NBER WORKING PAPER SERIES

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Denis Gorea
Virgiliu Midrigan

Working Paper 23345
http://www.nber.org/papers/w23345

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
April 2017

We thank Sonia Gilbukh for excellent research assistance, VV Chari, Morris Davis, Greg Kaplan, Ellen McGrattan, Karel Mertens, Giuseppe Moscarini, Kristoffer Nimark, Yaz Terajima and Gianluca Violante for helpful suggestions, as well as Neil Bhutta for kindly sharing his data with us. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

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JEL No. E21,E30

ABSTRACT

We study the severity of liquidity constraints in the U.S. housing market using a life-cycle model with uninsurable idiosyncratic risks in which houses are illiquid, but agents have the option to refinance their long-term mortgages or obtain home equity loans. The model reproduces well the distribution of individual-level balance sheets – the fraction of housing, mortgage debt and liquid assets in households' wealth, the fraction of hand-to-mouth homeowners (Kaplan and Violante, 2014), as well as the frequency of housing turnover and home equity extraction in the 2001 data. The model implies that 75% of homeowners are liquidity constrained and willing to pay an average of 8 cents to extract an additional dollar of liquidity from their home. Liquidity constraints imply sizable welfare losses equivalent to a 1.2% permanent reduction in consumption.

Denis Gorea
IDIS Viitorul
Chisinau, Moldova
denis.gorea@viitorul.org

Virgiliu Midrigan
Department of Economics
New York University
19 W. 4th St.
New York, NY 10012
and NBER
virgiliu.midrigan@nyu.edu

A online appendix is available at http://www.nber.org/data-appendix/w23345

1 Introduction

Housing wealth is the most important savings instrument for a large fraction of U.S. households. According to the Survey of Consumer Finances (SCF), about 70 percent of U.S. households own a home. Housing equity is by far the largest component of these individuals' balance sheets: it accounts for about 80% of the median homeowner's wealth. Housing, however, is a special type of asset because selling or buying a home involves substantial transaction costs. This set of observations led Kaplan and Violante (2014) and Kaplan et al. (2014) to argue that many households in the U.S. are wealthy, yet *hand-to-mouth*, with relatively low holdings of liquid assets.

The question we ask in this paper is: How liquid is housing wealth in the U.S.? That is, to what extent can homeowners tap the equity in their homes to smooth consumption fluctuations in response to income shocks? We answer this question using a quantitative life-cycle model with uninsurable idiosyncratic risks in which we explicitly model the key institutional details of the U.S. housing market. The model, parameterized to match salient characteristics of U.S. household balance sheets and frequency and size of home equity withdrawals, predicts sizable losses from liquidity constraints. Three quarters of homeowners in our model are liquidity constrained and would be willing to pay 8 cents, on average, for an additional dollar of liquidity extracted from their homes.

Agents in our model face persistent and transitory income shocks and can save in a liquid asset at a relatively low interest rate. They can either rent or purchase housing subject to non-convex transaction costs. Agents can borrow against the value of their home, at a relatively high interest rate, and are subject to loan-to-value and payment-to-income constraints. Mortgage loans are long-term securities which require payment of interest and principal over time. Finally, agents have two means of home equity extraction: *refinancing*, which entails a relatively large cost and *home equity loans*, which are relatively cheaper but are subject to more stringent debt limits. We think of these two options as capturing cash-out refinances and second-lien mortgage contracts in the data, respectively.

We confront the model with data from the SCF on the poorest 80% of households and the Panel Study of Income Dynamics (PSID) and use it to measure the severity of liquidity constraints of individual homeowners.[1] As we argue, data on household balance sheets and

[1]As we show below, agents in the top 20% of the wealth distribution have very large holdings of liquid assets and are unlikely to be liquidity constrained.

income processes is not sufficient to inform about the severity of liquidity constraints. If refinancing one's mortgage or other means of home equity extraction are relatively cheap, homeowners will purposefully choose to hold low amounts of the lower-return liquid asset and tap home equity whenever the need arises. Indeed, homeowners in the U.S. have access to a number of different options to extract home equity by cash-out refinancing or taking on a second-lien mortgage, such as a home equity loan. We therefore require that our model reproduces the evidence on the frequency and amount of home equity withdrawals assembled by Bhutta and Keys (2016) using a large panel of consumer credit records. These researchers find that about 12.5% of mortgage borrowers have extracted an average of $23,000 of home equity in 2001, the year prior to the boom and bust episode in the U.S.

An additional factor that shapes the severity of liquidity constraints is the maturity of the mortgage contract. The shorter this maturity, the faster must agents repay the principal on their mortgage and accumulate home equity. Repaying principal may be quite costly for homeowners who experience a string of negative income shocks, a force that exacerbates liquidity constraints. We thus require that our model matches the duration of the most widely-used mortgage contract in the U.S., the 30-year fixed-rate mortgage.

We find that liquidity constraints in the housing market are quite severe. About 20% of homeowners are hand-to-mouth, that is, at a kink in their Euler equation for liquid assets, consistent with the findings of Kaplan and Violante (2014). What this number implies for the severity of liquidity constraints depends on the magnitude of the costs of home equity extraction. We show that accounting for the Bhutta and Keys (2016) facts requires fairly high fixed costs of refinancing – about 5.5% of the value of one's home, and somewhat smaller costs of home equity extraction – about 2% of the value of one's home, consistent with other direct estimates. These costs imply that it is quite expensive for homeowners to tap housing equity to respond to negative income shocks.

Indeed, our model predicts that about 75% of homeowners are liquidity constrained, a number much greater than the fraction of those who are hand-to-mouth. We define a homeowner as liquidity constrained if she would be better off with a more liquid wealth portfolio. This group includes not only the hand-to-mouth homeowners, but also the marginal homeowners who are forced to sell their home or tap home equity and who would benefit from additional liquidity by exercising the option value of waiting. In addition, this group includes homeowners who are not hand-to-mouth, yet keep their consumption low for precautionary reasons, anticipating the possibility of negative income shocks and the need to make mortgage payments in the future. Overall, liquidity constrained agents in our model are willing to pay 8 cents on average for every dollar of liquidity they are able to extract. Absent costs of home equity extraction, the welfare of agents in our model would increase by 1.2% consumption equivalent units, a sizable number.

The requirement that mortgage borrowers build equity in their homes over time is quite onerous for agents in our model. Eliminating this requirement by replacing 30-year mortgages with interest-only perpetuities would reduce the severity of liquidity constraints by about one-third. Another factor that amplifies the severity of liquidity constraints is the wedge between the mortgage rate and the return on the liquid assets. Because of this wedge, some agents in our model choose to pay some of their mortgage debt sooner than required by their mortgage contract or not borrow at all, thus choosing to maintain a relatively illiquid position. Eliminating the 2.5% real after-tax wedge between the mortgage rate and liquid savings rate observed in the data would reduce the severity of liquidity constraints in half.

We also find that liquidity constraints are almost as severe in our model as they would be absent home equity loans. Eliminating these altogether would significantly reduce the frequency of home equity withdrawals, yet would not greatly amplify the severity of liquidity constraints. The 12.5% home equity extraction rate documented by Bhutta and Keys (2016) is therefore indicative of very severe constraints on U.S. homeowners' ability to tap home equity.

Interestingly, we find that agents in our model have a smoother consumption profile than agents in an otherwise identical Bewley version of the model without housing, even though our model predicts a higher fraction of hand-to-mouth agents. Thus, the option to sell one's home and extract home equity does provide an important cushion that allows agents to smooth consumption fluctuations, relative to that available in the one-asset model.

Our finding that liquidity constraints are severe has both normative and positive implications. We illustrate the normative implications by considering the effect of mortgage forbearance policies which reduce mortgage payments for homeowners experiencing a temporary spell of low income. Many lenders in the U.S. have such programs, but these are fairly limited in scope. We find that introducing such a policy in our model would have a limited impact, owing to the fact that liquidity constraints mostly bind for agents with low mortgage balances whose required mortgage payments are relatively low.

In our model many homeowners are liquidity constrained, yet not hand-to-mouth, reflecting a precautionary motive that leads them to save in the liquid asset in order to guard against negative income shocks in the future. This finding has important implications for how agents in our model respond to an unanticipated credit shock that loosens constraints on home equity borrowing. In our model aggregate consumption increases by about 15 cents for every dollar of increase in debt in the aggregate, with the rest used to replenish agents' liquid asset holdings. In contrast, models in which liquidity constraints are less severe imply much larger marginal propensities to consume out of additional debt. Liquidity constraints thus help rationalize the Midrigan and Philippon (2016) observation that the large expansion of household debt during 2001-2006 was accompanied by a much smaller increase in consumption spending across U.S. states.

We focus most of our analysis on studying the steady-state implications of liquidity constraints, and purposefully abstract from introducing aggregate dynamics. Although the question of how liquidity constraints vary over the business cycle is an important one, we do not pursue it here. Whether liquidity constraints bind more or less during a downturn accompanied by a large decline in house prices critically depends on the source of shocks triggering such dynamics. We have shown, in an earlier version of this paper,[2] that a decline in house prices may, in fact, trigger a relaxation of liquidity constraints since households reduce consumption due to a decline in their overall wealth. Since generating realistic time-series variation in equilibrium returns on housing is a challenging task even in the absence of frictions on home equity extraction,[3] and since frictions on home equity extraction introduce important non-convexities that are challenging to handle even in our partial equilibrium setting, we leave such extensions for future work.

Related Work This paper is part of a wider research agenda, developed by Hurst and Stafford (2004), Khandani et al. (2013), and Beraja et al. (2016), among others, studying liquidity management in the housing market.

In addition to Kaplan and Violante (2014), our paper is most closely related to the work of Chen et al. (2013) and Kaplan et al. (2015). Both of these papers study models of the housing market in which houses are illiquid, mortgages have long durations and households can extract equity from of their homes. Unlike these papers, which study the comovement of consumption, house prices and income at business cycle frequencies, our work focuses solely on measuring the severity of liquidity constraints in a stationary environment.

[2] Gorea and Midrigan (2015).

[3] See Favilukis et al. (2013).

Our work is also related to a number of papers that study the housing market: Davis and Heathcote (2005), Ríos-Rull and Sánchez-Marcos (2008), Kiyotaki et al. (2011), 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. Finally, Greenwald (2015) proposes a tractable New Keynesian model of long-term fixed-rate mortgages and studies the aggregate implications of mortgage refinancing.

The rest of the paper is organized as follows. Section 2 presents some evidence that motivates our modeling choices. Section 3 describes the model. Section 4 discusses the data we have used and our empirical strategy. Section 5 studies the severity of liquidity constraints and discusses several additional implications of the model. Section 6 presents several robustness checks we have conducted. Section 7 concludes.

2 Motivating Evidence

We show, using data from the 2001 Survey of Consumer Finances (SCF), that a large fraction of U.S. homeowners hold most of their wealth in the form of housing equity. Though this fact is well-established,[4] we report several statistics that we later use to evaluate our quantitative model. We also summarize the evidence on the amount of home equity extraction.

2.1 Data

We use the 2001 SCF to compute measures of the various components of household wealth. Here we briefly discuss the variables we have used.[5] Our measure of housing is the value of the primary residence owned by each household. We calculate mortgage debt by adding the remaining principal on all mortgages secured by the primary residence, including home equity loans and other second-lien loans.

[4]See Kaplan and Violante (2014).

[5]See our Appendix for a more detailed description of our measures of wealth and disposable income.

Our measure of liquid assets adds balances on all checking and savings accounts, money market deposits and mutual funds, certificates of deposit, directly held pooled investment funds, bonds, stocks, as well as secondary residential real estate. We subtract from these the amount owed on credit cards, installment loans as well as debt secured by secondary properties. Our inclusion of secondary properties in our measure of liquid assets is motivated by the observation that these are transacted quite often and are thus relatively liquid.[6] Most households do not own such properties, so this choice does not greatly affect our results.

We define total wealth as the sum of liquid assets and housing, net of mortgage debt. Importantly, our measure of wealth excludes retirements accounts. We account for the latter in our model by directly subtracting transfers into and out of these accounts from the 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 these from our definition of wealth does not change our statistics considerably.

2.2 Stylized Facts

Table 1 reports several key features of the data. We report statistics for the entire sample, as well as separately for those in the top 20% and bottom 80% of the wealth distribution.

The aggregate stock of liquid assets is quite high: its per-capita average is equal to \$114,000, or about two-thirds of overall wealth and more than three times annual income.[7] This average masks, however, a great deal of heterogeneity in the households' portfolio composition. The richest 20% of households have an average stock of liquid assets of about \$494,000, seven times their annual income. The poorest 80% of households, in contrast, have an average stock of liquid assets of only \$13,000, less than half their average annual income.

The lower tail of the distribution of liquid assets reveals an even more striking pattern. The richest 20% of households have sizable amounts of liquid assets even at the low end of the distribution – the 10th percentile is equal to \$23,700. In contrast, the poorest 80% of households have very few liquid assets. Among households in this group, the 10th percentile of liquid assets is equal to -\$1,200, the 25th percentile is equal to zero, while the 50% percentile is equal to only \$2,000, less then one-tenth of the average annual income of these households.

We find a similar pattern when we restrict our calculations to the sample of households

[6] See our Appendix for evidence on this.

[7] We have adjusted all variables for household size using the OECD equivalent scales. All numbers are expressed in 2001 USD.

who own a home. As Table 1 indicates, about 71% of all households own a home, a number that falls to 64% for those in the bottom 80% of the wealth distribution. The 25th percentile of liquid assets is equal to $278 for homeowners in this latter group, thus about 1% of their average income. The median liquid assets of these homeowners is also small, about $4,200.

Consider finally the share of housing equity (housing net of mortgage debt) in households' total wealth. Table 1 shows that for the population of homeowners overall, the median share of housing equity in total wealth is 77%. This pattern is even more pronounced when we focus on the poorest 80% of households: housing wealth accounts for 87% of all of the wealth of the median homeowner in this group.

Frequency of Housing Turnover and Home Equity Extraction. Whether housing wealth is liquid or not depends on the availability of opportunities to extract home equity. These include the option to sell a home, as well as to extract equity from an existing home.

Bhutta and Keys (2016) study a large, nationally representative panel of consumer credit records. They find that about 12.5% of individuals who had mortgage debt and did not transact their home extracted home equity in 2001. The median amount by which these individuals' mortgage balance increased was about 23% of the initial balance, or $23,000. Berger and Vavra (2015) report that about 5% of homes were sold in 2001. We target each of these numbers in our quantitative analysis below.

3 Model

This is an overlapping generations endowment economy. Agents live for a finite number of periods, are subject to idiosyncratic income shocks, derive utility from consumption and housing, and can save using a one-period liquid asset or by purchasing a home. We study a partial equilibrium setting – the interest rates agents face are exogenously given, as is the price of housing, which we normalize to unity. Agents can either rent or own a home. Selling one's house entails a fixed transaction cost. Agents can borrow against their home by taking on a mortgage, but doing so entails a fixed cost. There is no aggregate uncertainty. We next describe preferences, the income process, and the assets available for trade.

Preferences. Agents live for T periods, of which they work for the first J periods. There is no bequest motive. The utility function is time-separable, with an inter-temporal elasticity of substitution equal to one, a preference weight on consumption equal to α and a discount factor β. We let c denote the consumption of the endowment good and h denote the amount of housing the agent consumes. The life-time utility of a t-year old agent is

$$V_t = \alpha \log(c_t) + (1-\alpha)\log(h_t) + \beta \mathbb{E}_t V_{t+1}, \quad t < T,$$

$$V_T = \log(c_T).$$

Income. An agent i at age t receives income

$$y_{i,t} = \lambda_t z_{i,t} e_{i,t},$$

where $\lambda_t = 1$ during the first J years of one's life, and $\lambda_t = \lambda_R < 1$ during the last $T - J$ years, capturing the drop in income after retirement. Agents face persistent and transitory shocks to their income. The persistent component, z, is drawn at birth from $\mathbb{N}\left(\mu_z, \frac{\sigma_z^2}{1-\rho_z^2}\right)$ and evolves over time according to an AR(1) process:

$$\log(z_{i,t+1}) = \rho_z \log(z_{i,t}) + \varepsilon_{i,t}, \quad \varepsilon_{i,t} \sim \mathbb{N}(0, \sigma_z^2).$$

The transitory component e is i.i.d and drawn each period from $\mathbb{N}(0, \sigma_e^2)$.

Assets. Agents can save or borrow using a one-period risk-free *liquid asset* at an interest rate r_L. We assume a liquid asset borrowing limit, so that

$$a' \geq -\underline{a},$$

where $\underline{a}$ is the unsecured credit limit an agent can borrow. For simplicity, we assume no difference between the borrowing and lending rate on the liquid asset. In our Robustness section we consider an extension in which the borrowing rate is greater than the savings rate.

We let h denote the amount of housing the agent owns. Housing is subject to transaction costs equal to $F_S h$. These are incurred whenever one sells their home. We assume, in our computations, that the stock of houses is indivisible, but have chosen a grid size sufficiently large so that these indivisibilities do not have much impact on the agents' decision rules.

Mortgages. Agents can borrow against the value of their homes using mortgages. We follow Hatchondo and Martinez (2009) and Chatterjee and Eyigungor (2015) in assuming, for computational tractability, that mortgages are perpetuity contracts with geometrically decaying coupon payments. Let b denote the face value of the mortgage. The mortgage is characterized by an interest rate, $r_M > r_L$, as well as a parameter $\gamma \in [0,1]$ that determines the minimum fraction of principal that the borrower needs to repay each period and thus the duration of the mortgage. A borrower with a remaining mortgage debt of size b must make a minimum payment of $(1-\gamma+r_M)b$, of which a fraction is interest and the rest is principal.

We assume no curtailment penalties so borrowers can repay a greater fraction of the principal than stipulated by the mortgage contract.[8] Thus, a borrower who does not extract home equity chooses a new loan balance b' subject to the borrowing constraint

$$b' \leq \gamma b. \tag{1}$$

Home Equity Extraction. Agents have the option to relax the borrowing constraint in (1) by either refinancing their mortgage or by obtaining a home equity loan. *Refinancing* entails paying down the entire balance on the original loan and obtaining a new mortgage, at a cost equal to $F_M h$. We assume that this cost is the same whether the agent finances the purchase of a new home or refinances a mortgage on an existing home.

Agents who take on a new mortgage face two constraints on the amount they can borrow: a loan-to-value (LTV) constraint that restricts the total amount of debt below a fraction θ_M of the value of the home:

$$b' \leq \theta_M h, \tag{2}$$

as well as a payment-to-income (PTI) constraint that requires that the minimum mortgage payment not exceed a fraction θ_Y of the household's income:

$$(1-\gamma+r_M)b' \leq \theta_Y \lambda_{t+1} z. \tag{3}$$

This constraint only applies at mortgage origination.

A second option agents can use to extract home equity is a *home equity loan*. This option entails a smaller fixed cost, $F_X h$, but is subject to an additional limit: the size of the home equity loan cannot exceed a fraction θ_X of the value of one's home. Agents who exercise this option face, in addition to (2) and (3), a borrowing constraint:

$$b' - \gamma b \leq \theta_X h. \tag{4}$$

[8] Although some lenders do impose curtailment penalties, they typically apply them only in the first few years in the life of the mortgage and only if a borrower pre-pays more than 20% of the loan balance in any given year. McCollum et al. (2015) report that these limits rarely bind.

We think of these two options, refinancing and home equity loans, as loosely capturing two types of home equity withdrawals in the data. One option is cash-out refinancing, which entails taking on a new first-lien mortgage, at a relatively large closing cost, but a relatively low interest rate. A second option is a second-lien mortgage, such as a home equity loan or a home equity line of credit. In the data such an option entails relatively low closing costs, but relatively higher interest rates and therefore smaller loan amounts.[9] For computational tractability, we have opted to model the relatively small balances on second-lien loans as arising from exogenous limits on home equity loans, rather than interest rate differences between first and second-lien loans. Our approach saves an additional state variable and considerably simplifies computations. Importantly, assuming that agents have access to home equity loan allows the model to match the relatively high frequency and low amounts of home equity withdrawals documented by Bhutta and Keys (2016).

Rental Market An agent who does not own a home can rent h units of housing services at a rental rate R. Rental housing is not subject to adjustment costs or indivisibilities. In our quantitative section we calibrate R in order to match the homeownership rates in the data. We interpret the difference between this rental rate and the user cost of owner-occupied housing as capturing a number of reasons that make ownership preferable to renting, including moral hazard problems that exacerbate maintenance costs of rental property.[10]

Budget Constraints. Consider an agent who enters the period with a house of size h, outstanding mortgage debt b, liquid assets a and income y. The budget constraint of the agent varies depending on whether she rents, purchases a new home or remains in the existing home, as well as on whether she chooses to extract home equity.

Agents who rent face the budget constraint

$$c + a' + Rh' = y + (1 + r_L)a - (1 + r_M)b + (1 - F_S)h. \tag{5}$$

The right-hand side represents the agent's liquid wealth after she sells the house, incurring the selling cost $F_S h$, repays the principal and interest on the outstanding mortgage debt, $(1 + r_M)b$, and receives income y and interest and principal on the liquid account, $(1 + r_L)a$. The left-hand side sums consumption, c, liquid savings, a', and rental spending, Rh'.

[9] The median balance on first-lien mortgage loans in the 2001 SCF data is equal to \$85,000, while the median combined balance on second-lien loans is equal to \$17,000.

[10] See, for example, Chambers et al. (2009a,b).

Agents who purchase a new home face

$$c + a' + h' - b' + F_M h' \mathbb{I}_{b'>0} = y + (1 + r_L)a - (1 + r_M)b + (1 - F_S)h. \tag{6}$$

The right-hand side is identical to that of the renter. The left-hand side sums the agent's consumption and liquid savings, the cost of the new home, h', net of the new mortgage debt, b', if the agent chooses to borrow. If the agent does borrow, she incurs the fixed mortgage closing cost $F_M h'$ and faces the borrowing constraints in (2) and (3).

Inactive homeowners neither transact their house, nor extract home equity and face

$$c + a' = y + (1 + r_L)a - (r_M b + b - b'), \tag{7}$$

as well as the requirement that they pay down a fraction γ of their existing loan balance, summarized by (1). These agents consume or save their income and the balance on their liquid account, net of the payments on their mortgage. These payments include interest, $r_M b$, as well as principal, $b - b'$.

Agents who refinance their mortgage face

$$c + a' - b' + F_M h = y + (1 + r_L)a - (1 + r_M)b. \tag{8}$$

These agents pay back the entirety of their original mortgage, $(1 + r_M)b$, and take on a new mortgage b', the size of which is limited by the LTV and PTI constraints. Mortgage refinancing entails the fixed cost $F_M h$.

Finally, agents who obtain a new home equity loan face

$$c + a' - b' + F_X h = y + (1 + r_L)a - (1 + r_M)b, \tag{9}$$

which is similar to the budget constraint of agents who refinance, but entails a lower fixed cost $F_X h$. The additional constraint these agents face is on the amount of the loan in (4).

Recursive Formulation. Let m denote an agent's total wealth, including her income, liquid assets and the resale value of the home, net of the mortgage debt:

$$m = y + (1 + r_L)a + (1 - F_S)h - (1 + r_M)b. \tag{10}$$

The other state variables are the household's age, t, the permanent income component, z, the size of the house, h, as well as the mortgage debt, b. The value function satisfies

$$V_t(m, z, b, h) = \max_{a', b', h'} u(c, h') + \beta \mathbb{E}_{z', e'} V_{t+1}(m', z', b', h'), \tag{11}$$

where the maximization operator includes the choice of two continuous variables, a' and b', as well as the discrete choices of what house size to purchase, whether to rent, and whether to refinance into a new mortgage or take a home equity loan.

Value of Liquidity. For any given level of wealth m and housing stock h, the state variable b summarizes how liquid a household's portfolio is. A greater level of mortgage debt b, holding wealth and housing constant, implies a greater stock of liquid assets, a, and less home equity. A homeowner *values liquidity* if the value function increases in b, that is, if $\partial V_t(\cdot)/\partial b > 0$. We therefore let

$$p = \frac{\partial V_t(\cdot)}{\partial b} / u_{c,t} \tag{12}$$

denote a household's marginal valuation of liquidity, where $u_{c,t}$ is the marginal utility of consumption. This object gives the household's willingness to pay to exchange one unit of housing equity for one unit of liquid assets. We refer to agents for whom $p > 0$ as *liquidity constrained,* since such agents would be better off with a more liquid portfolio.

Three groups of homeowners value liquidity. The first are the *marginal* homeowners near the thresholds for home equity extraction. Since home equity extraction entails a fixed cost, marginal homeowners benefit from additional liquidity by exercising the option value to wait.

The second group of homeowners are the inactive ones. Their budget constraint is

$$c = m - (1 - F_S)h + b' - a', \tag{13}$$

and their borrowing constraint is given by (1). Since the outstanding mortgage debt b only appears in the borrowing constraint of these agents' problem, their marginal valuation of liquidity, $\partial V/\partial b$, is simply equal to γ times the multiplier on that constraint. Inactive agents are therefore liquidity constrained whenever the minimum mortgage payment constraint binds.

The third group of homeowners are those who take on a home equity loan. Recall that these agents face the limit in (4) on the size of the loan they can obtain. Their budget constraint is

$$c = m - (1 - F_S)h - F_X h + b' - a'. \tag{14}$$

Once again, their outstanding mortgage debt only enters these agents' problem through the borrowing constraint. Hence, the marginal value of liquidity for these agents is also proportional to the multiplier on the borrowing constraint in (4).

Decision Rules. The Euler equation for liquid savings is

$$u_{c,t}(m,z,h,b) = \beta(1+\tilde{r}_t(m,z,h,b))\mathbb{E}_{z',e'}u_{c,t+1}(m',z',h',b'), \tag{15}$$

where $\tilde{r}$ is the shadow interest rate faced by the agent and is equal to the interest rate on the liquid asset, r_L, plus the multiplier on the $a' \geq -\underline{a}$ constraint. We follow Kaplan and Violante (2014) in referring to households for whom this constraint binds as *hand-to-mouth*.

The Euler equation for mortgage debt is

$$\mathbb{E}_{z',e'}\frac{\partial V_{t+1}(m',z',h',b')}{\partial b'} \geq (r_M - \tilde{r}_t(m,z,h,b))\mathbb{E}_{z',e'}u_{c,t+1}(m',z',h',b'), \tag{16}$$

with equality if the borrowing constraint does not bind. The left-hand side of this expression is the expected marginal valuation of liquidity next period. The right-hand side is the cost of borrowing, given by the difference between the mortgage rate r_M and the effective return on the liquid asset, $\tilde{r}$. The agent thus trades off the interest cost of mortgage debt against the value of liquidity.

Our Appendix discusses in detail the solution method we used (projection methods to approximate the value functions, Gaussian quadrature to compute integrals, successive application of Brent's method to calculate optimal decision rules) and the accuracy of the approximation. We note here that the expected marginal valuation of liquidity, $\partial V_{t+1}/\partial b'$ is non-monotone in b', owing to non-convexities in the agent's choice set, which change the likelihood that the various options of home equity extraction will be exercised in the future. These monotonicities imply several local maxima that solve the Euler equation in (16), which require use of global optimization methods.

Figure 1 illustrates the workings of the model using an example of an individual household's lifecycle. This household purchases a smaller home at age 30, a larger one at age 50, and then downsizes during retirement. Consumption tracks income and is less volatile owing to the buffer of liquid assets. The loan-to-value ratio starts high when the household first purchases a house and falls gradually in most periods, as the household makes the minimum principal payments, setting $b' = \gamma b$. Thus, throughout most of her life, this agent is liquidity constrained. Notice also the few periods in which the homeowner repays her debt faster than required by the mortgage contract (for example at age 42). In these periods her income is unusually high, so she pays off a portion of her mortgage to reduce interest payments. Finally, notice the few periods when the household raises her LTV by taking a new home equity loan.

4 Quantification

We parameterize the model to match salient features of households' portfolio composition and frequency of home equity extraction described in Section 2, as well as moments of their income process. We next describe the income moments, our calibration strategy and evaluate the model along a number of dimensions not explicitly targeted in calibration. Given our focus on the steady-state implications of liquidity constraints, the statistics we target are those for 2001, the year prior to the boom-bust episode in the U.S. housing market.

4.1 Income Process

We use data from the 1999-2007 waves of the Panel Study of Income Dynamics (PSID) to parameterize the idiosyncratic income process. We compute taxable income for each household by adding wages net of pension contributions, social security income, pension income, unemployment compensation and other transfers. We then subtract federal and state income taxes and deflate the resulting data using the CPI and the OECD equivalence scales. The Appendix contains a more detailed description of our computations.

Our notion of income captures disposable income net of contributions or withdrawals from retirement accounts. This allows us to focus our analysis on a household's choice between housing and liquid wealth, and abstract from the choice of how much to save using retirement accounts. We conjecture that this choice is fairly innocuous. As Kaplan and Violante (2014) show, the median household's holdings of retirement assets are small, around $950.

4.2 Parameterization

A period in the model is 1 year. Agents enter at age 25 and live for $T = 66$ periods, that is, up to age 90. They work for $J = 40$ years, up to age 65, at which point they retire and experience a fall in income, which we capture using a discrete fall in λ_t.

We divide the parameters of the model into two groups. The first includes parameters that can be assigned without explicitly solving the model. The second includes parameters that are chosen in order to minimize the distance between a number of moments in the model and in the data. We next describe each set of parameters.

4.2.1 Assigned Parameters

We report these parameters in the left column of Panel B of Table 2.

Mortgage Debt. The mortgage contract is characterized by four parameters, the interest rate r_M, the fraction of principal to be repaid each period, γ, the maximum loan-to-value ratio, θ_M, as well as the maximum payment-to-income ratio, θ_Y.

The average 30-year fixed mortgage rate in 2001 was equal to 6.97%. We multiply this number by $1 - 0.239$, the average marginal subsidy on mortgage interest. We finally subtract the 2.8% inflation rate in 2001, which gives us a real after-tax interest rate of $r_M = 2.5\%$.[11]

We choose the parameter governing the duration of mortgages, γ, to match the *mortgage half-life*: the number of periods required for homeowners to repay half of the present value of their mortgage obligations. In the U.S., the typical mortgage is a 30-year fixed-rate mortgage in which the borrower repays a constant amount each period. The half-life of such a mortgage is the scalar τ which solves

$$\frac{1-(1+r_M)^{-\tau}}{1-(1+r_M)^{-30}} = \frac{1}{2}.$$

This equation implies a mortgage half-life of $\tau = 12.28$ years. In contrast, in our model mortgages are geometrically decaying perpetuities and the half-life satisfies

$$\left(\frac{\gamma}{1+r_M}\right)^{\tau} = \frac{1}{2}.$$

Matching the half-lives in the model and the data thus requires that we set

$$\gamma = (1+r_M)\left(\frac{1}{2}\right)^{\frac{1}{12.28}} = 0.969.$$

We set the maximum LTV equal to the highest possible value that can be sustained in our model without introducing a cost of default,

$$\theta_M = \frac{1-F_S}{1+r_M} = 0.917.$$

This value ensures that all homeowners have positive home equity and is close to the 90th percentile of the LTV distribution in the data of 0.92. Finally, we set the maximum payment-to-income ratio, θ_Y, equal to 0.35, consistent with the evidence in Greenwald (2015).

Liquid Asset. We use the evidence in Davis et al. (2006) to choose the return on the liquid asset, r_L. These researchers report an after-tax return on 3-year Treasuries of 2.9% for 2001, from which we subtract the 2.8% CPI inflation to arrive at $r_L = 0.1\%$.

Finally, we set the unsecured credit limit on the liquid asset, $\underline{a}$, equal to 0.036 of per-capita annual income, in order to match the 10th percentile of the liquid asset distribution in the Survey of Consumer Finances.

[11] See our Appendix for the data sources underlying these numbers.

Income Process. We use the PSID data to pin down the income process. We set the mean of the initial permanent income component, $\mu_z = -0.295$, by targeting a 0.21 log-point difference between the average income of households aged 45 to 55 and those aged 25 to 35. We set $\lambda_R = 0.717$ to match the 0.33 log-point difference between the average income of retirees and workers. This difference is relatively small owing to the inclusion of withdrawals from retirement accounts in our measure of income for retirees.

We choose the persistence and standard deviation of the two income components by first regressing the log of a household's income on an age polynomial. We then calculate the variance (0.43), as well as the first and second autocovariances (0.32 and 0.29, respectively) of the residuals from this regression.[12] We then set $\rho_z = 0.938$, $\sigma_z = 0.200$ and $\sigma_e = 0.307$ to exactly match these moments. These numbers are in line with existing estimates.[13]

4.2.2 Calibrated Parameters

We have a total of 7 remaining 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 right column of Panel B of Table 2. These are the fixed costs of selling a home, F_S, the fixed cost of obtaining a home equity loan, F_X, the fixed cost of obtaining a new mortgage, F_M, the limit on home equity loans, θ_X, the discount factor β, the preference weight on housing, α, as well as the rental rate of housing, R.

We choose these parameters to minimize the distance $\sum_{i=1}^{9} \left(\frac{\text{moment}_i^{\text{model}} - \text{moment}_i^{\text{data}}}{\text{moment}_i^{\text{data}}} \right)^2$ between 9 moments in the model and in the data. Panel A of Table 2 reports the values of the moments we target. These moments describe the composition of aggregate wealth into liquid and illiquid assets, the fractions of homeowners and mortgage borrowers, as well as the frequency with which homeowners sell their homes and extract home equity. In addition, we target the median amount by which a homeowner increases her mortgage balance whenever refinancing. Recall from our discussion in Section 2 that Bhutta and Keys (2016) find that 12.5% of homeowners that have mortgage debt extract home equity. Since one-third of homeowners have no mortgage debt, the sample of individuals with mortgage debt who extract home equity represents about 8.6% of all homeowners. We target this latter statistic.

Importantly, we target statistics for the poorest 80% of the households in the SCF sample.

[12] We show in the Appendix that these statistics are very similar for households whose head is older and younger than 65 years of age, respectively. We therefore assume that the income process in our model is the same before and after retirement.

[13] See for example, Floden and Lindé (2001) and Storesletten et al. (2004).

It is clear from Table 1 that the wealthier group of households have very large holdings of liquid assets and are thus unlikely to be liquidity constrained. Accounting for the large liquid holdings of the richer households would require adding additional sources of heterogeneity (say in the discount rates, or returns on liquid assets or income processes), which would complicate the model, without substantially changing any of our conclusions given the partial equilibrium nature of our exercise.[14]

Model Fit. The first four rows of Panel A of Table 2 report a number of aggregate per-capita wealth moments, all scaled by aggregate per-capita annual income. We reproduce well the aggregate wealth (1.45 in the data v.s. 1.55 in the model) and the value of the aggregate housing stock (1.82 v.s. 1.83), but understate the amount of mortgage debt (0.83 v.s. 0.61) and liquid assets (0.46 v.s. 0.33). We are unable to match these last two moments because of the large wedge between the mortgage and liquid interest rates (2.5% vs. 0.1%) we have assumed. This leaves us with one single parameter, the discount factor, to match a combination of these four statistics, but not each in isolation. As we show below, however, the model reproduces well the lower tails of the liquid asset distribution. Its failure to reproduce the aggregate thus stems from its inability to match the distribution of liquid assets at the upper tail, which is less consequential for the severity of liquidity constraints.

The model reproduces well all other statistics that we have targeted: the homeownership rate of 64% (63% in the model), the fraction of homeowners with a mortgage of 71% (72%), the frequency of home sales of 0.051, the 8.6% fraction of extractors, and the median amount extracted relative to the initial mortgage balance of 0.23. These last three statistics are identical in the model and in the data. We match these statistics well because we have introduced a parameter aimed at reproducing each in isolation. Intuitively, the rental rate R pins down the homeownership rate, the fixed cost of obtaining a new mortgage F_M pins down the fraction of borrowers, the fixed cost of obtaining a home equity loan F_X pins down the fraction of homeowners who extract equity, while the limit on home equity loans θ_X pins down the median amount extracted by those who do so.

Recall from our earlier discussion of Bhutta and Keys (2016) that the 8.6% number is the fraction of homeowners who extract home equity and have a positive mortgage balance. This statistic does not include those homeowners that start out without a mortgage but choose to take on a new housing-backed loan. When we include this latter group, the overall fraction of

[14] See the earlier draft of this paper, Gorea and Midrigan (2015), for an extension along these lines.

homeowners who extract equity increases to 11.1% in our model. Of these, 9.1% take home equity loans and thus borrow relatively little and 2% refinance their mortgage and borrow relatively large amounts.

Parameter Values. Panel B of Table 2 reports the parameter values we obtain. The cost of selling a home is equal to 6% of its value, in line with estimates of seller commission fees. The fixed cost of obtaining a new home equity loan is 2.1% of the value of one's home, while the fixed cost of obtaining a new mortgage is equal to 5.5%. Although there is quite a bit of variation in how much homeowners pay in closing costs and other fees when borrowing against their home, our estimates are in line with those reported elsewhere.[15]

Matching the median amount extracted in the data requires a limit on home equity loans of $\theta_X = 14.3\%$ of the value of one's home. The discount factor necessary to match the aggregate wealth in the data is equal to $\beta = 0.947$. The preference weight on consumption needed to match the aggregate housing stock is equal to $\alpha = 0.92$. Finally, the model requires a rental rate of housing of $R = 0.036$, thus quite a bit higher than the 2.5% interest rate on mortgages. When we add the fixed costs homeowners need pay to own a home, including the costs of home equity extraction, we find a median per-period user cost of housing of 0.031, about 15% lower than the rental rate. This premium compensates homeowners for the liquidity constraints they face and is necessary to match the homeownership rates in the data.[16] Overall, these parameters imply a median rate of return to owning a home[17] of 3.34%, a 10th percentile of 2.20% and a 90th percentile of 4.75%. The heterogeneity in these rates of return reflects difference in the duration of homeownership spells and the fact that homeowners can lever and thus amplify the returns to owning homes.

Additional Moments Not Targeted in Calibration. We next evaluate the model's ability to account for a number of additional features of the data, notably various quantiles of the distribution of individual household balance sheets. Since our focus is on measuring the severity of liquidity constraints faced by individual homeowners, it is imperative that the model reproduces well the distribution of liquid assets among homeowners, as well as the share of housing in their wealth. Table 3 reports these additional statistics.

[15] See www.federalreserve.gov/pubs/refinancings/, as well as our Appendix.

[16] See our Appendix for evidence on the relative cost of renting vs. owning a home.

[17] For each homeownership spell, we calculate the rate of return as the discount rate that implies a zero NPV of the flows associated with purchasing that particular home, including the transaction and home equity extraction costs.

Panels A and B of Table 3 report the distribution of liquid assets for renters and homeowners. The model reproduces the 10th, 25th, 50th and 75th percentiles of these distributions reasonably well. For example, the median renter has liquid assets of about 1% of per-capita aggregate income in the data and 3% in the model, while the median homeowner has liquid assets of about 15% of per-capita annual income in the data and 22% in the model. The 75th percentile of the renter's liquid asset distribution is equal to 15% in both the model and in the data, while the 75th percentile for homeowners is equal to 68% in the data and 58% in the model. Importantly, the model matches well the lower tails of the liquid asset distribution of homeowners. The 10th percentile is equal to −4% in both the model and in the data, while the 25th percentile is equal to 1% in the data and −1% in the model. About 25% of households have essentially no liquid assets, consistent with the findings of Kaplan and Violante (2014).

The model fails to match the 90th percentile of these distributions, which are substantially greater in the data (1 and 1.69 for renters and homeowners, respectively) than in the model (0.34 and 1.21, respectively). Since we focus on measuring liquidity constraints, which bind at the bottom of the liquid asset distribution, we conjecture that this discrepancy does not greatly affect our conclusions.

Panel C of Table 3 reports the distribution of housing values across agents in our model. The model reproduces this distribution reasonably well, though it somewhat understates the dispersion in house sizes. The model also matches well the distribution of loan-to-value ratios (Panel D) for those who borrow: the 25th percentile of 0.40 (0.37 in the model), the median of 0.64 (0.67), and the 75th percentile of 0.79 (0.80). Given that the model reproduces well the distribution of liquid assets, housing values and LTVs, it also matches well statistics derived from these. Panel E and F of Table 3 show that the model reproduces the housing share of homeowners' wealth – housing equity accounts for 87% of the median homeowner's wealth in the data and 84% in the model, as well as the overall wealth distribution, except for the very top.

To summarize, our model successfully reproduces salient features of the distribution of households' liquid assets, mortgage debt and housing. A large fraction of homeowners have small holdings of the liquid asset and thus concentrate a substantial fraction of their wealth in the housing market. We assess below the extent to which these homeowners can use their housing wealth to smooth consumption fluctuations.

5 Importance of Liquidity Constraints

We next study the model's implications for the severity of liquidity constraints. We find that the welfare costs of these constraints are sizable, about 1.2% consumption-equivalent units. We then ask: What institutional features of the housing market in the U.S., as captured by our parameterization, are most responsible for the severity of these constraints? We also evaluate the role of mortgage forbearance policies and discuss how liquidity constraints shape the model's implications for the consumption responses to an unanticipated credit shock.

5.1 Severity of Liquidity Constraints

Borrowing Constraints. Panel A of Table 4 shows that 86% of all homeowners are borrowing constrained. To understand what accounts for this large number, we note that the vast majority of homeowners (83.5%) in our model are the inactive ones, who neither extract home equity nor transact their home. Among these, 87% face a binding $b' \leq \gamma b$ constraint and thus make only the minimum required mortgage payment. Very few homeowners in our model thus choose to curtail their mortgage, a feature consistent with the U.S. evidence.[18]

Of the remaining homeowners, 11.1% are those who extract home equity without selling their home. Among these, 83% are constrained owing to the limits on how much they can extract even conditional on paying the fixed cost. Finally, 5.4% of homeowners purchase a new home. Among these, 74% are constrained.

Consumption Smoothing. We next ask: How do borrowing constraints shape homeowners' consumption choices? Panel B of Table 4 shows that one quarter of households in the ergodic steady state of our model are at the unsecured debt limit $\underline{a}$ and are thus hand-to-mouth. For these households, the median effective shadow interest rate $\tilde{r}$ is equal to 14.7%. Since homeowners are wealthier than renters, a smaller fraction of them, 21%, are hand-to-mouth, with a median shadow interest rate of 12.6%.

We next report the implications of these constraints for agents' ability to smooth consumption in response to income shocks. The metric we use are the insurance coefficients

$$\phi^P = 1 - \frac{\text{cov}(\Delta \log c_{it}, \varepsilon_{it})}{\text{var}(\varepsilon_{it})} \quad \text{and} \quad \phi^T = 1 - \frac{\text{cov}(\Delta \log c_{it}, e_{it})}{\text{var}(e_{it})},$$

[18]See Amromin et al. (2007) who find that only about 16% of homeowners that have a 30-year fixed-rate mortgage are ahead of schedule on their mortgage payments, and the references therein.

where ε_{it} and e_{it} are the persistent and transitory income shocks. These insurance coefficients range from 0 (consumption tracks income) to 1 (perfect consumption smoothing) and are widely used to assess the ability of households to smooth consumption fluctuations.[19]

Panel C. of Table 4 shows that the insurance coefficient for persistent income shocks is equal to 0.27 (0.32 for homeowners), and that to transitory shocks is equal to 0.72 (0.79 for homeowners). These numbers are somewhat larger for homeowners, who are richer on average. To interpret these coefficients, we next compare them to those in an otherwise identical one-asset Bewley model in which all parameters (including the interest rate on the liquid asset, r_L) are the same as in our Benchmark model.

Table 6 shows that the insurance coefficients for the two types of shocks fall to 0.22 and 0.67 in the Bewley model with $r_L = 0.1\%$, despite the lower fraction of hand-to-mouth households (14% vs. 25% in our Benchmark), and larger average holdings of the liquid asset (0.69 vs. 0.33 in our Benchmark). Achieving the same degree of consumption smoothing in the Bewley model as in our model would require raising the interest rate on liquid assets to 1.25%, in which case the average holdings of liquid assets would be about three times larger than in our Benchmark. Intuitively, the presence of a higher return asset – housing – allows agents in our model to accumulate a larger cushion of wealth than in the Bewley model. Even though this wealth is partially illiquid, agents can nevertheless tap it occasionally to smooth consumption.

Implications for Welfare. What are the welfare costs of frictions that prevent agents from tapping home equity? We answer this question by comparing the expected life-time value at birth of an agent in our economy to that in an economy in which which there is no fixed cost or limit on home equity loans ($F_X = 0$ and $\theta_X = \infty$). As Panel C of Table 4 reports, this difference is equal to 1.19% consumption equivalent units, a sizable amount. These welfare calculations must be interpreted with care in light of the partial equilibrium nature of our exercise. In general equilibrium a reduction in constraints on home equity extraction would increase house prices and thus dampen the welfare gains of households in the aggregate. We nevertheless find these welfare calculations a convenient way of summarizing the severity of liquidity constraints that individual homeowners face during their lifecycle.

[19] See for example Kaplan and Violante (2010).

5.2 Value of Liquidity

We next ask: How much do homeowners in our model value liquidity? Recall that we have defined the value of liquidity in (12) as a homeowner's marginal willingness to pay to exchange one unit of housing equity for one unit of liquid assets.

We answer this question by conducting an experiment we refer to as *liquidity injection.* We increase all homeowners' initial liquid assets and mortgage debt by some amount, Δb, keeping their overall wealth unchanged. We thus effectively offer homeowners a one-time opportunity to extract home equity for free. Due to non-convexities in the homeowners' choice sets, their response to and valuation of such interventions depend on their size. We thus report results for two different sizes of the liquidity injection, equal to 1% and 10% of the value of one's home.

Panel A of Table 5 shows that about 70% of all homeowners benefit from a liquidity injection equal to 1% of the value of one's home. This fraction increases as we increase the size of the injection: 76% of all homeowners benefit from an injection equal to 10% of the value of one's home. The additional 6% of homeowners are the marginal homeowners who postpone selling their house or withdrawing home equity when receiving a sufficiently large amount of liquidity.

The table also reports these homeowners' valuation of liquidity, which we compute using the discrete counterpart of (12). The average valuation of liquidity among all those who benefit from a 1% injection is equal to 10.2%. This number varies substantially across homeowners, with a 25th percentile equal to 3.2% and a 90th percentile equal to 24.3%. The average valuation of liquidity falls for the 10% injection, but is quite high, 7.9%.

Three groups of homeowners benefit from additional liquidity: marginal homeowners who use it to exercise the option value of waiting, hand-to-mouth homeowners, as well as homeowners who are neither hand-to-mouth nor marginal. Panel B of Table 5 reports several statistics for each of these groups.

Marginal homeowners value liquidity the most. This group accounts for 2.5% of all those who benefit from the 1% injection and 15% of those who benefit from the 10% injection. Because additional liquidity allows these agents to avoid paying the fixed costs of home equity extraction, their valuation of liquidity is quite high, about 19% (16%) on average. Notice that these agents *reduce* consumption in response to the liquidity injection: additional liquidity allows them to avoid tapping home equity which would have raised their consumption.

The second group of homeowners who value liquidity are the hand-to-mouth ones. These agents account for about a quarter of those who benefit, have a median valuation of 19% (10%), and consume a large fraction of the liquidity received. Clearly, these agents value liquidity because it allows them to raise their consumption immediately.

The third, most sizable group of homeowners who value liquidity are neither marginal, nor hand-to-mouth. These homeowners only raise consumption by about 9 cents for every additional dollar of liquidity and have a median valuation of liquidity of about 5% (4.3%). These homeowners value liquidity for precautionary reasons, anticipating to be constrained in the future.

Figure 2 illustrates this point by showing the distribution of the marginal propensities to consume, $\Delta c_{t+j}/\Delta b_t$, during the first ten years after a 1% injection for homeowners who are not marginal. Panel A shows the consumption responses of those homeowners who are hand to mouth in the period of the injection, while Panel B shows the responses of those who are not. Both panels report the median as well as the 7.5th, 25th, 75th and 92.5th percentiles of the distribution of consumption responses at each date after the injection, scaled by the amount of liquidity a homeowner receives initially. Clearly, hand-to-mouth households consume the additional liquidity immediately. They then gradually repay the additional debt by cutting consumption by a small amount in all future periods.

Non-hand-to-mouth agents, in contrast, consume very little of the injection initially. Notice, however, that the distribution of their marginal propensities to consume out of the additional liquidity fans out in the periods following the injection, with a sizable group of these agents experiencing a large increase in consumption at some point in the next few periods. Overall, about 50% of those in this second group experience an increase in consumption that is greater than half of the amount of liquidity received in the the first five years after the injection. Hence, these agents value liquidity due to the anticipation of ending up hand-to-mouth in future periods.

We thus conclude that liquidity constraints in our model distort the majority of homeowners' consumption choices, even though most homeowners are not hand-to-mouth.

5.3 Role of Each Friction

Homeowners in our model face several frictions that prevent them from using housing wealth to smooth consumption fluctuations: a fixed cost of obtaining a home equity loan, a limit on the size of the home equity loan, as well as the requirement that they build equity in their home over time. We next study the relative importance of each of these frictions by tracing out the effect of changing each parameter in isolation on the model's steady state implications.

Fixed Cost of Home Equity Loans. Figure 3 reports how the key implications of the model change as we vary the fixed cost F_X. The vertical lines show the corresponding values in our Benchmark parameterization. Eliminating the fixed cost visibly increases the fraction of homeowners who extract home equity – to about 60% as opposed to 8.6% in our Benchmark, the fraction of homeowners – to 90% as opposed to 63%, as well as the aggregate mortgage debt to income ratio – to about 1.05 as opposed to 0.60.

Also notice that absent this fixed cost, agents would hold much fewer liquid assets, one-third as much as in our benchmark model, owing to their relatively lower return. The fraction of hand-to-mouth homeowners would consequently increase from 21% in our benchmark to 44% absent the cost.

Overall, eliminating the fixed cost of home equity extraction would increase welfare by about 1.2% consumption equivalent units. We also note that housing in our model is almost as illiquid as it would be absent home equity loans altogether. Doubling the fixed cost relative to its Benchmark value reduces the fraction of homeowners who extract home equity to almost zero, but does not greatly reduce welfare, the homeownership rate or the portfolio composition of households. We thus conclude that the 8.6% home equity extraction rate reported by Bhutta and Keys (2016), which our model matches by design, is indicative of fairly severe constraints on U.S. homeowners' ability to tap home equity.

Mortgage Duration. Increasing γ raises mortgage duration by reducing the amount of principal the homeowner must repay each period. Figure 4 shows that varying γ from 0.92 to 1 raises the mortgage half-life from 6.5 to 28 years, raises the homeownership rate from 45% to almost 90%, raises the mortgage debt to income ratio from 0.25 to 1.05, and has a fairly limited impact on the households' liquid assets. Household welfare increase by about 0.4% consumption units when we replace the mortgage contracts in our benchmark model ($\gamma = 0.97$) with interest-only mortgages ($\gamma = 1$). The requirement that homeowners pay down their principal over time thus substantially exacerbates the severity of liquidity constraints.

Limit on Size of Home Equity Loans. Figure 5 traces out the effect of varying the limit on home equity loans, θ_X. We note that changing this limit has a relatively small impact. Eliminating it altogether raises the homeownership rate from 63% in our Benchmark to 71%, the mortgage debt to income ratio from 0.60 to 0.75, and reduces the liquid asset to income ratio from 0.33 to 0.30, raising welfare by only 0.12%. Intuitively, the wedge between the interest rate on debt and the liquid asset prevents homeowners from extracting too much home equity even when we completely eliminate the limit on home equity loans.

Payment to Income Constraint. We show in the Appendix that this constraint does not bind much in the vicinity of the 0.35 ratio we have assumed in our Benchmark model. Even reducing the payment to income constraint to 0.15 only reduces welfare by about 0.05%.

5.4 Additional Implications

We have shown that a substantial number of homeowners are liquidity constrained. This result has both normative and positive implications. We next illustrate these by studying the effect of mortgage forbearance policies and the economy's responses to a credit shock.

Mortgage Forbearance Policies. Such policies temporarily reduces mortgage payments for homeowners experiencing a transitory spell of low income. Although most lenders in the U.S. have such programs, these are limited in scope.[20] This observation motivated a 2010 proposal by the Mortgage Bankers Association (MBA) that requested federal funding for a program that would have reduced required mortgage payments to at most 31% of a homeowner's income for a period of up to 9 months. Under this proposal, the arrears would be added to the mortgage principal and thus extend the mortgage duration.[21] We next evaluate the effect of introducing such a policy, by changing the minimum mortgage payment to

$$\min\left[\nu y_{i,t}, (1-\gamma+r_M)b_{i,t}\right],$$

limiting required mortgage payments to a fraction ν of one's income, $y_{i,t}$. Table 7 shows the impact of varying ν from 30% to 10% on the model's steady state implications.

The policy has a limited impact for values of ν equal to 30% or 20% because too few agents choose a house size large enough for the payment-to-income ratio to exceed 30% or

[20] See our Appendix for more details on existing forbearance policies.
[21] See http://money.cnn.com/2010/02/24/real_estate/forbearance_for_unemployed/.

20% too often. When, in contrast, the policy is sufficiently generous so that $\nu = 10\%$, its impact is small, yet non-negligible: it increases the steady state homeownership rate from 63 to 77% and overall welfare by 0.2%.[22] Our model therefore predicts fairly limited gains from such policies. Intuitively, liquidity constraints mostly bind in our model for agents with relatively low mortgage balances, whose required payments are low. For example, the average valuation of liquidity is about 60% larger for homeowners in the lower half of the LTV distribution relative to those in the upper half. Mortgage forbearance policies, in contrast, are aimed at high LTV homeowners, who are relatively less liquidity constrained.

Response of Consumption to Credit Shocks. Motivated by the 2001-2009 boom-bust episode in the U.S. mortgage market, a number of researchers have studied the response of consumption to credit shocks.[23] We next study how liquidity constraints shape the response of consumption to a credit shock in our model.

We study the response of our model economy to a one-time unanticipated doubling of the home equity limit θ_X starting from the steady-state of the model, an experiment motivated by the Mian and Sufi (2011) observation that home equity-based borrowing was an important determinant of the rise of household leverage from 2002 to 2006. Here we do not explicitly model the source of the increase in home equity limits, but rather refer the reader to an earlier draft of this paper, Gorea and Midrigan (2015), in which we have explicitly modeled the change in credit limits as arising from increases in the equilibrium price of houses.

Figure 6 shows how the impact response of consumption and debt in the aggregate varies with the cost of home equity loans, F_X. Clearly, as this cost increases, consumption responds less to the credit shock: it increases by 1.25% absent costs of home equity extraction and only 0.1% when the cost of home equity extraction is prohibitively high. This effect is mechanical: the larger the fixed cost, the fewer homeowners extract equity and increase consumption.

The response of debt to the credit shock is, in contrast, hump-shaped in the size of the cost of home equity extraction due to two conflicting forces that shape the households' debt choices. On one hand, raising the fixed cost increases the homeowners' valuation of liquidity and they borrow not just for current consumption, but also to replenish their stocks of liquid

[22]These values of ν are not directly comparable to the 31% MBA number because in our model mortgage payments are net of the income tax deduction as well as inflation, whereas the MBA proposal refers to pre-tax and pre-inflation payments, which are larger.

[23]Mian and Sufi (2011, 2015), Eggertsson and Krugman (2012), Huo and Ríos-Rull (2014), Kaplan et al. (2015), Guerrieri and Lorenzoni (2015), Berger et al. (2015) and Midrigan and Philippon (2016).

assets. This force increases the amount agents borrow in response to a relaxation of credit limits, an effect that dominates when the cost of home equity loans is sufficiently low. On the other hand, as the fixed cost increases, fewer and fewer homeowners extract home equity and take advantage of the larger loan limits, which depresses the increase in debt.

The third panel in Figure 6 reports how the elasticity of consumption to debt $\Delta C/\Delta\text{Debt}$ varies with the cost of home equity extraction. This elasticity is highest, 0.6, when the cost is equal to 0, and falls to about 0.15 in our Benchmark parameterization. A 100 dollar increase in household mortgage debt is thus accompanied by only a 15 dollar increase in consumption spending. Liquidity constraints thus help rationalize the observation in Midrigan and Philippon (2016) that the large expansion of household debt during 2001-2006 was accompanied by a much smaller increase in consumption spending across U.S. states.

6 Robustness

We next discuss the robustness of our results to changes in parameters governing the return and limit on liquid assets, the intertemporal elasticity of substitution, as well as the volatility of transitory income shocks. We show that our conclusion that liquidity constraints in the U.S. housing market are sizable is robust to perturbations in these parameters.

6.1 Return on Liquid Asset

We report, in Panels A and B of Table 8, how the moments and parameter values change when we increase the interest rate on liquid assets from 0.1% in our Benchmark model to 1.25% and 2.5%, respectively. We keep all the assigned parameters unchanged and re-calibrate the endogenous ones by targeting the same set of moments used earlier. We only report a subset of the moments used in calibration – we replicate the remaining ones, including the homeownership rate and frequency of home equity extraction perfectly.

As the interest rate on liquid assets increases, both mortgage debt and liquid assets increase in the aggregate, to levels much closer to those in the data. Overall wealth, in contrast, changes little. Reducing the wedge between the mortgage and liquid rates thus allows us to better match the aggregate balance sheets of homeowners.

Panel A of Table 8 shows, however, that increasing the return on liquid assets substantially worsens the model's ability to match the lower tail of the distribution of liquid assets, which our Benchmark model matches well. For example, the median liquid assets of homeowners is equal to 0.15 of aggregate per-capita income in the data (0.22 in our Benchmark), but increases to 0.30 and 0.44 when we increase the return on liquid assets to 1.25% and 2.5%, respectively. Moreover, as Panel C of Table 8 shows, the fraction of hand-to-mouth households falls almost in half.

Panel C of Table 8 reports these models' predictions for the welfare costs of liquidity constraints. These fall from 1.19% in our Benchmark calibration to 0.96% and 0.61%, reflecting the counterfactually higher liquid asset holdings at the lower end of the distribution.

6.2 Wedge Between Borrowing and Savings Rate

We now introduce a wedge between the rate at which agents can borrow on the liquid asset, r_H, and the rate at which they can save, r_L. We set $r_H = 6.5\%$ based on the evidence in Davis et al. (2006) on the after-tax real credit card borrowing rates and leave $r_L = 0.1\%$ and all other parameters unchanged at their original values. Table 9 reports results for three versions of this model. We first assume, as in our Benchmark model, a constant unsecured credit limit $\underline{a}$. We then assume that this limit increases with the agents' income and consider larger and larger unsecured credit limits. Since the model's key moments do not visibly change when we introduce a wedge between the borrowing and savings rate, we leave all other parameters, including the ones we have previously endogenously calibrated, unchanged.

Constant Credit Limit. Consider first the economy with a constant unsecured credit limit $\underline{a}$. Table 9 shows that adding a wedge between the savings and borrowing rate on the liquid asset has little effect on the model's implications. Although liquid asset holdings increase slightly, owing to a mass of agents with zero liquid assets, the effect is negligible. For example, the 25th percentile of the liquid asset distribution increases from -0.01 to 0.01. Similarly, the average liquid assets increase from 0.33 to 0.34.

The table shows that the model's implications for the severity of liquidity constraints change little as well. The fraction of hand-to-mouth homeowners falls slightly, from 21% to 19%, of which 14% are at the debt limit $\underline{a}$, and 5% are at the kink with zero liquid assets. The statistics that capture the severity of liquidity constraints are virtually unchanged, as are the welfare losses, which are equal to 1.19%. We conclude that adding a wedge between the borrowing and savings rate on the liquid asset does not change our results much.

Larger Unsecured Credit Limit. We have so far assumed a constant unsecured credit limit $\underline{a}$, equal to 3.6% of per-capita aggregate income (\$990), a number we chose to match the 10th percentile of liquid assets in the data. Many homeowners, however, have much larger amounts of unsecured credit in the data. As Panel B of Table 9 shows, the 5th percentile of liquid assets of homeowners is equal to −12% of aggregate per-capita income (−\$3,300), the 3rd percentile is -22% $(-\$6,100)$, while the 1st percentile is -52% $(-\$14,300)$.

We next allow homeowners to borrow up to a fraction of their lowest possible income realization next period, $\underline{y}(z) = \lambda_R z^{\rho_z} \exp(\varepsilon_1 + e_1)$, where ε_1 and e_1 are the lowest draws of the persistent and transitory income shocks in our quadrature-based approximation. The last two columns of Panels A and B of Table 9 show how the key moments change as we increase the liquid credit limit to 50% and 90% of $\underline{y}(z)$. These two numbers are approximately chosen to reproduce the 3rd and 1st percentiles of the homeowner's liquid assets.

Clearly, the model now predicts much more negative liquid asset holdings at the bottom of the distribution and a greater fraction (up to 1/3) of hand-to-mouth homeowners. Most of the aggregate moments change little, however. Importantly, as Panel C of Table 9 shows, the welfare costs of liquidity constraints only fall from 1.19% to 1.14% and 1.07%, respectively. Intuitively, since unsecured debt is relatively expensive, this option does not greatly increase homeowners' ability to smooth consumption. We conclude that our results are robust to raising the unsecured credit limit.

6.3 Elasticity of Intertemporal Substitution

In our Benchmark parameterization we have assumed a unitary EIS. In our Appendix we report the effect of reducing the EIS in half. We find that the welfare costs of liquidity constraints fall only slightly when we reduce the EIS, from 1.19% to 0.98%. This drop reflects changes in all other endogenously chosen parameters needed to allow the model to match the data, including the discount rate and the weight of housing in preferences.

6.4 Volatility of Transitory Income Shocks

One additional concern we have is that our income process may be measured with noise, which would bias upwards our estimate of the volatility of transitory income shocks ($\sigma_e = 0.31$). In our Appendix we report the effect of reducing σ_e in half and to zero, respectively. We find that the welfare costs of liquidity constraints fall somewhat, but are nevertheless high, 0.95% and 0.81%, respectively. Our results are therefore not driven by the large volatility of transitory income shocks we have assumed.

7 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 75% of homeowners are liquidity constrained and are willing to pay an average of 8 cents for the right to extract an additional dollar from their home. Removing constraints on home equity extraction would raise welfare by the equivalent of a 1.2% permanent increase in consumption. Mortgage forbearance policies have a limited impact, owing to the prevalence of liquidity constraints among homeowners with low mortgage payments. Liquidity constraints also shape the response of consumption to aggregate credit shocks: consumption in our model comoves much less with household debt than in economies without constraints on home equity extraction.

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Table 1: Liquid Assets of US Households. 2001 SCF

	All HHs	Richest 20%	Poorest 80%
mean income	36,000	68,000	27,500
mean wealth	177,700	696,900	39,800
mean liquid assets	113,800	494,100	12,600
fraction homeowners	0.71	0.97	0.64
Lower tail of distribution of liquid assets. All households			
10th percentile	-656	23,700	-1,200
25th percentile	154	71,300	0
50th percentile	5,110	171,200	2,000
Lower tail of distribution of liquid assets. Homeowners			
10th percentile	-386	22,600	-1,060
25th percentile	1,170	69,800	278
50th percentile	11,500	165,900	4,230
Share of housing equity in homeowner's wealth			
25th percentile	0.46	0.24	0.64
50th percentile	0.77	0.43	0.87
75th percentile	0.96	0.70	0.99

Note: All statistics adjusted for HH size using OECD equivalence scales and reported in 2001 US Dollars. See Section 2.1 for a description of the variables we use.

Table 2: Parameterization

A. Moments Used in Calibration

	Data	Model
Aggregate wealth to income	1.45	1.55
Aggregate housing to income	1.82	1.83
Aggregate mortgage debt to income	0.83	0.61
Aggregate liquid assets to income	0.46	0.33
Fraction homeowners	0.64	0.63
Fraction homeowners with a mortgage	0.71	0.72
Fraction homeowners who sell house	0.051	0.051
Fraction homeowners who extract equity	0.086	0.086
Mean amount extracted relative initial balance	0.23	0.23

B. Parameter Values

Assigned			*Calibrated*		
T	66	Number of years to live	F_S	0.060	Fixed cost of selling house
J	40	Period of retirement	F_X	0.021	Fixed cost of home equity loan
r_M	0.025	Mortgage interest rate	F_M	0.055	Fixed cost of new mortgage
γ	0.969	Coupon depreciation	θ_X	0.143	Limit on home equity loan
θ_M	0.917	Maximum LTV	β	0.947	Discount factor
θ_Y	0.35	Maximum PTI	α	0.920	Preference weight consumption
r_L	0.001	Liquid interest rate	R	0.036	Rental rate on housing
$\underline{a}$	0.036	Liquid credit limit (rel. aggregate y)			
μ_z	-0.295	Mean log initial income draw			
λ_R	0.717	Relative income in retirement			
ρ_z	0.938	AR(1) persistent income component			
σ_z	0.200	S.D. persistent income component			
σ_e	0.307	S.D. transitory income shocks			

Table 3: Moments Not Used in Calibration

	Data	Model		Data	Model
A. Liquid assets / Aggregate income. Renters			*B. Liquid assets / Aggregate income. Homeowners*		
10th percentile	-0.05	-0.04	10th percentile	-0.04	-0.04
25th percentile	0.00	-0.04	25th percentile	0.01	-0.01
50th percentile	0.01	0.03	50th percentile	0.15	0.22
75th percentile	0.15	0.15	75th percentile	0.68	0.58
90th percentile	1.00	0.34	90th percentile	1.69	1.21
C. Housing value / Mean income homeowners			*D. LTV ratio. Borrowers*		
10th percentile	0.67	0.87	10th percentile	0.19	0.13
25th percentile	1.30	1.21	25th percentile	0.40	0.37
50th percentile	2.18	1.74	50th percentile	0.64	0.67
75th percentile	3.33	2.47	75th percentile	0.79	0.80
90th percentile	4.93	4.16	90th percentile	0.92	0.88
E. Share housing equity in homeowner's wealth			*F. Wealth / Aggregate Income*		
10th percentile	0.36	0.54	10th percentile	0.00	-0.04
25th percentile	0.64	0.69	25th percentile	0.04	0.09
50th percentile	0.87	0.84	50th percentile	0.73	0.61
75th percentile	0.99	1.01	75th percentile	2.34	2.08
90th percentile	1.04	1.06	90th percentile	3.94	4.60

Table 4: Severity of Liquidity Constraints

A. Borrowing Constrained Homeowners

	% homeowners	% constrained
All homeowners	100	86.0
Inactive	83.5	87.2
Extract home equity	11.1	83.0
Purchase new home	5.4	73.9

B. Hand-to-Mouth Households

	All agents	Homeowners	Renters
Fraction hand-to-mouth	0.25	0.21	0.33
Median shadow rate if htm, %	14.7	12.6	18.5

C. Insurance Coefficients and Welfare Cost

	All agents	Homeowners	Renters
Persistent shocks, ϕ^P	0.27	0.32	0.17
Transitory shocks ϕ^T	0.72	0.79	0.55
Welfare cost, cons. equiv.	1.19%		

Table 5: Value of Liquidity

A. Value of Liquidity, p

	$\Delta b \leq 0.01h$	$\Delta b \leq 0.10h$
Fraction $p > 0$	0.70	0.76
Value of liquidity $p \mid p > 0$		
mean, %	10.2	7.9
25th percentile, %	3.2	2.9
50th percentile, %	6.8	6.4
75th percentile, %	13.4	11.4
90th percentile, %	24.3	16.8

B. Value of Liquidity by Type of Homeowner

	$\Delta b \leq 0.01h$	$\Delta b \leq 0.10h$
I. Marginal		
percent of those with $p > 0$	2.5	15.3
median p, %	19.2	15.9
median $\Delta c/\Delta b$	-5.3	-0.14
II. Hand-to-mouth		
percent of those with $p > 0$	26.5	20.8
median p, %	19.1	10.4
median $\Delta c/\Delta b$	1	0.47
III. Not marginal and not hand-to-mouth		
percent of those with $p > 0$	71.0	63.9
median p, %	5.0	4.3
median $\Delta c/\Delta b$	0.08	0.09

Table 6: Comparison with Bewley Model

	Benchmark	Bewley, $r_L =$		
		-1.25%	0.1%	1.25%
mean liquid assets	0.33	0.47	0.68	0.98
median liquid assets	0.10	0.11	0.19	0.27
fraction HtM	0.25	0.20	0.14	0.12
ϕ persistent	0.27	0.19	0.22	0.26
ϕ transitory	0.72	0.61	0.67	0.72

Table 7: Effect of Mortgage Forbearance Policies

	Benchmark	$\nu =$		
		0.3	0.2	0.1
aggregate housing to income	1.83	1.86	1.92	2.16
aggregate mortgage debt to income	0.60	0.63	0.70	0.95
fraction homeowners	0.63	0.64	0.66	0.77
fraction homeowners who extract	0.086	0.086	0.085	0.069
welfare gains, cons. equiv., %	-	0.01	0.03	0.20

Table 8: Robustness: Vary Interest Rate on Liquid Asset

A. Wealth Moments

	Data	$r_L = 0.1\%$	$r_L = 1.25\%$	$r_L = 2.5\%$
I. Aggregate Moments				
wealth to income	1.45	1.55	1.59	1.52
housing to income	1.82	1.83	1.82	1.77
mortgage debt to income	0.83	0.61	0.67	0.84
liquid assets to income	0.46	0.33	0.43	0.59
II. Distribution of Liquid Assets, rel. aggregate income				
10th percentile	-0.04	-0.04	-0.04	-0.04
25th percentile	0.01	-0.01	0.04	0.10
50th percentile	0.15	0.22	0.30	0.44
75th percentile	0.68	0.58	0.75	1.14
90th percentile	1.69	1.21	1.48	2.24

B. Parameter Values

	$r_L = 0.1\%$	$r_L = 1.25\%$	$r_L = 2.5\%$
discount factor, β	0.947	0.946	0.941
cost of selling home, F_S	0.060	0.046	0.024
cost of new mortgage, F_M	0.055	0.063	0.087
cost of extracting, F_X	0.021	0.019	0.018
limit on amount extract, θ_X	0.143	0.157	0.162
preference housing, α	0.920	0.921	0.918
rental rate housing, R	0.036	0.036	0.039

C. Severity of Liquidity Constraints, Homeowners

	$r_L = 0.1\%$	$r_L = 1.25\%$	$r_L = 2.5\%$
Fraction borrowing constrained	0.86	0.92	1
Fraction hand-to-mouth	0.21	0.16	0.12
Fraction who value 1% injection	0.70	0.75	0.92
Mean valuation of 1% injection, %	10.2	8.3	7.6
Welfare cost, cons. equiv., %	1.19	0.96	0.61

Table 9: Robustness: Higher Interest Rate Liquid Credit, $r_H = 6.5\%$

A. Moments Used in Calibration

	Data	$\underline{a} = 0.036$	$\underline{a} = 0.5\underline{y}(z)$	$\underline{a} = 0.9\underline{y}(z)$
aggregate wealth to income	1.45	1.56	1.58	1.55
aggregate housing to income	1.82	1.82	1.87	1.87
aggregate mortgage debt to income	0.83	0.61	0.62	0.60
aggregate liquid assets to income	0.46	0.34	0.33	0.28
fraction homeowners	0.64	0.62	0.63	0.63
fraction homeowners with mortgage	0.71	0.72	0.71	0.70
fraction homeowners who sell house	0.051	0.051	0.049	0.049
fraction homeowners who extract	0.086	0.083	0.073	0.062
median extracted / initial balance	0.23	0.23	0.23	0.22

B. Distribution Liquid Assets Owners. Scaled by Aggregate Income

	Data	$\underline{a} = 0.036$	$\underline{a} = 0.5\underline{y}(z)$	$\underline{a} = 0.9\underline{y}(z)$
1st percentile	-0.52	-0.04	-0.28	-0.49
3rd percentile	-0.22	-0.04	-0.21	-0.33
5th percentile	-0.12	-0.04	-0.18	-0.32
10th percentile	-0.04	-0.04	-0.12	-0.20
25th percentile	0.01	0.01	0	-0.05
50th percentile	0.15	0.24	0.18	0.13

C. Severity of Liquidity Constraints, Homeowners

	$\underline{a} = 0.036$	$\underline{a} = 0.5\underline{y}(z)$	$\underline{a} = 0.9\underline{y}(z)$
Fraction borrowing constrained	0.84	0.85	0.86
Fraction hand-to-mouth	0.19	0.29	0.34
with $a' = 0$	0.05	0.05	0.05
Fraction who value 1% injection	0.70	0.71	0.73
Mean valuation of 1% injection, %	10.1	9.9	10.0
Welfare cost, cons. equiv., %	1.19	1.14	1.07

Figure 1: Example of Individual Life-Cycle

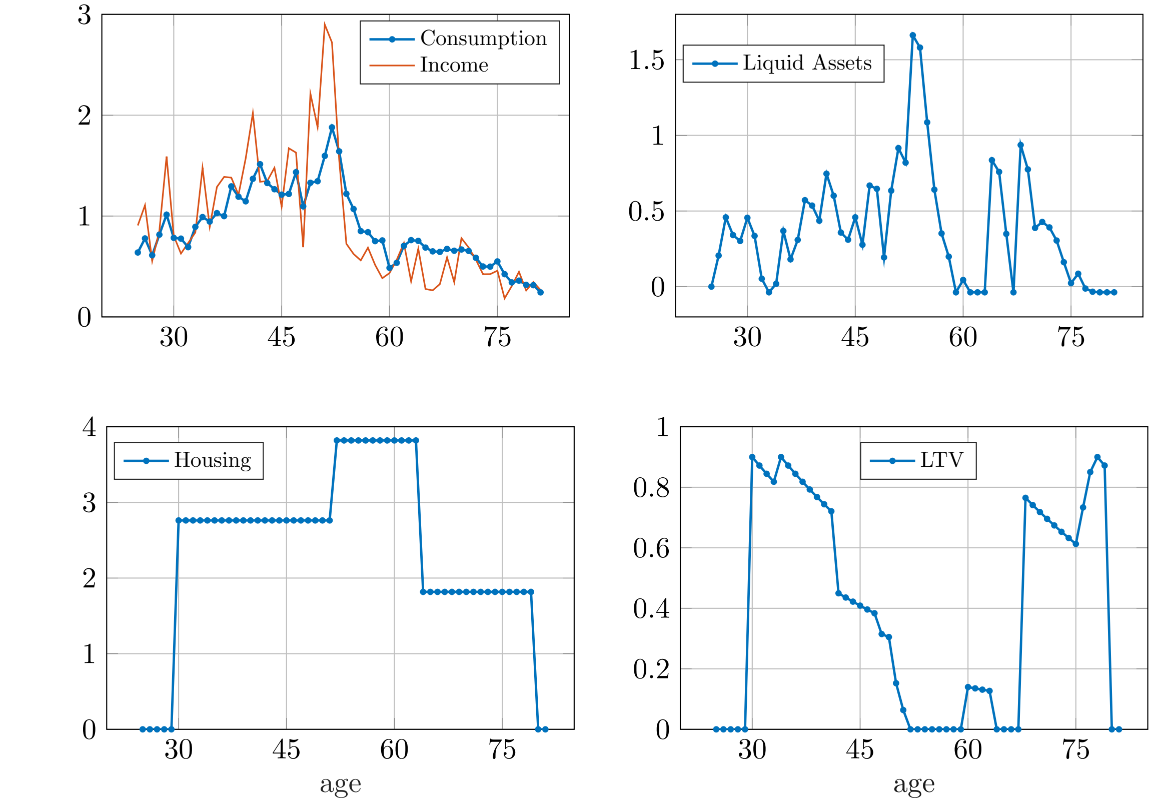

Figure 2: Consumption Response to Liquidity Injection

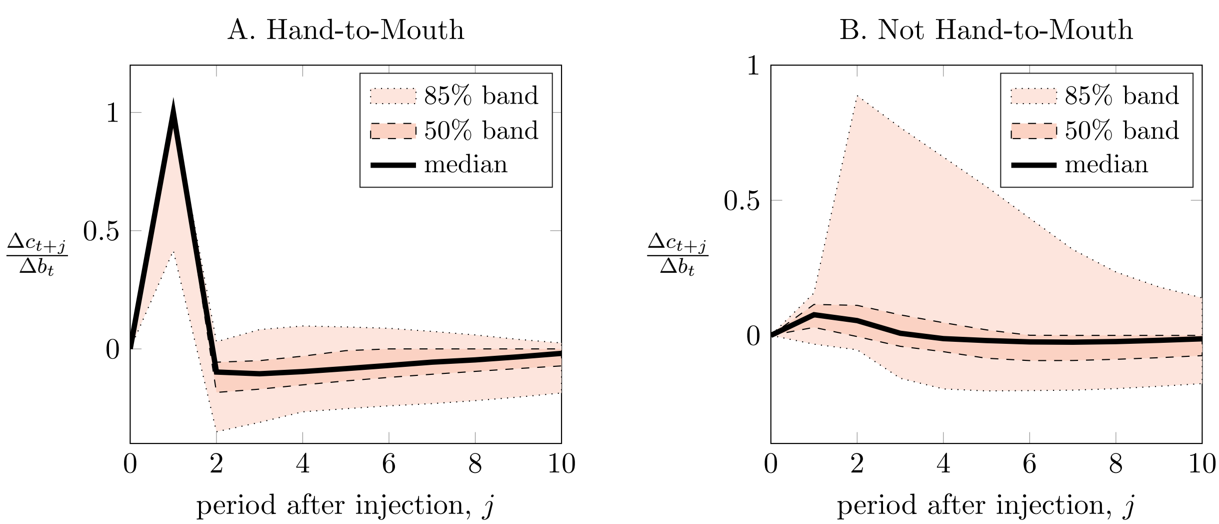

Figure 3: Vary Cost of Home Equity Loan, F_X

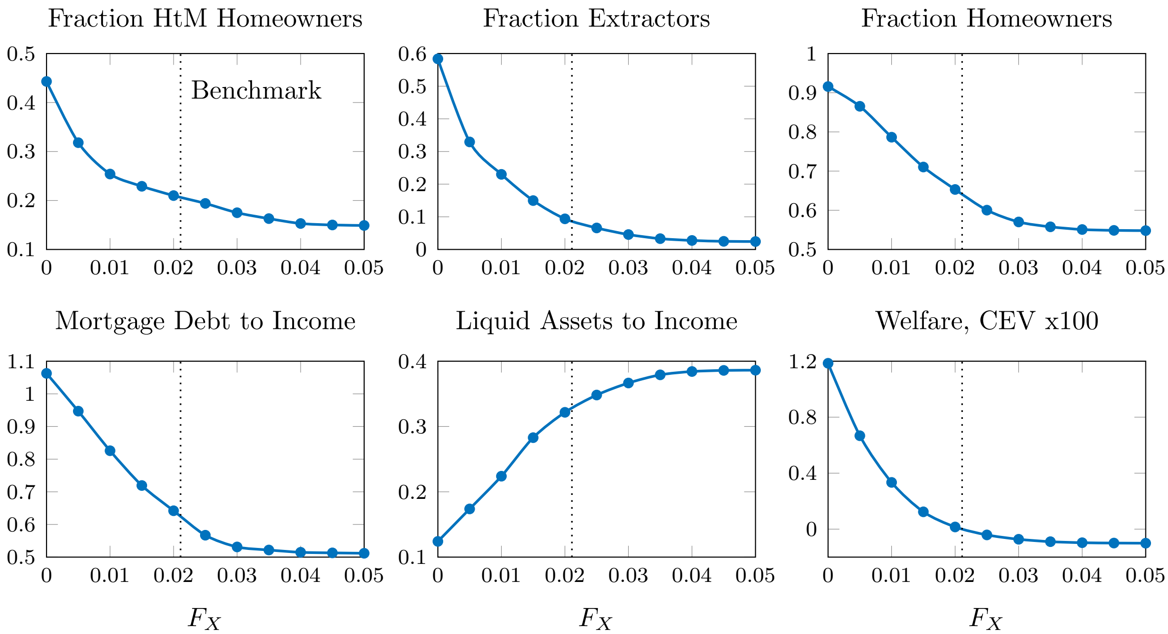

Figure 4: Vary Mortgage Duration, γ

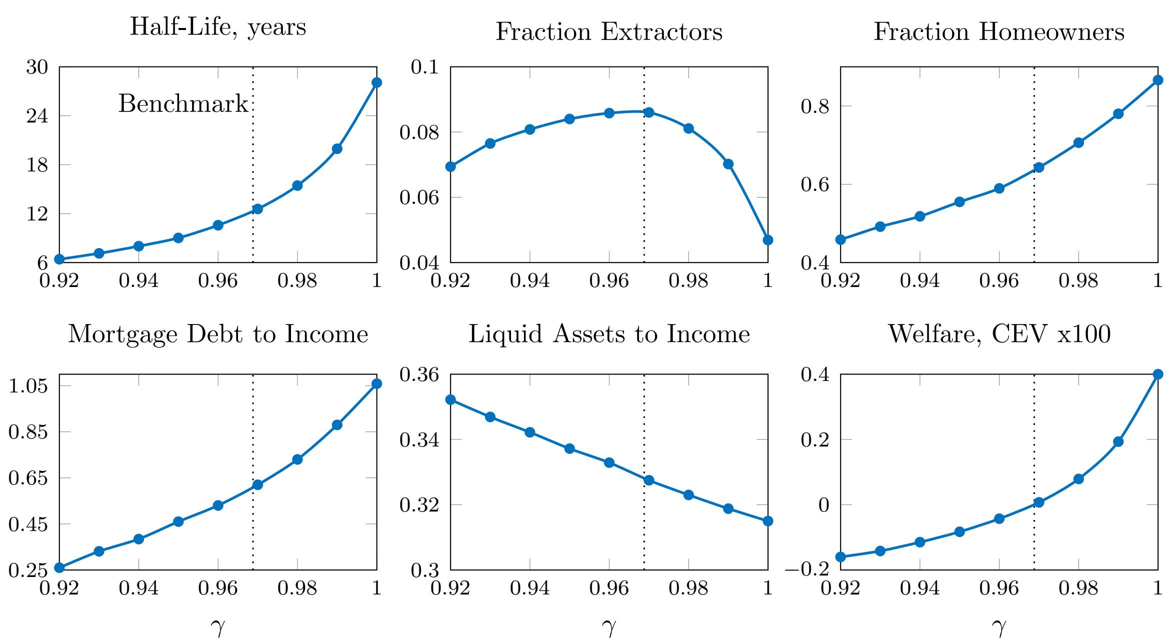

Figure 5: Vary Limit on Home Equity Extraction, θ_X

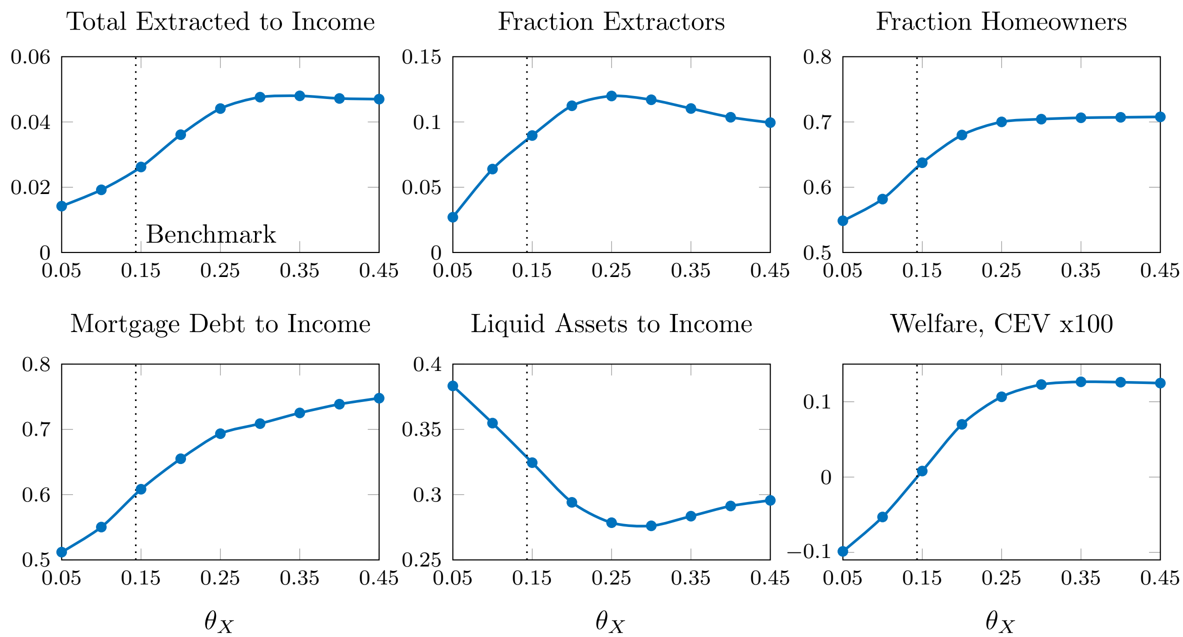

Figure 6: Impact Response to a Credit Shock