are most severe when agents have a greater share of their total wealth in housing. In periods of rising house prices the share of housing in total wealth automatically increases: agents are therefore more liquidity constrained and value more the ability to convert some of the additional housing wealth into consumption. In contrast, in periods of falling house prices the share of housing net worth in total wealth automatically falls. In such periods agents value liquidity less: a decline in house prices leads households

[3] See also Mian and Sufi (2011).

to cut consumption, due to wealth effects, and thus reduces their need for liquid assets. We also find that policies aimed at replenishing the liquidity positions of those households whose consumption falls most after a decline in house prices may not necessarily raise aggregate consumption. As in Glover et al. (2011), older households in our model are most adversely affected by a decrease in house prices. Such agents would choose, however, to exercise their option value of waiting before selling their homes and would thus cut consumption in response to a liquidity injection.

We also use our model to study the role of mortgage refinancing in alleviating liquidity constraints and amplifying the response of consumption to changes in house prices. The last 25 years have witnessed a remarkable surge in the amount of cash-out refinancing undertaken by homeowners. The face value of newly cash-out refinanced loans increased from less than 1% of disposable income in the early 90s to about 10% of disposable income at the peak of the housing boom. We show that in our model moving from an environment with no refinancing to the level of refinancing activity observed in the 2000s increases homeownership rates substantially, from 62% to 69%, by allowing homeowners to hold on to their homes for longer. Although the option to cash-out refinance substantially alleviates liquidity constraints, it also amplifies the impact of fluctuations in house prices on aggregate consumption, by disproportionately increasing homeownership rates among retirees. Since older generations have greater marginal propensities to consume out of housing wealth, owing to their shorter horizons, their consumption is most sensitive to changes in house prices. Overall, we find that consumption was 60% more volatile during the 2001-2011 period than it would have been absent cash-out refinancing.

Related Work We view this paper as part of a wider research agenda, developed by Hurst and Stafford (2004), Laibson et al. (2007), Khandani et al. (2013), Attanasio et al. (2011), Kaplan and Violante (2014), Kaplan et al. (2014), Chen et al. (2013), Mian and Sufi (2011, 2015) and Kaplan et al. (2015) among others, aimed at understanding the role of liquidity management in the housing market.

Our focus on understanding the role of refinancing activity is most closely related to the empirical work of Khandani et al. (2013), Mian and Sufi (2011, 2015), and quantitative analysis of Chen et al. (2013). Our work builds on the model of Chen et al. (2013), who study the cyclical properties of cash-out and rate refinancing, but differs along several dimensions motivated by our explicit focus on liquidity constraints. First, ours is a life-cycle economy.

Second, the housing market in our model is in equilibrium. Third, liquidity constraints are particularly severe in our model because of the *forced savings* aspect of mortgage contracts. Agents in our model are contractually required to build up equity in their homes by paying both interest and principal on their mortgages, as they are in the data. In contrast, mortgage contracts in Chen et al. (2013) are interest-only perpetuities.

Our focus on liquidity constraints is motivated by the findings of Kaplan and Violante (2014) and Kaplan et al. (2014) that a substantial number of U.S. households are wealthy hand-to-mouth agents that hold large fractions of their portfolios in illiquid assets. In contrast to Kaplan and Violante (2014), our model explicitly focuses on the housing market and introduces a number of assumptions aimed at capturing the institutional details of this market. Our focus on measuring the severity of liquidity constraints is also different than their focus on accounting for the large marginal propensity to consume out of tax rebates. As we noted above, the two concepts are somewhat distinct. In our model the most constrained agents, the retirees, have the lowest marginal propensities to consume out of a liquid transfer.

Our paper is also closely related to the work of Kaplan et al. (2015). Though the two papers differ in many of the modeling details, both study life-cycle models of the housing market in which houses are illiquid, mortgages have long durations and households can extract equity out of their homes. In contrast to our focus on measuring the severity of liquidity constraints, Kaplan et al. (2015) study the comovement of consumption, house prices and income at business cycle frequencies by introducing several sources of aggregate uncertainty. Our model, by comparison, is less suitable for studying cyclical fluctuations since we abstract from aggregate risk in our analysis.

Our work is also related to a number of papers that study the housing market and its aggregate implications: Davis and Heathcote (2005), Ríos-Rull and Sánchez-Marcos (2008), Kiyotaki et al. (2011), Iacoviello and Pavan (2013), Justiniano et al. (2014, 2015), Landvoigt et al. (2015), and Favilukis et al. (2013). In contrast to these papers, which typically assume one-period-ahead mortgage contracts and no costs of refinancing, our analysis explicitly introduces long-term mortgages that are costly to refinance and is thus more suitable for understanding the role of liquidity constraints. Chambers et al. (2009a,b) study rich models of the mortgage and housing market but unlike us focus on understanding changes in the homeownership rates and optimal mortgage choice, as do Campbell and Cocco (2003). Chatterjee and Eyigungor (2015) and Corbae and Quintin (2015) study models of the housing market with long-term mortgages but unlike us focus on understanding the foreclosure crisis. Greenwald (2015) proposes a tractable New Keynesian model of long-term fixed-rate mortgages and studies the aggregate implications of mortgage refinancing. Finally, a number of authors, including Lorenzoni and Guerrieri (2011), Midrigan and Philippon (2011), Eggertsson and Krugman (2012), Kehoe et al. (2014) and Huo and Ríos-Rull (2014) study economies in which credit shocks reduce household consumption and, through various mechanisms, trigger a drop in aggregate output.

The rest of the paper is organized as follows. Section 2 describes our model. Section 3 discusses the data we have used and our empirical strategy. Section 4 discusses a number of results based on the steady state of our model. Section 5 discusses our transition experiments. Section 6 concludes.

2 Model

This is an overlapping generations endowment economy in which agents live for a finite number of periods, are subject to transitory idiosyncratic income shocks, derive utility from consumption and housing services, and can save either via a one-period liquid asset or by purchasing a home. We assume a small open economy so that the one-period interest rate is constant. Agents can either rent or own a home. While the stock of rental housing can be freely adjusted each period, buying or selling owner-occupied housing entails transaction costs. Agents can choose to borrow against the value of their home but doing so requires a fixed borrowing cost. There is no aggregate uncertainty: rather, we study the steady-state properties of the model and the transition dynamics in response to unanticipated shocks. We next describe agents' preferences, their income process, as well as the asset, rental and housing markets.

Preferences. An agent lives for T periods and has no bequest motive. The utility is of the Epstein-Zin form with an intertemporal elasticity of substitution equal to 1, a risk aversion parameter σ, a preference weight on consumption equal to α and a discount factor β. We let c denote the consumption of the endowment good and s denote the amount of housing services the agent consumes. The life-time utility of a j-year old agent is

$$V_j = (1-\beta)\left[\alpha \log(c_j) + (1-\alpha)\log(s_j)\right] + \frac{\beta}{1-\sigma}\log\left(E\exp\left((1-\sigma)V_{j+1}\right)\right), \quad j < T, \tag{1}$$

$$V_T = (1-\beta)\left[\alpha \log(c_T) + (1-\alpha)\log(s_T)\right].$$

Income. An agent of age j receives income

$$y_j = \lambda_j z e,$$

where λ_j is deterministic and captures the hump shape of life-cycle earnings, z is a permanent component that is drawn at birth from a normal distribution $N(0, \sigma_z^2)$ and stays constant thereafter and e is an i.i.d shock drawn each period from $N(0, \sigma_e^2)$. Here y_j captures disposable income: income after taxes, transfers and contributions to retirement accounts during an agent's working life, and social security payments and withdrawals from retirement accounts during the retirement stage.

Assets. Agents can save using a one-period risk-free asset a at an interest rate r, as well as by purchasing housing. We refer to the one-period asset as the *liquid asset*. Let P_t be the price of housing in period t. Buying or selling a house of size h entails a transaction cost equal to a fraction F of the value of one's home. The cost $FP_t h$ is denominated in units of the endowment good. Thus an agent that would like to change its housing stock from h to h' in period t spends a total of $FP_t(h' + h)$ units of the good. We implicitly assume that transaction costs are split equally between the buyer and the seller so that F is one-half the total cost of transacting a home. We assume that the stock of houses is indivisible so that $h \in \{0, h_1, ..., h_K\}$.

Whenever agents buy a home, they have the option to sign a mortgage contract with a financial intermediary. For a house of size h, the agent can borrow up to $\bar{\theta} P_t h$ units of the endowment good. Here $\bar{\theta}$ is the maximum loan-to-value ratio. We follow Li et al. (2014) in assuming that there are no additional frictions in the mortgage market: competition among financial intermediaries thus bids down the mortgage rate to r, the interest rate on the one-period security. Since the return on both securities is r, while the liquid asset provides a liquidity service, an agent that obtains a mortgage borrows up to the maximum value. For this reason, early repayment of the mortgage loan is suboptimal in this economy. We make the assumption of frictionless mortgage contracts for computational tractability: a wedge between the rate at which agents borrow in the mortgage market and save in the liquid account would require that we solve for the optimal pre-payment decisions of homeowners as well as the initial loan-to-value ratio and would complicate our analysis considerably.[4]

[4] Amromin et al. (2007) find that only about 16% of homeowners that have a 30-year fixed-rate mortgage are ahead of time on their mortgage payments and are thus classified as prepayers.

Obtaining a mortgage on a newly-purchased home requires a fixed cost $F_N P_t h$, once again proportional to the value of the home (or equivalently, to the amount borrowed). These loans correspond to first-lien originations in the data. Agents that already own a home have the option to pay another fixed cost, $F_R P_t h$, where $F_R > F_N$, to refinance their mortgage. Paying this fixed cost allows homeowners to increase their loan-to-value ratio to the maximum allowed $\bar{\theta}$. Since the interest rate is constant in our economy, refinancing in our model corresponds to cash-out refinancing in the data. Assuming two costs of obtaining a mortgage, one for newly-purchased homes, and another for existing homes, allows us to simultaneously match the fraction of homeowners that have a mortgage as well as the fraction of homeowners that refinance. We think of the gap between F_R and F_N as reflecting economies of scope that arise if buyers acquire a mortgage at the same time when buying their home.

We follow Hatchondo and Martinez (2009), Arellano and Ramanarayanan (2012) and Chatterjee and Eyigungor (2015) in assuming, for computational tractability, that mortgages are perpetuity contracts with geometrically decaying coupon payments. Let q be the price of a security. Issuing b units of such a security requires that the borrower repays b units of the good next period, γb in two periods, $\gamma^2 b$ in three periods, and so on, until the owner sells the house, at which point the borrower repays the remaining value of the outstanding loan. Because financial intermediaries are risk-neutral, competitive and face no frictions, the price of a security satisfies a no-arbitrage restriction, $q = \frac{1}{1+r}(1 + \gamma q)$, which pins down the price of the security:

$$q = \frac{1}{1 + r - \gamma}. \tag{2}$$

The duration of such a security (defined as the weighted average of the maturity of each cash flow) is

$$\frac{1}{q} \sum_{t=1}^{\infty} t \left(\frac{1}{1+r} \right)^t \gamma^{t-1} = \frac{1+r}{1+r-\gamma} \tag{3}$$

and we choose γ to match the average duration of mortgage contracts in the data. This specification of the mortgage contracts is convenient because it allows us to only keep track of the remaining balance on the mortgage. This balance evolves over time according to $b' = \gamma b$ as long as the owner does not refinance.

We also assume that agents can borrow in the liquid market up to a constant amount θ_c (which we think of as unsecured credit) plus an additional fraction θ_h of the value of their home equity:

$$a' \geq -\theta_c - \theta_h (Ph' - qb'). \tag{4}$$

Here a' is the amount of liquid savings the agent carries into the next period.

The parameter θ_h determines the extent to which the homeowner can costlessly transfer funds from its home equity to the liquid account. If θ_h is equal to 1, this is a standard economy with a Kiyotaki and Moore (1997)-type collateral constraint in which agents can freely tap equity from their home and houses are liquid. If θ_h is close to 0, home equity extraction is costly and must be done either by selling one's home or refinancing. As we will show below, our calibration requires a small but positive value of θ_h to match the lower tail of the distribution of liquid assets of homeowners in the data.

Rental Market We assume that housing services derive from the end-of-period housing stock. Thus an owner who has a house of size h at the end of the period derives period utility $u(c,h)$.

Our modeling of the rental market is parsimonious. An agent that does not own a home can rent s units of housing services at a rental rate R. Unlike owner-occupied housing, rental housing is not subject to any adjustment costs or indivisibilities, but, as in Chambers et al. (2009a,b), is subject to depreciation. We think of this depreciation as capturing a number of reasons that make housing ownership preferable to renting, including mortgage interest deductions, moral hazard problems that exacerbate maintenance costs of rental property, etc.

We assume that the aggregate stock of rental housing S_t is not subject to any adjustment costs. Renters pay a rate R per unit of house rented in the period in which they rent. Since rental housing depreciates at a rate δ, no-arbitrage requires that the rental rate is equal to

$$R = \frac{r+\delta}{1+r}.$$

Finally, we assume that an agent can either rent or own. That is, homeowners derive no utility from consuming housing services in addition to those provided by their homes.

Budget constraint. Consider an agent with a beginning-of-period house of size h_{t-1} and outstanding mortgage debt b_{t-1}. We introduce two indicator variables: $\xi_t = 1$ if the agent transacts its house ($h_t \neq h_{t-1}$) and $\mu_t = 1$ if the agent refinances its mortgage so that it obtains a new mortgage balance

$$qb_t = \bar{\theta} P_t h_t.$$

Recall that transacting one's home, $\xi_t = 1$, entails paying the fixed cost F. Obtaining a new mortgage, $\mu_t = 1$, requires paying F_N if $\xi_t = 1$ (new home purchase) or F_R if $\xi_t = 0$ (refinance existing mortgage).

The budget constraint is therefore:

$$c_t + a_t + P_t\left(h_t - h_{t-1}\right) + FP_t\left(h_t + h_{t-1}\right)\xi_t - q\left(b_t - \gamma b_{t-1}\right) + \left[F_N \xi_t + F_R\left(1 - \xi_t\right)\right] P_t h_t \mu_t + R s_t$$
$$= \left(1 + r\right) a_{t-1} + y_t - b_{t-1}.$$

The right hand side of this expression adds the amount of liquid assets and income net of the coupon payment b_{t-1} on the existing mortgage. The left-hand side adds the amount of consumption, liquid savings, as well as the amount spent if purchasing a new house,

$$P_t\left(h_t - h_{t-1}\right) + F\left(P_t h_t + P_t h_{t-1}\right)\xi_t,$$

the change in mortgage debt, net of the financing costs,

$$-q\left(b_t - \gamma b_{t-1}\right) + \left[F_N \xi_t + F_R\left(1 - \xi_t\right)\right] P_t h_t \mu_t,$$

and rental spending Rs_t for agents that have an end-of-period housing stock equal to $h_t = 0$.

The agent can avoid paying the fixed cost of transacting houses by setting $h_t = h_{t-1}$. Similarly, it can avoid paying the mortgage cost by either leaving its mortgage balance unchanged ($b_t = \gamma b_{t-1}$) if it does not transact the house, or by not borrowing at all ($b_t = 0$) if it does transact a house.

In our numerical experiments the majority of homeowners neither refinance nor transact their house, and so face a budget constraint

$$c_t + a_t = y_t + \left(1 + r\right) a_{t-1} - b_{t-1}.$$

The amount the household has available to spend thus consists of its income and liquid assets net of coupon payments on the mortgage debt. Since the coupon payments include both interest payments and principal, mortgage contracts require agents to continue saving over time in their illiquid asset by building home equity. Indeed, if γ and δ are sufficiently low, as in our numerical experiments, payments on the mortgage contract will initially exceed rent expenditures on an equally-sized rental home. This is the case as long as

$$b = \frac{\bar{\theta} P}{q} = \bar{\theta}(1 + r - \gamma) \geq R = \frac{r + \delta}{1 + r},$$

where we used the fact that the price of owner-occupied housing is equal to $P = 1$ in the steady state of the model. Such contractually imposed *forced savings* may be costly for agents with a temporarily low stream of income and may lead them to downsize or refinance their mortgage.

Recursive formulation. Let θ_t denote an agent's remaining loan-to-value (LTV) ratio

$$\theta_t = \frac{qb_t}{P_t h_t}.$$

Consider an agent that enters the period with liquid assets a_{t-1}, house size h_{t-1}, an LTV ratio of θ_{t-1}, permanent income component z, transitory income component e_t and discount factor β. As we explain below, we assume that β differs across agents.

Each period the agent makes its choice of a_t, h_t and θ_t in order to maximize its life-time utility. For an agent that refinances at t, we have

$$\theta_t = \bar{\theta}.$$

In contrast, if the agent does not refinance its mortgage, its loan-to-value ratio evolves over time according to

$$\theta_t = \gamma\theta_{t-1}\frac{P_{t-1}}{P_t}.$$

Absent a change in house prices, the loan to value ratio falls geometrically at rate γ.

Various choices of h_t and θ_t leave the agent with different amounts of liquid assets, ω_t, available after the housing transactions take place:

$$\begin{aligned} \omega_t &= y_t + (1+r)\, a_{t-1} - \frac{\theta_{t-1}}{q} P_{t-1} h_{t-1} - P_t\left(h_t - h_{t-1}\right) \\ &\quad - \left(FP_t h_t + FP_t h_{t-1}\right)\xi_t + \left(\theta_t P_t h_t - \gamma\theta_{t-1} P_{t-1} h_{t-1}\right) - \left[F_N \xi_t + F_R\left(1-\xi_t\right)\right] P_t h_t \mu_t \end{aligned}$$

These liquid assets include income, y_t, the gross return on last period's liquid savings, a_{t-1}, as well as the proceeds, if any, from housing transactions net of payments on outstanding mortgage debt. We find it useful to introduce a change of variables and define

$$\hat{a}_t = a_t + \theta_c + \theta_h\left(1-\theta_t\right) P_t h_t$$

to be the *distance to the borrowing limit*. Clearly, $\hat{a}_t \geq 0$ for both renters and homeowners. Similarly, let

$$\hat{\omega}_t = \omega_t + \theta_c + \theta_h\left(1-\theta_t\right) P_t h_t$$

With this formulation, the budget constraint becomes

$$c_t + Rs_t + \hat{a}_t = \hat{\omega}_t$$

and since $\hat{a}_t$ is required to be nonnegative, a homeowner's consumption must satisfy the date t *cash-on-hand constraint*

$$c_t \leq \hat{\omega}_t.$$

We refer to $\hat{\omega}_t$ as *cash-on-hand* since it gives the maximum amount a homeowner can consume in a given period.

Let $V_{j,t}$ be the agent's value after the housing and mortgage choices are made, while $W_{j,t}$ be the (expected) continuation value. We have:

$$V_{j,t}\left(\hat{\omega}_t, h_t, \theta_t, \beta, z\right) = \max_{c,\ \hat{a}_t \geqslant 0} \left(1-\beta\right) u\left(c_t, h_t\right) + \beta W_{j,t+1}\left(\hat{a}_t, h_t, \theta_t, \beta, z\right).$$

Here period utility is a function of whether the agent chooses to rent or own:

$$u\left(c_t, h_t\right) = \begin{cases} \alpha \log c_t + (1-\alpha)\log h_t \text{ if } h_t > 0 \\ \log c_t + (1-\alpha)\log\left(\frac{1-\alpha}{\alpha}R^{-1}\right) \text{ if } h_t = 0 \end{cases}$$

and the budget constraint is simply

$$\left[1\mathcal{I}_{h_t>0} + \frac{1}{\alpha}\mathcal{I}_{h_t=0}\right] c_t + \hat{a}_t = \hat{\omega}_t,$$

where h_t and θ_t are the *end-of-period* housing and loan to value ratio. Here we have used the fact that the renter's choice of housing services is static and satisfies

$$s = \frac{1-\alpha}{\alpha} R^{-1} c.$$

The optimal choice of savings satisfies the Euler equation:

$$(1-\beta)\frac{\alpha}{c_t} \geq \beta \frac{\partial W_{j,t+1}\left(\hat{a}_t, h_t, \theta_t, \beta, z\right)}{\partial \hat{a}_t}$$

which holds with equality if the cash-on-hand constraint, $\hat{a}_t \geq 0$, does not bind.

To evaluate the continuation value, we integrate over the transitory income shocks (with c.d.f. $\Phi(e)$) and evaluate, for each possible choice of h_t, ξ_t and μ_t :

$$W_{j,t}\left(\hat{a}_{t-1}, h_{t-1}, \theta_{t-1}, \beta, z\right) = \frac{1}{1-\sigma}\log\left(\int \exp\left(\max_{h_t,\xi_t,\mu_t} (1-\sigma) V_{j,t}\left(\hat{\omega}_t(e), h_t, \theta_t, \beta, z\right)\right) \mathrm{d}\Phi(e)\right)$$

where $\hat{\omega}_t$ evolves according to

$$\begin{aligned} \hat{\omega}_t &= \lambda_j z e + (1+r)\hat{a}_{t-1} - \frac{\theta_{t-1}}{q} P_{t-1} h_{t-1} - P_t\left(h_t - h_{t-1}\right) \\ &\quad - \left(FPh_t + FPh_{t-1}\right)\xi_t + \left(\theta_t P_t h_t - \gamma\theta_{t-1}P_{t-1}h_{t-1}\right) - \left[F_N \xi_t + F_R\left(1-\xi_t\right)\right] P_t h_t \mu_t \\ &\quad - r\theta_c + \theta_h\left[\left(1-\theta_t\right)P_t h_t - (1+r)\left(1-\theta_{t-1}\right)P_{t-1}h_{t-1}\right]. \end{aligned}$$

Supply of Housing. We assume that housing is produced by perfectly competitive construction firms. We also assume adjustment costs in housing investment: producing $x_{h,t}$ units of (owner-occupied) housing requires an investment of

$$y_{h,t} = x_{h,t} + \frac{\phi}{2}\left(\frac{x_{h,t}}{H_{t-1}}\right)^2 H_{t-1}$$

units of the endowment good, where H_{t-1} is the aggregate stock of housing at the beginning of the period and $x_{h,t}$ is an individual construction firm's output. Construction firms maximize their profits (which they consume themselves rather than rebate to households):

$$\max_{x_{h,t}} P_t x_{h,t} - x_{h,t} - \frac{\phi}{2}\left(\frac{x_{h,t}}{H_{t-1}}\right)^2 H_{t-1}$$

and so choose $x_{h,t}$ to ensure that

$$P_t = 1 + \phi\left(\frac{x_{h,t}}{H_{t-1}}\right).$$

In equilibrium, $x_{h,t} = H_t - H_{t-1}$ since all construction firms are identical, so

$$P_t = 1 + \phi\left(\frac{H_t}{H_{t-1}} - 1\right).$$

The price of housing is thus equal to 1 in the steady state, the same as that of a unit of rental housing, but, depending on the (inverse) housing supply elasticity, ϕ, will increase in periods in which demand for housing exceeds the previously available stock.

Aggregate Resource Constraint. Let C_t be aggregate consumption, A_t aggregate liquid savings, S_t the aggregate stock of rental housing, and D_t the aggregate amount of mortgage debt. Since the stock of rental rental housing is liquid, we can write total savings, A_t, as the sum of claims to rental housing as well as financial wealth, B_t:

$$A_t = (1 - R)S_t + B_t.$$

Summing up the budget constraints of all agents, and substituting the expression for the price of housing, we have

$$C_t + S_t - (1-\delta)\, S_{t-1} + B_t - D_t + F_t^{TR} + H_t - H_{t-1} + \frac{\phi}{2}\left(\frac{H_t}{H_{t-1}} - 1\right)^2 H_{t-1}$$
$$= (1+r)\,(B_{t-1} - D_{t-1}) + Y_t,$$

where F_t^{TR} is the sum of the fixed costs of transacting houses and refinancing mortgages. This says that in the aggregate consumption is equal to the aggregate endowment, net of investment in rental and owner-occupied housing as well as net of changes in the economy's net foreign asset position, $B_t - D_t$.

Default. We allow agents the option to default when house prices unexpectedly fall. Since we study experiments in which house price changes are unanticipated zero-probability events, the option to default does not change the pricing of mortgage securities or the agents' decision rules.

An agent that defaults is excluded from the housing market for a period, $h_t = 0$, loses its existing home, $h_{t-1} = 0$, but no longer has any outstanding debt, $\theta_t = 0$. In addition, we reset the agent's liquid assets to $\max(a_{t-1}, -\theta_c)$ so that the agent also defaults on the amount of liquid debt that is in excess of the unsecured credit limit θ_c. We assume that the homes that are defaulted on are sold, and the proceeds from these sales, net of the transaction costs, are returned to financial intermediaries. About 2% of all mortgage debt is defaulted upon in our numerical experiments below in the years with the declining house prices of 2007-2009.

3 Empirics

We next describe how we have selected the parameters of the model. We choose values for the key parameters so that the model replicates salient features of the cross-sectional distribution of income, liquid and housing wealth, mortgage debt, frequency with which households transact houses and the share of cash-out refinances in new mortgage debt. We use data from the Survey of Consumer Finances (SCF), Panel Study of Income Dynamics (PSID), the Federal Housing Finance Agency (FHFA) and the Mortgage Bankers Association (MBA) to construct empirical counterparts for the moments we calculate in the model. This section describes the variables we have used, our calibration strategy, and compares the empirical and model-based moments. Since the period we study (2001-2011) was characterized by a large boom and bust in the housing market, we target statistics from 2001 in our calibration and use numbers from the rest of the years to evaluate the model.

3.1 Data

Income Process. We use a sample of households from the 1999-2007 waves of the Panel Study of Income Dynamics (PSID) to calibrate our income process. Our goal is to construct income series that correspond to the counterpart for income in our model. Our concept of income in the model is disposable income, net of taxes as well as pension contributions for workers, and inclusive of social security and pension income for retirees. We thus compute taxable income for each household by adding wages (net of pension contributions), social security income, taxable pension income, unemployment compensation, workers' compensation, supplemental social security, other welfare, child support, and transfers from relatives for both the head of the household and his/her spouse. Our measure of disposable income is then constructed by subtracting federal income and state taxes generated by TAXSIM from the taxable income of each household. Lastly, we deflate disposable income using the Bureau of Labor Statistics Consumer Price Index and convert this number into per-person units by applying the OECD equivalence scales based on the number of household members. The Appendix contains a more detailed description of our computations. We exploit the panel nature of the PSID data in order to parameterize the process for idiosyncratic income risk of individual agents in our model.

Wealth. We use the 2001-2013 waves of the Survey of Consumer Finances (SCF) to compute our measures of various components of household wealth.

The value of housing is based on the self-reported value of the primary residence owned by each household. Our measure of mortgage debt is computed by summing up the remaining principal on all mortgages secured by the primary residence. The loan-to-value ratio is calculated by dividing mortgage debt by the value of housing. Housing net worth is the difference between the value of the house and the value of mortgage debt.

We compute our measure of liquid assets by summing up the value of all checking accounts, saving accounts, money market deposits, money market mutual fund accounts, certificates of deposit, directly held pooled investment funds, saving bonds, stocks, as well as other residential real estate, nonresidential real estate net of mortgages, and other non financial assets. We subtract from these the balances on credit cards, home equity loans, outstanding balances on home equity lines of credit and other mortgage debt on secondary real estate. Notice that our inclusion of residential real estate (rental properties, secondary homes) as part of liquid assets is motivated by the specifics of our model in which rental housing property is part of the agents' liquid assets. Very few agents own secondary residential properties so this choice does not change our estimate of liquid wealth much, but these properties are transacted often so it makes less sense to include them as part of the illiquid housing stock. Similarly, we are motivated by the specifics of our model in treating home equity loans as negative liquid assets, since credit secured by housing is treated as negative balances on the liquid asset in the model. Once again, we find that very few households have such home equity lines of credit in 2001, so this choice has little impact on the moments we report.

Finally, we define total wealth as the sum of liquid assets and housing net worth. Our measure of wealth thus excludes retirements accounts, since transfers into and out of these accounts are directly added to a household's measure of disposable income. As Kaplan and Violante (2014) point out, retirement accounts make up less than 2% of the median household's wealth in the U.S., so our choice to exclude retirement accounts from our definition of wealth does not change these statistics much. This choice simplifies our computations considerably, as it allows us to avoid keeping track of yet another state variable (amount saved in the retirement account) in our numerical analysis.

We also use the SCF data to compute average rental spending, fraction of homeowners and fraction of homeowners that have a mortgage. Some of the moments we report below scale individual household wealth measures by income. We use a similar procedure to that described above for the PSID in order to construct our measure of disposable income using the SCF data. The Appendix provides more details on how we construct our measures of wealth and income.

Consumption, Turnover and Refinancing. We use three additional aggregate time-series in our quantitative analysis. The consumption-to-income ratio is based on data from the U.S. Bureau of Economic Analysis. Our measure of consumption is constructed by subtracting expenditures on housing and utilities from total personal consumption expenditures. Our measure of income is aggregate disposable personal income. The fraction of homes sold out of the total housing stock is constructed with data from the Census and the National Association of Realtors using the approach of Berger and Vavra (2015). We follow Khandani et al. (2013) and calculate the share of cash-out refinancing in total new mortgage debt by using data on the value of mortgage originations compiled by the Mortgage Bankers Association (MBA) and data on the share of cash-out refinances in total refinanced volume of mortgages from the Federal Housing Finance Agency (FHFA). The Appendix explains in detail how we merge the information from these two datasets to arrive at our measure of cash-out refinancing.

3.2 Parameterization

We assume that a period in the model corresponds to 2 years. Agents enter our economy at age 25 and live for $T = 30$ periods, that is, up to age 85. They work for 20 periods, up to age 65, at which point they retire and experience a fall in income, which we capture using a fall in λ_j. Retirees continue to be subject to income shocks after retirement, just as workers. We set the coefficient of relative risk aversion, σ, equal to 5 and the interest rate equal to 0.04 per year.

We assume that there are two types of households that differ in their rate of time preference. We let β_1 and β_2 denote the discount factors of the two types, and τ the fraction of the type 1 (impatient) households in the economy. We introduce preference heterogeneity in order to allow the model to reproduce the concentration of liquid assets and wealth in the U.S. On one hand, the ratio of average liquid assets (wealth) to income is very large, 1.5 (2.4). On the other hand, the ratio of median liquid assets (wealth) to income is extremely low, 0.1 (0.5). A model with a single discount factor can either match the former or the latter, but not both features of the data.

We divide the rest of the parameters into two groups. The first group includes parameters that are assigned exogenously, by choosing them to match moments that can be computed without solving the model. The second group are parameters that are chosen endogenously, by minimizing the distance between a number of moments in the model and in the data. We next describe each set of parameters.

3.2.1 Assigned Parameters.

We first describe the parameters we have assigned. These are reported in the left column of Panel B of Table 1.

Income Process. We use a panel of income observations from the PSID to pin down the income process. We first regress the log of a household's income on a quadratic polynomial in age and a time dummy for households aged 65 or less. The resulting coefficients on the age polynomial are 0.0365 and -0.0032, implying that λ_j gradually increases by about 37% from age 25 to age 50 and stays relatively flat thereafter. We pin down the drop in income upon retirement by computing the difference between the average income of retirees and workers in our sample. The drop in income upon retirement is only equal to 33%, owing to the fact that we include social security and pension income as well as withdrawals from retirement accounts in our measure of income for retirees.

We pin down the variance of the permanent and transitory income components, σ_z^2 and σ_e^2 by matching the variance and autocovariance of the residuals $\varepsilon_{i,t}$, in the regressions of log income on age described above. Since the permanent and transitory components of an individual's income are additive in logs, we have

$$\sigma_z^2 = \text{cov}\left(\varepsilon_{i,t},\, \varepsilon_{i,t-1}\right) \text{ and } \sigma_e^2 = \text{var}\left(\varepsilon_{i,t}\right) - \text{cov}\left(\log \varepsilon_{i,t},\, \varepsilon_{i,t-1}\right).$$

The variance of the residuals is equal to 0.428 and the first-order autocovariance is equal to 0.313[5], which implies a standard deviation of the permanent component equal to $\sigma_z = 0.559$ and a standard deviation of the transitory component equal to $\sigma_e = 0.339$. We note that the autocovariances decline very slowly with the horizon (0.313, 0.294, 0.265 and 0.257 at horizons of 2, 4, 6 and 8 years), suggesting that our permanent-transitory income specification is a reasonable description of the income process in the data.

Mortgage Debt The mortgage contract is characterized by two parameters, the maximum loan to value ratio, $\bar{\theta}$, and the rate at which coupon payments depreciate, γ. We set $\bar{\theta}$ equal to 0.85 so as to match the upper tail of the distribution of LTVs in the data. We choose a value for γ so as to ensure that the duration of our mortgage security, defined in equation (3), corresponds to that of a 25-year mortgage (the average maturity of a mortgage held by households in our sample). This gives a value of γ equal to 0.874.

Housing Grid We assume 9 points for the housing grid, ranging from $h_{\min}$ to $h_{\max}$. We assume that h^{κ} is uniformly-spaced, where $\kappa \in (0, 1)$ determines how much finer the grid is for low values of h. We have experimented with alternative values for $h_{\min}$, $h_{\max}$ and κ and have chosen those that imply the most uniform distribution of agents across these housing sizes in the steady state of our model. This gives $h_{\min} = 0.35$, $h_{\max} = 14$,[6] and $\kappa = 0.35$. Since the price of houses is equal to 1 in the steady state, the smallest house size corresponds thus to 0.35 of two-year's worth of per-capita disposable income, or about 25,000 dollars, while the largest house size amounts to 14 times per-capita disposable income, or 1.1 million dollars.

3.2.2 Calibrated Parameters

We have a total of 10 parameters that we choose by minimizing the distance between a number of moments in the model and in the data. The parameter values are reported in the

[5] Since a period in the model is 2 years, the autocovariance measure we report is the covariance of annual income in a given year, say 2001 and income 2 years earlier, say 1999.

[6] All numbers we report here and below are expressed in units of the per-capita aggregate income Y in the economy.

right column of Panel B of Table 1. These include the unsecured and secured liquid debt limits, θ_c and θ_h, the discount factors, β_1 and β_2, the fraction of impatient agents, τ, the fixed cost of transacting a home, F, the fixed cost of obtaining a mortgage when purchasing a new home, F_N, the fixed cost of refinancing a mortgage, F_R, the weight on consumption in preferences, α, as well as the rate at which rental housing depreciates, δ.

We choose these parameters so as to minimize the distance

$$\sum_{i=1}^{70} \text{weight}_i \left(\frac{\text{moment}_i^{\text{model}} - \text{moment}_i^{\text{data}}}{1 + \text{abs}(\text{moment}_i^{\text{data}})} \right)^2$$

between a set of 70 moments in the model and in the data. Panels A and C of Table 1 report the moments we target and their values both in the model and in the data. The moments in Panel A are ratios of several key aggregate wealth measures, the fractions of homeowners and borrowers, the frequency with which homes are transacted and the share of cash-out refinances in new mortgage debt. These are critical moments in our calibration and are therefore assigned a relatively large weight in our objective function. The rest of the moments describe various percentiles (10th, 25th, 50th, 75th, 90th) of the distribution of housing values across homeowners, loan to value ratios for mortgage borrowers, ratio of mortgage debt to income, housing net worth, liquid assets and total wealth. We next describe the fit of our model and then the parameter values that minimize the objective function.

Model Fit. Recall that our data targets are for 2001. When discussing individual moments, we report the ones from the data in text and those from the model in parentheses.

Panel A of Table 1 shows that the aggregate value of housing to aggregate income ratio is equal to 1.26 (1.25). To interpret this number recall that our model is bi-annual, so that the ratio of housing to annual disposable income is equal to 2.5. This number is somewhat greater than what is typically reported due to the peculiarities of how we define income (net of taxes/transfers and contributions to retirement accounts).[7] The fraction of homeowners is equal to 0.68 (0.69). The fraction of houses sold in a given (two-year) period is equal to 0.10 in both the model and in the data. The ratio of average spending on rent is equal to 0.17 (0.18) of the average income of renters.

[7]For example, the 2013 SCF nominal estimates based on public data, http://www.federalreserve.gov/econresdata/scf/scfindex.htm, report a mean value of housing of $181,800 per homeowner, a 0.677 homeownership rate and a $69,100 mean value of income, implying a mean housing to income ratio of 1.78 in 2001.

Consider next the statistics that describe the amount of mortgage debt taken on by households. The ratio of aggregate mortgage debt to aggregate income is 0.37 (0.38). Mortgage debt amounts to 0.29 (0.30) of the aggregate value of the housing stock. A large fraction of homeowners, 0.36 (0.37), do not have a mortgage. For those that do have a mortgage, the average LTV is 0.52 (0.57). Finally, the face value of newly cash-out refinanced mortgages is equal to 0.38 (0.38) of the combined face value of newly cash-out refinanced mortgages and mortgages that finance new home purchases.[8]

We next discuss the moments related to the household's portfolio composition. The ratio of aggregate housing net worth to aggregate income is 0.90 (0.88). Excluding non-homeowners, this ratio increases to 1.15 (1.24). The vast majority of a homeowner's wealth is in housing: the average share of housing net worth in total wealth for homeowners is equal to 0.72 (0.69). Despite the preponderance of housing in the average homeowner's wealth, liquid assets are about 70% greater in the aggregate than housing net worth – the portfolios of the those at the top of the wealth distribution contain a large fraction of stocks and other securities that we categorize as liquid assets. The ratio of aggregate liquid assets to aggregate income is equal to 1.54 (1.05), a feature that our model does not replicate too well. The model reproduces better, however, the average of the ratio of liquid assets to income of individual households, 1.25 (1.18).[9] Finally, the model understates the ratio of aggregate wealth to aggregate income (2.44 in the data vs. 1.93 in the model), owing to its inability to match the stock of liquid assets in the aggregate.

Consider next a subset of the additional moments reported in Panel C of Table 1. The model does a good job at matching the entire distribution of the ratio of housing value to the average income of homeowners. This ratio ranges from a 10th percentile of 0.32 (0.41) to a median of 1.07 (1.08) to a 90th percentile of 3.28 (2.73). Similarly, the model matches quite well the LTV distribution of mortgage holders, which ranges from a 10th percentile of 0.13 (0.22) to a median of 0.55 (0.54) to a 90th percentile of 0.87 (0.85).

Another set of moments that will be important in our discussion below is the share of housing in homeowners' total net worth. This ranges from a 10th percentile of 0.25 (0.27) to a median of 0.78 (0.67) to a 90th percentile of 1.02 (1.07). A small subset of homeowners thus have negative liquid assets, mostly in the form of credit card debt and home equity lines

[8]Since refinancing in our model corresponds to cash-out refinancing in the data, this statistic excludes the face value of rate-refinance mortgages that do not change the face value of one's loan.

[9]To be clear, the difference between these two sets of numbers simply reflects Jensen's inequality: 1.54 is the ratio of means and 1.25 is the mean of the ratios.

of credit. The model also matches reasonably well the ratio of liquids assets to income for individual households. This ratio ranges from a 10th percentile of -0.03 (-0.05) to a median of 0.09 (0.16) to a 90th percentile of 2.63 (3.47). Overall, these numbers suggest that about 25% of households have essentially no liquid assets, consistent with the findings of Kaplan and Violante (2014) who report a fraction of hand-to-mouth agents of 28% for 2001.

Finally, the bottom two panels of numbers in Panel C of Table 1 show that the model does a reasonable job of matching moments of the wealth distribution of homeowners and of all agents. Homeowners are wealthier (the median wealth is equal to 0.93 (1.12) of the average homeowner's income) than the population as a whole (the median wealth is 0.52 (0.61) of the average income), but there is enormous heterogeneity of wealth across both sub-groups which the model matches quite well.

Parameter Values. We next discuss the parameter values that achieve the best fit. Panel B of Table 1 shows that the unsecured credit limit is equal to $\theta_c = 0.041$ units of the per-capita aggregate income. Homeowners can borrow up to a fraction $\theta_h = 0.046$ of the value of their home equity. Impatient agents have a two-year discount factor equal to 0.841, while patient agents have a discount factor of 0.977. The fraction of impatient agents is equal to 0.685. The fixed cost of transacting a home is equal to $F = 0.027$ of the value of one's home, in line with existing evidence. The fixed costs of borrowing and refinancing are, in contrast, higher. The cost of obtaining a new mortgage is equal to 5.1% of the value of one's home (or equivalently 6% of the amount borrowed). The cost of refinancing a mortgage is even larger: 9.1% of the value of one's home (10.7% of the amount borrowed). These costs are at the upper end of existing estimates,[10] but are necessary to ensure that the model matches the share of cash-out refinances in new mortgage debt in the data and the fact that only two-thirds of homeowners own a mortgage. One way to rationalize the relatively high costs of refinancing is to recognize that prepayment penalties in the data may be steep, especially for subprime mortgage contracts, and that low-credit homeowners may face prohibitively high refinancing costs simply because they fail to meet lending standards.

[10] Typical estimates are in the neighborhood of 3-6%. See www.federalreserve.gov/pubs/refinancings/#cost.

4 Steady-State Analysis

We next describe the decision rules of agents in our model and the model's predictions about the severity of liquidity constraints in the steady state. We also discuss how changes in homeowner's ability to cash-out refinance their mortgages alter the steady-state implications of the model.

Decision Rules. Figure 2a reports the consumption, savings, housing and mortgage decisions of an agent that has a relatively low stock of liquid assets, ranging from the credit limit to 2 units of the endowment good. The agent in this example has a house of size 2 which it finds optimal not to adjust (upper-right panel) for the entire range of liquid assets considered here. When the agent has a very low level of liquid assets, it chooses to pay the fixed cost F_R and refinance its mortgage, as indicated by an increase in its mortgage balance in the lower-right panel of the figure. The discrete nature of the mortgage refinance decision imparts a jump in the agent's consumption-savings choices. First, notice in the upper-left panel that the agent's cash on-hand, $\hat{\omega}_t$, experiences a jump at the point at which the agent refinances. An agent just to the right of that point consumes exactly all of its cash on hand and borrows all the way to the credit limit. Refinancing allows this agent to increase its consumption by cutting sharply on the total amount of wealth it carries into the next period (lower-left panel) at the expense of paying the fixed cost F_R.

Figure 2b reports the same decision rules for an agent that has a relative large stock of liquid assets, ranging from 2 to 5. There are three regions of interest, for relatively low, medium and high amounts of the liquid assets. In the low region (liquid assets below 3.9), the agent is inactive: it neither transacts its home, nor refinances. In this region consumption, cash-on-hand and liquid savings all increase in the amount of liquid assets the agent has initially.

Consider next the medium region (liquid assets between 3.9 and 4.2). Here the agent is sufficiently wealthy that it finds optimal to increase the size of its housing stock. The agent does so by taking on a new mortgage, for which it must pay a fixed cost F_N. Taking on a mortgage allows the agent to increase its cash-on-hand and the amount of liquid savings it carries into the next period. Importantly, even though the agent's cash-on-hand discretely increases, the agent's consumption experiences a decline when entering this region, as does the agent's total wealth. Despite having more cash on hand, the agent who buys a bigger home and takes on a bigger mortgage recognizes that it will have to repay principal and interest on its mortgage in the future. It therefore saves, by increasing the amount of liquid savings and cutting back its consumption.

Finally, the agent that starts with a sufficiently large stock of liquid assets (above 4.2) may find it optimal to not take on a new mortgage when purchasing a bigger home, thus saving the fixed cost F_N. Cash-on-hand, consumption and liquid savings all discretely fall when entering this region, even though the agent's overall wealth goes up. To conclude, the option to refinance adds a lot of richness to an agent's ability to manage its liquid holdings over time and implies considerable non-linearity in its decision rules.

Role of the Option to Refinance. We next ask: to what extent does the option to refinance alter the behavior of agents in our model? Table 2 reports several key moments in two counterfactual experiments. In the first experiment, we shut down the option to extract home equity altogether by making the refinance cost prohibitively high, $F_R = \infty$, and by eliminating the option to borrow against home equity, $\theta_h = 0$. We leave the rest of the parameters unchanged. In the second experiment, we cut the refinance cost F_R in half and double θ_h, making it easier for homeowners to withdraw home equity from their homes.

The second column on Table 2 shows that the fraction of homeowners increases quite a bit in the presence of the option to refinance, from 0.62 in the economy without refinancing to 0.69 in our Benchmark model. Notice also that refinancing disproportionately affects the homeownership rates of older homeowners. Older agents have relatively little income and would like to consume our of their housing wealth. The option to refinance allows such agents to postpone selling their homes by allowing them a cheaper way to tap into their housing wealth. Introducing the option to refinance thus increases the homeownership rates of older agents (aged 65-85) the most, from 0.69 to 0.79.

Introducing the option to refinance has several additional effects. First, it allows homeowners to transact their houses less frequently: 0.10 of the homes are sold in any given period as opposed to 0.13 in the economy without refinancing. Agents that receive a series of negative income shocks have the option to refinance rather than sell their homes in order to replenish their stock of liquid assets. Second, notice that the aggregate mortgage debt to income ratio increases quite a bit, from 0.32 in the economy without refinancing to 0.38 in our Benchmark model.

These effects are reinforced further in the version of the model with cheap refinancing.

Notice that the fraction of homeowners increases further, from 0.69 to 0.83, and more so for older agents. The frequency with which homes are transacted falls from 0.10 to 0.07. Refinance loans now account for 79% of all new mortgage debt, compared to 38% in the benchmark model, and the overall amount of mortgage debt in the economy increases from 0.38 to 0.61. These experiments illustrate that the option to refinance is quite valuable: it makes homes more valuable by allowing agents, especially retirees, to tap into their home equity in times of negative income shocks and considerably reduces the amount of housing turnover.

Measuring Liquidity Constraints. We next describe how we measure the severity of liquidity constraints in the model. A simple metric for how tight liquidity constraints are is the multiplier on the date-t cash-on-hand constraint, $c_t \leq \hat{\omega}_t$. This multiplier only captures static considerations, however. Agents may choose to keep their consumption too low, relative to what it would be optimal absent costs of tapping home equity, in order to save in anticipation of binding *future* cash-on-hand constraints. Alternatively, agents may choose to pay transaction or refinancing costs in order to replenish their cash-on-hand. Such actions are costly yet once again are not captured by the multiplier on the cash-on-hand constraint. Our measure of liquidity constraints is thus a broader one, capturing both static as well as dynamic considerations.

We measure the severity of liquidity constraints by conducting a set of experiments that we label *liquidity injections.* In these experiments we allow all homeowners (including those that have no mortgage) to partially refinance their mortgage debt at no cost by making a transfer $x_{i,t}$ from home equity to the liquid account. The amount of the transfer is determined as follows. Each agent receives a fraction of the transfer that is proportional to its income and its housing size:

$$x_{i,t} = \psi_t y_{i,t} h_{i,t-1},$$

where ψ_t is chosen so that in the aggregate the total amount of transfer is 10% of the aggregate endowment. We assume a transfer that is increasing in both an agent's income and initial housing stock since wealthier agents consume more and need a larger transfer to alleviate the liquidity constraints. Assuming that the transfer is lump-sum, however, does not greatly change our findings.

Formally, we increase agent i's LTV to

$$\theta_{i,t-1}^{new} = \theta_{i,t-1} + \min\left(\frac{x_{i,t}}{P_{t-1}h_{i,t-1}}, \max\left[0, \left(\bar{\theta}\frac{P_t}{P_{t-1}} - \theta_{i,t-1}\right)\right]\right) \tag{5}$$

and its liquid assets to

$$a_{i,t-1}^{new} = a_{i,t-1} + \left(\theta_{i,t-1}^{new} - \theta_{i,t-1}\right) P_{t-1}h_{i,t-1}. \tag{6}$$

In words, agents whose initial loan-to-value ratio, $\theta_{i,t-1}$, is sufficiently below $\bar{\theta}$ simply receive $x_{i,t}$ units of the endowment good in their liquid account and see their mortgage debt $qb_{i,t-1} = \theta_{i,t-1}P_{t-1}h_{i,t-1}$ increase by the same amount. For agents with a sufficiently high initial LTV such a transfer may increase their new LTV above the permissible limit, $\bar{\theta}\frac{P_t}{P_{t-1}}$, and we therefore cap the amount of the transfer to ensure that the new LTV (after accounting for the change in house prices) is below the maximum. This specification of the liquidity injection ensures that the transfer does not change the total amount of wealth in the economy but only its composition: agents that would default on the additional amount borrowed on the mortgage do not qualify for the injection. The liquidity injection is thus simply a conversion of illiquid assets (housing wealth) into liquid assets, at a rate of one-for-one, and not a net transfer of wealth. Its purpose is to identify the severity of liquidity constraints and not to evaluate alternative policies aimed at subsidizing heavily indebted homeowners.

Figure 3a illustrates the effect a liquidity injection has on agents' decision rules. We first consider the agent with relatively low liquid assets discussed above but now zoom in on the region close to the threshold at which the agent refinances its mortgage. There are three regions of interest here. First, agents with very low levels of the liquid asset (less then 0.25) refinance regardless of whether they receive the injection or not. Since refinancing requires fully paying down the original mortgage, the injection has no effect on these agents' cash-on-hand, consumption or savings. The intermediate region (liquid assets between 0.25 and 0.35) is the region in which the agent would refinance absent the injection but is able to avoid refinancing because of the injection. Since refinancing would have entailed a discrete jump in an agent's cash-on-hand and therefore consumption, the liquidity injection, by postponing refinancing, *reduces* the agent's consumption in this region. Finally, the third region (liquid assets above 0.35) is the region with a relatively large stock of liquid assets in which the agent is inactive regardless of whether it receives the injection or not. In this region the agent takes advantage of the additional liquid assets by increasing its consumption.

Our measures of the severity of liquidity constraints are based on computing an agent's gains from receiving the liquidity injection. We compute these gains in two ways. First, we compute the increase in welfare (expressed in consumption equivalent units) an agent experiences as a result of the injection. The lower-right panel of Figure 3a shows that the largest welfare gains (equivalent to a 0.25% permanent increase in consumption) accrue to the agent that is just indifferent between refinancing or not.

This figure makes two important points. First, welfare does not increase only for agents who experience an increase in consumption due to the transfer and thus have a positive marginal propensity to consume out of it. Those agents that are immediately to the left of the refinance threshold also greatly value the injection and are thus liquidity constrained even though their marginal propensity to consume out of it is *negative*. Second, the measure of agents who value liquidity and are therefore liquidity constrained according to our metric is much greater than the measure of agents who are at their cash-on-hand limit, $c_t \leq \hat{\omega}_t$, in the current period. For example, those agents who refinance are not at the borrowing limit, yet would have benefited from a liquidity injection that would have allowed them to save on the refinancing costs. Similarly, agents that do not refinance and who are not at the borrowing limit save in the liquid asset in order to be able to afford next period's mortgage payments and to guard against the possibility of a transitory negative income shock. Such agents also greatly value the opportunity to convert some of their illiquid housing wealth into liquid assets.

A second statistic that we use to measure the severity of liquidity constraints is an agent's *willingness to pay* for a transfer that converts illiquid into liquid wealth. We ask: what fraction of the liquid transfer would the household have to give up to be indifferent between receiving the liquidity injection or not? We assume here that an agent's liquid assets increase by only a fraction $1 - \xi_{i,t}$ of the amount by which the agent's mortgage debt increases, so that its liquid assets after the injection are equal to

$$a^{new}_{i,t-1} = a_{i,t-1} + (1 - \xi_{i,t}) \left(\theta^{new}_{i,t-1} - \theta_{i,t-1}\right) P_{t-1} h_{i,t-1}. \quad (7)$$

Starting from a value of $\xi_{i,t}$ equal to 0 we gradually increase $\xi_{i,t}$ to the point at which the agent is indifferent between receiving the injection or not. We refer to this threshold value of $\xi_{i,t}$ as the *liquidity premium* and think of it as the price the agent is willing to pay to be able to convert illiquid into liquid assets. The lower-right panel of Figure 3a shows that this premium is quite large for the agent in our example. It reaches a maximum of 0.20 at its peak but is positive and equal to about 0.05 even for an agent with 0.75 liquid assets whose consumption is below its cash-on-hand. Thus, the agent in this example is willing to trade its illiquid assets at a steep discount in order to be able to replenish its stock of liquid assets.

Figure 3b shows the effect of a liquidity injection on the agent with a relatively large stock of liquid assets. We once again zoom in on the region of most interest in which the agent is sufficiently rich so as to be willing to purchase a larger-sized home. Interestingly, in this region a liquidity injection allows the agent to exercise its option value of waiting for a larger region of the asset space. Notice that in the intermediate region of the asset space the agent chooses to *not* upgrade the size of its home because of the liquidity injection even though it would have done so otherwise.

To understand this result, notice that the agent's choice of whether to upgrade its housing is based on comparing its life-time utility, $V_{j,t}\left(\hat{\omega}_t(h_t), h_t, \theta_t, \beta, z\right)$ for $h_t = h_{t-1}$ versus $h_t = h^{\text{new}}$. The value of purchasing a new home is unaffected by the liquidity injection since purchasing a new home entails paying down the original mortgage which makes the injection inconsequential. The value of staying in the existing home increases, however, with the liquidity injection. It follows then that the liquidity injection makes the value of inaction more valuable and thus increases the range of liquid assets for which the agent exercises the option to wait.

Notice that in this particular example the marginal propensity to consume out of the transfer is everywhere non-negative and larger exactly for the agent who chooses to wait because of the injection even though he would have upgraded its home absent the injection. Purchasing a larger home would have discretely reduced the agent's consumption (despite the increase in cash-on-hand that arises due to the larger mortgage balance) since the agent recognizes that it needs to save more in order to finance its future mortgage payments. The injection, by allowing the agent to postpone purchasing a bigger home, prevents consumption from falling for a larger region of the asset space and thus implies a positive marginal propensity to consume from the transfer. Of course, the reverse would be true for an agent that is about to downsize its home. Downsizing raises an agent's consumption and a liquidity injection would *reduce* an agent's consumption by making it more valuable to exercise the option to wait before doing so.

Finally, notice that although the agent in this example does value the liquidity injection, it gains little from it. The maximum increase in welfare is equivalent to a 0.025% increase in life-time consumption, and the liquidity premium is 0.03 at most. Not surprisingly, liquidity injections are not very valuable for agents with a large stock of liquid assets.

The Severity of Liquidity Constraints. Having described our metric for the severity of liquidity constraints, we next discuss what these measures are for agents in the ergodic steady state of our model. These measures are reported in the first column of Table 3.

First note that the liquidity injection would greatly increase the agents' ability to exercise the option to wait discussed above: 17.4% of the agents that would have transacted their house absent the injection no longer do so, while 41.9% of the agents that would have refinanced their mortgage no longer do so. These numbers suggest indeed that a lot of resources are expended in the benchmark economy by agents paying costly transaction and refinance costs in order to convert some of their housing wealth into liquid assets.

Second, notice that the marginal propensity to consume (MPC) out of the transfer is 7.1% in the aggregate. Given that the transfer amounts to 10% of aggregate income (income here is almost exactly equal to aggregate consumption), the effect of the transfer is to increase aggregate consumption by 0.71%. Notice also that the marginal propensity to consume varies quite a bit across agents: agents at the 75th percentile of the MPC distribution consume 18.5% of the injection, while those at the 90th percentile consume 44.5% of it. As discussed above, however, the MPC to consume out of the transfer is not necessarily an accurate measure of how liquidity constrained agents are: some of the most constrained agents cut their consumption in response to the injection by postponing the sale of their home or the refinancing of their mortgage. Overall, the 5th percentile of the MPC distribution is equal to -7.5%, the 10th percentile is -2.4% and a total of 23% of homeowners cut consumption in response to the liquidity injection.[11]

Third, notice that the average liquidity premium is 0.056 for homeowners in the model. That is, a homeowner is on average indifferent between converting 1 unit from housing wealth into 0.944 units of the liquid asset. The mean masks, however, a lot of heterogeneity in individual agents' willingness to pay for the transfer. While the median homeowner would only accept a discount of 2% for the transfer, the 75th percentile of the distribution is 9.5% while the 90% percentile is 16.6%. A small subset of agents are thus extremely constrained and are willing to pay a steep price for the ability to convert illiquid wealth into liquid wealth.

We note that in our model all homeowners, except for those that refinance or transact their homes, value the liquidity injection. This follows from our assumption of a zero wedge between the mortgage rate and the interest rate on liquid assets. Had the mortgage rate

[11] To save on space, we do not report these last 3 numbers in the table.

been higher some agents would prefer to pay off their mortgage debt more rapidly than contractually required and would not value the liquidity injection. For this reason we find it useful to report, as a more conservative measure of who is liquidity constrained, the fraction of homeowners with a liquidity premium of greater than 5%. This number is equal to 36.3% of all homeowners (25.1% of all agents, including renters) in our Benchmark model, in line with Kaplan and Violante (2014) estimates of the fraction of wealthy hand-to-mouth households.

In Figure 4 we focus on the top 50% of the most constrained homeowners and divide them into deciles based on the liquidity premium ξ they would be willing to pay for the liquidity injection. We compute, for each of these deciles, both the mean liquidity premium as well as the average share of housing equity in total household wealth,

$$(1-\theta_{t-1})P_{t-1}h_{t-1}/(a_t+(1-\theta_{t-1})P_{t-1}h_{t-1}),$$

for homeowners in each decile. We note that those in the lowest decile (those with ξ between the 50th and 60th percentile of the distribution) have a liquidity premium equal to 2.5% on average as well as a fairly low share of housing in total wealth, about 50% on average. In contrast, agents in the top 5th percentile of the ξ distribution have a liquidity premium in excess of 25% as well as an average share of housing in wealth very close to 1. The strong correlation between the liquidity premium and the housing share in wealth is evident in this figure. This strong relationship will be important in determining how the severity of liquidity constraints changes in the time-series in response to fluctuations in house prices in our experiments below.

The next set of statistics we report in Table 3 are the welfare gains from the liquidity injection. The average homeowner's life-time utility increases by the equivalent of a 0.11% permanent increase in consumption, a number that once again masks considerable heterogeneity. While the median homeowner's welfare increases by only 0.02%, the top 10 percent most constrained agents experience a 0.31% increase in welfare due to the injection.

We also find it informative to report how the severity of liquidity constraints varies across different age groups. Notice first that the average marginal propensity to consume out of the transfer is fairly low (0.048) for young agents (ages 25-45), high (0.103) for middle-aged agents (ages 45-65) and low again (0.040) for older agents (ages 65-85). Young homeowners have relatively little housing wealth and therefore consume little out of the injection. Middle-aged homeowners, in contrast, have a fairly large share of their wealth in housing and so consume a greater fraction of the injection. Finally, many of the older homeowners are near their downsizing or refinance thresholds and so have negative MPCs out of the injection.

Even though older agents have low average MPCs out of the injection, they are precisely the agents who are most liquidity constrained and thus value the injections the most. To see this, notice that the average liquidity premium of older homeowners is equal to 0.064, greater than that of the middle-aged (0.056) and that of the young homeowners (0.043). Similarly, older homeowners experience a 15.3% increase in welfare due to the injection, much greater than that of middle-aged homeowners (9.5%) and young homeowners (6.1%). These numbers reinforce our point that liquidity constraints do not necessarily manifest themselves in the form of high marginal propensities to consume out of a transfer. In our economy the oldest agents are the most constrained and yet have the lowest average MPCs.

The last two columns of Table 3 also report what our measures of liquidity constraints are in the economies without refinancing and with cheap refinancing discussed earlier. Interestingly, eliminating the option to refinance does not change the average severity of liquidity premium much: its average value increases to 5.8% from 5.6% in our Benchmark model, while the welfare gains from a liquidity injection only increase on average from 11% to 12.6%. Clearly, a selection effect is at play here: since refinancing increases substantially the fraction of homeowners (from 0.62 to 0.69), it does not greatly reduce the magnitude of the liquidity constraints for the *average* homeowner. In contrast, reducing the refinancing cost in half has important effects both on the extensive margin (the fraction of homeowners increases from 0.69 to 0.83) and the intensive margins (the average premium falls from 5.6% to 2.9%), thus substantially alleviating liquidity constraints for homeowners.

We conclude this section by recapitulating our key findings. First, liquidity constraints are fairly severe in our model economy. About one-third of homeowners would be willing to pay a premium in excess of 5% for the ability to convert part of their housing wealth into a liquid asset. Second, the multiplier on the current period's cash-on-hand constraint is not a sufficient statistic for how liquidity constrained agents are. A number of agents pay costly refinancing or transaction fees in order to replenish their liquid accounts or save in order to finance future periods' mortgage payments and consumption. Such agents are liquidity constrained even though they do not consume all of their cash-on-hand in the current period. Third, the marginal propensity to consume out of a transfer is also an imperfect measure of who is liquidity constrained. Although many liquidity-constrained households indeed have high MPCs out of a transfer, many have negative MPCs. Fourth, the severity of liquidity constraints is strongly correlated with an agent's share of housing equity in total wealth as well as age. Finally, a reduction in the cost of refinancing mortgages raises substantially the homeownership rate and reduces the severity of liquidity constraints.

5 Transition Dynamics

We next study how agents in our model respond to a housing boom and bust of the type observed in the 2001-2011 U.S. data. We assume that fluctuations in house prices arise due to changes in agents' preferences for owner-occupied housing. We modify homeowner's period utility to

$$\alpha \log c_t + \nu_t (1 - \alpha) \log h_t$$

and study the economy's responses to permanent, unanticipated shocks to the preference parameter ν_t. We have also experimented with shocks that reduce refinancing and new mortgage origination costs but found, as Justiniano et al. (2014) do, that such shocks lead to an excessive increase in the ratio of aggregate mortgage debt to income and housing values compared to that observed in the data.[12] We think of the preference shocks as capturing, in a parsimonious way, the many innovations in the housing market during the 2001-2011 period that effectively increased agents' demand for housing, such as a relaxation of credit limits for subprime borrowers as in Landvoigt et al. (2015) or a reduction in the housing risk premium as in Favilukis et al. (2013).

We first characterize the model's impulse responses to shocks that trigger an increase (decrease) in house prices, and then solve for the time path of the shocks that allows the model to exactly replicate the path for house prices observed in the U.S. data. We use these experiments to ask three questions. First, what role did cash-out refinancing play in exacerbating the boom and bust in aggregate consumption in this period? We find that refinancing played a crucial role: an economy in which agents cannot refinance their homes would imply a much less volatile path for consumption than we observe in the benchmark model and in the data. Second, was the collapse in house prices between 2007 and 2009 associated with a large increase in the severity of liquidity constraints? We find that the answer is no: liquidity constraints are more severe during the years of the housing boom and less so during the housing bust. Third, would policies that replenish agents' liquid assets help reduce the drop in aggregate consumption? Once again, the answer is no: the largest drop in consumption occurs for retirees who have *negative* MPCs out of liquidity transfers.

[12] The Appendix reports results based on these experiments.

5.1 Impulse Responses

We first consider the economy's responses to a one-time, unanticipated, permanent increase in housing preferences ν_t. The traditional approach to solving for the transition dynamics in response to such shocks is by iterating on the path for house prices that clears the housing market along the transition to a new steady-state. We found, however, that the transition dynamics are extremely slow in our model which makes the traditional solution method computationally infeasible. We thus opted to follow instead the approach of Landvoigt et al. (2015) and endow agents with a simple forecasting rule for how house prices evolve over time. In particular, since house price evolve gradually in our model, we simply assume that agents forecast that all future house prices will be equal to the currently observed house prices:

$$P_{t+j} = P_t, \text{ for } j \geq 1.$$

Figure 5 shows the response of the economy to a permanent increase in the preference for housing that generates, in equilibrium, a 10% increase in house prices on impact. The upper-left panel of the figure shows that the shock is about 13%, while the house price evolves slowly: it increases to 10% above the steady-state level on impact, falls to 9.3% in the second period after the shock and gradually declines to 8.6% above the steady-state level by period 10. The mistakes our agents make using the forecasting rule we assume are thus not too large. The rest of the panels of the figure show that the mortgage debt to income ratio gradually increases over time, by about 5 percentage points, and that the share of refinanced debt in new mortgage originations increases slightly, from 0.38 to 0.45, suggesting that approximately 40% of the increase in debt is accounted for by refinancing. Finally, the aggregate consumption to income ratio increases by 1.25% on impact and falls gradually below its steady-state level as households cut consumption in future periods to repay the additional debt.

Figure 6 shows that the impulse responses to a negative housing preference shock are virtually the mirror image of those to a positive shock. Once again, the price of houses evolves gradually, mortgage debt to income falls by about 5 percentage points, while consumption falls on impact by about 1.25%. The only visible differences in these responses is that the amount of refinancing falls much more now.

We next ask: what is the role of mortgage refinancing in accounting for the responsiveness of aggregate consumption to house price changes? We answer this question by studying the impulse responses of the economy discussed above in which mortgage refinancing is prohibitively expensive. The upper-right panel of Figure 7 shows that absent refinancing a preference shock that generates a 10% increase in house prices would generate a more modest expansion in consumption of 0.8% on impact. Refinancing thus increases the sensitivity of consumption to house prices by about 50%. The lower panels of Figure 7 show that refinancing also amplifies the response of consumption to a *decline* in house prices, by a similar factor of about 50%.

Two mechanisms can potentially account for the greater consumption responses in the economy with refinancing. On one hand, the ability to refinance allows liquidity-constrained homeowners to tap into the higher housing wealth following the shock and increase their consumption by more. This mechanism only works in response to increases in house prices and thus cannot be too potent since we see similar amplification effects in response to both negative and positive shocks.

The second mechanism is as follows. As we have discussed above, refinancing allows older households to tap into their housing wealth and postpone the sale of their homes. Refinancing thus increases the homeownership rates of retirees and exposes them more to changes in wealth associated with changes in house prices. Since older agents have a shorter horizon, their marginal propensity to consume out of changes in housing wealth is greater. Hence, refinancing amplifies the effect of house prices on consumption by increasing the homeownership rates of older homeowners whose consumption is most sensitive to changes in wealth. The fact that refinancing increases the sensitivity of consumption to house prices by the same amount for both positive and negative shocks implies that the second mechanism is mostly at play in our model.

5.2 The 2001-2011 Boom and Bust in the U.S. Housing Market

We next feed the model a series of housing shocks ν_t chosen so that the model exactly replicates the path for house prices in the U.S. data reported in Figure 1. Once again, every single shock is unanticipated and agents assume that it will last forever. They also forecast that house prices will stay at their current value in the future.

The increase in house prices in the U.S. was also associated with a fairly large increase in construction activity. In contrast to the impulse responses above, in which we have assumed that housing is in fixed supply, we now pin down a value for the inverse elasticity of housing supply, ϕ, to ensure that the model matches the 30% rise (15% in our bi-annual model) in mortgage debt to income from 2001 to 2007. Intuitively, the higher the housing supply elasticity, the greater the expansion in mortgage debt necessary to allow homeowners to purchase the additional housing produced by the construction sector. The implied value of ϕ is equal to 12.5, which implies a 5.7% expansion of the housing stock in the period we study.[13]

Figures 8 and 9 report the evolution of the key aggregate variables in our model and compares them to the corresponding time-series in the SCF data. House prices (shown in Figure 1) increase by about 26% in real terms from 2001 to 2007 and fall by about 34% from 2007 to 2011, numbers that our model matches by design. The value of housing to income increases from 1.25 in the steady state to about 1.63, thus by about 30%. The upper-left panel of Figure 8 shows that, relative to income, the absolute value of the increase in the value of the housing stock is 0.38 in the model and 0.47 in the SCF data. Our model can generate a larger increase in the value of housing by appealing to a greater housing supply elasticity, but doing so would exaggerate the increase in mortgage debt and therefore the consumption response.

The upper-right panel of Figure 8 shows that the model matches, again by design, the run-up in mortgage debt to income. The absolute value of the increase in mortgage debt from 2001 to 2007 is equal to 0.15 units of aggregate income in both the model and the data. The model does miss somewhat the timing of when most of the increase in debt occurred (earlier in the data compared to the model) and somewhat overstates the decline in mortgage debt in the recession. Nevertheless, the model is capable of accounting for the fact that mortgage debt is, as in the data, much more sensitive to increases in house prices than to similarly-sized decreases in house prices. This is simply due to the long-term nature of mortgage debt. Households can borrow more in response to increases in house prices, but cannot be forced to repay their long-term debt faster when house prices fall, a point emphasized by Justiniano et al. (2014) as well as Kaplan et al. (2015).

The lower-left panel of Figure 8 shows that the model matches reasonably well the stable aggregate mortgage debt to housing ratio in the data from 2001 to 2006, a feature that models attributing the entirety of the housing boom to a rise in loan-to-value ratios have trouble accounting for.[14] The aggregate loan-to-value ratio increases during the bust, both

[13] According to the Census data used by Berger and Vavra (2015), total housing inventory increased by 5.3% in this period.

[14] See Justiniano et al. (2014) who make this point.

in the model and in the data, owing to a relatively slow deleveraging process combined with a sharp drop in the value of the housing stock. Finally, the lower-right panel of Figure 8 shows that the model somewhat understates the increase in the housing net worth to income ratio from 2001 to 2007 in the data: the absolute value of the change in housing wealth was 0.31 times aggregate income in the data (0.23 in the model). In contrast, the model matches almost entirely the decline in housing net worth from 2007 to 2011 (the drop in housing net worth was 0.30 times aggregate income in the data and 0.31 in the model).

Figure 9 shows the evolution of several additional time-series. As was the case with housing net worth, the model accounts for only about two-thirds of the overall increase in housing wealth during the boom. In contrast, the model matches well the response of the consumption to income ratio. This ratio increases by 2.2% from 2001 to 2005 and falls by about 5.1% from 2005 to 2009, both in the model and in the data.

Notice also that the model replicates fairly well the observation that the share of cash-out refinances to mortgage debt was fairly stable, at about 40%, in the years of the boom, suggesting that about 40% of the rise in mortgage debt was due to refinancing. The refinance share of mortgage debt falls however much more in the model (to about 20%) than in the data (30%) during the years of the decline in house prices. Finally, the model also matches the increase in the amount of housing turnover during the boom and its subsequent decline during the bust. The share of homes sold in a given (2-year) period increases from 10 to 12.7% in the model during boom (10 to 13.4% in the data) and falls to 7.4% in the model and 6.9% in the data in 2011.

To conclude, the model matches well a number of aggregate statistics characterizing the evolution of the U.S. housing market during the 2001-2011 period. We next use the model to ask several questions about the role of refinancing and severity of liquidity constraints in this time period.

5.3 Role of Mortgage Refinancing

We next ask: what role did cash-out refinancing play in exacerbating the boom and bust in aggregate consumption in the 2001-2011 period? We answer this question by studying the transition dynamics of the economies described above in which we i) altogether eliminate the option to cash-out refinance and ii) reduce the cost of refinancing in half. We choose the path for shocks in both economies to ensure that they match the path for prices in the data (Figure 1), though feeding the model the same sequence for shocks from our benchmark model would give virtually identical results.

Figure 10 shows that the evolution of the housing-to-income and wealth-to-income ratio are very similar in the economy with and without refinancing. In contrast, debt to income fluctuates somewhat less without refinancing: it only increases by 12% of income compare to 15% in the Benchmark model. The key effect refinancing has is on the dynamics of consumption. Absent refinancing the consumption-income ratio increases by only 1.2% from 2001 to 2005 (compared to 2.2% in the Benchmark model) and falls by only 3.2% from 2005 to 2009 (compared to 5.1% in the Benchmark model). Refinancing thus amplifies the response of consumption to changes in house prices by about 60%.

Consider next, in Figure 11, the alternative counterfactual in which we make cash-out refinancing twice as cheap. We now see that consumption is much more sensitive to changes in house prices. The consumption-income ratio increases by 4.4% from 2001 to 2005, thus twice as much as in the Benchmark model, and falls by about 10.4% from 2005 to 2009, again twice as much as in the Benchmark model. Notice that the consumption response is greatly amplified in the economy with cheap refinancing even though the dynamics of the wealth-to-income ratio is virtually the same as in our Benchmark model. As discussed above, the option to refinance amplifies consumption fluctuations because it increases the homeownership rate among the old and exposes them more to changes in wealth caused by changes in house prices.

5.4 Evolution of Liquidity Constraints During the Boom and Bust

We next study how the severity of liquidity constraints varies over time in response to fluctuations in house prices. We argue that liquidity constraints are in fact more severe during the years of the housing boom and less so during the years of the collapse in house prices.

Figure 12 (upper-left) panel shows that the fraction of liquidity constrained homeowners, those willing to pay at least 5% to convert housing into liquid wealth, increases from 36% in steady state (which recall corresponds to 2001 in the data) to 44% in 2003 and then gradually declines to about 25% in 2009 and 2011. Similarly, the mean premium agents are willing to pay for a liquidity injection is equal to 5.6% in 2001, increases to 6.5% in 2003 and again falls, to about 4% during the years following the collapse in house prices. Moreover, the welfare gains from the liquidity injection are on average equal to 0.11% in 2001, 0.12% in the years of the housing boom and fall to about 0.09% during the years of the housing bust. Finally, the marginal propensity to consume out of the transfer is also somewhat lower during the years of the bust (about 6% in the aggregate) compared to the years of the boom (about 7%). All of our measures thus suggest that liquidity constraints are more severe during periods with rising housing prices as opposed to declining house prices.

The intuition for why liquidity constraints are more severe during the boom and less so during the collapse in house prices is as follows. Recall from Figure 4 that liquidity constraints are most severe for agents whose housing wealth accounts for a greater share of their total wealth. In periods of rising house prices the share of housing wealth in total wealth increases since adjustment costs prevent agents from rebalancing their portfolios too quickly. Agents are therefore more liquidity constrained and value more the ability to convert some of this additional housing wealth into liquid assets in order to finance consumption. In contrast, in periods of falling house prices the share of housing net worth in total wealth falls. Hence agents value liquidity injections less: the latter would reduce the share of housing wealth in total wealth even further and are not as valuable for households who are about to cut consumption in response to the house price drops.

We do not claim that liquidity constraints were less severe during the 2007-2009 recession: the increase in the unemployment rate and temporary decline in income during this period may have well increased the fraction of liquidity constrained homeowners. Rather, our model suggests that house price declines *alone* do not necessarily tighten liquidity constraints, despite the fact that in our model a collapse in house prices leads to a decline in household debt and refinancing activity similar to what we have observed in the data. This result follows directly from the fact that house price changes alter the composition of household's balance sheets by increasing the share of liquid assets when house prices decline.

5.5 Liquidity Constraints and the 2007-2009 Drop in Consumption

We next ask: what is the role of liquidity constraints in amplifying the consumption drop following the sharp drop in house prices post 2007? We answer this question by first identifying the agents that experience the largest consumption declines, and then asking whether such agents indeed face high MPCs out of liquid transfers. We find that consumption falls most for retirees who, although liquidity constrained, have *negative* MPCs out of liquidity transfers. This suggests that liquidity injections aimed at agents that have experienced the largest consumption declines would actually reduce consumption further, rather than increase it.

We make this argument by conducting the following counterfactual experiment. Recall that the largest decline in house prices (a 17.4% drop) occurs in 2007-2009 in both our model and in the data. We solve for the equilibrium of our model, starting from the initial 2007 distribution of households over income and the various components of their balance sheets, but assuming that the preference shock in 2009 is such that house prices are unchanged from 2007 to 2009. We then compare the allocations in our original model in which house prices decline to those in this counterfactual economy in which house prices are unchanged.

Table 4 shows shows that consumption in the aggregate is 3% lower for homeowners and 0.7% lower for renters in the economy with the drop in house prices relative to the economy in which house prices are constant. Renters cut their consumption due to substitution effects: they save more in order to afford the downpayment for the now cheaper homes. Homeowners, in contrast, cut consumption due to a combination of wealth, liquidity and substitution effects. Notice, however, that substitution effects cannot explain the aggregate consumption drop because the housing market is in equilibrium. In the aggregate, a decline in house prices is associated with a *decrease* in the housing stock (due to the response of the construction sector), not an increase as would be the case in partial equilibrium.

Since renters account for only about one quarter of total consumption spending, the overall drop in consumption in the aggregate caused by the decline in house prices is equal to 2.4%, half as large as the 5.1% actual drop in consumption from 2007 to 2009 in our Benchmark model. About half of the consumption drop in our Benchmark model arises solely because households would have had to cut consumption to repay their mortgage debt even in the absence of a drop in house prices.

Consider next how the sensitivity of consumption to changes in house prices varies across homeowners of various age groups. Clearly, the average consumption response is increasing with age. The very young homeowners actually increase their consumption by 0.5%. These agents recognize that they are wealthier since they will need to pay less in the future to upgrade their housing stock. Agents in the middle of the age distribution cut their consumption, but only by a modest amount, ranging from 0.7% for the 35-45 year olds to 1.3% for the 55-65 year olds. In contrast, retirees cut their consumption by a significant amount: 2.6% for those aged 65-75 and 8.2% for those aged 75-85. Since agents in this last group are wealthier, they account for a disproportionate share of aggregate consumption (17.8%) and thus about 60% of the overall consumption drop ($0.178 \times 0.082/0.024$).

The reason why the oldest homeowners in our model cut their consumption by most is the same as in Glover et al. (2011).[15] These agents have a large stock of housing relative to income (their median housing to income ratio is 3.2 compared to 2.2 overall), both because they have had time to accumulate more wealth as well as because incomes in retirement are lower. They rely therefore relatively more on housing wealth in order to finance consumption. Moreover, since there is no bequest motive in our model, these agents have relatively short horizons and cannot smooth out the wealth losses associated with the housing price drops across many future periods, as younger homeowners can.

We are now ready to answer our final question: to what extent do liquidity constraints exacerbate the consumption drop following a drop in house prices? To do so, we calculate the average premium agents are willing to pay in 2009 for a liquidity injection and their average marginal propensity to consume out of it. Notice that although older agents are indeed more liquidity constrained (their liquidity premium ranges from 4 to 4.6%, greater than for the other age groups), the marginal propensity to consume out of the injection actually *negative* for the oldest group of households that account for the bulk of the consumption drop. As explained above, liquidity injections increase the option value of waiting both for younger agents looking to increase their housing stock as well as older agents about to downsize. A liquidity transfer targeted towards the older would thus allow these agents to hold on to their houses for longer and thus keep their consumption lower than it would have been if they were to downsize. We thus conclude that liquidity constraints cannot explain the consumption drop of older agents, the ones that account for the bulk of the aggregate consumption drop.

6 Conclusions

We have studied the severity of liquidity constraints in the U.S. housing market. We found that frictions that prevent homeowners from tapping into housing wealth are sizable: about a third of homeowners would be willing to pay a discount in excess of 5% to convert housing wealth into liquid assets. Because liquidity constraints affect a large fraction of homeowners, a wave of refinancing, of the type the U.S. has experienced at the turn of the century, substantially increases homeownership rates. Refinancing, however, also increases the sensitivity of aggregate consumption to fluctuations in house prices, by increasing homeownership rates

[15] Attanasio et al. (2011) and Kaplan et al. (2015) also report a greater sensitivity of older agent's consumption to changes in house prices in overlapping generations model of the housing market. Moreover, Kaplan et al. (2015) also provide empirical evidence for this mechanism using disaggregated expenditure data.

among retirees who are most liquidity constrained, most likely to refinance and have the highest marginal propensities to consume out of housing wealth.

Interestingly, we have found that liquidity constraints are more severe during a boom in house prices than during a bust. This follows from the fact that an increase in house prices increases the share of housing in total wealth and makes liquidity relatively scarce. Conversely, a drop in house prices increases the share of liquid assets in total wealth, reducing the liquidity premium. Finally, agents whose consumption falls most after a housing price collapse have a negative marginal propensity to consume out of a transfers. Transfers targeted at the most adversely affected homeowners may thus not necessarily increase consumption.

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Table 1: Parameterization

Panel A: Key Moments Used in Calibration

	Data	Model
Housing		
Aggregate housing to Aggregate income	1.26	1.25
Fraction homeowners	0.68	0.69
Fraction of homes sold in a period	0.10	0.10
Mean rental spending / Mean income (renters)	0.17	0.18
Mortgage debt		
Aggregate mortgage debt / Aggregate income	0.37	0.38
Aggregate mortgage debt / Aggregate housing value	0.29	0.30
Fraction homeowners without a mortgage	0.36	0.37
Mean LTV for mortgage holders	0.52	0.57
Share refin. debt in new mortgage debt	0.38	0.38
Housing net worth		
Aggregate net worth to Aggregate income	0.90	0.88
Mean net worth (owners) /Mean income (owners)	1.15	1.24
Mean share net worth in total wealth (owners)	0.72	0.69
Liquid assets		
Aggregate liquid assets / Aggregate income	1.54	1.05
Mean liquid assets to income ratio	1.25	1.18
Total wealth		
Aggregate wealth to Aggregate income	2.44	1.93
Mean wealth (owners) / Mean income (owners)	2.94	2.67

Panel B: Parameter Values

Assigned			*Calibrated*		
	2 years	Period length	θ_c	0.041	Unsecured credit limit
T	30	Number periods to live	θ_h	0.046	Home equity credit limit
σ	5	CRRA	β_1	0.841	Impatient discount factor
$\bar{\theta}$	0.85	Maximum LTV	β_2	0.977	Patient discount factor
σ_z	0.559	S.d. permanent income component	τ	0.685	Fraction impatient
σ_e	0.339	S.d. transitory income shocks	F	0.027	Fixed cost of transacting home
$h_{\min}$	0.35	Smallest house size	F_N	0.051	Fixed cost of new mortgage
$h_{\max}$	14	Largest house size	F_R	0.091	Fixed cost of refinancing
κ	0.35	Scale for housing grid	α	0.848	Preference weight consumption
γ	0.874	Coupon depreciation	δ	0.046	Depreciation rental housing

Panel C: Additional Moments Used in Calibration

	Data	Model		Data	Model
Housing value (owners) / Mean income (owners)			*Loan to value ratio for mortgage holders*		
10th percentile	0.32	0.41	10th percentile	0.13	0.22
25th percentile	0.61	0.64	25th percentile	0.31	0.37
50th percentile	1.07	1.08	50th percentile	0.55	0.54
75th percentile	1.91	1.70	75th percentile	0.74	0.74
90th percentile	3.28	2.73	90th percentile	0.87	0.85
Mortgage debt (owners) / Mean income (owners)			*Mortgage debt to housing value*		
10th percentile	0.00	0.00	Ratio of means (borrowers)	0.46	0.57
25th percentile	0.00	0.00	Ratio of medians (borrowers)	0.51	0.45
50th percentile	0.25	0.32	Ratio of means (all owners)	0.29	0.30
75th percentile	0.71	0.77	Ratio of medians (all owners)	0.23	0.30
90th percentile	1.20	1.29			
Housing net worth: share of total wealth			*Housing net worth (owners) / Mean income (owners)*		
10th percentile	0.25	0.27	10th percentile	0.10	0.20
25th percentile	0.47	0.43	25th percentile	0.26	0.37
50th percentile	0.78	0.67	50th percentile	0.66	0.77
75th percentile	0.96	0.96	75th percentile	1.34	1.45
90th percentile	1.02	1.07	90th percentile	2.61	2.43
Liquid assets (all) / Mean income (all)			*Liquid assets to income ratio*		
10th percentile	-0.01	-0.04	10th percentile	-0.03	-0.05
25th percentile	0.00	0.01	25th percentile	0.00	0.01
50th percentile	0.07	0.12	50th percentile	0.09	0.16
75th percentile	0.58	0.92	75th percentile	0.64	0.83
90th percentile	2.66	2.39	90th percentile	2.63	3.47
Liquid asset to income ratio, 10th percentile, by homeownership status					
Owners	-0.03	-0.05	Renters	-0.03	-0.05
Wealth (owners) / Mean income (owners)			*Wealth (all) / Mean income (all)*		
10th percentile	0.11	0.28	10th percentile	0.00	0.01
25th percentile	0.33	0.54	25th percentile	0.05	0.12
50th percentile	0.93	1.12	50th percentile	0.52	0.61
75th percentile	2.38	3.09	75th percentile	1.78	1.79
90th percentile	5.70	6.50	90th percentile	4.83	4.81

Table 2: Effect of Refinancing on Key Moments

	Benchmark	No Refin.	Cheap Refin.
Housing			
Aggregate housing to Aggregate income	1.25	1.14	1.49
Fraction homeowners	0.69	0.62	0.83
Fraction of homes sold in a period	0.10	0.13	0.07
Share refin. debt in new mortgage debt	0.38	0	0.79
Homeownership rate by age			
25-45 year olds	0.45	0.41	0.61
45-65 year olds	0.83	0.76	0.95
65-85 year olds	0.79	0.69	0.95
Mortgage debt			
Aggregate mortgage debt / Aggregate income	0.38	0.32	0.61
Aggregate mortgage debt / Aggregate housing value	0.30	0.28	0.41
Fraction homeowners without a mortgage	0.37	0.41	0.29
Mean LTV for mortgage holders	0.57	0.56	0.63
Housing net worth			
Aggregate net worth to Aggregate income	0.88	0.83	0.88
Liquid assets			
Aggregate liquid assets / Aggregate income	1.05	1.08	1.05
Mean liquid assets to income ratio	1.18	1.21	1.16

Table 3: Impact of a 10% Liqudity Injection on Homeowners

	Benchmark	No Refin.	Cheap Refin.
Fraction that would have paid a fixed cost and no longer do so			
Transact house	0.174	0.255	0.056
Refinance mortgage	0.419	-	0.320
Marginal propensity to consume			
Mean	0.071	0.069	0.058
50th percentile	0.013	0.012	0.006
75th percentile	0.185	0.178	0.161
90th percentile	0.445	0.455	0.409
Mean, 25-45 year olds	0.048	0.041	0.053
Mean, 45-65 year olds	0.103	0.102	0.083
Mean, 65-85 year olds	0.040	0.037	0.030
Liquidity premium, $\xi_{i,t}$			
Mean	0.056	0.058	0.029
50th percentile	0.020	0.024	0
75th percentile	0.095	0.089	0.032
90th percentile	0.166	0.179	0.100
Fraction with $\xi_{i,t} \geq 0.05$	0.363	0.382	0.260
Mean, 25-45 year olds	0.043	0.042	0.029
Mean, 45-65 year olds	0.056	0.064	0.034
Mean, 65-85 year olds	0.064	0.074	0.038
Welfare gains, CEV, %			
Mean	0.110	0.126	0.065
50th percentile	0.020	0.024	0.003
75th percentile	0.152	0.179	0.070
90th percentile	0.313	0.376	0.190
Mean, 25-45 year olds	0.061	0.062	0.038
Mean, 45-65 year olds	0.095	0.118	0.053
Mean, 65-85 year olds	0.153	0.179	0.096

Table 4: Effect of 2007-2009 House Price Drop on Consumption

	Homeowners, by age						
	all	25-35	35-45	45-55	55-65	65-75	75-85
Mean consumption change	-0.030	0.005	-0.007	-0.008	-0.013	-0.026	-0.082
Fraction agents	0.597	0.032	0.085	0.110	0.136	0.136	0.098
Fraction of aggregate consumption	0.757	0.032	0.086	0.125	0.163	0.174	0.178
Median housing/income	2.23	1.56	1.76	2.00	2.02	2.87	3.21
Mean liquidity premium	0.039	0.012	0.035	0.038	0.040	0.046	0.040
Mean MPC liquidity injection	0.027	0.012	0.027	0.038	0.071	0.015	-0.005
	Renters, by age						
	all	25-35	35-45	45-55	55-65	65-75	75-85
Mean consumption change	-0.007	-0.001	-0.010	-0.013	-0.018	-0.014	0
Fraction agents	0.403	0.135	0.082	0.057	0.031	0.031	0.068
Fraction of aggregate consumption	0.243	0.079	0.053	0.037	0.016	0.013	0.044

Figure 1: The Boom and Bust in U.S. Housing Market

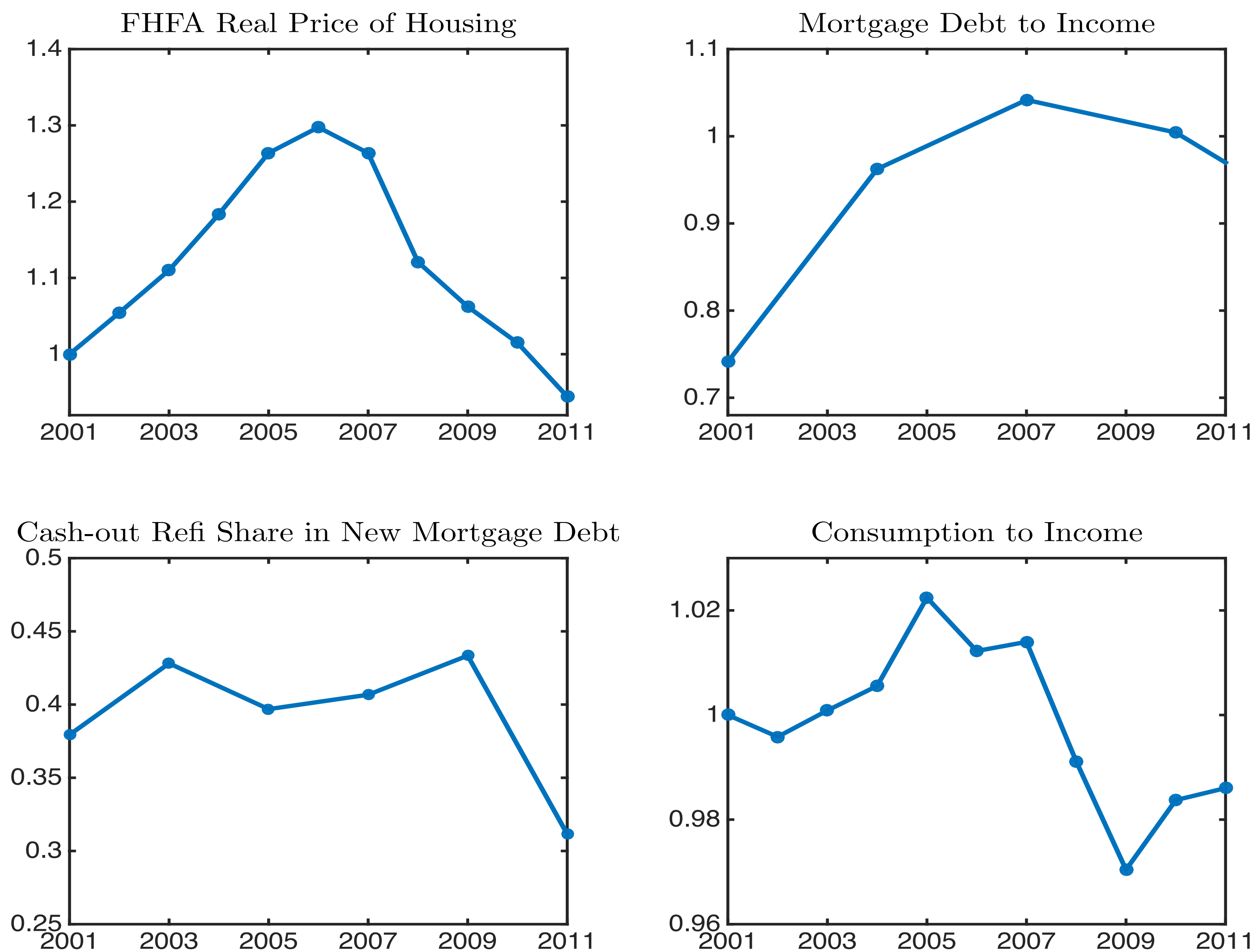

Figure 2a: Decision Rules. Agent with Low Liquid Assets

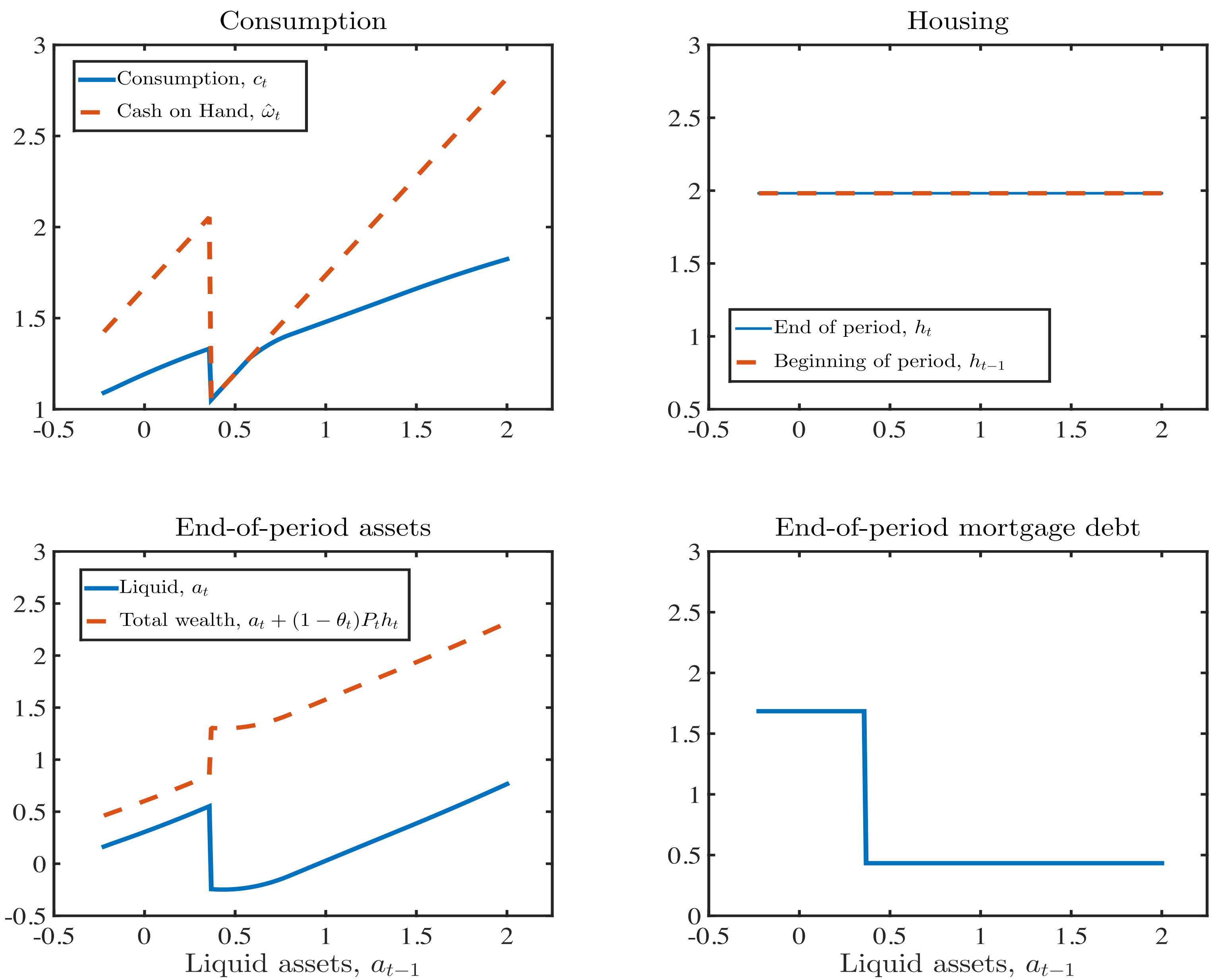

Figure 2b: Decision Rules. Agent with High Liquid Assets

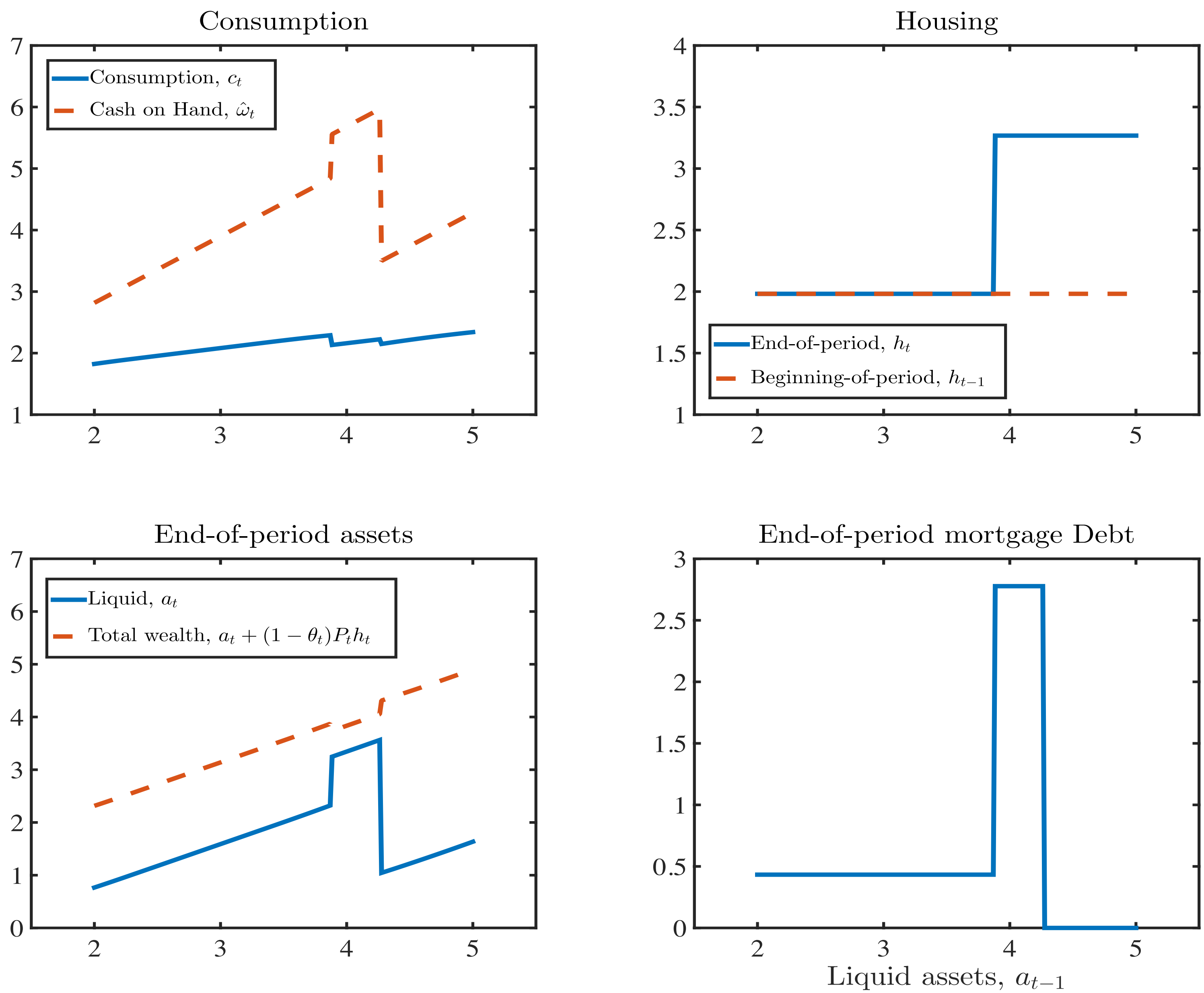

Figure 3a: Effect of Liquidity Injection on HH Decision Rules: Agent with Low Liquid Assets

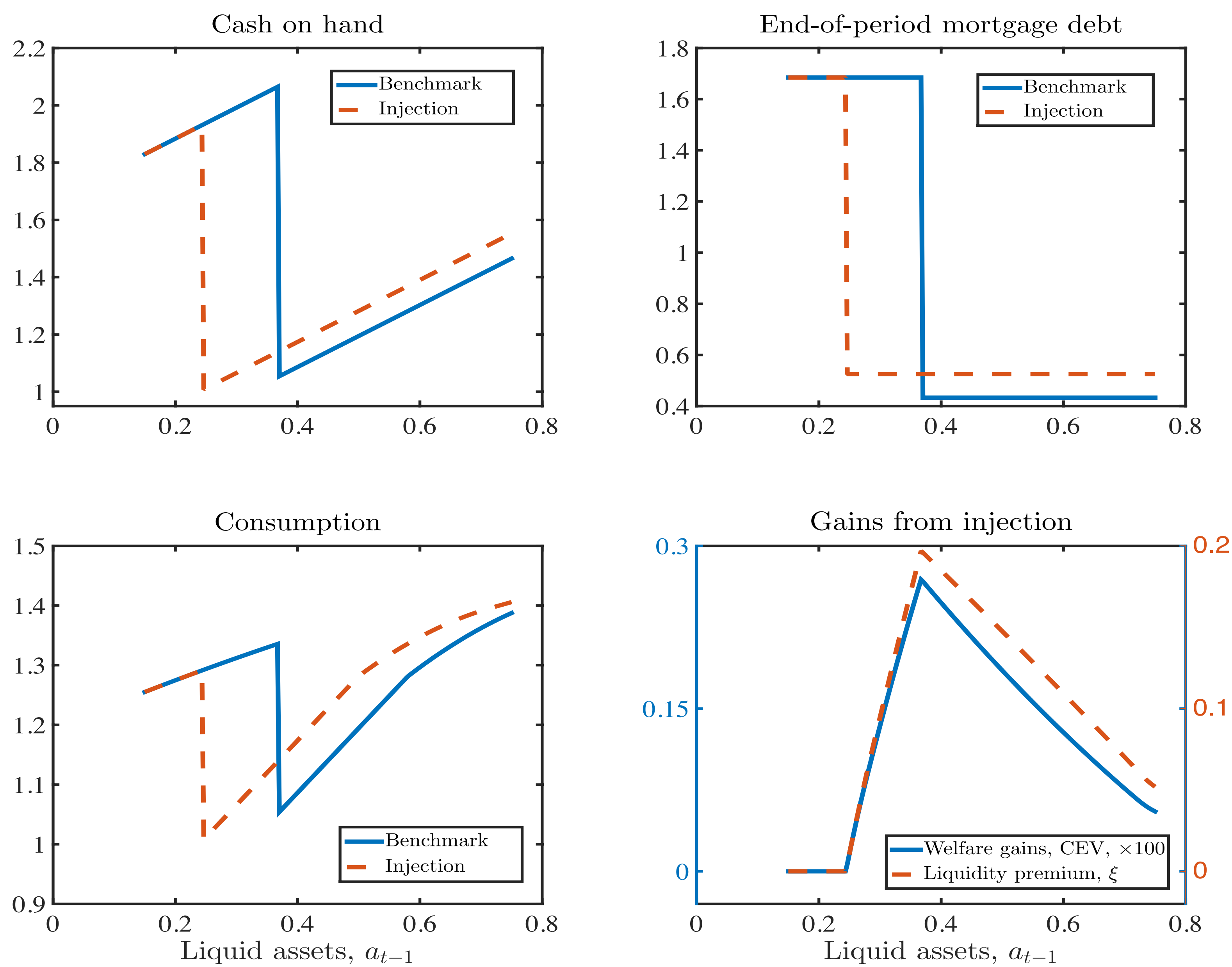

Figure 3b: Effect of Liquidity Injection on HH Decision Rules: Agent with High Liquid Assets

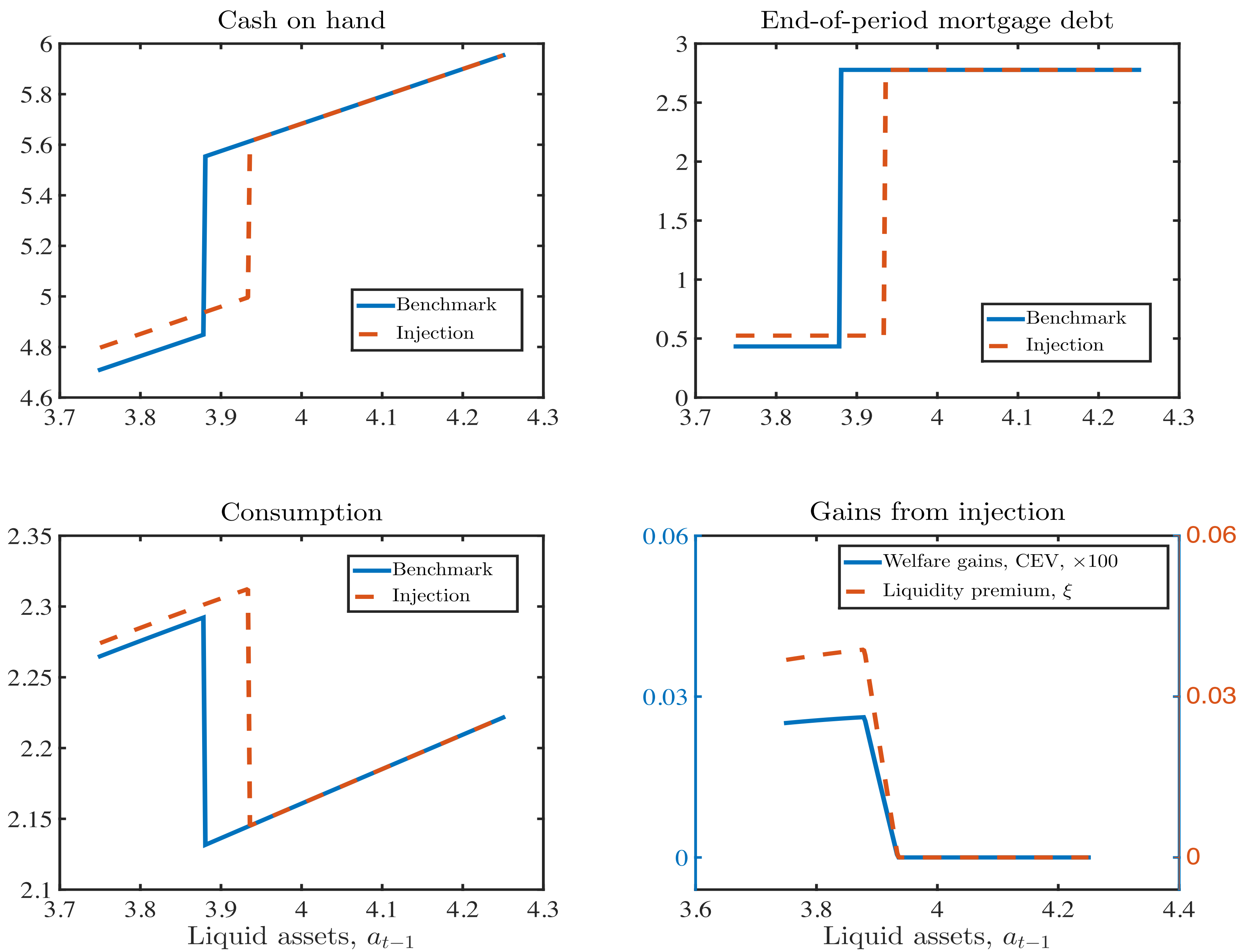

Figure 4: Liquidity Premium vs. Housing Share in Wealth

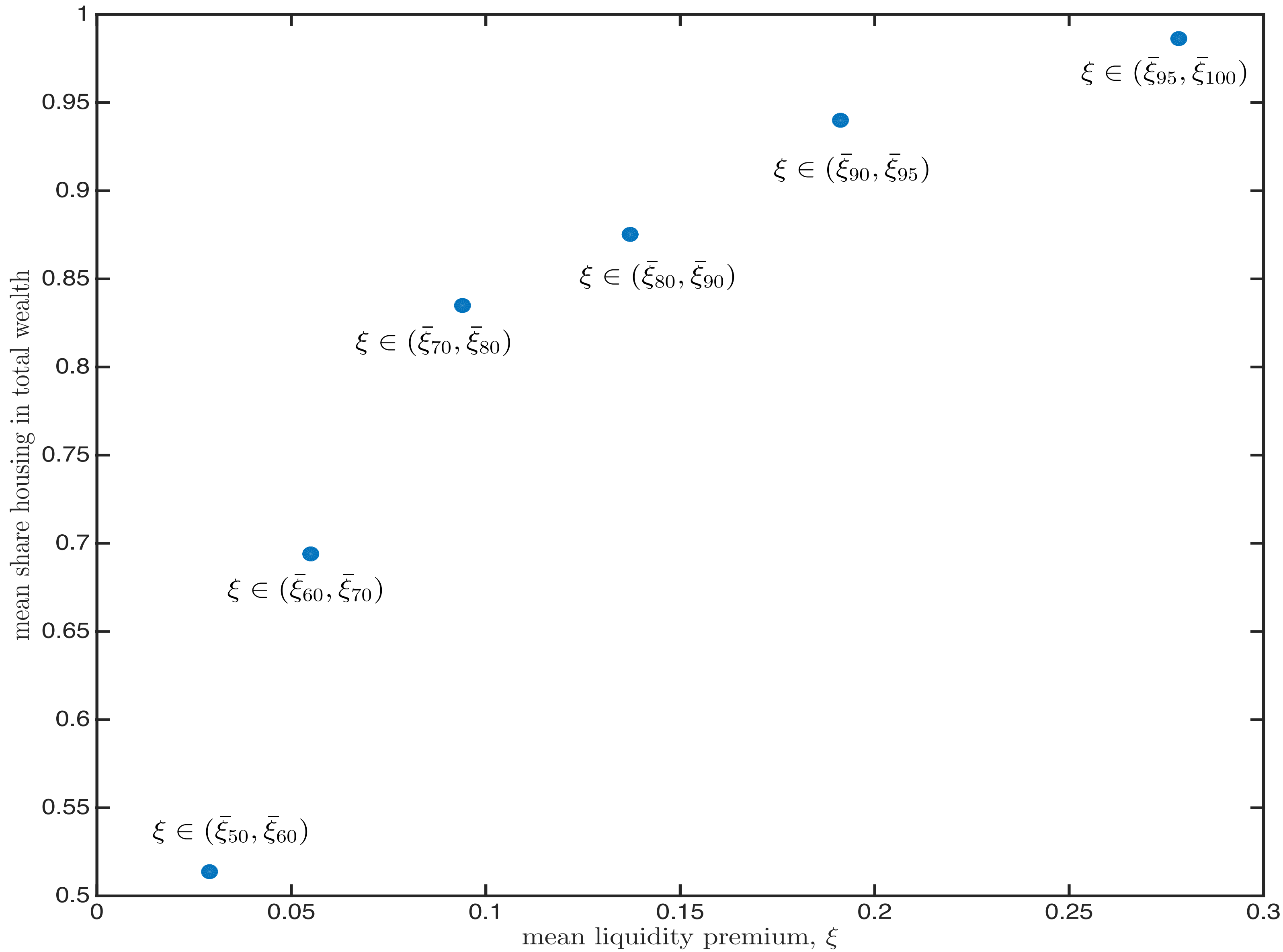

Figure 5: Impulse Response to Positive Housing Demand Shock

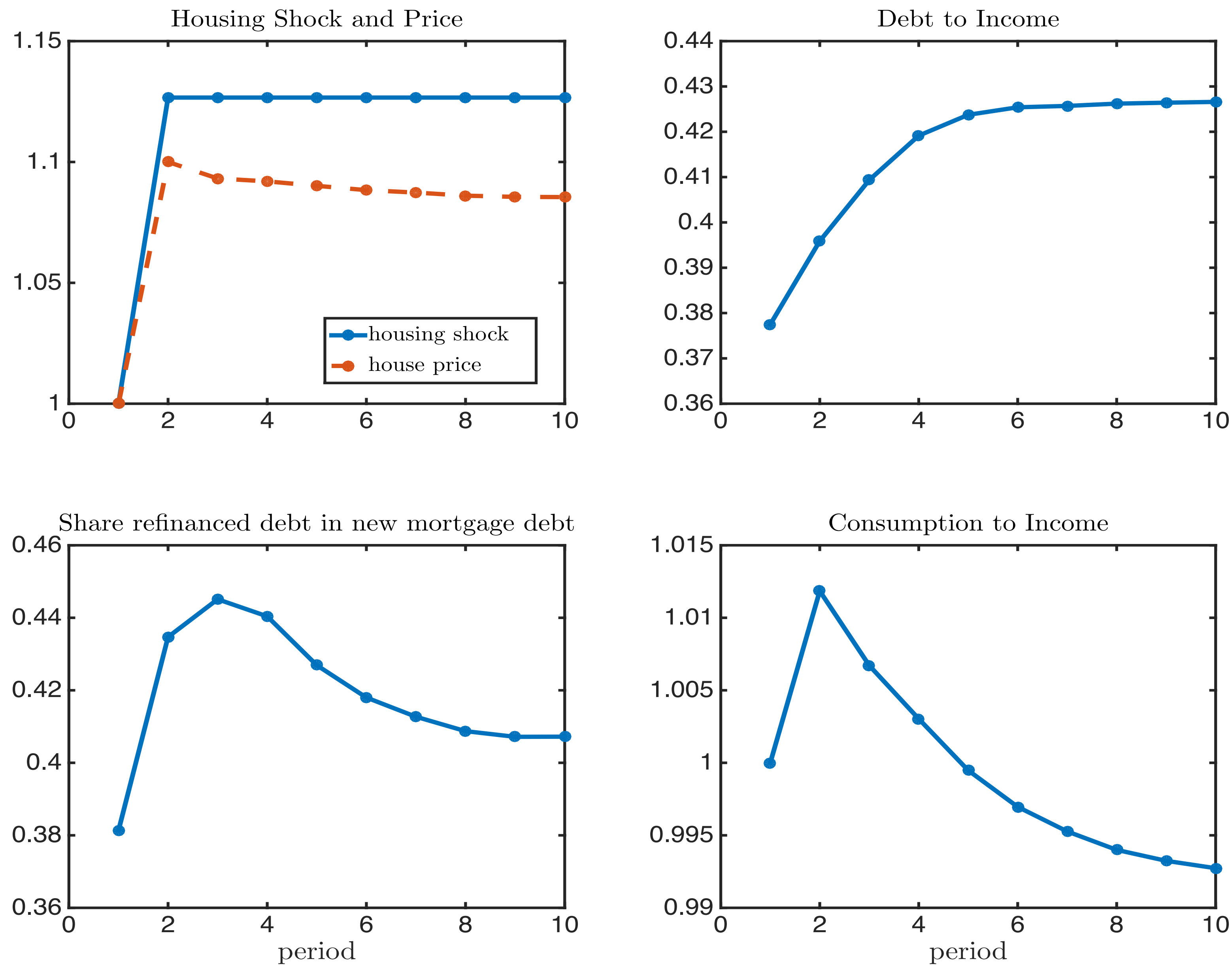

Figure 6: Impulse Response to Negative Housing Demand Shock

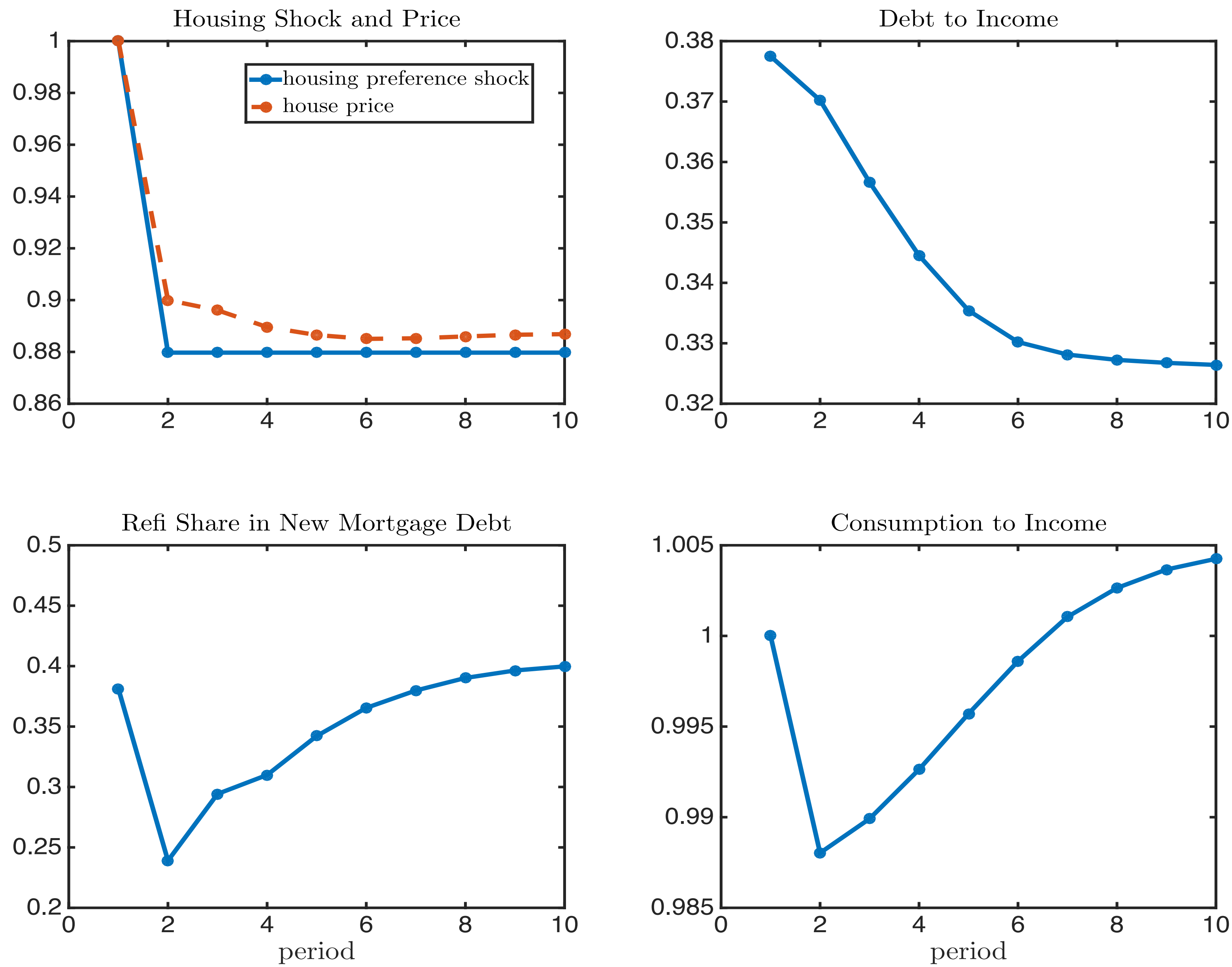

Figure 7: Impulse Responses to Housing Demand Shocks Absent Refinancing

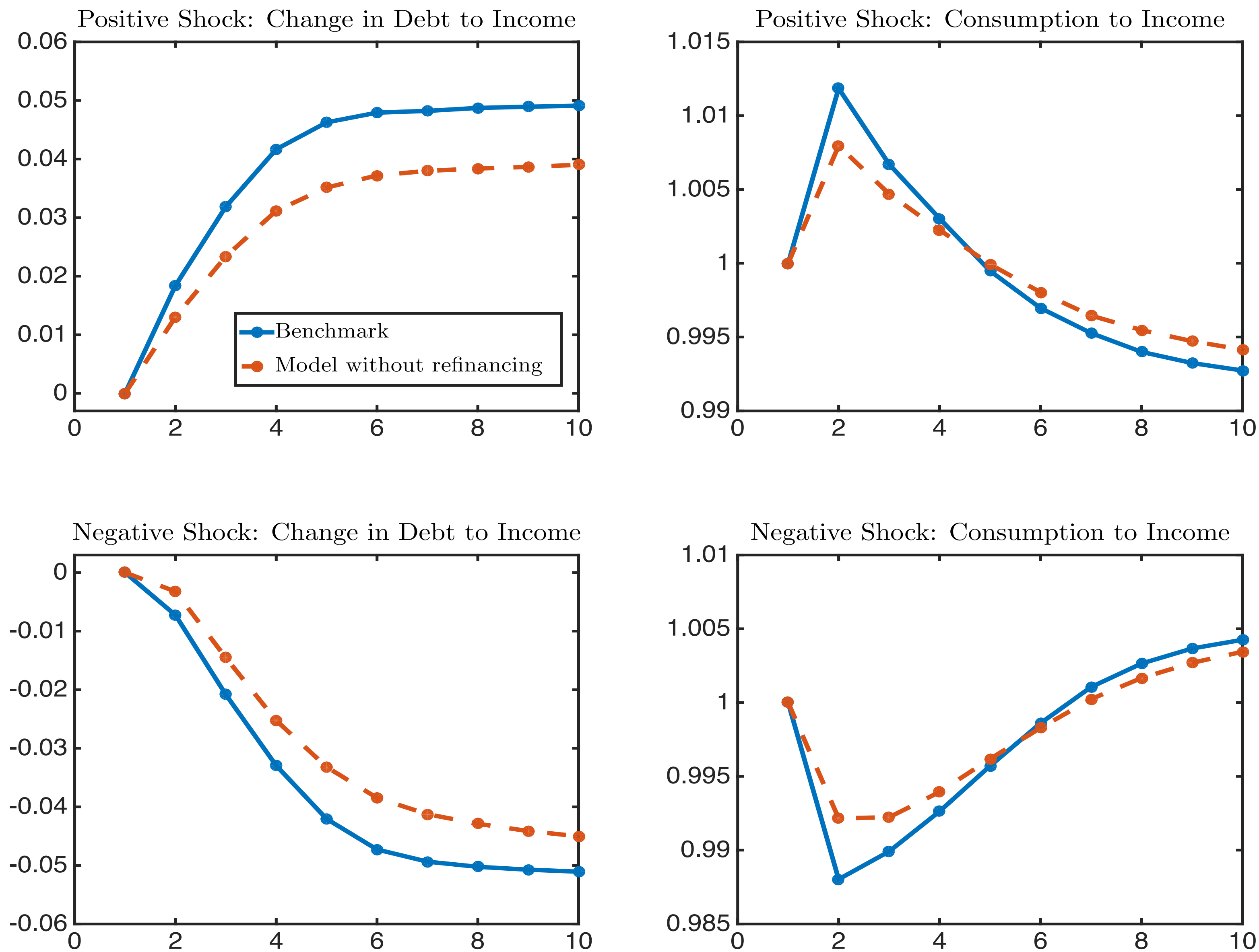

Figure 8: Evolution of Housing and Debt

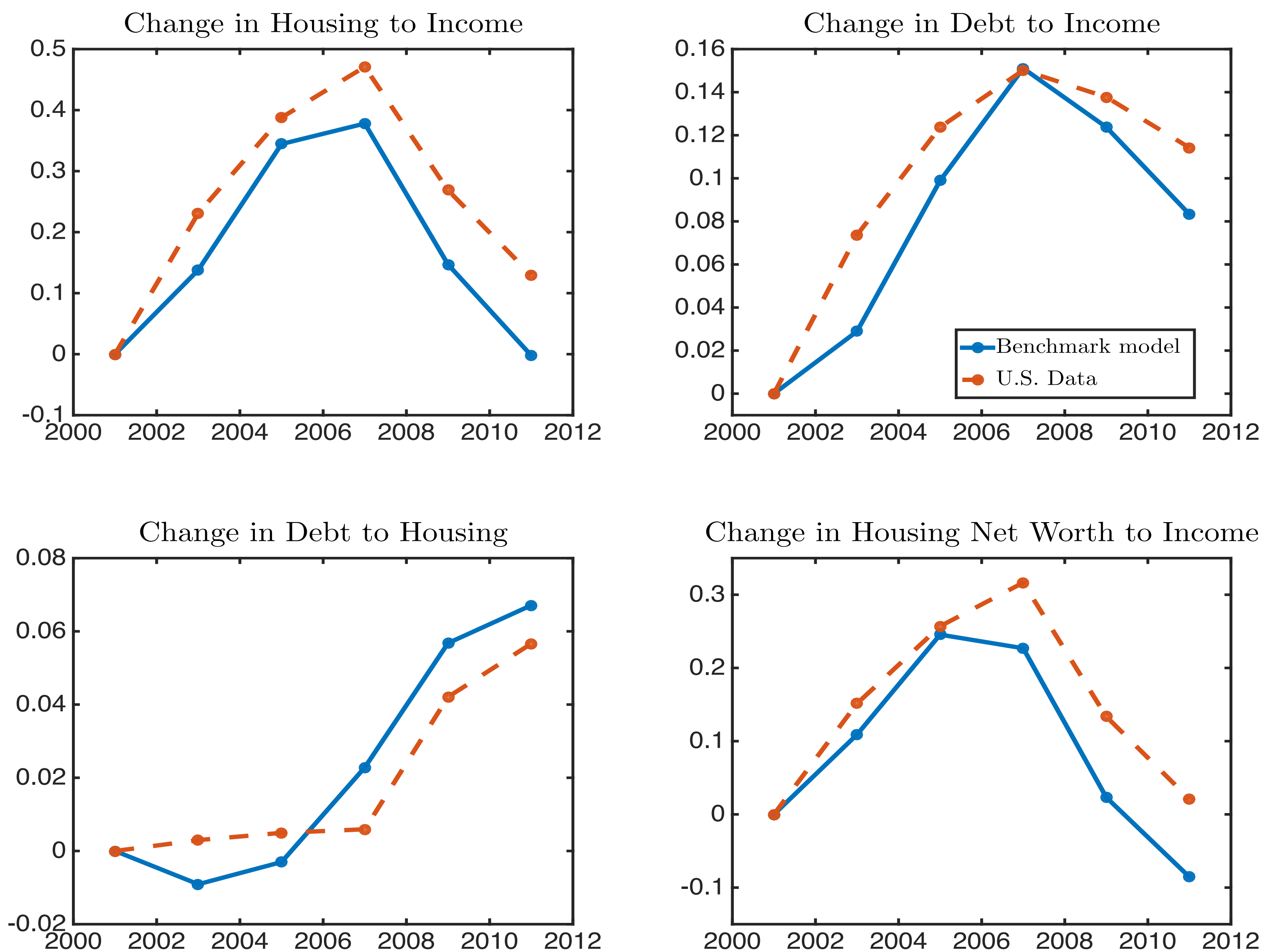

Figure 9: Evolution of Wealth and Consumption

Figure 10: Transitions in Economy without Refinancing

Figure 11: Transitions in Economy with Cheap Refinancing

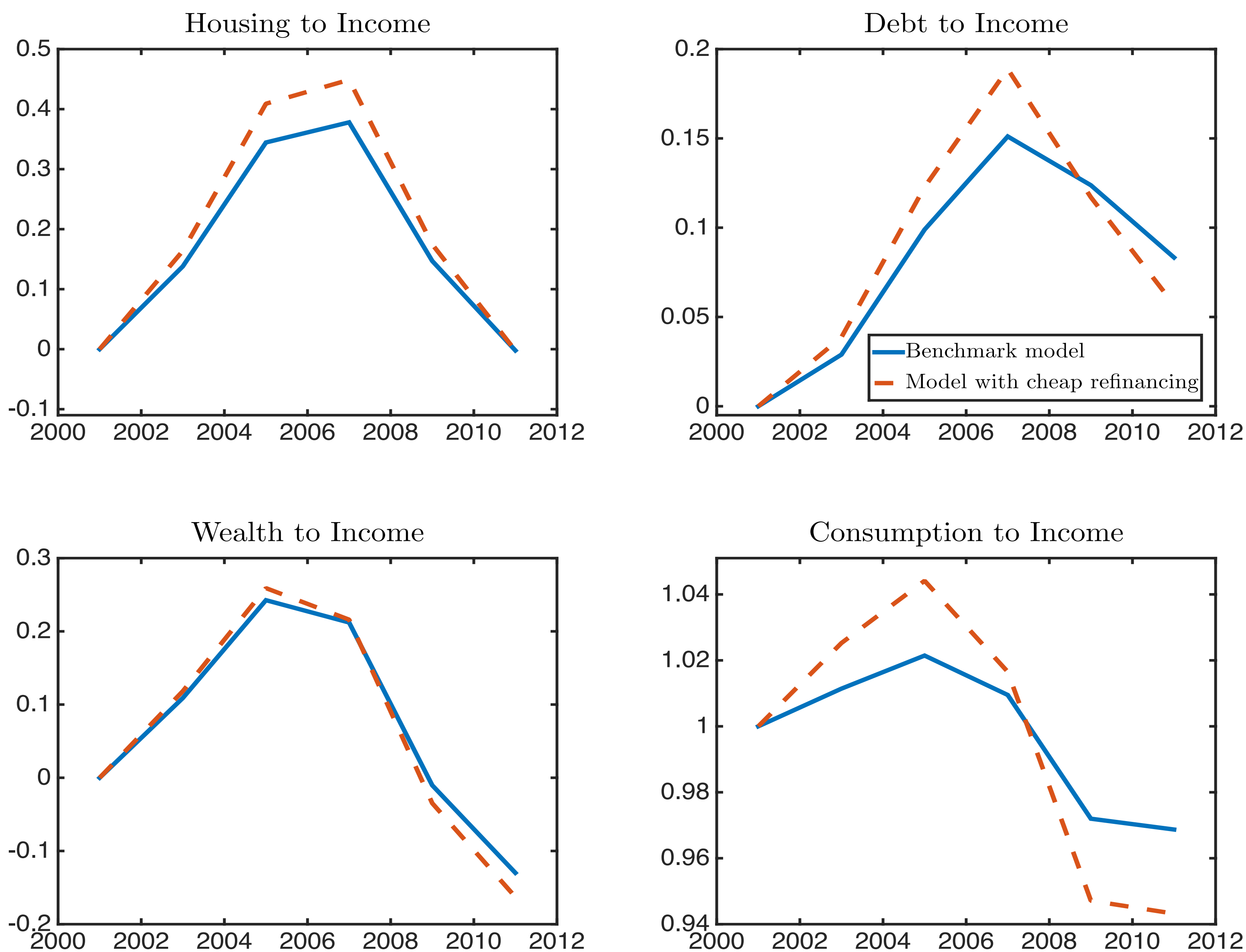

Figure 12: Severity of Liquidity Constraints over Time