Online Appendix
Not For Publication

Liquidity Constraints in the U.S. Housing Market

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Contents

This appendix describes in great detail the datasets and procedures that we have used to compute the moments and the assigned parameters in our paper. It also provides more details on the computational routines used to solve our model and presents further robustness checks that were not included in the main text.

1 Income process

We use data from the *Single-year Family Files* of the Panel Study of Income Dynamics to estimate the parameters of the income process. Starting in 1999, the PSID waves are released at a biennial frequency. It's important to note that the year of release is not the year for which the data have been collected. For example, the PSID wave for 1999 would actually report data for 1998. For each wave between 1999 and 2007, we use the nationally representative SRC sample of the PSID to create measures of annual income stemming from labor or transfers. For observations that are not reported at the annual level, we convert the income measures using additional information on the frequency with which each type of income is obtained. We drop observations for which the age, education and marital status of the head is not reported.

After constructing the income variables of interest, we use Taxsim to compute the tax liabilities of each household in our sample. We provide Taxsim with the state of residence for each household in order to get a measure of state taxes that households are liable for. Married household heads are assigned the joint filing status. Unmarried households that have children residing within the household are assigned a household head status in Taxsim. All the other households are considered filing separately. To compute household income before taxes, we specify in Taxsim the 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 if married. After running Taxsim, we get a measure of state and federal taxes that we subtract from our measure of total pre-tax household income. We then adjust after-tax income for inflation using the CPI index, where the base year is 1998. Lastly, we apply the OECD equivalence scale to get our final measure of per capita deflated disposable income.

Next, we use the *Cross-year Individual File* of the PSID to generate an unique ID that combines the personal number of each individual ever surveyed in the PSID with the family identifier of the household in which this individual resides in a given year. We need to create this new ID because the *Single-year Family Files* used to compute our measure of disposable income don't record an identifier that could help us track the same household across different PSID waves. For each wave between 1999 and 2007, we keep only the household heads that are still living with their family and merge this data with data on disposable income that we computed earlier. We drop the observations for which the age of the head is inconsistent between the *Cross-year Individual File* and the *Single-year Family Files*. We also drop observations that are splitoffs, namely observations for which the household head moved in or out during the year of survey. We do this in order to make sure that any changes in average household income don't come from households in which the head has changed between two years (i.e., we want to avoid cases in which family income dropped by 50% between two years just because the former head left the family after a divorce). We then pool all the waves together and drop the households that are inconsistent about the age and education of their head across consecutive PSID waves. This data filter guarantees that we keep track of the same household head and their household unit across time (e.g., age of head does not grow by more or less than two years between two survey waves). The result of pooling the waves together is a panel dataset that is used to compute the parameters of the income process required for our model.

We restrict our sample to households for which the household head is between 25 and 85 years old. We also ensure that our panel is balanced by focusing only on the households for which we have all observations for the 1999-2007 PSID waves. After applying these two data filters, we regress log income on a constant, age of head, age of head squared and a time dummy for all households whose head is 64 years old or less:

$$\log\left(\text{income}\right)_{it} = \alpha + \psi_1 \text{age} + \psi_2 \frac{\text{age}^2}{10} + \delta_t + \varepsilon_{it} \tag{1}$$

where ψ_1 and ψ_1 are the parameters of interest that generate the hump-shaped profile of earning in our model. We also regress log income on a constant and a time dummy for households whose household head is 65 years old or above. The coefficient on the constant in this regression is the mean log income for retirees in our model. We use the difference between this mean and the mean of fitted values for age 64 in Regression (1) to compute the log change in income at retirement (ψ_3).

Aside from the age-specific part of the income process, we also estimate the variance and autocovariances (1st and 2nd) of the residuals $\overline{\varepsilon_{i,t}}$, in the regressions of log income described above. We use these moments to pin down the variance of the permanent and transitory income components, σ_z^2 and σ_e^2, as well as ρ_z in our model.

When computing the variance and autocovariance from our panel, we exclude the residuals for observations that we qualify as outliers. In this sense, we compute for each household the difference between observed log income and mean log income across time ($\Delta_{it} = \log\left(\text{income}\right)_{it} - \overline{\log\left(\text{income}\right)_{i}}$). When estimating the variance and the autocovariance we exclude the observations that are in the top and bottom 1 percent of the distribution of these differences (Δ_{it}).

To ensure that we don't understate or overstate income risk that retirees face, we repeated the regressions above when retirees are included in the sample. Aside from the factors used in Regression (1), we also add a dummy equal to one if the household head is aged 65 or above. After we estimate the regression, we divide the sample into workers and retirees and compute the variance, first and second autocovariances of the residuals, as well as the standard deviation of the first difference in residuals. Table 1 presents the results of this exercise. Our findings suggest that income risk is very similar across the two groups of households: workers and retirees.

2 Moments

Data from the Survey of Consumer Finances (SCF) is used to compute the majority of moments to which we calibrate our model. The SCF data comes in two formats: (i) *Full Public Data Set* that contains all variables except for the private ones that could identify the reporting household, (ii) *Summary Extract Public Data* which consists of a sample of summary measures computed by the FRB Staff. We combine these two datasets for the purpose of this study, because some data needed to compute the moments used for calibration is not readily available in the *Summary Extract Public Data*.

Most of our moments have income as a common denominator. We compute disposable income using SCF data in a similar way we did for PSID data. Namely, we specify various income components from the Summary Extract Public Data file for each wave and run Taxsim in order to calculate the tax liabilities. We split household wage and business income in two unequal parts, awarding 75% of total income to the head of the household. We then assume that each of earners allocates 6% of their income towards pension contributions. Next, we use the reported measures for social security benefits as well as transfers to proxy for other incomes that the household receives every year. We run Taxsim and subtract the resulting federal tax from pre-tax income.[1] The final output of this routine is a measure of after-tax income. We also use the *Full Public Data Set* to compute the rent paid by households each year. Rent and the after tax income are then equivalized using the OECD equivalence scales.

Aside from income, our moments rely on some measure of household wealth (e.g., net worth, liquid assets, mortgage debt, etc.). Our measure of housing assets is based on the value of the primary residence alone. Liquid assets are the sum of checking accounts, saving accounts, money market deposits, money market mutual fund accounts, certificates of deposit, directly held pooled investment funds, saving bonds, stocks, other residential real estate, nonresidential real estate net of mortgages, and other non-financial assets.[2] Mortgage debt is the sum of all mortgages on the primary residence (including home equity loans and

[1] State taxes are not computed by Taxsim because SCF does not report in the publicly available files the state in which each household resides at the time of survey.

[2] Other non-financial assets include oil and gas leases, futures contracts, royalties, proceeds from lawsuits or estates in settlement, and loans made to others.

outstanding balances on home equity lines of credit).[3] Liquid debt is the sum of the credit card balances and other mortgage debt on secondary real estate. Housing net worth is the value of the primary residence less any mortgage debt on this residence. Each of these wealth statistics is equivalized using OECD equivalence scales. Lastly, we exclude households whose head is not aged between 25 and 85 years when computing the moments using SCF data, as well as households who have net worth above the 80th percentile of the net worth distribution.

3 Housing turnover

We follow Berger and Vavra (2015) when it comes to computing the share of homes that have been transacted in the total number of homes available in the U.S. Data on existing home sales comes from the National Association of Realtors (NAR). We add to that the number of new homes that have been sold in a given year to come up with the total number of houses that have been transacted. Data on new one family homes that have been sold is sourced from the U.S. Bureau of the Census. From the same source we obtain the total housing stock in a given year. We divide total number of homes that have been transacted by total housing stock to obtain a measure of housing turnover.

4 Secondary homes vs. primary residences

We chose to include other residential real estate in our measure of liquid assets, as opposed to having it be part of the housing assets, for the following reasons. First, as described in the main text, very few homeowners own a secondary home in the data and adding the secondary home to the housing wealth would change our moments by very little.[4] Second, and more importantly, according to the breakdown provided by National Association of Realtors (2014) secondary homes are very different in nature from primary residences:

- A buyer of a secondary home intends to keep it for a median duration of 5-to-6 years, as opposed to a duration of 8 years for buyers of primary residences. As a consequence, the market for secondary residences should have a higher turnover rate.
- On average only 30 percent of secondary home sales are used as vacation properties, while the rest of the secondary home sales are used as investment properties that earn

[3] We include the second lien loans in our calculations of mortgage debt in order to ensure that we capture all household debt. In the 2001 SCF data, second lien loans are held by households whose income is 1.5 times larger than the average income. These households also have a higher wealth relative to aggregate income when compared to all others (2.05 for those who have second liens vs. 1.45 for all households in the sample).

[4] In the 2001 SCF wave, only 11.3 percent of all families owned other residential properties aside from the primary residence, which represented 4.7 percent of the value of total assets.

returns. Moreover, at least a quarter of the homeowners who own vacation homes purchase them with an intention to rent to others.

- Between 40 and 50 percent of secondary home owners use cash when purchasing such properties, while the ones who use mortgages finance a lower share of the purchase via debt than homeowners getting a mortgage to buy a primary residence. Furthermore, homeowners that own a secondary home also have higher incomes on average than owners of primary residences.

The arguments above support our conjecture that the market for secondary homes is different from the market for primary residences, and likely to be more liquid.

5 Returns on housing and renting

In our benchmark calibration, we obtain a rental rate of 3.6%, close to the population weighted national average net rental yield of 4.3% reported by Eisfeldt and Demers (2015). These authors use data on large institutional investors to compute yields for rental investments. While institutional investors have different investment horizons compared to U.S. households and are subject to different borrowing constraints, it is encouraging to see that our rental rate is within the 2-10 percent interval obtained by Eisfeldt and Demers (2015).

Our rent to price ratio is also consistent with to the annual rent-price ratio in Sommer et al. (2013), Hedlund (2016) and Hedlund and Garriga (2016). Given that our mortgage rate is set at 2.5% , it implies a 44 percent premium (3.6/2.5) between renting and owning (without taking into account the transaction and refinancing costs which would further bring the premium down). This roughly matches the evidence in Trulia (2016), showing that the premium between renting and owning has varied in the interval of 34-40 percent between 2012 and 2016.

6 Forbearance programs

The academic literature on the magnitude of forbearance programs in the U.S. mortgage market is rather scarce. While most commercial banks have guidelines implementing such programs (as well as Fannie Mae and Freddie Mac), there is little evidence on how often these programs are used and how successful they are in curing delinquencies, especially for loan renegotiations prior to 2006. The scarce existing evidence presented below does however point to the fact that forbearance programs are rarely offered to delinquent borrowers.

Adelino et al. (2013) use a contract-change algorithm that compares the properties of a given loan across time to infer whether the loan was modified during 2006-2011. They find that in 2006 only 10000 loans per quarter were modifications (i.e. payment, interest or term have changed) in a dataset that covers 60 percent of the U.S. mortgage market. While their algorithm cannot identify forbearance programs clearly, the low number of modifications per quarter indicate that delinquent mortgage loans were rarely renegotiated before the crisis. They also explore changes in the payment size after loan modifications and find that in 2006, households that received payment reductions after modifications were getting only a 10 percent cut to their payments as a result of the modification (on average). This again highlights that very few households are getting significant payment relief even when they become delinquent on their loans and enter into renegotiation programs with loan providers/servicers.

Agarwal et al. (2011) is another study that relies on loan level data to track loan renegotiations. In contrast to Adelino et al. (2013), Agarwal et al. (2011) observe the renegotiation status reported by loan providers in their dataset. Hence they don't need to rely on any algorithm to track mortgages across time and give a more accurate breakdown of renegotiation arrangements by type. The downside is that they focus only on 2008-2009, a period when a lot of government mortgage assistance programs started being implemented. The big take-away for our purposes is that principal deferral were relatively rare (3 percent of all loan modifications). Term extensions were also a rare renegotiation status (about 15 percent of all loan modifications).

Moreover, when tracking renegotiated loans across time, they find that only 2.6 percent of delinquencies entered a repayment plan within the first 6 months after the start of their delinquency. After six more months, more than half of borrowers in their sample were in liquidation mode, about 23 percent of loans have been renegotiated, and about 25 percent had no action. This highlights, that even during a period with a high number of delinquencies, loan renegotiations were an infrequent solution.

The last piece of evidence that we reviewed comes from Orr et al. (2011). These authors study the effects of the Homeowners Emergency Mortgage Assistance Program (HEMAP), a Pennsylvania state policy that provides forebearance programs to borrowers who become delinquent on their mortgages due to short unemployment spells or are subject to financial hardship beyond their control. HEMAP offers temporary loans so that households in need can keep current on their original loan until they get enough income to repay the HEMAP transition loan. This policy was introduced in 1983, and until 2009, 183 thousand borrowers applied for such a loan. Out of these, only 23 percent were approved for HEMAP. Around 80 percent of loan recipients have retained ownership of their residences, repaying the HEMAP loan and getting current on their old mortgage. Despite its success and being self-sustaining (borrowers pay interest on HEMAP loans), the state of Pennsylvania canceled this forbearance program in 2011.

7 Interest rate wedge

We use data from three sources to set our real interest rate on mortgage debt. First, we obtain the average 30-year fixed mortgage rate for 2001 from the FRED database (6.97%). Second, we multiply this rate by (1-0.2391), where 23.91% is the average 2001 marginal tax subsidy on mortgage interest paid as reported by TAXSIM (federal plus state tax rate subsidy, see http://users.nber.org/~taxsim/marginal-tax-rates/at.html). Lastly, we subtract the 2001 percent change in CPI (2.8%) from the rate obtained above, to arrive at $6.97 \cdot (1 - 0.2391) - 2.8 = 2.5\%$. We obtained the average annual change in CPI from the FRED database (Consumer Price Index for All Urban Consumers: All Items).

We set our real return on the liquid asset r_L based on the evidence in Davis et al. (2006). They report an after-tax risk-free return of 2.9% for 2001 (see their Table 1, row 6), from which we subtract the 2001 change in CPI to arrive at $r_L = 0.1\%$

8 Equity extraction

We use data from four sources to compute our equity extraction moments: (i) median extracted / initial balance, (ii) equity extracted / aggregate income, and (iii) fraction of homeowners that extract equity. The median extracted to initial balance is set to 23.3%, based on the 2001 value of the median percent change in balances for equity extractors reported in Bhutta and Keys (2016) (see their Table 1, column 8). To compute the equity-extracted-to-aggregate-income ratio, we use data on aggregate equity extracted in 2001 from Bhutta and Keys (2016) (see their Appendix Figure 3) and the 2001 aggregate disposable personal income from the FRED database.

Lastly, we make use of data from two additional sources in order to calculate the fraction of homeowners who extract housing equity. Bhutta and Keys (2016) report the fraction of extractors in their sample (see their Table 1, Column 5). Note that their sample is a subsample of the total population, as they include in their analysis only homeowners that haven't moved and that have a mortgage. In order to infer the share of this subsample in the sample of all homeowners, we employ data from the SCF and the PSID. First, we determine the fraction of homeowners who have a mortgage in the 2001 SCF data. Second, we use data from the PSID to determine the fraction of homeowners that did not move in 2001 (based on the 2003 wave, using the answers to the question in which homeowners are asked if they have moved during the previous two years). Lastly, we multiply these two ratios to the share of extractors in Bhutta and Keys (2016), to arrive at the fraction of homeowners that extracted housing equity.

9 Cost of refinancing and closing costs

The average closing costs typically range between 2 to 8 percent of the purchase price (see http://michaelbluejay.com/house/interest.html). These costs include lender-related costs, as well as property-associated expenses. Some of these costs are fixed amounts (e.g., appraisal, credit report, survey and title fees), while others are expressed in percentage terms of the original sale price or mortgage loan size (e.g. origination and insurance fees, property taxes, etc.).

Using the calculator in the link above, we can get a sense of how accurate our estimates of closing and refi costs are. The median sale price of houses sold in 2001 was 173,100 USD according to the FRED database. This would imply lender related costs of 5.2% of sale price or about 33% of average income (computed based on the 2001 SCF data used in our calibration exercise), as well as property related costs of 2.5% of the house price (or 16% of mean 2001 income). These numbers are somewhat higher than the ones assumed by Agarwal et al. (2013) (2000 USD + 1% of mortgage amount closing costs), but are consistent with our parameter values and estimates provided by the Federal Reserve Board (see https://www.federalreserve.gov/pubs/refinancings//#cost).

10 Robustness

In this section we present three robustness checks in which we vary the elasticity of inter-temporal substitution (σ), the standard deviation of the transitory income shock (σ_e) and payment to income constraint (θ_Y). The first two parameters influence the shape of the household's savings and consumption choices while the latter influences that amount it can borrow, and changing them might alter the results of our benchmark model. However, as we show below, varying σ, σ_e and θ_Y has only minor effects on our main results.

10.1 Elasticity of Inter-temporal Substitution

In our Benchmark parameterization we have assumed a unitary EIS. We next consider the effect of reducing the EIS in half, by assuming $u(c,h) = \left(c^{\alpha}h^{1-\alpha}\right)^{1-\sigma}/(1-\sigma)$, and setting $\sigma = 2$. We keep all other exogenously assigned parameters unchanged and recalibrate the endogenous ones by requiring the model to match the original set of moments in the data. Table 2 reports the moments and new parameter values in this experiment.

With a higher value of σ agents prefer a smoother consumption path and find it optimal to hold a more liquid portfolio of assets: notice in Panel A of Table 2 that the model is now capable of matching better the high average holdings of mortgage debt and liquid assets. The better fit in the aggregate comes, however, at the expense of a worse fit at the lower end of the liquid asset distribution. As Table 3 shows, the model now predicts a smaller fraction of hand-to-mouth homeowners: 14% as opposed to 21% in our benchmark.

Interestingly, the welfare costs of liquidity constraints fall when we reduce the EIS, from 1.19% to 0.98%. This drop reflects the change in all other endogenously chosen parameters needed to allow the model to match the data. For example, with a lower σ the model requires a much lower discount factor (0.90 vs. 0.95 originally) and lower weight on consumption in preferences (0.91 vs. 0.92), effects that reduce the welfare loss of liquidity constraints.

10.2 Standard Deviation of Transitory Income Shock

Our income process may be measured with noise. As a consequence, our estimated value for the standard deviation of the transitory income shock might be too high ($\sigma_e = 0.307$ in our benchmark calibration). In this section we report how our results change when we assume σ_e to be equal to half of the original value ($\sigma_e = 0.153$), as well as results for the case of no transitory income shocks ($\sigma_e = 0$). Similar to our robustness check for different EIS, we keep all other exogenously specified parameters unchanged and recalibrate the endogenous parameters so that the model matches the moments in the data.

Panel A of Table 4 reports the moments for our benchmark case and the two sets of values for different σ_e. Most of the moments are similar across the three specifications. The only noticeable difference stems from the aggregate liquid assets to income ratio. As we reduce the standard deviation of the transitory income shock, households find it optimal to hold fewer liquid assets (0.33 in the benchmark vs. 0.23 for $\sigma_e = 0$). As Panel C of the same table points out, the reduction in liquid assets comes primarily from the upper tail of the liquid asset holdings' distribution. The parameter values necessary to produce the moments for the $\sigma_e = 0.153$ and $\sigma_e = 0$ are also similar to the ones in our benchmark case. Across the board, the difference in values comes only in the third digit for each parameter (see Panel B of Table 4).

We also looked into how changes in σ_e affect our results on who values liquidity and the welfare costs of liquidity constraints. Table 5 shows that our benchmark results are robust to changes in the riskiness of the income process. The welfare costs of liquidity constraints are somewhat lower when we reduce σ_e. When future income streams are less risky, fewer households are likely to be liquidity constrained and won't value much any addition to their liquid asset holdings. Nonetheless, even in the case of no transitory income shocks ($\sigma_e = 0$), 64% of the households value a 1% injection and the welfare costs of liquidity constraints are substantial (0.81% vs 1.19% in the benchmark). Hence, we conclude that changes in how we measure the riskiness of the income process σ_e lead only to modest changes in our benchmark results.

10.3 Payment to Income Constraint

The payment to income constraint, θ_Y, limits a homeowner's ability to extract home equity, either when refinancing a new mortgage or taking on a new home equity loan. Figure 1 shows, however, 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% and has a fairly limited effect on all other variables.

11 Computational Appendix

11.1 Overview

The state variables of an individual homeowner are: age j, the liquid assets a, existing housing h, housing debt b, productivity z, and transitory productivity e. Let

$$m = y + (1 + r_L)\, a - (1 + r_M)\, qb + (1 - F_S)\, h$$

denote an agent's total wealth at the beginning of the period. This is simply the total amount of resources available to the agent if it were to sell its home and repay all of its debt. We also define the household's loan to value ratio,

$$\theta = \frac{qb}{h}$$

and use m and θ to summarize the agent's financial position. Using this notation, the budget constraint can be written:

$$c + a' + (h' - h + F_S h)\, \mathbb{I}^S + F_M h' \mathbb{I}^M + F_X h \mathbb{I}^X + Rs = y + (1 + r_L)\, a - \frac{\theta h}{q} + \theta' h' - \gamma \theta h$$

where $\mathbb{I}^S$, $\mathbb{I}^M$ and $\mathbb{I}^X$ are indicator variables for cases when the household sells its home, takes a new mortgage or extract equity respectively. Since $\frac{\theta h}{q} + \gamma\theta h = \frac{1+\gamma q}{q}\theta h = (1 + r_M)\, \theta h = (1 + r_M)\, qb$ is just the outstanding value of the mortgage, including interest, we have

$$c + a' + (h' - (1 - F_S)\, h)\, \mathbb{I}^S + F_M h' \mathbb{I}^M + F_X h \mathbb{I}^X + Rs = m + \theta' h' - (1 - F_S)\, h$$

or

$$c + a' + h' \mathbb{I}^S + (1 - F_S)\, h \left(1 - \mathbb{I}^S\right) + F_M h' \mathbb{I}^M + F_X h \mathbb{I}^X + Rs = m + \theta' h'$$

In this formulation, an agent chooses each period how much to borrow, $\theta' h'$ (with costs of borrowing that depend on whether he takes on a new mortgage or a home equity line of credit) and how much housing to purchase. If the agent buys a new house, she pays h' and if she stays in her existing home, she pays $(1 - F_S)\, h$, thus effectively facing a lower price for staying in the same home.

The value of an agent is

$$V_j\,(m, z, \theta, h)$$

where $h = 0$ denotes someone who has no home and thus was a renter in the previous period. This value is the maximum of 5 options the agent has, each of which we define below. Before we do so, let the expected continuation value be

$$W_j\,(w, z, \theta, h) = \mathbb{E}_{z',e'} V_j\,(m', z', \theta, h)$$

with

$$m' = \lambda_j \exp(z') \exp(e') + (1 + r_L)\, a - (1 + r_M)\, \theta h + (1 - F_S)\, h$$

and

$$w = (1 + r_L)\, a - (1 + r_M)\, \theta h + (1 - F_S)\, h$$

be the total wealth of the agent. After the income shock is realized, the agent's cash on hand is

$$m' = w + \lambda_j \exp(z') \exp(e')$$

Defining the continuation value W is useful computationally because it allows us to compute the integral only once and use W when conducting optimization over the various choices. Also, keeping track of total wealth is rather useful because we do not have to solve the housing choice for different values of θ and h for agents that update their housing stock which is the most expensive part of the computation. For a given m, the level of θ and h is irrelevant for agents that change the size of their house, as can be seen from the budget constraint.

Before we proceed, notice that a renter optimally chooses to set

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

and therefore enjoys utility

$$u\left(c, \frac{1-\alpha}{\alpha} R^{-1} c\right)$$

Thus let

$$\hat{u}\,(c, h') = u\left(c, \frac{1-\alpha}{\alpha} R^{-1} c\right) \text{ if } h' = 0$$

$$\hat{u}\,(c, h') = u\,(c, h) \text{ if } h' > 0$$

Also note that an agent that chooses to remain a renter will have a total expenditure $c + Rs = \frac{1}{\alpha} c$, a feature that we use in defining the budget constraints for renters below.

We solved the dynamic program of the agent using projection methods, by interpolating the value of the household at each age with a combination of cubic (wealth, liquid assets) and linear splines (housing, exogenous income process). We have used Gaussian quadrature to integrate the uncertainty about the transitory and permanent income shocks, as well as to calculate the Markov transition probability required to calculate the ergodic steady state.

We have solved the household's problem in two ways, both of which we describe below. We have found similar results for both approaches we consider, as well as when we increase the number of nodes used in the functional interpolation.

11.2 First Approach: Jointly Solve the Mortgage Debt and Liquid Asset Choice

11.2.1 Options

The different options for an agent are:

1. Keep house size unchanged, do not extract home equity:

$$V_j^1(m, z, \theta, h) = \max_{a', \theta'} \hat{u}(c, h) + \beta W_{j+1}(w', z, \theta', h)$$

subject to

$$c = [m - (1 - F_S) h + \theta' h - a'] [\mathbb{I}_{h>0} + \alpha \mathbb{I}_{h=0}]$$

$$w' = (1 + r_L) a' + (1 - F_S) h - (1 + r_M) \theta' h$$

$$\theta' \leq \gamma\theta$$

Hence, if the agent entered the period with a positive stock of housing, it will continue to be an owner at this node, and thus only spend c units of the good for any given level of consumption. In contrast, an agent that enters the period with no housing will have to rent at this node, and thus spend a total of $\alpha^{-1}c$ units for a given level c of consumption. The budget constraint thus reflects these two different options. We solve this problem sequentially, first guessing an θ' and then solving for a' given the guess for θ'. Consider now the bounds on θ' that agents face. These depend on what individual agents do, so we enumerate these for each of the options separately. Since we require $c > c_{\min}$, (a very small, put positive number, to avoid infinities at $c = 0$) we have

$$\theta' > \frac{1}{h} \max\Big[0, a_{\min} + c_{\min} + (1 - F_S) h - m\Big]$$

Note that in principle this lower bound may exceed the upper bound of $\gamma\theta$, in which case the agent cannot afford to undertake this option. This will happen for households that experience a sequence of large negative income shocks who find they can no longer afford the minimum payments on their original mortgage.

2. Keep house size unchanged, take on a new mortgage

$$V_j^2(m, z, \theta, h) = \max_{a', \theta'} \hat{u}(c, h) + \beta W_{j+1}(w', z, \theta', h)$$

subject to

$$c = [m - (1 - F_S) h + \theta' h - F_M h - a'] [\mathbb{I}_{h>0} + \alpha \mathbb{I}_{h=0}]$$

$$w' = (1 + r_L) a' + (1 - F_S) h - (1 + r_M) \theta' h$$

$$\theta' \leq \min \left[\theta_M, \frac{q \theta_Y \lambda_j \exp(z)}{h} \right]$$

The last part of the minimum function here is the LTI constraint: $\theta' h \leq q \theta_y \lambda_j \exp(z)$. The lower bound on θ' needed to ensure a minimum level of consumption is

$$\theta' > \frac{1}{h} \max \Big[0, a_{\min} + c_{\min} + (1 - F_S) h + F_M h - m \Big]$$

Thus we need to only check the outcomes for agents with

$$q \theta_Y \lambda_j \exp(z) > a_{\min} + c_{\min} + (1 - F_S) h + F_M h - m$$

3. Keep house size unchanged, take on a home equity line of credit:

$$V_j^3(m, z, \theta, h) = \max_{a', \theta'} \hat{u}(c, h) + \beta W_{j+1}(w', z, \theta', h)$$

subject to

$$c = [m - (1 - F_S) h + \theta' h - F_X h - a'] [\mathbb{I}_{h>0} + \alpha \mathbb{I}_{h=0}]$$

$$w' = (1 + r_L) a' + (1 - F_S) h - (1 + r_M) \theta' h$$

$$\theta' \leq \min \left[\gamma \theta + \theta_X, \theta_M, \frac{q \theta_Y \lambda_j \exp(z)}{h} \right]$$

The lower bound on θ' needed to ensure a minimum level of consumption is

$$\theta' > \frac{1}{h} \max \Big[0, a_{\min} + c_{\min} + (1 - F_S) h + F_X h - m \Big]$$

Thus, this option is only available for agents with

$$q \theta_Y \lambda_j \exp(z) > a_{\min} + c_{\min} + (1 - F_S) h + F_X h - m$$

4. Change house size, do not borrow:

$$V_j^4(m, z, \theta, h) = \max_{a', h' > 0} u(c, h') + \beta W_{j+1}(w, z, 0, h')$$

subject to

$$c = m - h' - a'$$

$$w' = (1 + r_L)\, a' + (1 - F_S)\, h'$$

Note that at this node the utility function is evaluated only at $h' > 0$ given our assumption that the end-of-period housing stock enters the utility function. Here we do not need to consider the option to set $h' = 0$ which we allow for separately below. The agent cannot purchase a house bigger than

$$h' < m - a_{\min} - c_{\min}$$

or else it violates the consumption lower bound.

5. Change house size and take on a mortgage

$$V_j^5(m, z, \theta, h) = \max_{a', h' > 0, \theta'} u(c, h') + \beta W_{j+1}(w, z, \theta', h')$$

subject to

$$c = m - (1 + F_M)\, h' + \theta' h' - a'$$

$$\theta' \leq \min\left(\theta_M, \frac{q \theta_Y \lambda_j \exp(z)}{h'}\right)$$

$$w' = (1 + r_L)\, a' + (1 - F_S)\, h' - (1 + r_M)\, \theta' h'$$

We solve this problem by searching over the discrete values in $h' \in [h_{\min}, h_{\max}]$ and then θ'. Consider first the second second step. For any given choice of h', the bounds on θ' are

$$\theta' > \frac{1}{h'}\left[a_{\min} + c_{\min} + (1 + F_M)\, h' - m\right]$$

For the conjectured choice of h' to be feasible, we require that the choice set for θ' be non-empty, so that

$$\frac{1}{h'}\left[a_{\min} + c_{\min} + (1 + F_M)\, h' - m\right] < \theta_M$$

This gives an upper bound on h' where we can search:

$$(1 + F_M)\, h' < (m - a_{\min} - c_{\min} + \theta_M h')$$

Thus we need

$$h' < \frac{1}{1 + F_M - \theta_M}(m - a_{\min} - c_{\min})$$

In addition, we require

$$q\theta_Y \lambda_j \exp(z) > a_{\min} + c_{\min} + (1+F_M) h' - m$$

6. Become a renter:

$$V_j^6(m,z,\theta,h) = \max_{a'} u\left(c, \frac{1-\alpha}{\alpha}\frac{1}{R}c\right) + \beta W_{j+1}(w,z,0,0)$$

subject to

$$c = \alpha[m - a']$$

$$w' = (1+r_L) a'$$

where we have imposed the optimal rental choice.

11.2.2 Bounds on State Variables

Clearly,

$$a' \in [a_{\min}, a_{\max}]$$

where $a_{\max}$ is some large upper bound that we guess and then verify does not bind and $a_{\min} = -\theta_c$. We guess (and then verify these do not bind) that homeowners choose houses in the interval

$$h' \leq h_{\max}$$

Given the bounds on a and the law of motion for

$$m = \lambda_j z e + (1+r_L) a - (1+r_M)\theta h + (1-F_S) h$$

imply that the bounds on wealth are

$$m \in \Big[\lambda_{\min} z_{\min} e_{\min} + (1+r_H) a_{\min},\ \lambda_{\max} z_{\max} e_{\max} + (1+r_L) a_{\max} + (1-F_S) h_{\max}\Big]$$

Also, wealth lies between

$$w \in [(1+r_H) a_{\min},\ \ (1+r_L) a_{\max} + (1-F_S) h_{\max}]$$

Finally, θ must lie in

$$\theta \in \Big[0, \theta_M\Big]$$

where we implicitly assume that the bounds on income and housing are such that θ_M is the one that binds for rich households.

11.2.3 Solution Method

How do we solve for the optimal a' and θ' for a given level of house prices? Notice that all that changes across various options is the amount of wealth the agent has available for consumption. Moreover, the initial LTV θ only matters because it affects the bound on θ' but is inconsequential otherwise.

Thus, let us solve the portfolio choice problem for an agent with ω units of output available for consumption if it were to borrow to the limit. Depending on the option, ω differs.

$$\text{Option 1: } \omega = m - (1 - F_S)\, h' + \theta_M h'$$

$$\text{Option 2: } \omega = m - (1 - F_S)\, h' - F_M h' + \theta_M h'$$

$$\text{Option 3: } \omega = m - (1 - F_S)\, h' - F_X h' + \theta_M h'$$

$$\text{Option 4: } \omega = m - h' + \theta_M h'$$

$$\text{Option 5: } \omega = m - (1 + F_M)\, h' + \theta_M h'$$

$$\text{Option 6: } \omega = m$$

The problem at some node

$$(\omega, z, h')$$

where h' is the housing stock the agent carries into the NEXT period, is

$$\max_{\theta', a'} u\left(\omega - a' + (\theta' - \theta_M)\, h', h'\right) + \beta W_{j+1}\left(w', z, \theta', h'\right)$$

where

$$w' = (1 + r_L)\, a' + (1 - F_S)\, h' - (1 + r_M)\, \theta' h'$$

Before we explain the method, note that we need to restrict ω to ensure the problem is well-defined at all points in the state space. Since $\theta_M < (1 - F_S)$, ω is highest for an agent without housing, so $\omega_{\max} = m_{\max}$. For a lower bound, notice that the agent can get the most consumption if it borrows to the limit, so $\omega \geq a_{\min} + c_{\min}$. Thus, we can restrict

$$\omega \in \left[a_{\min} + c_{\min}, \lambda_{\max} z_{\max} e_{\max} + (1 + r_L)\, a_{\max} + (1 - F_S)\, h_{\max}\right]$$

and search in this interval only.

Having solved for $\theta'(\omega, z, h')$ we turn now to the optimal h' and a' choices at each node in the (m, z, θ, h) space. Consider each option in isolation:

1. Keep house size unchanged, do not extract home equity:

$$V_j^1(m, z, \theta, h) = \max_{a', \theta'} \hat{u}(c, h) + \beta W_{j+1}(w', z, \theta', h)$$

subject to

$$c = [m - (1 - F_S) h + \theta' h - a'] [\mathbb{I}_{h>0} + \alpha \mathbb{I}_{h=0}]$$

$$w' = (1 + r_L) a' + (1 - F_S) h - (1 + r_M) \theta' h$$

$$\theta' \leq \gamma \theta$$

Here

$$\omega = m - (1 - F_S) h + \theta_M h$$

and since we require

$$\omega > \omega_{\min}$$

we do not allow agents who fail to satisfy this condition this choice. For all other agents, we set

$$\theta' = \min [\gamma \theta, \ \theta (\omega)]$$

and solve for the optimal choice of a' for all agents with

$$\tilde{\omega} = \omega + (\theta' - \theta_M) h$$

Since

$$\tilde{\omega} > a_{\min} + c_{\min}$$

for consumption to exceed the minimum level, we discard this option for agents that do not satisfy it at $\theta' = \min [\gamma \theta, \ \theta (\omega)]$. Notice here we require

$$\theta' > \frac{1}{h} \max \Big[0, a_{\min} + c_{\min} + (1 - F_S) h - m \Big]$$

so if $\gamma \theta$ is less than this cutoff, we do not search at all.

2. Keep house size unchanged, new mortgage:

$$V_j^2 (m, z, \theta, h) = \max_{a', \theta'} \hat{u} (c, h) + \beta W_{j+1} (w', z, \theta', h)$$

subject to

$$c = [m - (1 - F_S) h + \theta' h - F_M h - a']$$

$$w' = (1 + r_L) a' + (1 - F_S) h - (1 + r_M) \theta' h$$

$$\theta' \leq \theta_M$$

The lower bound on θ' needed to ensure a minimum level of consumption is

$$\theta' > \frac{1}{h} \max \Big[0, a_{\min} + c_{\min} + (1 - F_S) h + F_M h - m \Big]$$

Here we have

$$\omega = m - (1 - F_S)\,h - F_M h + \theta_M h$$

At this node we solve for the unconstrained optimal choice of

$$\theta'(\omega, z, h)$$

3. Keep house size unchanged, extract home equity:

$$V_j^3(m, z, \theta, h) = \max_{a', \theta'} \hat{u}(c, h) + \beta W_{j+1}(w', z, \theta', h)$$

subject to

$$c = [m - (1 - F_S)\,h + \theta' h - F_X h - a']\,[\mathbb{I}_{h>0} + \alpha \mathbb{I}_{h=0}]$$

$$w' = (1 + r_L)\,a' + (1 - F_S)\,h - (1 + r_M)\,\theta' h$$

$$\theta' \leq \min[\gamma\theta + \theta_X, \theta_M]$$

The lower bound on θ' needed to ensure a minimum level of consumption is

$$\theta' > \frac{1}{h}\max\Big[0, a_{\min} + c_{\min} + (1 - F_S)\,h + F_X h - m\Big]$$

Here we have

$$\omega = m - (1 - F_S)\,h - F_X h + \theta_M h$$

Recall that in Step 2. above we have already solved for the unconstrained optimal choice of

$$\theta'(\omega, z, h)$$

If this choice satisfies the borrowing limit

$$\theta'(\omega, z, h) < \gamma\theta + \theta_X$$

we accept it. Otherwise we impose $\theta' = \gamma\theta + \theta_X$ and solve for the a' consistent with this choice.

4. Change house size, do not borrow:

$$V_j^4(m, z, \theta, h) = \max_{a', h' > 0} u(c, h') + \beta W_{j+1}(w, z, 0, h')$$

subject to

$$c = m - h' - a'$$

$$w' = (1 + r_L)\,a' + (1 - F_S)\,h'$$

Note that at this node the utility function is evaluated only at $h' > 0$ given our assumption that the end-of-period housing stock enters the utility function. Recall that we require

$$h' < m - \omega_{\min}$$

or else it violates the consumption lower bound. For any h' that satisfies this restriction, we set $\theta' = 0$ and solve for the a' that solves the Euler equation. Notice that at this node we have

$$\omega = m - h' + \theta_M h'$$

5. Change house size, take on a mortgage:

$$V_j^5(m, z, \theta, h) = \max_{a', h' > 0, \theta'} u(c, h') + \beta W_{j+1}(w, z, \theta', h')$$

subject to

$$c = m - (1 + F_M) h' + \theta' h' - a'$$

$$\theta' \leq \theta_M$$

$$w' = (1 + r_L) a' + (1 - F_S) h' - (1 + r_M) \theta' h'$$

We solve this problem by searching over the discrete values in $h' \in [h_{\min}, h_{\max}]$ and then θ'. Recall that we require

$$h' < \frac{1}{1 + F_M - \theta_M}(m - \omega_{\min})$$

For any particular choice of h' that satisfies this restriction, we have

$$\omega = m - (1 + F_M) h' + \theta_M h'$$

For this point, we have already computed $\theta'(\omega, z, h')$ and so let

$$\tilde{\omega} = \omega + (\theta'(\omega, z, h') - \theta_M) h'$$

At this point we solve once again for optimal $a'(\tilde{\omega}, z, \theta', h')$

6. Become a renter:

$$V_j^6(m, z, \theta, h) = \max_{a'} u\left(c, \frac{1 - \alpha}{\alpha} \frac{1}{R} c\right) + \beta W_{j+1}(w, z, 0, 0)$$

subject to

$$c = \alpha [m - a']$$

$$w' = (1 + r_L)\, a'$$

where we have imposed the optimal rental choice. Anyone can undertake this option, so we solve using $\theta' = 0$ and

$$\tilde{\omega} = m$$

at nodes (m, z) since at this point the old value of θ and h is irrelevant. Here we need

$$\tilde{\omega} > \omega_{\min}$$

but this is satisfied since

$$m_{\min} > \omega_{\min}$$

In some of the options above there are multiple pairs local optima (θ', a') that solve the above maximization problems. The reason is that the value of liquidity is non-monotone due to non-convexities associated with the various options of home equity extraction available. Thus, we use a global solution method to solve for (θ', a'), by applying sequentially Brent's method in one dimension in various intervals of the choice set.

11.3 Second Approach: Solve for θ' and a' Separately by Introducing an Additional Value Function

To simplify computations, we define yet another value function, $N_j(\omega, h', \theta', z)$, which gives the consumer's value conditional on having made a given choice of h' and θ' and having been left with ω units of output available to divide between consumption and liquid savings. That is, ω is given by

$$\omega = m + \theta' h' - h'\mathbb{I}^S - (1 - F_S)\, h \left(1 - \mathbb{I}^S\right) - F_M h'\mathbb{I}^M - F_X h\mathbb{I}^X$$

and N is given by

$$N_j(\omega, h', \theta', z) = \max_{a'} \hat{u}(c, h') + \beta W_{j+1}(w, h', \theta', z)$$

s.t.

$$c = [\omega - a'] \left[\mathbb{I}_{h'>0} + \alpha \mathbb{I}_{h'=0}\right]$$

The maximization problem is relatively straightforward to solve.

In particular, the FOC is

$$u_c(c, h') \geq \beta (1 + r_L)\, W_{j+1,1}(w, h', \theta', z)$$

with equality if $a > a_{\min}$.

Consider next the other problem, that of choosing h' and θ'. We can use the function

N to reduce the maximization problem that defines V. Below we write again the 5 values corresponding to the different options the agent has, but now use the definition of N to reduce the dimensionality of the choice set. The different options are:

1. Keep house size unchanged, do not extract home equity:

$$V_j^1 (m, h, \theta, z) = \max_{\theta'} N_j (\omega, h, \theta', z)$$

   subject to

$$\omega = m - (1 - F_S) h + \theta' h$$

$$\theta' \leq \gamma\theta$$

   To solve for θ' we first partition its space and use Brent's method to maximize N in each partition, to guard against the possibility of multipla local maxima which arise here due to non-convexities.

2. Keep house size unchanged, take new mortgage:

$$V_j^2 (m, h, \theta, z) = \max_{\theta'} N_j (\omega, h, \theta', z)$$

   subject to

$$\omega = m - (1 - F_S) h + \theta' h - F_M h$$

$$\theta' \leq \theta_M$$

3. Keep house size unchanged, obtain HELOC:

$$V_j^3 (m, h, \theta, z) = \max_{\theta'} N_j (\omega, h, \theta', z)$$

   subject to

$$\omega = m - (1 - F_S) h + \theta' h - F_X h$$

$$\theta' \leq \min [\gamma\theta + \theta_X, \theta_M]$$

4. Change house size, do not borrow:

$$V_j^4 (m, h, \theta, z) = \max_{h'} N_j (\omega, h', 0, z)$$

   subject to

$$\omega = m - h'$$

5. Change house size, take on a mortgage:

$$V_j^5(m,h,\theta,z) = \max_{h',\theta'} N_j(\omega,h',\theta',z)$$

subject to

$$\omega = m + \theta' h' - (1+F_M)\,h'$$

6. Become a renter:

$$V_j^6(m,h,\theta,z) = N_j(\omega,0,0,z)$$

subject to

$$\omega = m$$

11.4 Accuracy of Approximation

Table 6 reports moments derived from a particular parameterization of the model solved using each of the two approaches above. In all of these experiments we uses 7 points of Gaussian quadrature for the distribution of transitory income shocks, 9 for the distribution of persistent income shocks, and a 9 point grid for housing. Table 6 shows how the results change as we change n_θ, n_w, n_m and n_o – the degree of the spline approximation of the endogenous continuous state variables in the problems above. Given that there is no discernible difference in these moments for say, $n_\theta = 15$ vs. $n_\theta = 25$, in practice we have used $n_\theta = 21$, $n_w = 21$ and $n_o = 61$ (order of the cubic spline).

Table 1: Income risk: Workers vs. Retirees

	$\text{var}(\overline{\varepsilon_{i,t}})$	$\text{cov}(\overline{\varepsilon_{i,t}}, \overline{\varepsilon_{i,t-1}})$	$\text{cov}(\overline{\varepsilon_{i,t}}, \overline{\varepsilon_{i,t-2}})$	$\text{std dev}(\overline{\varepsilon_{i,t}} - \overline{\varepsilon_{i,t-1}})$
Workers (age$<$ 65)	0.43	0.31	0.29	0.41
Retirees (age$\geq$ 65)	0.47	0.35	0.36	0.38

Table 2: Vary Elasticity of Intertemporal Substitution

A. Moments Used in Calibration

	Data	$\sigma = 1$	$\sigma = 2$
aggregate wealth to income	1.45	1.55	1.55
aggregate housing to income	1.82	1.83	1.82
aggregate mortgage debt to income	0.83	0.61	0.66
aggregate liquid assets to income	0.46	0.33	0.39
fraction homeowners	0.64	0.63	0.64
fraction homeowners with mortgage	0.71	0.72	0.77
fraction homeowners who sell house	0.051	0.051	0.051
fraction homeowners who extract	0.086	0.086	0.086
median extracted / initial balance	0.23	0.23	0.23

B. Parameter Values

	$\sigma = 1$	$\sigma = 2$
discount factor, β	0.947	0.902
cost of selling home, F_S	0.060	0.065
cost of new mortgage, F_M	0.055	0.059
cost of extracting, F_X	0.021	0.024
limit on amount extract, θ_X	0.143	0.145
preference housing, α	0.920	0.908
rental rate housing, R	0.036	0.039

C. Distribution Liquid Assets Owners. Scaled by Aggregate Income

	Data	$\sigma = 1$	$\sigma = 2$
10th percentile	-0.04	-0.04	-0.04
25th percentile	0.01	-0.01	0.04
50th percentile	0.15	0.22	0.31
75th percentile	0.68	0.58	0.68
90th percentile	1.69	1.21	1.36

Table 3: Welfare Costs of Liquidity Constraints (vary σ)

	$\sigma = 1$	$\sigma = 2$
Fraction hand-to-mouth	0.21	0.14
Fraction borrowing constrained	0.86	0.83
Fraction who value 1% injection	0.70	0.69
Mean valuation of 1% injection, %	10.2	11.5
Welfare cost, CEV $\times 100$	1.19	0.98

Table 4: Vary Standard Deviation of Transitory Income Shock

A. Moments Used in Calibration

	Data	$\sigma_e = 0.307$	$\sigma_e = 0.153$	$\sigma_e = 0$
aggregate wealth to income	1.45	1.55	1.43	1.46
aggregate housing to income	1.82	1.83	1.83	1.82
aggregate mortgage debt to income	0.83	0.61	0.65	0.59
aggregate liquid assets to income	0.46	0.33	0.24	0.23
fraction homeowners	0.64	0.63	0.66	0.64
fraction homeowners with mortgage	0.71	0.72	0.72	0.71
fraction homeowners who sell house	0.051	0.051	0.051	0.051
fraction homeowners who extract	0.086	0.086	0.086	0.086
median extracted / initial balance	0.23	0.23	0.23	0.24

B. Parameter Values

	$\sigma_e = 0.307$	$\sigma_e = 0.153$	$\sigma_e = 0$
discount factor, β	0.947	0.948	0.951
cost of selling home, F_S	0.060	0.057	0.057
cost of new mortgage, F_M	0.055	0.056	0.059
cost of extracting, F_X	0.021	0.021	0.020
limit on amount extract, θ_X	0.143	0.152	0.146
preference housing, α	0.920	0.923	0.923
rental rate housing, R	0.036	0.037	0.037

C. Distribution Liquid Assets Owners. Scaled by Aggregate Income

	Data	$\sigma_e = 0.307$	$\sigma_e = 0.153$	$\sigma_e = 0$
10th percentile	-0.04	-0.04	-0.05	-0.05
25th percentile	0.01	-0.01	-0.05	-0.05
50th percentile	0.15	0.22	0.10	0.08
75th percentile	0.68	0.58	0.38	0.36
90th percentile	1.69	1.21	0.95	0.99

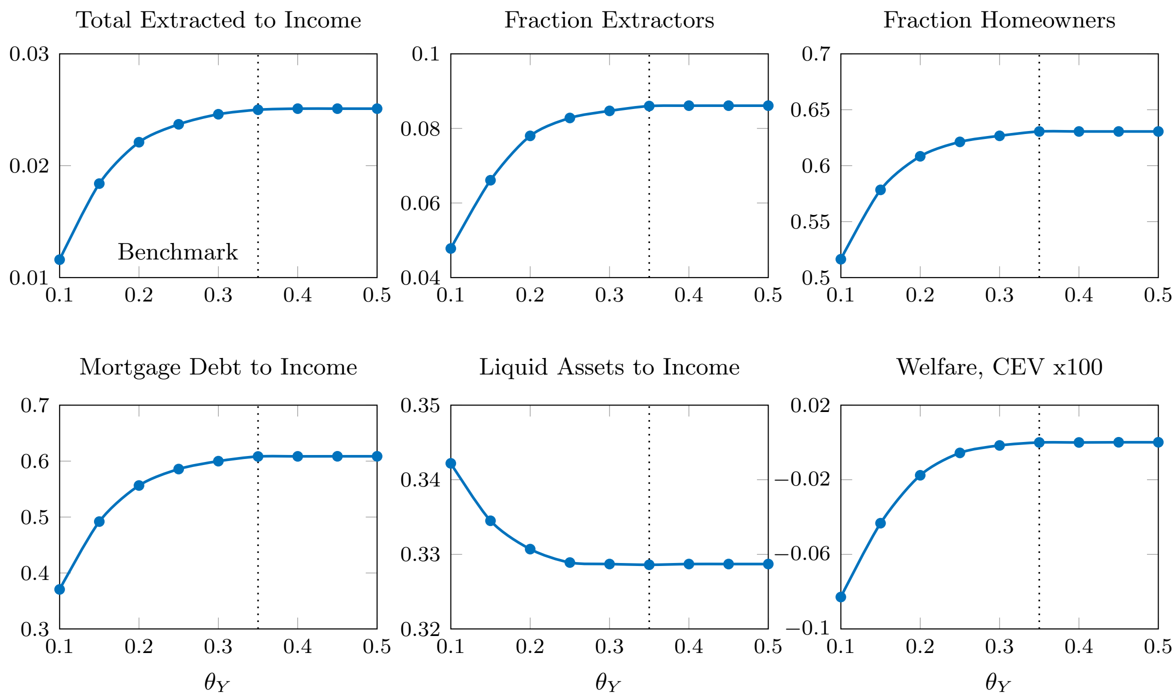
Table 5: Welfare Costs of Liquidity Constraints (vary σ_e)

	$\sigma_e = 0.307$	$\sigma_e = 0.153$	$\sigma_e = 0$
Fraction hand-to-mouth	0.21	0.25	0.28
Fraction borrowing constrained	0.86	0.86	0.85
Fraction who value 1% injection	0.70	0.66	0.64
Mean valuation of 1% injection, %	10.2	10.2	10.8
Welfare cost, CEV ×100	1.19	0.95	0.81

Table 6: Moments Computed using Two Solution Methods and Various Grid Sizes (n)

		Jointly			**Separately**	
	n=15	n=25	n=51	n=15	n=25	n=51
aggregate wealth to income	2.44	2.45	2.46	2.45	2.45	2.46
aggregate housing to income	1.99	2.01	2.05	2.00	2.01	2.05
aggregate mortgage debt to income	0.19	0.18	0.18	0.19	0.18	0.18
aggregate liquid assets to income	0.65	0.62	0.59	0.64	0.62	0.59
fraction homeowners	0.64	0.67	0.67	0.65	0.67	0.67
fraction homeowners without mortgage	0.57	0.59	0.60	0.59	0.60	0.60
fraction homeowners who sell house	0.058	0.051	0.044	0.058	0.051	0.044
fraction homeowners who extract	0.058	0.065	0.084	0.061	0.063	0.082
median extracted / initial balance	0.54	0.34	0.41	0.54	0.34	0.41

Figure 1: Vary Payment-to-Income Constraint, θ_Y



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