Houses as ATMs?
Mortgage Refinancing and Macroeconomic Uncertainty*

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Abstract

Can liquidity constraints explain the dramatic build-up of household leverage during the housing boom of mid-2000s? To answer this question we estimate a structural model of household liquidity management in the presence of long-term mortgages and short-term home equity loans. Households face counter-cyclical idiosyncratic labor income uncertainty and borrowing constraints, which affect optimal choices of leverage, precautionary saving in liquid assets and illiquid home equity, debt repayment, mortgage refinancing, and default. Taking the observed historical path of house prices, aggregate income, and interest rates as given, the model quantitatively accounts for the run-up in household debt and consumption boom prior to the financial crisis, their subsequent collapse, and weak recovery following the Great Recession, especially among the most constrained households.

JEL Codes: E21, E44, G21

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1 Introduction

We show that a rational model of home equity-based borrowing by liquidity-constrained households can quantitatively account for the empirical patterns in household leverage and consumption over the last decade. In the aggregate, taking the observed historical path of house prices, aggregate household income, and interest rates as exogenously given, our model reproduces both the dramatic run-up in the housing debt over the period 2000-2006, and the sharp contraction in consumption that followed, most pronounced among the highly-levered households. In the cross section, the interaction of idiosyncratic labor income shocks with liquidity constraints, absent any ex ante heterogeneity, generates wide dispersion in liquid assets, debt holdings, and the ability of households to refinance their mortgages. This dispersion implies diverging paths of consumption following the Great Recession for households with different boom-time leverage.

Both the origins of the recent financial crisis and the severity of the Great Recession are often attributed to the increase in consumer indebtedness during the period of house price run-up in mid-2000s and the subsequent deterioration of household balance sheets with the sharp decline in house prices (e.g., Dynan (2012), Mian, Rao, and Sufi (2013)). There is less consensus about the structural forces driving both the borrowing boom and the consumption slump that followed (e.g., see Cooper (2012)). In particular, the expansion of household leverage and growth of consumer expenditures financed with extracted home equity over the period of house price boom as documented by Mian and Sufi (2010) is consistent with liquidity-constrained households taking advantage of relaxed housing collateral constraints. These facts are also qualitatively consistent with alternative explanations featuring self-control problems on the part of consumers (e.g., Laibson (1997)), irrationally optimistic expectations about future income and house prices, and/or moral hazard on the part of mortgage originators (e.g., Keys, Mukherjee, Seru, and Vig (2010)).

In order to provide a benchmark for evaluating the alternative explanations of the observed household behavior both prior to the recent financial crisis and during the Great Recession, we build a quantitative framework of the consumption, saving, and mortgage financing decisions of households who are subject to idiosyncratic labor income risk and liquidity constraints, following the partial-equilibrium approach of Campbell and Cocco (2003). Our analysis focuses on households' optimal choices of leverage, precautionary savings in liquid assets and illiquid home equity, as well as the dynamic decisions in debt repayment, mortgage refinancing, cash-out, and default. The model captures the relevant frictions impacting the households' ability to smooth consumption over time and across states of nature when borrowing collateralized with housing wealth is the main source of consumer credit. We estimate the structural parameters of the model by targeting the key moments of household consumption, asset and debt holdings, and the aggregate dynamics of mortgage refinancing and equity extraction in relation to macroeconomic conditions.

While much of the existing literature treats mortgage refinancing and home-equity-backed borrowing in isolation, our analysis indicates that an integrated approach is important for understanding both. Specifically, the decision to refinance trades off the benefits of refinancing, including lower interest rates and/or higher liquidity, against the substantial costs of originating a new loan, both financial and non-pecuniary. Our model also incorporates two sets of realistic borrowing constraints, the loan-to-value (LTV) constraint and the loan-to-income (LTI) constraint, which require that the refinanced loan amount is not too large relative to current house value and household income, respectively. Another important feature of our model is the counter-cyclical volatility of idiosyncratic labor income growth, documented by Storesletten, Telmer, and Yaron (2004) (see also Meghir and Pistaferri (2004)). This property of the labor income process implies that a macroeconomic downturn not only can make more households become liquidity constrained, but also make households more concerned about the increased uncertainty of future income.

Together, these ingredients generate a set of new predictions about household refinancing and consumption decisions. First, because households do not have access to complete financial markets, the embedded options to default, prepay, or refinance the mortgage can no longer be analyzed in the standard option-pricing framework. In particular, interest rates are not the only consideration in refinancing. The ability to convert some of the home equity into liquid assets can make refinancing more attractive even when the costs of borrowing are higher than before, a puzzle for traditional models that consider lowering the interest rate as the only reason to refinance a fixed rate mortgage.[1]

Second, the interactions between labor income risk, house price risk, and liquidity constraints can cause households to preemptively refinance before actually becoming constrained. Because idiosyncratic labor income risk jumps up significantly in recessions, households may refinance early to build up a buffer stock of liquid assets preemptively in order to avoid being caught by a binding loan-to-income constraint in the future. Similarly, because house price shocks are persistent, refinancing activity might increase following a drop in house price due to the concern that the loan-to-value constraint might become binding soon. Such preemptive behavior is unique to our model due to the combination of long-term loans and realistic modeling of the origination process, and does not apply to models with only short-term debt. Households build up precautionary savings using both liquid assets and home equity. Since liquid assets provide limited returns while home equity is itself illiquid due to the refinancing costs and the limits on loan-to-income and loan-to-value ratios, households dynamically balance these two types of savings, holding more home equity when labor income risk is relatively low, and switching to stockpiling liquidity when labor income risk is high and constraints become tighter. Compared to models of one period debt and/or frictionless access to borrowing, our model of long-term mortgages generates greater accumulation of debt for financially constrained households, because debt and liquid assets are imperfect substitutes. It also generates a more pro-longed deleveraging process, since households are not required to pay back their debt at the end of each period but rather rebalance it optimally in response to changing conditions.

Third, even though households in the model face identical schedules of refinancing costs, their refinancing decisions can differ significantly due to idiosyncratic labor income risk and the resulting dispersion in balance sheet positions, which might appear suboptimal according to standard theory.[2] The model thus helps to connect aggregate refinancing activity with the cross section of household characteristics by identifying the economic mechanisms behind the

[1] Hurst and Stafford (2004) first pointed out this possibility and supported it with empirical evidence using household-level data from an earlier time period.

[2] In his AFA presidential address Campbell (2006) reviews the literature on mortgage refinancing and calls for a deeper analysis of the underlying economic causes of "suboptimal" exercise of the prepayment option by many households.

individual households' decisions.

Fourth, our sensitivity analysis indicates that differences in preference parameters could also have nontrivial effects on refinancing. Households with low discount rates or high risk aversion will choose lower mortgage balances and refinance less frequently, and their refinancing activities are less sensitive to mortgage rate changes but more sensitive to aggregate income shocks. A higher elasticity of intertemporal substitution leads to higher leverage, more frequent refinancing, and higher sensitivity of refinancing to changes in both mortgage rates and aggregate income.

Long-term mortgages with a fixed rate and an option to prepay the outstanding balance prior to maturity, typically by obtaining a new loan (refinancing), have long been the mainstay of the U.S. housing market. A quantitative model that captures these features of the mortgage market is valuable for two reasons. On the one hand, systematic prepayment is the main source of risk in the $8-trillion market for residential mortgage-backed securities (MBS) as prepayment tends to accelerate cashflow to MBS investors when interest rates are low and extend duration when discount rates are high. On the other hand, the tremendous quantity of mortgage debt outstanding and the amount of home equity extraction mean that refinancing is a central part of households' financial and consumption decisions. According to the Flow of Funds, mortgages accounted for over 70% of the total liabilities of U.S. households and nonprofit organizations in 2012. Moreover, on average about 70% of refinanced loans involve cash-out, and U.S. households extracted over $1.7 trillion of home equity via refinancing from 1993 to 2010, corresponding to 11.5% of new loan balances.[3]

Besides the level of mortgage debt and the amount and frequency of refinancing, our estimation targets the time-series behavior of aggregate equity extraction. To this end we document new empirical stylized facts that help us identify the key structural parameters of the model. We show that in the data, both mortgage refinancing and cash-out appear to respond negatively to the business cycle, even after controlling for the cyclicality of mortgage rates. Refinancing is also positively related to growth in house prices, which drives the

[3]These figures are conservative as they are based on the estimates for conforming loans provided by Freddie Mac and therefore exclude certain kinds of mortgage loans, such as subprime. In particular, survey-based analysis in Greenspan and Kennedy (2008) suggests much greater magnitudes of home equity extraction.

tightness of the borrowing constraints.

The estimated structural model quantifies the degree to which refinancing costs as well as the lack of home equity constrain the ability of households to smooth consumption in the face of macroeconomic uncertainty. By feeding in the actual time series of macroeconomic shocks, the model successfully replicates the significant run-up in household leverage for households experiencing large house price appreciation, compared to the situation of relatively stable house prices. Since our simulated moments estimation only targets a few reduced-form correlations between aggregate variables but not their realizations, such a test presents a high hurdle for the model.

The model also generates the dynamics of individual consumption, liquid assets, leverage, as well as mortgage refinancing decisions for the cross section of households. Due to the long-term nature of mortgages, debt reduction following a sequence of adverse shocks during the Great Recession occurs slowly, as households optimally adjust their debt and asset positions. In contrast, in models that only allow for short-term mortgage loans, households cannot ride out periods of high uncertainty by borrowing against their homes because falling house prices during a recession lead to a painful deleveraging as households are forced to repay the loans by the tightening collateral constraints (e.g. Favilukis, Ludvigson, and Van Nieuwerburgh (2011), Guerrieri and Lorenzoni (2011), and Midrigan and Philippon (2011)).[4] We show that even in the presence of long-term debt the effect of deleveraging on consumption is substantial, with households in the top quintile of the leverage distribution experiencing real consumption drops of 10% more than the average.

Our simulation-based evidence also demonstrates that the interaction between interest rates and household liquidity constraints is important for assessing the effect of monetary policy on refinancing activity.[5] When many households are liquidity constrained their

[4]Empirical evidence in Carroll, Slacálek, and Sommer (2012) suggests that the increase in labor income uncertainty, rather than the tightening of credit constraints by themselves, may be the driver of the consumption decline during the Great Recession.

[5]Mortgage refinancing featured prominently in Alan Greenspan's defense of low interest rates as a way of stimulating household consumption during the "jobless recovery" from the 2001 recession: "Overall, the economy has made impressive gains in output and real incomes; however, progress in creating jobs has been limited. ... The very low level of interest rates ... encouraged household spending through a variety of channels. ... The lowest home mortgage rates in decades were a major contributor ... engendering a large extraction of cash from home equity. A significant part of that cash supported personal consumption expenditures and

refinancing behavior becomes insensitive to changes in interest rates, especially in the face of depressed values of housing collateral or high debt service ratios. At the same time, our analysis suggests that a monetary easing in the early stages of an economic downturn, when both aggregate income falls and its cross-sectional dispersion rises, can elicit a sharper response of refinancing activity than what standard models would predict based solely on interest rate changes.

Finally, our model generates new insights for analyzing the effectiveness of various government programs that aim to stimulate the economy by providing direct support to the mortgage markets. Examples of these extraordinary policy measures undertaken following the Great Recession include lowering long-term mortgage rates (via the large scale asset purchases by the U.S. Federal Reserve Board) and relaxing the loan-to-value requirements for homeowners who are underwater (via the Home Affordable Refinance Program or HARP). Our analysis suggests that it is important to coordinate such programs. For example, households that are not able to refinance due to binding refinancing restrictions will benefit little from low interest rates. It also helps guide the design of "selective refinancing" programs – using criteria that help identify temporarily distressed households who can benefit greatly from relaxed borrowing constraints without significantly raising the risk of default. For example, we find that relaxing the loan-to-income constraint (similarly to FHA loans) may be just as helpful in consumption smoothing as relaxing the loan-to-value constraint, but could result in a smaller increase in mortgage defaults. Finally, our simulation analysis based on the historical time-series indicates that the tightening of credit standards by mortgage lenders may have contributed significantly to the slow recovery of consumption following the Great Recession by restricting the ability of constrained homeowners to refinance.

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home improvement. In addition, many households took out cash in the process of refinancing, often using the proceeds to substitute for higher-cost consumer debt. That refinancing also permitted some households to lower the monthly carrying costs for their homes and thus freed up funds for other expenditures." (Testimony of Chairman Alan Greenspan; Federal Reserve Board's semiannual Monetary Policy Report to the Congress Before the Committee on Financial Services, U.S. House of Representatives, February 11, 2004).

1.1 Literature

There is a large literature on mortgage refinancing. The fixed-income asset pricing literature focuses on the optimal exercise of the call option embedded in the mortgage (e.g., Dunn and McConnell (1981), Dunn and Spatt (2005)). Boudoukh, Richardson, Stanton, and Whitelaw (1997) and Gabaix, Krishnamurthy, and Vigneron (2007) present evidence of systematic variation in prepayment risk that is not fully explained by interest rate dynamics, while Duarte, Longstaff, and Yu (2007) document sensitivity of agency mortgage prices to macroeconomic conditions captured by stock returns. The wide divergence of prepayment behavior across households has been attributed to heterogeneity in the costs of refinancing (e.g., Stanton (1995), Deng, Quigley, and Van Order (2000)), including those arising from behavioral biases (e.g., Agarwal, Driscoll, and Laibson (2002)); Downing, Stanton, and Wallace (2005) consider the role of house prices. Campbell and Cocco (2003) and Koijen, Van Hemert, and Van Nieuwerburgh (2009) analyze the choice between adjustable and fixed-rate mortgages. Longstaff (2004) and Mayer, Piskorski, and Tchistyi (2010) consider equilibrium mortgage rates in environments where refinancing is constrained by borrower creditworthiness.

Macro asset pricing literature on housing collateral emphasizes the implicit risk-sharing role of mortgage finance and its impact on risk premia (e.g., Lustig and Van Nieuwerburgh (2005), Favilukis, Ludvigson, and Van Nieuwerburgh (2011)). In the context of household risk management, Sinai and Souleles (2005) argue theoretically that homeowners trade off house price risk against rent risk, while Piazzesi and Schneider (2009) study the interaction of housing and uninsurable inflation risk.

A large literature aims to understand the importance of housing wealth for determining consumption: recent contributions include Campbell and Cocco (2007), Carroll, Otsuka, and Slacalek (2011), Case, Quigley, and Shiller (2011), and Calomiris, Longhofer, and Miles (2012). While there is disagreement as to whether there is a pure *wealth* effect of housing on consumption in the aggregate, most authors agree that the *collateral* value of housing wealth influences the consumption of constrained households. In particular, Caplin, Freeman, and Tracy (1997) and Lustig and Van Nieuwerburgh (2010) show that housing collateral mutes the consumption responses to regional income shocks. Hurst and Stafford (2004) were the first to explicitly consider the role of mortgage refinancing as a mechanism of accessing home equity for the purpose of smoothing consumption in a stylized model and provide household-level evidence. The dual role of durable goods (such as housing) as both a source of consumable service flow and collateral, as well as its role for household saving is explored theoretically in Fernandez-Villaverde and Krueger (2011), while Rios-Rull and Sanchez-Marcos (2008) and He, Wright, and Zhu (2012) endogenize house prices in similar environments. Campbell and Hercowitz (2005) use a general equilibrium model to argue that the increased accessibility of housing collateral contributed to the "Great Moderation." Our model is closely related to Attanasio, Leicester, and Wakefield (2011) who focus on the sensitivity of consumption to housing wealth by matching key features of the U.K. housing market.

While our portfolio-choice setting treats house prices and mortgage rates as exogenous, the key elements of our model could be fruitfully incorporated into equilibrium settings considered in a number of recent papers. For example, Landvoigt, Piazzesi, and Schneider (2012) evaluate the impact of credit availability on the cross-section of house prices in an assignment framework. Chatterjee and Eyigungor (2011) study mortgage default in a model with both long-term loans and endogenous pricing of debt and housing collateral, but without the possibility of refinancing. Jeske, Krueger, and Mitman (2011) evaluate the aggregate implications of the government guarantees against mortgage default risk. Corbae and Quintin (2013) analyze the role of high-leverage mortgage products in engendering the foreclosure crisis that followed the housing boom at the onset of the Great Recession. Khandani, Lo, and Merton (2009) show that home equity extraction via mortgage refinancing that is driven by rapid house price appreciation substantially increases the systematic component of mortgage default risk, and provide estimates of its effect on the valuation of mortgage debt.

Finally, our paper is related to the broader literature on household liquidity management and portfolio choice with frictions. The focus of this literature is on the role of transaction costs (as in the tradition of Baumol-Tobin inventory models) in inhibiting households' ability to self-insure by accumulating financial assets and/or durable goods (e.g., Bertola, Guiso, and Pistaferri (2005), Alvarez, Guiso, and Lippi (2010), and Kaplan and Violante (2011)), the implications of costly rebalancing for the optimal portfolio choice as well as asset pricing (e.g., Heaton and Lucas (1996), Lynch (1996), Gabaix and Laibson (2002), Gomes and Michaelides (2005), Abel, Eberly, and Panageas (2013)), and the impact of incomplete markets on option exercise (e.g., Chen, Miao, and Wang (2010)).

2 New Stylized Facts

In this section we document some new stylized facts on how households access liquidity in response to aggregate economic conditions via mortgage refinancing as well as other forms of home equity-based borrowing. These facts suggest that mortgage refinancing and home-equity withdrawal are closely linked. The evidence motivates our modeling approach and helps with the identification of the structural parameters.

2.1 Aggregate refinancing behavior

We begin with the empirical evidence on how mortgage refinancing activities at the aggregate level relate to interest rates and macroeconomic conditions. The measures we use are the refinancing applications index from the Mortgage Bankers Association (the refi index) and the data on cash-out volume from Freddie Mac.

Figure 1 Panel A plots the MBA refi index (solid line) and the differences between the 30-year conventional mortgage rate and its past 3-year moving average (dash line). Not surprisingly, refinancing activity increased in the early 90s and especially around 2003, both of which are periods of significant drops in mortgage rates. This is consistent with households refinancing to take advantage of newly available low mortgage rates. Panel B plots the refi index along with the year-over-year growth rate in industrial production (dash line). The refi index rose significantly during the 2001 recession, in early 2008 – the onset of the Great Recession, and again during the Great Recession in 2009. While this evidence is consistent with the interpretation that households refinance to smooth consumption when experiencing bad income shocks or refinance preemptively in anticipation of worsening economic conditions in the future, it could also be driven by pro-cyclical variation in mortgage rates.

To further investigate the dynamics of the aggregate refinancing activity, we regress the

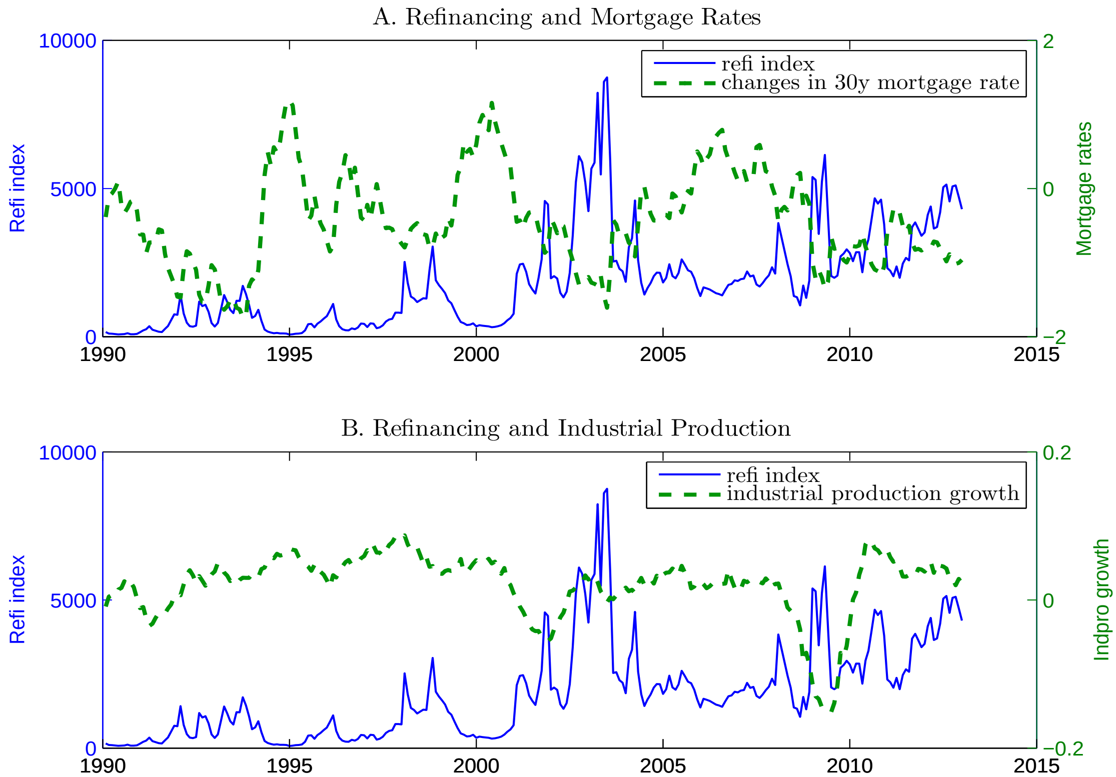

Figure 1: **Refinancing, Interest Rates, and Macroeconomic Conditions.** The refi index is from the Mortgage Bankers Association. The change in 30-year mortgage rate is defined as the difference between the 30-year conventional mortgage rate and its past 3-year moving average. The industrial production growth is computed on a year-over-year basis using monthly data.

refi index on a host of financial and macroeconomic variables:

$$REFI_t = \beta_0^{REFI} + \beta_Z^{REFI} \Delta IP_t + \beta_H^{REFI} \Delta HPI_t + \beta_R^{REFI} R_t^{M30} + \beta_{Rl}^{REFI} \Delta R_t^{M30} + \beta_r^{REFI} r_t^{1Y} + \epsilon_t, \tag{1}$$

where ΔIP_t is the year-on-year growth in the Industrial Production index, ΔHPI_t is the year-on-year growth in the Case-Shiller housing price index, R_t^{M30} is the 30-year fixed mortgage rate, $\Delta R^{M30} = R_t^{M30} - R_{lag,t}^{M30}$ with $R_{lag,t}^{M30}$ being a lagged 30-year fixed mortgage rate (we try both the 12-month lagged rate and the average rate in the past 3 years), and r_t^{1Y} is the 1-year Treasury rate. To make the coefficients easier to interpret, we rescale the MBA refi index to have a mean of 8%, which is the average annual refinancing rate for homeowners according to the Home Mortgage Disclosure Act (HMDA) and Census data.

Table 1 reports the results. Among the key drivers of mortgage refinancing are the current 30-year mortgage rate and the change in the mortgage rate, both of which come in with negative and significant coefficients. This is consistent with the standard theory of mortgage refinancing, which argues that the primary reason to refinance is to take advantage of lower interest rates and thus lower interest payments. House price growth affects refinancing positively, since an increase in house prices implies an increase in home equity that can be cashed out. The industrial production growth, a direct measure of economic activity, has a robustly significant and negative coefficient even after controlling for mortgage rates and house price growth. This again suggests that households refinance more in economic downturns, beyond what can be explained by the changes in interest rates.

A potential reason for the negative relation between refinancing activity and the growth in industrial production is that the latter is a proxy for the effects of interest rates not captured by the term structure variables in (1). In the Appendix, we present further evidence on the negative response of mortgage refinancing to economic activity using state-level data. This helps us to separate the effect of low interest rates from that of deteriorating economic conditions, insofar as the local economic activity measures are less synchronized with the interest rates than are the aggregate measures, and that households cannot diversify away state-level shocks.

2.2 Aggregate home equity withdrawal

The aggregate refinancing rate does not distinguish between cash-out refinancing (taking out a loan with a larger balance than the previous one) from those that result in the same or lower loan balances. We now examine how actual withdrawal of home equity by households relates to macroeconomic conditions and influences refinancing activity.

Figure 2 Panel A plots the time series of the percentage of refinancing for which the loan amount (i) is raised by 5% or more (classified as cash-out), (ii) remains within 5% of the original amount (classified as no change), or (iii) is reduced by 5% or more (classified as pay-down). On average, 61% of refinancing over this period are cash-outs, which shows the importance of cash-outs in mortgage refinancing. The share of cash-outs is visibly higher

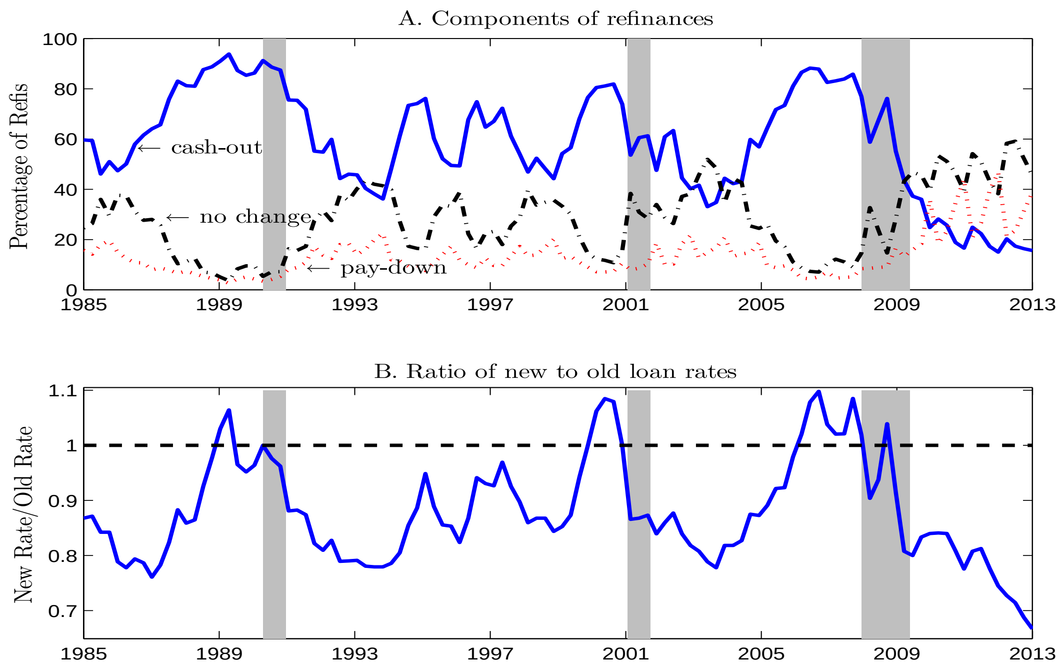

Figure 2: **Fraction of cash-out and the median rate ratio for refinance loans.** Panel A plots the percentage of refinancing resulting in 5% higher loan amount (cash-out), no change, or lower loan amount (pay-down). Panel B plots the median ratio of new to old loan rates upon refinance. The data is from Freddie Mac for the period 1985Q1 to 2012Q4.

towards the end of each expansion, and it declines coming out of recessions. In contrast, the fraction of refinancing that results in no change in loan balance or pay-down typically rises following a recession, presumably because households refinance to take advantage of the lower mortgage rates and to repay the loans they take out entering the recession.

Since the standard theory predicts that the primary driver of refinancing is lowering the borrowing costs, it is informative to examine under what conditions refinancing actually lowers borrowers' loan rates. Panel B of Figure 2 plots the median of the ratio of new mortgage rates to the old rates on the refinanced loans (adjustable rate mortgages are excluded). Households tend to refinance despite higher rates towards the end of expansions and the beginning of recessions, when the median rate ratio often exceeds unity, but at lower rates coming out of recessions.

This evidence strongly suggests that interest savings are not the only driver of refinancing. An important role may be played by the ability of borrowers to alleviate liquidity constraints either by increasing the loan amount (cash-out) or extending the loan term (thus reducing the monthly payments).[6] Indeed, the correlation between the rate ratio and the cash-out share in Panel A is 78%. Given that labor income is not tradable and other non-collateralized personal loans (e.g., credit card loans) are expensive, mortgage loans are a major source of credit for liquidity constrained households. This is consistent with household-level evidence in Hurst and Stafford (2004) that the most liquidity-constrained households refinance following negative income shocks even as interest rates increase in order to access their home equity.

Next, we examine to what extent does home equity extraction help smooth shocks to income in the aggregate. We separately examine two types of home equity withdrawal to study the potentially different roles that senior and junior mortgage loans play in smoothing income shocks. The first measure is cash-out refinancing of first-lien conforming mortgages, while the second combines home equity loans and lines of credit (HEL+HELOC, computed as the net change of the outstanding balances reported in the Flow of Funds). We normalize the dollar amount of total home equity withdrawn each year by the personal income in the previous year and then regress it on real personal income growth, house price growth, and several interest rate variables as in the regression of refi rates:

$$HEW_t^j = \beta_0^j + \beta_Z^j \Delta PI_t + \beta_H^j \Delta HPI_t + \beta_R^j R_t^{M30} + \beta_{Rl}^j \Delta R_t^{M30} + \beta_r^j r_t^{1Y} + \epsilon_t. \tag{2}$$

where $j \in \{\text{Cash-out}, \text{HELOC}\}$, HEW_t is the home equity withdrawal in a year (via cash-out or HELOC) scaled by the total personal income in the previous year, ΔPI_t is the one-year growth rate in real personal income, $\Delta R_t^{M30} = R_t^{M30} - R_{t-1}^{M30}$, and the other variables are the same as defined in (1).

The results are shown in Table 2. Like refinancing rates, cash-out volume is negatively related to the level of 30-year mortgage rate. However, it is positively related to the change in 30-year mortgage rate, the opposite of the case for refi (see Table 1). When households decide when to cash out, they not only compare the level of current mortgage rate to old rates, but also to the costs of other sources of financing (e.g., rates on credit card debt).

[6] Households are strictly worse off by refinancing into a higher rate loan in the case of "no-change" or "pay-down" refinancing as long as the loan's time to maturity remains the same. In the case of "pay-down", the households will be better off by choosing to prepay instead.

Moreover, the degree of liquidity constraint households face is a key factor. In fact, that the cash-out volume tends to rise as mortgage rates rise is consistent with the fact that both the cash-out share and the rate ratio tend to peak at the end of expansions and beginning of recessions (see Figure 2). Finally, similar to the case of refinancing, house price growth is positively related to both measures of home equity withdrawal, with an effect of essentially identical magnitude, indicating that out of an extra $1 of home equity 6 cents are withdrawn in the same year.

Over the sample, after controlling for house price growth and interest rates, growth in real personal income is significantly negatively correlated with cash-out from first-lien mortgages, but it has no significant relation with equity withdrawal via home equity loans and lines of credit. This result suggests that households primarily use refinancing of senior-lien mortgage loans rather than junior HEL(OC)s for consumption smoothing (in fact, households often use funds extracted upon cash-out to repay outstanding junior loans, as well as other forms of debt, such as credit card balances). The magnitude of the coefficient on personal income growth suggests that if real income drops by 10%, households on average increase cash-out from their first-lien mortgages by 1.3% of income to offset this effect. While this estimated effect applies to the aggregate data, there is clearly substantial underlying heterogeneity across households in terms of homeownership, income, leverage, among others, which will potentially lead to different cash-out responses to income shocks. We study these effects in our model next, where we posit that all households are ex ante identical but experience different histories of idiosyncratic shocks.

3 The Model

In this section, we present a dynamic model of household consumption, saving, and borrowing decisions with incomplete markets. This model will focus on understanding households' decisions on how to finance consumption and homeownership over time, including the choice of being a homeowner or a renter, as well as the choices of refinancing, prepayment, and default. The households are confronted with idiosyncratic shocks to income and aggregate shocks to interest rates, income growth, and house value. Since our focus is on understanding households' behavior in the face of realistic macroeconomic risks and constraints, we try to capture the key elements of the institutional environment of the U.S. housing finance while taking asset prices (including house prices) as exogenous.

3.1 Households preferences and endowments

The economy is populated by ex-ante identical, infinitely lived households, indexed by i. We assume households have recursive utility over consumption as in Epstein and Zin (1989) and Weil (1990),

$$U_t = \left[(1-\delta)\, X_t^{\frac{1-\gamma}{\theta}} + \delta \mathbb{E}_t \left[U_{t+1}^{1-\gamma} \right]^{\frac{1}{\theta}} \right]^{\frac{\theta}{1-\gamma}}, \tag{3}$$

where

$$\theta = \frac{1-\gamma}{1-\frac{1}{\psi}},$$

and X_t is a Cobb-Douglas aggregator of nonhousing consumption and housing services.[7] The parameters in these preferences include the discount factor δ, the coefficient of relative risk aversion γ, and the intertemporal elasticity of substitution (IES) ψ, as well as the Cobb-Douglas parameter ν for the relative importance of housing services. The parameter θ is an index of the deviation with respect to the benchmark CRRA utility function (when $\theta = 1$, the inverse of the IES coincides with risk aversion as in the CRRA case).

Each household is endowed with one unit of labor supplied inelastically that receives a before-tax wage y_{it}. The nominal income y_{it} for household i has an aggregate component, Y_t, an idiosyncratic component, $\tilde{y}_{it}$, as well as adjustment for inflation:

$$y_{it} = P_t \, Y_t \, \tilde{y}_{it}. \tag{4}$$

First, P_t is the price level in the economy at time t. For tractability, we assume the (gross) inflation rate is constant, defined as $P_{t+1}/P_t = \pi$. Second, Y_t is the real aggregate income. The growth rate of aggregate real income $Z_{t+1} = Y_{t+1}/Y_t$ is part of the aggregate state variables in

[7] Piazzesi, Schneider, and Tuzel (2007) argue for a preference structure that is close to Cobb-Douglas based on the joint behavior of the U.S. housing expenditure shares and asset prices over time, while Davis and Ortalo-Magne (2011) show that a Cobb-Douglas specification is broadly consistent with the cross-sectional U.S. data.

this model. We specify the dynamics of Z_t in Section 3.3. Third, $\tilde{y}_{it}$ is the idiosyncratic labor income component, which follows an autoregressive process with state-dependent conditional volatility, i.e., heteroscedastic innovations,

$$\log \tilde{y}_{it} = \log \mu_y(Z_t) + \rho_y \log \tilde{y}_{i,t-1} + \sigma(Z_t)\epsilon^y_{it}, \quad \epsilon^y_{it} \sim \mathcal{N}(0,1). \tag{5}$$

The counter-cyclical nature of the idiosyncratic labor income risk, which is captured here by having $\sigma(Z_t)$ decreasing in Z_t, is emphasized by Storesletten, Telmer, and Yaron (2004). We set $\log \mu_y(Z) = -\frac{1}{2}\frac{\sigma^2(Z)}{1+\rho_y}$ so that the cross-sectional mean of the idiosyncratic components of income $\tilde{y}_{it}$ implied by the stationary distribution equals to unity in every period.[8]

Finally, the income tax rate is τ.

3.2 Household assets and liabilities

Liquid Assets Households have access to a savings account that earns interest equal to the nominal short rate r_t. The nominal short rate is another aggregate state variable in this model, and we specify its dynamics in Section 3.3. The balance of the savings account is a_{it}. We also refer to the savings account as the households' liquid assets. Interest income is taxed at the same rate τ as labor income.

Houses Households can own h_{it} units of housing, valued proportionally at price P^H_t per unit. We assume that the nominal house price level P^H_t has a component that grows at the same rate as the economy (i.e., nominal aggregate income), and another component that represents the aggregate risk inherent in the housing market's transitory deviations from the trend in aggregate income. Therefore, the per-unit house price is

$$P^H_t = \bar{H}\ P_t\ Y_t\ p^H_t, \tag{6}$$

[8] Guvenen, Ozkan, and Song (2012) show that it is the negative skewness of labor earning that increases during macroeconomic downturns, rather than the variance. Modeling the income process in such a way would be an interesting extension of our model, which we leave for future research.

where $\bar{H}$ is the long-run house price-to-income ratio, Y_t is the real aggregate income, and p_t^H follows a stationary process that reflects transitory shocks to house prices. Thus, real house price level is cointegrated with real aggregate income. We specify the process for p_t^H as part of the aggregate state variables in Section 3.3.

We allow h_{it} to take a finite set of values. This stock of housing generates housing service flow $h_{it}Y_t$. Indexing per unit housing service to real aggregate income Y_t ensures that aggregate housing and non-housing consumption are consistent with balanced growth. A sale or a purchase of a home incurs a proportional transaction cost ϕ_h. Therefore, while households can adjust their own stock of housing every period by trading it up or down, this adjustment is costly as it requires payment of the proportional cost on each leg of the transaction).[9]

Debt There are two types of borrowing allowed for the households, both of which are collateralized by the house: long-term mortgages and short-term home equity lines of credit (HELOC). For simplicity, long-term mortgage contracts are assumed to be perpetual interest-only mortgages. Households have to make mortgage payment $k_{it}b_{it}$ every period, based on the outstanding mortgage balance b_{it} and the (fixed) mortgage coupon rate k_{it}. The households can deduct the mortgage interest expense, which is the full mortgage payment for an interest-only mortgage, from their taxable income y_{it}.

The HELOC is modeled as a one-period debt with floating interest rate benchmarked to the riskfree rate r_t,

$$r_t^{HL} = r_t + \vartheta, \tag{7}$$

where $\vartheta > 0$ is the spread over the risk-free rate. The HELOC balance is subject to the borrowing constraints every period, which we specify below. HELOC transactions are costless. Due to the interest rate differential and the fact that the borrowing constraints described below are imposed on HELOC every period, it is never optimal to simultaneously hold

[9]Our approach implicitly treats house size as fundamentally limited by the availability of fixed factors such as land, similarly to the approaches in Ortalo-Magné and Rady (2006) and Corbae and Quintin (2013). Alternatively, one can model housing stock as fully adjustable through investment and depreciation, e.g. as in Favilukis, Ludvigson, and Van Nieuwerburgh (2011) and Iacoviello and Pavan (2013). Kiyotaki, Michaelides, and Nikolov (2011) explicitly consider the combination of both fixed and adjustable factors in the total value of the housing stock.

non-zero balances in HELOC and liquid assets. Thus, we denote the HELOC balance with $-a^{-}_{i,t}$ and the savings balance with $a^{+}_{i,t}$, where $a^{+}_{i,t} = \max(a_{i,t}, 0)$ and $a^{-}_{i,t} = \min(a_{i,t}, 0)$.

Mortgage Refinancing and Repayment Households have the option to refinance the long-term mortgage and reset the coupon rate $k_{i,t+1}$ to the current market mortgage rate R_t; they can increase or decrease the outstanding mortgage loan balance at that time, so that in general $b_{i,t+1} \neq b_{i,t}$; in particular, they can increase the loan balance (cash-out) only by refinancing into a new loan. The refinancing decision is denoted by the indicator I^{RF}_{it}, with $I^{RF}_{it} = 1$ if the home loan is refinanced at time t and $I^{RF}_{it} = 0$ otherwise, so that dynamics of the mortgage rate k_{it} are given by the law of motion:

$$k_{i,t+1} = k_{it}\ (1 - I^{RF}_{it}) + R_t I^{RF}_{it}. \tag{8}$$

For tractability, we specify the mortgage rate R_t as an exogenous function of the aggregate state vector $S_t \equiv (Z_t, p^H_t, r_t)$.

When households decide to refinance, they incur a cost. For example, if a household refinances into a new loan with balance $b_{i,t+1}$, they will incur a refinancing cost equal to $\phi(b_{i,t+1}; S_t)$. Therefore, the net proceeds from refinancing will in fact be equal to $b_{i,t+1} - b_{i,t} - \phi(b_{i,t+1}; S_t)$. The refinancing costs include the opportunity cost of time spent on the refinancing process, which does not depend on the loan amount, as well as direct fees associated with issuing a new mortgage, which tend to scale with the loan size. We assume that the cost of refinancing has both a quasi-fixed component and a proportional component. Given that the economy is growing over time, the fixed cost of refinancing is scaled with the nominal aggregate income, capturing the idea that the opportunity cost of time is proportional to market wage. We assume the following functional form:

$$\phi(b_{i,t+1}; S_t) = \phi_0\ P_t Y_t + \phi_1\ b_{i,t+1}. \tag{9}$$

Households can reduce their mortgage balance costlessly at any time by repaying the mortgage, i.e., choosing $b_{i,t+1} < b_{i,t}$ and keeping the coupon rate the same, $k_{i,t+1} = k_{i,t}$.

Collateral and debt service constraints Households are only allowed to borrow against a fraction of the full value of their home. If a household chooses to refinance its long-term mortgage (i.e., $I_{it}^{RF} = 1$), the new combined balances of all loans, both mortgage ($b_{i,t+1}$ and HELOC $-a_{i,t+1}^{-}$), must satisfy the following constraint:

$$\left(b_{i,t+1} - a_{i,t+1}^{-}\right) I_{it}^{RF} \leq \xi_{LTV} \; P_t^H h_{it}, \tag{10}$$

where the constant $\xi_{LTV} \geq 0$ controls the tightness of the *loan-to-value constraint* (LTV). In addition, every period when the HELOC balance is positive ($a_{i,t+1}^{-} < 0$), the total amount of borrowing is again subject to the LTV constraint:

$$\left(b_{i,t+1} - a_{i,t+1}^{-}\right) 1_{\{a_{i,t+1}^{-} < 0\}} \leq \xi_{LTV} P_t^H h_{it}. \tag{11}$$

Similarly, there is a set of *loan-to-income constraints* (LTI) on the long-term mortgage and HELOC:

$$\left(b_{i,t+1} - a_{i,t+1}^{-}\right) I_{it}^{RF} \leq \xi_{LTI} \; y_{i,t}, \tag{12}$$

$$\left(b_{i,t+1} - a_{i,t+1}^{-}\right) 1_{\{a_{i,t+1}^{-} < 0\}} \leq \xi_{LTI} \; y_{i,t}, \tag{13}$$

with $\xi_{LTI} \geq 0$, which mimic the debt-to-income constraint widely used in practice by mortgage lenders, in particular, for conforming loans.

Finally, we impose an upper bound on the HELOC balance as a fraction $-\underline{a}$ of permanent income,

$$a_{i,t+1}^{-} \geq \underline{a} P_t Y_t. \tag{14}$$

This constraint is motivated by the common practice that limits the size of HELOC loans to reduce the risk of default.[10]

Homeowners have the option to sell their homes at any time and become renters. When they do so, they repay the outstanding mortgage balance – including current mortgage coupon

[10] Since these loans are smaller, they are presumably not screened as thoroughly by the lenders, which is why we assume there is no cost to originate them.

payment and HELOC balance – using the net proceeds of house sales and their stock of liquid assets.

Default Homeowners have the option to default on their mortgages as well as HELOCs and become renters. When a household defaults on any of its debt, its home is ceased, as well as a portion of its liquid assets, so that the household is left with ζa in liquid wealth. Thus, the parameter $\zeta \in [0, 1]$ is a way to capture in reduced form full or partial recourse, as well as other costs of default, such as its effect on the credit history. Furthermore, the household that defaulted on its mortgage will be excluded from the housing market for a stochastic period of time. With probability ω each period, it will regain eligibility for becoming a homeowner, at which point the household can choose to buy a house or remain a renter.

Renting As a renter, a household can adjust its consumption of housing services every period. The Cobb-Douglas specification implies that renter households will allocate a constant fraction ν of their total consumption expenditures to rent. In addition, renters may suffer disutility from not owning a home.

Renters can become homeowners by purchasing a house, using savings and borrowing. Buying a house incurs the same transaction cost ϕ_h as selling, and originating a new mortgage loan incurs the same cost $\phi(b_{i,t+1}; S_t)$ as refinancing an existing loan.

In summary, Figure 3 shows a diagram that represents the households' homeownership decisions. As a homeowner, a household can choose to continue with the current mortgage by making the payments, repay part of the mortgage balance, sell the house at market value and become a renter, or default on the mortgage and rent. As a renter, a household can choose to remain a renter or buy a house. This approach broadly follows Campbell and Cocco (2010) in the treatment of the homeownership and default decision.

3.3 Summary of exogenous shocks

In total, there are three aggregate state variables, summarized in the aggregate state vector $S_t = (Z_t, p_t^H, r_t)$. We assume that S_t follows a first-order vector autoregressive process (VAR)

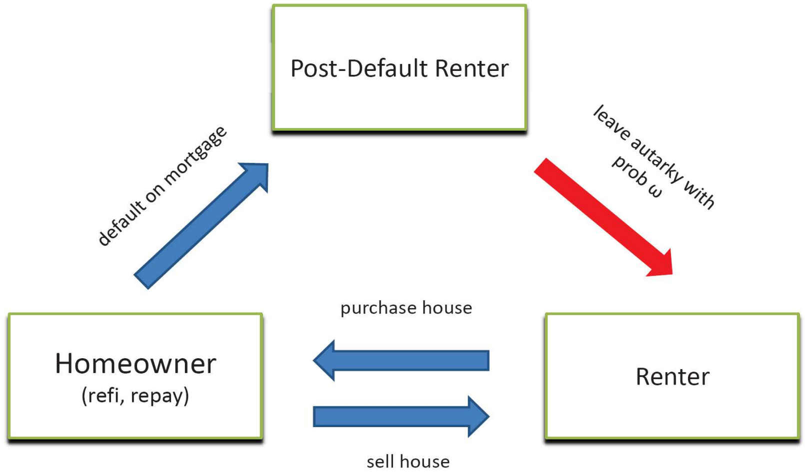

Figure 3: **Homeowner, renter, and post-default renter diagram.**

in logarithms:

$$\log S_{t+1} = \mu_S + \Phi_S \log S_t + \sqrt{\Sigma_S} \epsilon^S_{t+1}. \tag{15}$$

We assume that the mortgage rate R_t is a function of the aggregate state variables. We choose the following linear-quadratic specification for R_t, which is motivated empirically (see Section 4.1):

$$\log R(S) = \kappa_0 + \kappa_1' \log S + \kappa_2 \left(\log p^H_t\right)^2. \tag{16}$$

For an individual household, the vector of exogenous state variables, denoted by s_{it}, contains the individual labor income and the aggregate states: $s_{it} \equiv (y_{it}, S_t)$. We assume that all households bear the same aggregate risks since we focus on the "average" household that is likely to need to use home equity to smooth consumption (there is some evidence in the recent literature that wealthier households are disproportionately affected by aggregate fluctuations, see e.g., Parker and Vissing-Jørgensen (2009)).

3.4 Household problem

Next, we specify the problem for homeowners and renters. In order to simplify notation, we drop subscripts t and use primes to denote next period variables.

Homeowner problem The problem for homeowner i is to choose nominal consumption c_i, the house size h_i, the position in the liquid asset (or HELOC) a_i', as well as the decision to refinance or repay early (both of which result in a new mortgage balance b_i'), sell the house, or default on the debt, so as to maximize the expected lifetime utility of real consumption.

The household problem can be formalized as follows,

$$U_i^h(a_i, b_i, k_i, h_i, s_i) = \max_{a_i', b_i', h_i', I_i^{RF}} \left[(1-\delta) \left((h_i Y)^{\nu} (c_i/P)^{1-\nu} \right)^{\frac{1-\gamma}{\theta}} + \delta \mathbb{E} \left[\max \left(U_i^{h\prime}, U_i^{hr\prime}, U_i^{hd\prime} \right)^{1-\gamma} \right]^{\frac{1}{\theta}} \right]^{\frac{\theta}{1-\gamma}} \tag{17}$$

subject to

$$\begin{aligned} c_i + \frac{a_i^{+\prime}}{1+(1-\tau)r} + \frac{a_i^{-\prime}}{1+r^{HL}} + b_i &= (1-\tau)(y_i - k_i b_i) + a_i + b_i' - \phi(b_i'; S)\ I_i^{RF} \\ &\quad + I_i^M P^H \left((1-\phi_h)\, h_i - (1+\phi_h)\, h_i' \right) \qquad (18) \\ (b_i' - b_i)\ (1 - I_i^{RF}) &\leq 0, \\ c_i, b_i' &\geq 0, \end{aligned}$$

along with the law of motion for mortgage rate k_i (8), the LTV and LTI constraints (10)-(13), and the upper bound on HELOC (14). We denote the value function of the household in the homeowner state by $U_i^h(a_i, b_i, k_i, h_i, s_i)$, by $U_i^{hr}(a_i, b_i, k_i, h_i, s_i)$ in a state of transition from homeowner to renter by selling the home, and by $U_i^{hd}(a_i, b_i, k_i, h_i, s_i)$ in a state of transition from homeowner to renter by defaulting on the mortgage.

Upon transition from homeownership to renter state the proceeds from selling the house $(1-\phi_h)h_i P^H$ are added to the resource constraint while the mortgage and HELOC borrowing must be repaid. The problem for the household making the transition from the homeowner to the renter state by selling its home is then given by

$$U_i^{hr}(a_i, b_i, k_i, h_i, s_i) = \max_{a_i'} \left[(1-\delta) \left((h_i Y)^{\nu} (c_i/P)^{1-\nu} \right)^{\frac{1-\gamma}{\theta}} + \delta \mathbb{E} \left[U_i^r(a_i', s_i')^{1-\gamma} \right]^{\frac{1}{\theta}} \right]^{\frac{\theta}{1-\gamma}}, \tag{19}$$

subject to

$$
\begin{aligned}
c_i + \frac{a_i'}{1+(1-\tau)r} &= (1-\tau)(y_i - k_i b_i) + a_i + (1-\phi_h)h_i P^H - b_i, \\
a_i', c_i &\geq 0,
\end{aligned}
\tag{20}
$$

where $U_i^r(a_i, s_i)$ denotes the value function of an unrestricted renter who is allowed to buy a house immediately.

If a household defaults on its mortgage, it also becomes a renter, but with the added restriction that it will be excluded from the housing market for a period of time. This transition problem is given by

$$
U_i^{hd}(a_i, b_i, k_i, h_i, s_i) = \max_{a_i'} \left[(1-\delta)\left((h_i Y)^{\nu} (c_i/P)^{1-\nu} \right)^{\frac{1-\gamma}{\theta}} + \delta \mathbb{E}\left[U_i^d(a_i', s_i')^{1-\gamma} \right]^{\frac{1}{\theta}} \right]^{\frac{\theta}{1-\gamma}} \tag{21}
$$

subject to

$$
c_i + \frac{a_i'}{1+(1-\tau)r} = (1-\tau)y_i + \zeta a_i^+, \tag{22}
$$

$$
a_i', c_i \geq 0,
$$

where $U_i^d(a_i, s_i)$ denotes the value function of a restricted renter who is currently excluded from the housing market due to defaulting on its mortgage. In both (21) and (22), the constraint $a_i \geq 0$ is due to the fact that HELOC is unavailable to renters.

Renter problem For convenience, we define three different types of renters: unrestricted renter, restricted renter, and a renter in transition to become a homeowner, with value functions $U_i^r(a_i, s_i)$, $U_i^d(a_i, s_i)$, and $U_i^{rh}(a_i, s_i)$, respectively. We assume that rent per unit of house size is indexed to nominal aggregate income, with the ratio of rent to aggregate nominal income equal to a constant ϖ. The problem for an unrestricted renter is to choose the size of the rental house h_i^r, the non-housing consumption c_i, and the liquid assets for the next period a', such that

$$U_i^r(a_i,s_i)=\max_{h_i^r,a_i'\geq 0}\left[(1-\delta)\left((h_i^rY)^{\nu}(c_i/P)^{1-\nu}\right)^{\frac{1-\gamma}{\theta}}+\delta\mathbb{E}\left[\max\left(U_i^{rh}(a_i',s_i'),U_i^r(a_i',s_i')\right)^{1-\gamma}\right]^{\frac{1}{\theta}}\right]^{\frac{\theta}{1-\gamma}} \tag{23}$$

subject to the positivity of consumption and the budget constraint:

$$h_i^r\varpi PY+c_i=(1-\tau)y_i+a_i-\frac{a_i'}{1+(1-\tau)r}. \tag{24}$$

The intratemporal optimization implies

$$\frac{h_i^rPY\varpi}{c_i}=\frac{\nu}{1-\nu}.$$

That is, the ratio of rental expense and non-housing consumption is constant. This condition helps simplify the Bellman equation (23) and the renter budget constraint (24) into

$$U_i^r(a_i,s_i)=\max_{a_i'\geq 0}\left[(1-\delta)\overline{\eta}\,(c_i/P)^{\frac{1-\gamma}{\theta}}+\delta\mathbb{E}\left[\max\left(U_i^{rh}(a_i',s_i'),U_i^r(a_i',s_i')\right)^{1-\gamma}\right]^{\frac{1}{\theta}}\right]^{\frac{\theta}{1-\gamma}} \tag{25}$$

and

$$\frac{c_i}{1-\nu}=(1-\tau)y_i+a_i-\frac{a_i'}{1+(1-\tau)r}, \tag{26}$$

where

$$\overline{\eta}\doteq\left(\frac{\nu}{(1-\nu)\varpi}\right)^{\frac{\nu(1-\gamma)}{\theta}}. \tag{27}$$

In what follows, we treat $\overline{\eta}$ rather than ϖ as the structural parameter to be estimated, since it can be thought of as capturing the relative disutility of renting relative to owning a home.[11]

The transition problem for the household from the renter to the homeowner state is given by

$$U_i^{rh}(a_i,s_i)=\max_{a_i',b_i',h_i'}\left[(1-\delta)\left(\overline{\eta}\,(c_i/P)\right)^{\frac{1-\gamma}{\theta}}+\delta\,\mathbb{E}\left[U_i^h(a_i',b_i',k_i,h_i,s_i')^{1-\gamma}\right]^{\frac{1}{\theta}}\right]^{\frac{\theta}{1-\gamma}}, \tag{28}$$

[11]Such an effect could be identified separately only if ϖ was being tied down by the observed price/rent ratios in the data. In order to keep parameter space manageable, we do not attempt to disentangle these two structural forces in our estimation.

subject to

$$\frac{c_i}{1-\nu} = (1-\tau)y_i + a_i - \frac{a_i'}{1+(1-\tau)r} + b_i' - \phi(b_i'; S) - (1+\phi_h)h_i'P^H, \tag{29}$$

$$c_i, b_i' \geq 0,$$

as well as the LTV and LTI constraints (10)-(13) and the constraint on HELOC (14).

The problem of a restricted (post-default) renter is given by

$$\begin{aligned} U_i^d(a_i, s_i) &= \max_{a_i' \geq 0} \Bigg[(1-\delta)\left(\overline{\eta}\left(c_i/P\right)\right)^{\frac{1-\gamma}{\theta}} + \delta \mathbb{E}\left[(1-\omega)\left(U_i^d(a_i', s_i')\right)^{1-\gamma}\right]^{\frac{1}{\theta}} \\ &\qquad + \delta \mathbb{E}\left[\omega \max\left(U_i^{rh}(a_i', s_i'), U_i^r(a_i', s_i')\right)^{1-\gamma}\right]^{\frac{1}{\theta}} \Bigg]^{\frac{\theta}{1-\gamma}}, \end{aligned} \tag{30}$$

subject to the positivity of consumption as well as the renter budget constraint (26).

Since households have homothetic preferences, we rescale the problem with respect to the price level P_t and the permanent aggregate income Y_t in order to make it stationary.

4 Structural Estimation

This section describes the empirical implementation of the model in Section 3. To solve the model, we discretize the state space and apply standard numerical dynamic programming techniques. We estimate the model parameters in three steps. First, we specify the dynamics of the exogenous state variables based on empirical estimates. Second, we set the institutional parameters to broadly represent the environment faced by U.S. households. Third, we estimate the preference and transaction cost parameters by matching the model-implied moments (computed from the simulation of a large panel of households) of household assets, liabilities, and consumption, as well as the dynamics of mortgage refinancing, with the data, taking the pre-estimated state variable dynamics and pre-set institutional parameters as given. Thus, our approach is essentially a version of the simulated method of moments (e.g., Duffie and Singleton (1993)) where a set of "nuisance" parameters are pre-specified before the structural parameters are estimated.[12]

4.1 Exogenously specified parameters

Aggregate state variable dynamics We first estimate the VAR(1) for the aggregate state variables in (15) using annual data. The variables we use are the U.S. real GDP growth rate (our proxy for the real growth rate in aggregate income Z in the model), the one-year Treasury bill rate (as proxy for the nominal short rate r_t), and the demeaned log house price-GDP ratio computed using the S&P Case-Shiller house price index (HPI) and GDP data (as proxy for the transitory component in house price h_t). The descriptive statistics for these aggregate state variables and the estimated parameters of the VAR are reported in Table 3. We then approximate the VAR with a discrete-state Markov chain using the method of Tauchen and Hussey (1991). The state variables (Z, p^H, r) are discretized using 2, 10, and 10 grid points, respectively.

The three aggregate state variables are plotted in Panels A-C in Figure 4 for the period 1987-2012 (blue solid lines), along with the corresponding values on the grid (red circle lines). Panel A shows that the 2-state approximation tracks the history of real growth well over all, but it understates the severity of the drop during the Great Recession and slightly overstates the extent of the recovery thereafter. Panel B shows the highly persistent deviations of house prices from the trend of real economic growth, which our model captures closely. Panel C shows that the discretized process for r_t tracks the nominal short term rate very well.

For tractability, we have specified the mortgage rate R_t as an exogenous quadratic function of all the aggregate state variables as in Equation (16). Panel C of Table 3 reports the regression estimates of this relation based on the 30-year conforming mortgage rate (our empirical proxy for R). We obtain an R-square of 95% with just 4 explanatory variables $(Z_t, p_t^H, r_t, (p_t^H)^2)$, suggesting that this exogenous function $R(S)$ captures most of the time

[12] Dridi, Guay, and Renault (2007) provide a formal justification of such an approach based on the indirect inference methodology (Smith (1993), Gallant and Tauchen (1996), and Gourieroux, Monfort, and Renault (1993)). Laibson, Repetto, and Tobacman (2007) follow a similar strategy for estimating the structural parameters in a household consumption and liquidity management model with hyperbolic discounting. Gourinchas and Parker (2002) pioneered structural estimation of household consumption-saving models. Hennessy and Whited (2005) is a notable example of structural estimation of a debt and investment choice model in corporate finance.

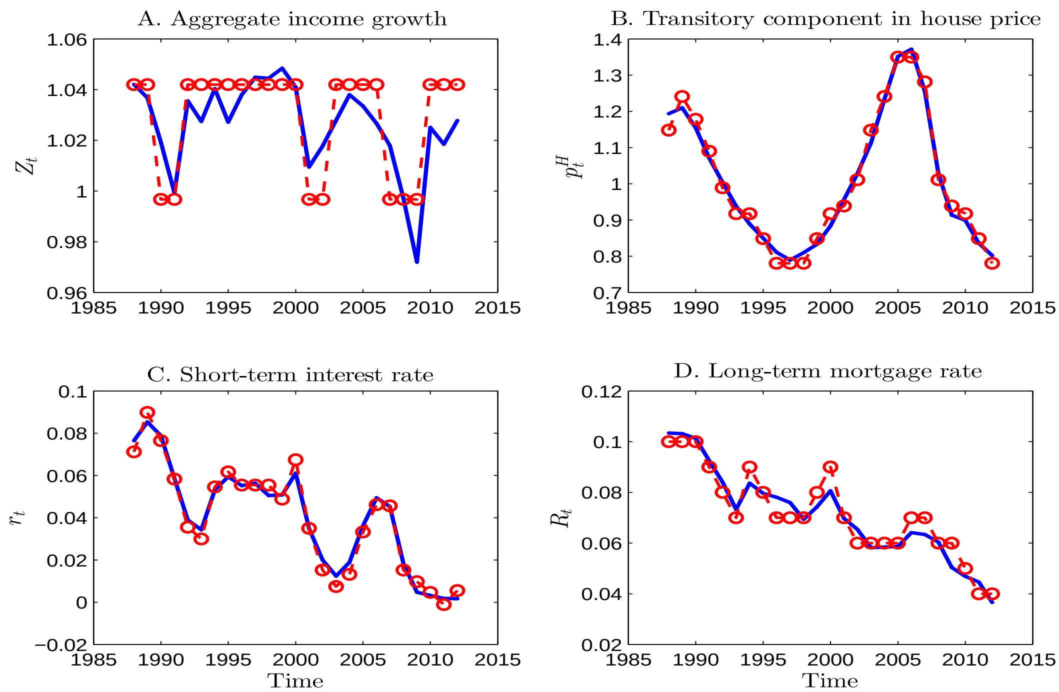

Figure 4: **Time series of exogenous state variables.**

variation in the long-term mortgage rate. Since the household's fixed mortgage rate k_{it} is part of the endogenous state variables that spans the same states as R_t, in order to keep the size of the state space manageable we use a coarser grid for the latter with 7 points based on the implied distribution of $R(S)$. Panel D of Figure 4 plots the long-term mortgage rate in the data and the corresponding value on the grid. The discretized process for R_t tracks the history of the mortgage rates closely throughout the sample.

Given the relatively smooth evolution of inflation over the sample period, we assume a constant inflation rate $\pi = 2.85\%$ per annum. The choice of the long-run mean of the ratio of house price to income $\bar{H} = 4$ is based on estimates obtained using micro data (in the Survey of Consumer Finances for 2001, a year when the house price to GDP ratio is close to its long-run mean, the average ratio of housing assets to income among homeowners with positive income equals approximately 3.95).

Idiosyncratic state variable dynamics The idiosyncratic component of the income process $\tilde{y}_{it}$ is discretized as a Markov chain with 12 grid points. The conditional volatility of $\tilde{y}_{it}$ depends on whether the economy is in the good or bad state, as in Storesletten, Telmer, and Yaron (2007). Based on their estimates, in our benchmark calibration, the conditional volatility of the log idiosyncratic income component in the good states (when Z is at the high growth level) is $\sigma(Z_G) = 12\%$, whereas in the bad state (when Z is at the low growth level) it is $\sigma(Z_B) = 21\%$. The autocorrelation parameter is $\rho_y = 0.95$.

Institutional parameters Several exogenously set parameters reflect the main institutional features of the U.S. economy for homeowners and renters. First, personal income tax rate is set at $\tau = 25\%$. Second, the set of borrowing constraint includes (i) the constraint on the loan-to-value ratio $\xi_{LTV} = 80\%$, (ii) the constraint on the loan-to-income ratio $\xi_{LTI} = 3.5$, which are broadly consistent with the conforming loan requirements, and (iii) the upper bound on HELOC balances is $-\underline{a} = 30\%$ of aggregate income. Third, the period of exclusion from debt markets for households who defaulted on a mortgage loan is on average 7 years, as represented by the probability of return to credit markets in one year equal to $\omega = 0.15$. Finally, we set $\zeta = 1$, so that a household does not lose any of its liquid assets after defaulting on the mortgage. We experimented with a range of values that capture partial recourse, but we omit these results in the interest of brevity as they are not essential for our central message. Most of these choices closely follow Campbell and Cocco (2010).

The idiosyncratic labor income and institutional parameters are summarized in panel A of Table 4.

4.2 Simulated moments estimation

The remaining structural parameters include the preference parameters (δ, γ, ψ), the rental expense share parameter η, and the cost parameters for mortgage refinancing (ϕ_0, ϕ_1) and house sales ϕ_h. We estimate $\Theta \equiv (\delta, \gamma, \psi, \nu, \varpi, \phi_0, \phi_1, \phi_h)$, taking as given the set of pre-specified parameters $\Theta_0 \equiv (\mu_S, \Phi_S, \Sigma_S, \pi, \mu_y, \rho_y, \sigma_y(\cdot), \bar{H}, \tau, \kappa_0, \kappa_1, \kappa_2, \xi_{LTI}, \xi_{LTV}, \underline{a}, \zeta, \omega, \vartheta)$, by minimizing a standard objective function:

$$\hat{\Theta} = \arg\min_{\Theta} \left(M - m(\Theta, \Theta_0)\right)' \mathbf{W} \left(M - m(\Theta, \Theta_0)\right),$$

where $m(\Theta, \Theta_0)$ is the vector of reduced-form statistics of the simulated variables, M are their empirical counterparts, and W is a weighting matrix.

For each set of parameter values, we first solve for the optimal policies from the household problem numerically. Then, we simulate a panel of households, which are initialized by randomly drawing pairs of liquid assets a_i and mortgage balance b_i over the state space for all N households in the cross section. We use a cross section of $N = 1000$ households and compute all of the statistics m along the aggregate time path of $T = 2000$ (annual) periods, after burn-in.

Data targets We estimate the preference and transaction cost parameters by targeting 14 moments of the data. These include 3 unconditional means applying to the whole population: (1) aggregate ratio of nondurable and non-housing services consumption to income (from NIPA), (2) average household-level consumption growth volatility (based on the Consumer Expenditure Survey estimates reported by Wachter and Yogo (2010)), and (3) the average homeownership rate (from the U.S. Census).

There are 6 moments relevant to the homeowner subset of the population: (4) average ratio of liquid asset holdings to income, and (5) average ratio of household mortgage debt to income (both based on 2001 Survey of Consumer Finances, or SCF); (6) the average ratio of HELOC balances to income; (7) the average number of refinance loans relative to the number of homeowner households (based on HMDA and Census data); (8) the average loan-to-income ratio upon refinancing (from SCF); (9) dollar cash-out as a share of aggregate refinancing volume (data from Freddie Mac). There is also one moment for the renter population: (10) the average ratio of liquid asset holdings to income for the renter subset of the population (from SCF).[13] All the moments from SCF are based on the truncated sample from the 2001 Survey of Consumer Finances, whereby we exclude the top 20% of the wealth distribution (based on liquid assets as a measure of wealth).[14] In the data, the wealth distribution is

[13]We define liquid assets in the SCF data as the total value of checking/savings accounts, bonds, and public equity holdings, including both directly-held stocks and mutual funds. Kaplan and Violante (2011) use a similar definition. For mortgage debt we use the first lien loan collateralized by the primary residence of the household, whereas the combined balance of the junior lien loans on the same residence is classified as HEL(OC).

[14]Gomes and Michaelides (2005) similarly truncate the empirical distribution from the SCF.

heavily skewed to the right, which implies that its mean is much higher than the median (1.33 vs. 0.10 for the liquid asset holdings, according to the 2001 SCF) and therefore not representative of a typical household that our model aims to replicate, whereas the mean of the bottom 80% of the distribution is close to the median of the entire sample.[15]

The remaining 4 moments describe the dynamics of refinancing and cash-out behavior estimated via linear regressions of these variables on aggregate income growth and house price growth rates as documented in Section 2. Table 5 reports both the target empirical moments and the simulated moments corresponding to the minimized objective function, as well as several additional moments that were not targeted in the estimation.

Since we use more moments than parameters, the model is over-identified. We use a diagonal weighing matrix that is scaled by the empirical moments in question as a normalization, that is, $\mathbf{W} = \text{diag}(M)^{-1}\mathbf{S}\,\text{diag}(M)^{-1}$, where $\text{diag}(M)$ is a diagonal matrix with the empirical moments as the diagonal elements. The diagonal matrix $\mathbf{S}$ has elements of ones corresponding to all of the moments, except: (i) average debt balances and the refinancing rate have the weight equal 6, (ii) liquid asset holdings and average consumption growth volatility for homeowners each have the weight of 4, (iii) the 4 regression coefficients, which have the weight of 3, and (iv) the mean liquid assets of renters have the weight of 0.1. These weights reflect the fact that we are most interested in capturing the leverage and liquidity choices of homeowners. We use this pre-specified weighting matrix rather than a matrix that is based on the estimated variance-covariance matrix of moments (such as the efficient GMM weighting matrix of Hansen (1982)) in order to make sure that the information in some of the economically important but relatively poorly estimated moments (like the regression coefficients) is not down-weighed too much, as it is important for identification. Since the objective function is highly nonlinear, we use a global search algorithm to ensure that the resulting estimates are not due to local minima.

Numerical Implementation The household problem is solved numerically using a standard value function iteration (VFI) procedure on a very large grid (more than 1.9 million

[15]In our model all households are ex ante identical, and all of the heterogeneity is due to idiosyncratic shocks, which are transitory. Moreover, in our model household preferences are homothetic, while explaining the large amount of asset holdings by the wealthy households typically requires non-homotheticities, e.g. Carroll (2000), DeNardi (2004), Roussanov (2010).

total grid points, with 1920 points for the exogenous states and 960 points for the endogenous states). Moreover, we need to solve the model repeatedly in the estimation. These requirements make the computational problem rather challenging. To make the estimation feasible, we programmed the numerical solution in CUDA language and ran the VFI on a Nvidia C2050 (Fermi) graphics card (with 448 CUDA cores). The estimation was implemented with a global optimization routine capable of using up to 8 graphics cards simultaneously. This (software and hardware) implementation yields a significant improvement in speed, allowing us to estimate the model in less than one week. The same estimation problem will take 400 times as long on a standard desktop computer.

Simulation-based inference In order to be able to evaluate the statistical significance of the mismatch between the target and simulated moments, as well as the uncertainty about the estimated parameter values, we need to estimate the variance-covariance matrix of the sample moments, Ξ. Since we use a combination of time-series and cross-sectional moments, using data directly is not feasible. Instead, we construct the variance-covariance matrix of the *simulated* moments under the null that the model is true (with the parameters set at the estimated values). In order to estimate this matrix we simulate $N_A = 80$ paths of aggregate variables and generate a panel of $N = 1000$ households using these aggregate shocks and simulated idiosyncratic shocks so that it matches the small sample length $T_D = 25$ years available in the data. For each of the aggregate paths we compute the full set of moments, and estimate the variance-covariance matrix of these moment vectors across simulations. While the simulated moments used in estimation are based on long samples of length T, i.e. are essentially population moments, the variance-covariance matrix estimated using the short-sample simulated moments measures the sampling uncertainty about the moments estimated in the data under the null of the model.

In addition, we construct standard errors for the estimated parameters from the Ξ matrix using the standard delta method, where the derivatives of the moments with respect to the parameters are approximated using numerical finite differences.

4.3 Estimation results

Targeted moments The targeted empirical moments as well as their simulated model counterparts are reported in panel A of Table 5 along with the simulated standard errors.

In our model, the average ratio of consumption to income at 0.71 is slightly above the 0.66 in the NIPA data (using both nondurable and durable goods expenditures, as well as non-housing services); according to the model this moment is estimated very precisely, with a standard error of 1%, which implies that statistically this difference is significant, even though it is economically small. The model-implied annual household-level consumption growth volatility of 16.4% is much higher than the 9% target estimated by Wachter and Yogo (2010), which is constructed to reduce measurement error, but it is consistent with the estimate of Brav, Constantinides, and Geczy (2002) based on the CEX data (16-18% for households with total assets exceeding \$2,000). The model implies an average homeownership rate of 67.4%, quite close to the 66% average homeownership rate in the data.

Notice that the 16.4% household-level consumption growth volatility is only slightly below the unconditional labor income growth volatility of 16.6%, implying limited consumption smoothing on average. There is tension in the model as it tries to match simultaneously a low level of average liquid asset holdings, a high level of average debt holdings (both of which require low risk aversion), and a moderate consumption volatility (which requires high risk aversion). Although home equity can help homeowners smooth income shocks in bad times, the financial leverage tends to raise consumption volatility on average.

The model also does a good job matching the average liquid asset holding and mortgage balances for homeowners in the data. Mortgage debt is a fraction 0.96 of household income on average, compared to 0.98 in the SCF data. This is in contrast to an average house price to income ratio of $\bar{H} = 4$. Households pay down a part of the mortgage balances over time for two reasons. First, mortgage borrowing is generally a costly way to finance consumption due to the interest rate differential between mortgage loans and personal savings. Except when the term structure of interest rates is sufficiently flat that the effective (after-tax) borrowing rate is equal to or lower than the short rate, households optimally choose to repay part of their mortgage debt rather than holding too much in liquid assets. Second, by partially repaying the mortgage debt, households can maintain some home equity "for the rainy day." Since accessing housing collateral is costly, home equity is an illiquid form of saving that can be tapped for consumption purposes infrequently, e.g., following large negative income shocks. The model also matches the average holdings of second-lien loans reasonably well (0.07 of household income in the data vs. 0.08 in the model, insignificantly different statistically given the standard error of 0.01).

Despite the low return on liquid assets, households still hold liquid assets equal to 24% of income in the model, which is close to the amount observed in the SCF data (28%). It is more efficient to use liquid assets to buffer small fluctuations in income due to the costs of accessing home equity via cash-out refinancing. Liquid assets also become highly valuable in cases when the borrowing constraints (LTV or LTI) bind.[16] The model implies a reasonable level of liquid asset holdings for renters at 15% of annual household income vs. 18% in the SCF data.

About 11.3% of homeowners per year refinance their mortgages in the model, compared to 8% in the data. The average loan-to-income ratio for the new loans originated from refinancing in the model (2.74) is significantly higher than the average value in the 2001 SCF (1.41) and the HMDA data for 1993-2009 (1.90). Accordingly, the amount cashed out conditional on refinancing is also high, equaling to 51% of new loan balances, compared to 12% in the data. Estimates from the data are based on the average cash-out share of refinance originations for prime, conventional loans, as provided by Freddie Mac, and average loan-to-income data available from HMDA. To the extent that these estimates are representative of the U.S. homeowners, the model predicts too much cash-out as well as too frequent refinancing into large mortgages in general, with the differences being both economically and statistically significant. It is a challenge for the model to simultaneously match the refinancing rate and the dollar amounts of cashed-out home equity. While raising the fixed cost of loan origination helps reduce the frequency of refinancing, it makes households cash out even more each time

[16] Using 2004 SCF data, Vissing-Jørgensen (2007) estimates that by using their lower-return liquid assets to accelerate the repayment of higher-cost housing debt U.S. consumers would have saved $16.3 billion - see discussion in Guiso and Sodini (2013). Telyukova (2013) analyzes the role of liquidity in explaining the related puzzle of concurrent credit card debt and savings account holdings documented by Gross and Souleles (2002), while Laibson, Repetto, and Tobacman (2003) argue that consumer self-control problems may be necessary to explain quantitatively the extent of the puzzle.

they refinance.

On the set of moments from the refi and cash-out regressions, the model matches the signs and approximately the magnitudes of all the coefficients on income growth (β_Z) and on house price growth (β_H), especially in the case of cash-out regression. Both the refinancing rate and the dollar cash-out to income ratio comove positively with house price growth, and negatively with income growth, as we find in the data. While these regression coefficients are estimated quite imprecisely, as evidenced by the large standard errors that we report, targeting these coefficients is important for capturing the cyclical dynamics of household demand for liquidity, which helps to identify some of our key structural parameters.

Parameter estimates Next, the estimated values of the preference and transaction cost parameters are reported in panel B of Table 4, accompanied with the standard errors in the parentheses. The preference parameters implied by the moments above are the subjective discount factor $\delta = 0.920$, the coefficient of relative risk aversion $\gamma = 3.036$, and the intertemporal elasticity of substitution $\psi = 0.301$. These parameters imply a moderate degree of risk aversion and a limited willingness to substitute consumption intertemporally, i.e. a desire for a smooth consumption profile over time. These parameter estimates are driven largely by the low target level of liquid asset holdings, high debt levels, and the observed sensitivity to changes in interest rates and economic conditions embedded in the refinancing frequency and the regression coefficients. In particular, our estimate of the IES is close to the estimate obtained by Vissing-Jørgensen (2002) using stockholder household-consumption data from the CEX (0.299).[17]

While a number of studies that estimate the IES using the aggregate log-linearized Euler equation following Hall (1988) find values very close to zero, such an approach would not be valid in an economy that conforms to our model, given the substantial heterogeneity

[17] Our estimate of the IES differs from values typically used to reconcile asset pricing facts with consumption dynamics in representative-agent models. For example, Bansal, Kiku, and Yaron (2012) estimate IES of around 2 using aggregate consumption and asset price data, while their estimate of the coefficient of relative risk aversion is twice as large as ours. This is not surprising since the only risky asset that we target in the data is housing (and mortgage). Moreover, we target households in the bottom 80% of the wealth distribution, who exhibit low rates of stock market participation. Vissing-Jørgensen (2002) obtains estimates of the IES above one for households in the upper tail of the wealth distribution who participate in financial markets; see also Attanasio and Weber (1995) and Vissing-Jørgensen and Attanasio (2003).

and frictions.[18] In fact, as Table 5 Panel B reports, the estimated slope coefficient from the regression of consumption growth on the lagged risk-free interest rate based on the simulated data from the benchmark model is only 0.09, while the coefficient from the regression of consumption growth on the lagged long-term mortgage rate R is 0.10, both about one third of the true value.

The rental expense parameter $\eta = 0.750$ implies he average rent/income ratio $\varpi = 0.0614$, given the other parameter estimates. This parameter is identified jointly by the average consumption-income ratio and the share of homeowners as well as the balance sheet moments, since the benefit of homeownership is in large part the avoidance of rental expenses but also the asset and collateral value of housing. Introspection suggests that the implied rent/income ratio is rather low and therefore that the house is a relatively attractive investment from the standpoint of the model, since the level of rent at which a marginal household is indifferent between renting and owning is on a low end.

Households use debt primarily as a way of smoothing consumption and financing new home purchases. Existing debt balances are refinanced either to reduce the coupon rate k, or to cash-out equity. The quasi-fixed and proportional costs of refinancing, ϕ_0 and ϕ_1, are primarily identified by targeting empirically observed average refinancing rates, in terms of both frequency and loan size. They are also influenced by the average level of mortgage debt, since higher transaction costs make higher balances less attractive by effectively lowering the value of the refinancing option, as well as by making home-equity withdrawal via cash-out more expensive. Anecdotal evidence suggests that explicit costs of roughly $2\% - 5\%$ of loan amount are paid when refinancing a mortgage loan of average size, in addition to non-pecuniary information processing costs and the opportunity cost of time required to process the transaction. In the estimation, we obtain a quasi-fixed cost of 15.4% of permanent income (or 3.9% of the house value on average) and a proportional cost of 1.4%, which is comparable to the costs calibrated by Campbell and Cocco (2003).[19]

[18] Carroll (2001) and Hansen, Heaton, Lee, and Roussanov (2007) discuss some of the issues associated with the standard approaches to estimating the IES.

[19] Empirically the bulk of explicit cost of refinancing can be attributed to title insurance, which is proportional to house value, whereas the non-monetary costs such as the opportunity cost of time spend searching for an attractive mortgage rate and preparing the necessary documents are likely quasi-fixed.

The model implies that the cost of buying (or selling) a house ϕ_h is 13.5% of the house value. This parameter is identified primarily by the average homeownership rate but also by the asset holding levels among homeowners and renters, since this parameter controls the cost of transition from one group to another. This estimated cost is high, although it is meant to capture the psychic and physical costs of moving, besides the actual pecuniary transaction costs (such as transfer taxes and realtor commissions).

As indicated by the standard errors, most of the parameters are estimated fairly precisely in the sense that the sampling uncertainty about the data moments, under the null of the model, translates into tight confidence bands for the point estimates. All of the parameters are statistically significantly different from zero, and the discount factor δ is also statistically significantly lower than unity. Interestingly, the coefficient of relative risk aversion cannot be distinguished from the inverse of the IES, suggesting that the standard separable utility function with constant relative risk aversion provides a reasonable description of household preferences.

In order to verify that our model is well specified and that the estimated model parameters are indeed economically reasonable, in the remainder of the paper we conduct a series of detailed sensitivity analysis exercises as well as evaluate the model by confronting it with features of the data that are not targeted in the estimation. These include additional aggregate moments, cross-sectional statistics, and actual realizations of the aggregate variables in the time series.

Additional moments Panel B of Table 5 reports several additional moments that are not targeted in the structural estimation. The ability of the model to match these moments can be seen as a successful out-of-sample test. The volatility of aggregate consumption growth in the model is 3.9%, compared to 2.7% in the data. The model also matches reasonably well the sensitivities of both the total refinancing rate and the dollar cash-out to the fluctuations in the mortgage rate. In the refinancing regression, the coefficient on mortgage rate, β_R^{REFI}, is -1.09 in the model, compared to -1.91 in the data. In the cash-out regression, $\beta_R = -0.83$ in the model vs. -0.43 in the data. Recall that we do not target these particular coefficients in our estimation. The substantial sampling uncertainty about these moments swamps whatever differences that remain between the regression moments.

4.4 Sensitivity analysis

We now analyze the sensitivity of the simulated moments to the estimated parameters, which underpins our structural identification. Table 6 displays the values of simulated moments for different values of the key parameters in Θ, compared to the baseline case. For each of the seven estimated parameters we consider two values equidistant from the point estimates in either direction. Our discussion focuses on the key effect of each of the parameters.

Subjective discount factor δ Making households more patient via a larger δ increases the prevalence of homeownership, and increases household savings in the form of liquid asset holdings and home equity while lowering average mortgage balances). HELOC balances stay essentially the same (even though HELOC is more expensive than the mortgage on average in terms of the interest rate, it can be cheaper to access when liquidity is needed). As mortgage balances decline with higher δ, so does the frequency of refinancing and the sensitivity of refinancing to interest rates (β_R^{REFI} closer to 0). When the benefit of interest savings from refinancing is small, only those suffering from large income shocks find it worthwhile to pay the fixed costs of refinancing, as evidenced by the higher loan-to-income ratios and cash-out share for the new loans after refinancing. Moreover, under higher δ, while households cash-out more following negative aggregate income shocks (more negative β_Z), the consumption growth is still more affected by income shocks (larger β_Z^C), suggesting that households save the cashed-out home equity rather than consuming it. Finally, the average consumption/income ratio is higher with more patient households, again due to the fact that they have accumulated more savings via liquid assets and home equity.

Coefficient of relative risk aversion γ Increasing the risk aversion leads to more precautionary savings in the forms of liquid asset holdings and home equity (through both higher homeownership and lower mortgage balances), but also reduces the usage of HELOC as households accumulate enough liquid assets. Refinancing is mainly driven by the need to withdraw home equity rather than the purely financial incentive of lowering the mortgage rate, as cash-out/refi ratios increase in risk aversion and the sensitivity of refinancing to mortgage rate β_R^{REFI} moves closer to 0. Like the patient households, risk-averse households also cash-out more following negative aggregate consumption shocks (more negative β_Z) and shocks to mortgage rates (more negative β_R).

Intertemporal elasticity of substitution ψ A higher IES lowers liquid asset holdings, increases mortgage balances, and raises consumption volatility. This is due to the reason that households are less concerned with smoothing consumption over time, and the effects are qualitatively similar to those of a lower risk aversion. However, while a lower risk aversion coefficient reduces homeownership (which is driven by weaker precautionary savings motive), a higher IES raises homeownership. This is because the higher IES makes the refinancing option associated with owning a house more valuable, whereby households can better take advantage of house price appreciation and drop in interest rate.

The IES is also important for the dynamics of refinancing and cash-out. With a higher ψ, households are more willing to substitute consumption over time, therefore both cash-out and consumption are responding more to the changes in interest rates, as shown in a more negative β_R and a larger β_R^C.

Cost of refinancing ϕ_0, ϕ_1 Raising the quasi-fixed cost ϕ_0 of refinancing reduces the frequency of refinancing while increasing the new loan size and its cash-out component. Since costly refinancing makes mortgages effectively more expensive, average mortgage balances decline, as does homeownership. Its effect on the total leverage is partly offset by higher HELOC balances. Since lower mortgage balance reduces the risk in the household balance sheet, the precautionary holding of liquid assets is also lower. Raising the proportional cost parameter ϕ_1 has very similar effects. It might appear surprising that higher proportional refinancing cost increases the average new loan size and the cash-out share. This is driven by the composition effect: households are less likely to refinance for the purpose of lowering mortgage rates (β_R^{REFI} is -0.83 with high ϕ_1, compared to -1.09 in baseline case) but more likely to refinance to cash out home equity.

5 Model Evaluation and Quantitative Implications

We evaluate the quantitative performance of our model along several dimensions. Using a series of comparative statics, we first investigate the effects of the key structural features of the model on its ability to reproduce the key targeted moments of the data, as well as their additional quantitative implications. We then use the estimated parameters of the model to evaluate its ability to explain both the cross-sectional and the time-series features of the data that were not targeted in estimation.

5.1 Comparative statics

In order to analyze the model's mechanism we compute a range of comparative statics for its key structural elements. We report the simulated moments from the model for each of the model specification alongside the baseline that uses the estimated parameter values, similarly to the sensitivity analysis described above.

Labor income risk Table 7 displays the comparative statics that pertain to the underlying dynamics and the key frictions faced by the households in the model. Specification in column (2) shuts down heteroscedasticity in the idiosyncratic labor income process by setting $\sigma(Z_G) = \sigma(Z_B) = 18\%$. In this case, the reduction in risk due to the removal of the countercyclical variation in income uncertainty leads households to choose slightly higher leverage than in the baseline (mortgage-to-income ratio rises from 0.94 to 0.97), while the consumption growth volatility at both the individual and aggregate level change very little, the latter being somewhat lower to the reduction in the sensitivity of consumption to aggregate income shocks.

With higher mortgage balances, homeowners also refinance their mortgages slightly more frequently. In particular, refinance becomes more sensitive to changes in mortgage rates (β_R^{REFI} changing from -0.97 to -1.06), while cashout becomes more sensitive to changes in aggregate income (β_Z changing from -0.19 to -0.25) and mortgage rates (β_R changing from -0.57 to -0.59).

In specification (3) we magnify the time-varying labor income uncertainty by increasing the value of $\sigma(Z_B)$ from 21% in the baseline case to 30%. In response, homeowner households reduce their leverage (mortgage debt to income ratio drops to 0.81) and all households accumulate more liquid assets (asset to income ratio rises from 0.24 to 0.31 for homeowners and from 0.15 to 0.22 for renters), yet the consumption volatility at at the aggregate level is higher, at 4.5% (even though individual consumption growth volatility is slightly lower on average, at 15.6%). Homeownership rate increases from 67.7% under the baseline to 71.7%, pointing to the consumption-smoothing role of home equity. Given lower mortgage balances, refinancing is less frequent, at 9.5%, but households withdraw slightly more equity upon refinancing, with the ratio of cash-out amount to new loan balance increasing from 0.51 to 0.54. This is because households are more likely to encounter large negative shocks that require them to access housing collateral for consumption smoothing. Furthermore, refinancing becomes less sensitive to interest rates (β_R^{REFI} changes from -0.97 to -0.8).

Relaxing the constraints Specifications (4) and (5) consider the cases where the borrowing constraints imposed on mortgage origination and refinancing are relaxed. In case (4) we remove the LTI constraint ($\xi_{LTI} = \infty$). Naturally, the average mortgage balances are almost 66% higher, at 1.56 (relative to income), compared to 0.94 in the baseline. Refinancing becomes more frequent (15.8% per year) and more sensitive to interest rate changes ($\beta_R^{REFI} = -1.30$). Removing the LTI constraint also enables households to cashout more following aggregate income shocks, as β_Z becomes over twice as large as in the baseline case at -0.45. As a result, despite the fact that consumption growth becomes more volatile at the aggregate level, its sensitivity to aggregate income shocks β_Z^C remains essentially the same as in the baseline case. Greater leverage also leads to a slight increase in the default rate, albeit it is still just less than one percent of homeowner households per year.

In specification (5) we instead relax the LTV constraint by setting $\xi_{LTV} = 125\%$, mimicking the Homeowner Affordable Refinance Program (HARP) instituted by the U.S. government in 2011, which is intended to allow underwater homeowners who are current on their mortgage payments and whose loans were guaranteed by the government-sponsored enterprizes (GSEs) Fannie Mae and Freddy Mac to refinance. Similar to case (4), relaxing the LTV constraint leads to higher mortgage balances and higher consumption volatility. Refinancing also becomes slightly more frequent, and cash-out is more sensitive to shocks to aggregate income as well as interest rates.

Interestingly, households now cash-out more, not less, following drops in house prices (β_H changes from 0.10 in the baseline case to -0.27). Two effects are at work in determining how cash-out responds to house price shocks. On the one hand, a rise in house price relaxes the LTV constraint, which helps generating a positive relation between cash-out and house price changes. On the other hand, because house price shocks are persistent, households will want to cash-out preemptively following drops in house prices, before the LTV constraint binds. The first effect dominates when the LTV constraint is relatively tight (as in the baseline case), while the second effect dominates when ξ_{LTV} is raised to 125%.

Most notably, relaxing the housing collateral constraint raises the default rate sharply, to 1.9% of homeowners per year. This is not surprising, as with higher leverage it is more likely that a household would find its home equity negative after a decline in house prices, which is a necessary (but not sufficient) condition for a strategic default to be optimal (Corbae and Quintin (2013) analyze the effect of the loosening and subsequent tightening of leverage constraints on mortgage default following the decline in house prices; see also Campbell and Cocco (2010) for a detailed analysis of household default decisions in the presence of labor income shocks and different mortgage products).

This result is in sharp contrast to the case of relaxing the LTI constraint. In the presence of the LTV constraint, relaxing the LTI constraint has very limited impact on mortgage default, but it can already help facilitate consumption smoothing by boosting cashout refinancing in bad times. In this sense, a program that relaxes the LTI constraint instead of the LTV constraint (like the HARP) might be able to relax the household financial constraints without causing as much a rise in default risk. Moreover, the different sensitivity of default risk to the LTI and LTV constraint as captured in our model will also be important for mortgage pricing and mortgage contract design.

Not surprisingly, relaxing either the LTI or the LTV constraint increases the rate of homeownership substantially, to 81.9% and 77.4%. respectively. Since houses are valued for their housing services as well as potential saving vehicles, lowering barriers to entry into housing markets increases demand.

Finally, in specification (6) we examine whether our results are sensitive to the availability of HELOCs. In the absence of HELOCs, households hold more liquid assets, but the other predictions including mortgage balance, consumption volatility, and cashout response to aggregate income shocks are all similar to the baseline case, conditional on homeownership. The homeownership rate itself is somewhat lower though, at 61.6% vs 67% under the baseline, which suggests that the flexibility offered by HELOCs is valuable in reducing the effective cost of owning a house. As discussed before, HELOCs are used mainly to smooth small idiosyncratic income shocks. Without HELOCs, households simply substitute into liquid assets, and their consumption and mortgage financing behaviors are not significantly altered.

5.2 Cross-sectional implications

Having examined the aggregate implications of the estimated model, we now turn to its cross-sectional predictions. We focus on the behavior of homeowners with respect to their use of mortgage debt as a key tool of balance sheet adjustment.

Figure 5 presents the key variables capturing the household refinancing behavior for the quintiles of households sorted on income relative to the aggregate (i.e., on the idiosyncratic component $\tilde{y}$), conditional on homeownership (panels in the left column) and on the ratio of debt to income (panels in the right column). In the model, liquidity needs drive much of the refinancing behavior. Consequently, conditional on refinancing, the average dollar cash-out to income ratio is decreasing in income (Panel A), from close to 1.5 in the bottom quintile to about 0.25 in the top. At the same time, it is also decreasing in debt to income ratios, largely due to the LTI constraint, from just under 3.5 in the bottom two quintiles (households who go from essentially zero debt all the way up to the constraint) down to approximately 1 in the top quintile.

The average refinancing households in all the income quintiles have nonzero HELOC balances before refinancing, as evidenced by negative average asset holdings before refinancing in panels C and D. This suggests that liquidity-constrained households first borrow using short-term HELOCs, which have no transaction costs, and then switch to cashing out home

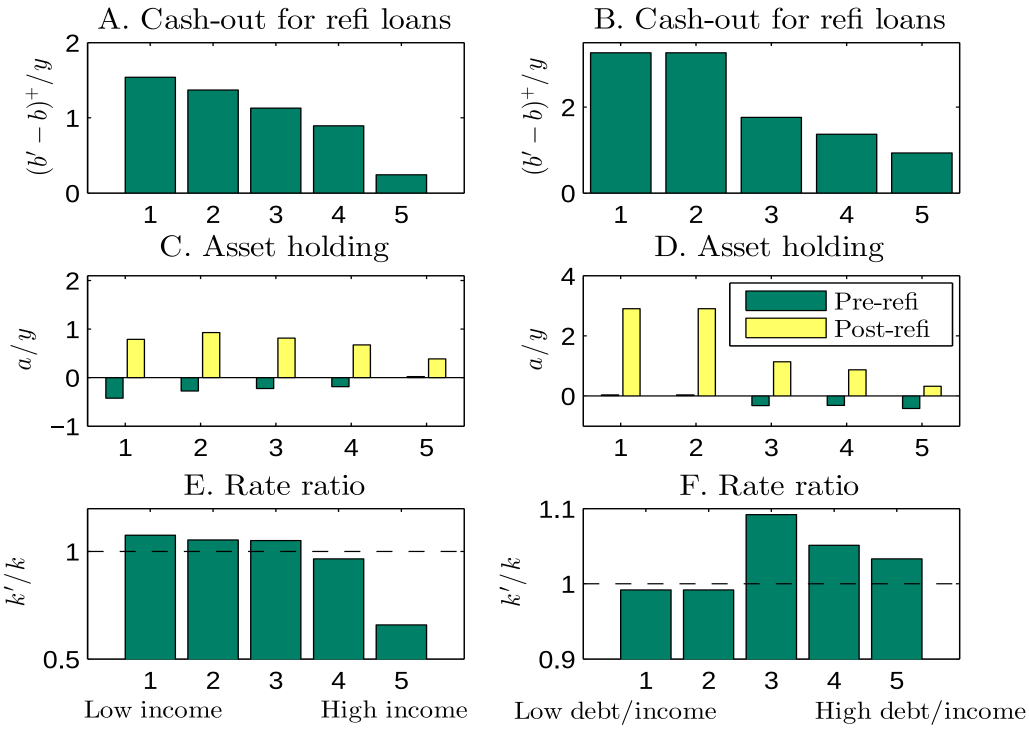

Figure 5: **Cross-sectional features of refinancing: model.**

equity when the liquidity needs become sufficiently strong. The asset-to-income ratio is increasing in income (Panel C), ranging from -0.32 for the bottom quintile to 0.02 for the top quintile. After refinancing, the cashed-out home equity not only helps pay down the HELOC balances, but substantially boosts the liquid asset positions, up to around 80% of annual income for the bottom two quintiles, and about 50% for the fourth quintile. Similarly for the debt/income sort (Panel D), high debt households repay HELOC balances, leaving relatively little of the cashed-out funds available for consumption (roughly one half of income in the top quintile and just above one year's income in the middle quintile), where as the 40% households with no debt enter the period in which they refinance with on average a tiny amount of liquid assets, leaving with over 3 times one year's income.

As a clear indication that it is liquidity demands that drive much of the refinancing for relatively low income homeowners, the ratio of the new mortgage rate obtained upon refinancing k' to the old rate k is above unity for the bottom three quintiles, and significantly below unity (at 0.7) for the top income quintile (Panel E). The low income households are

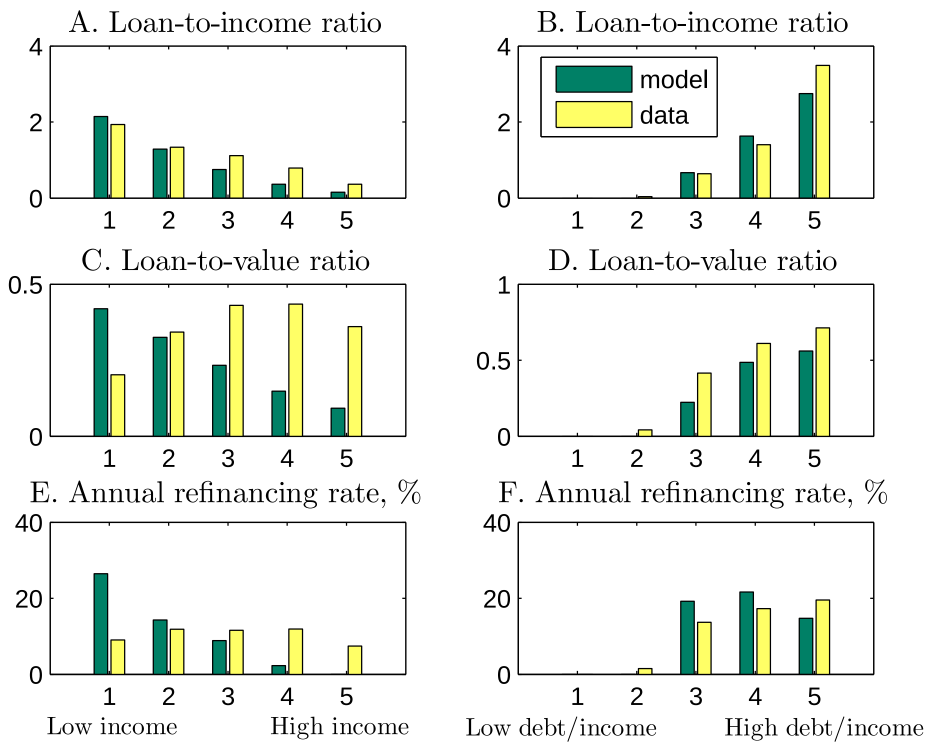

Figure 6: **Comparing the cross-sectional implication of the model with the data.**

willing to *increase* their average debt service cost in order to access liquidity. On the other hand, the high income households tend to have lower mortgage balances, which means that they will require a significant drop in mortgage rate to be willing to incur the fixed cost for refinancing. However, since larger debt holdings increase the incentive to lower financing costs, the rate ratio declines as a function of debt relative to income across the top three deciles of debt/income ratio, where households enter the period with substantial debt holdings.

Next, we confront the model's cross-sectional predictions with empirical evidence in Figure 6. We use data from SCF for years 1998, 2001, 2004, 2007, and 2010, which contain questions about mortgage refinancing. In the model, we sort households into quintiles based on relative income and on the ratio of debt to income as before (conditional on homeownership); in the data, we sort households based on income relative to the value of their primary residence (panels in the left column) and based on debt relative to income (panels in the right column); we sort within each year and then average the values over all years.

The model matches the cross-sectional distribution of mortgage debt-to-income ratios remarkably well (Panels A and B). The bottom quintile of income on average has mortgage balances that are about twice as large as annual income on average (slightly above in the model, slightly below in the data); these decline to just over a single year's worth of income in the second quintile, and down to about a quarter of annual income in the top quintile (other than for the bottom group, the model undershoots these levels somewhat). The increase in loan balances relative to income across quintiles of its own distributions is of a similar magnitude.

The model's ability to match the unconditional distribution of loan-to-value ratios (LTV) is weaker when sorted on income (Panel C) than when sorted on debt relative to income (Panel D). In the data, the average mortgage debt relative to home value is hump-shaped in income/house ratio, ranging from about 0.2 in the bottom quintile, peaking at about 0.4 in quintiles 3 and 4, and declining slightly in the top quintile. In the model, the ratio is monotonically decreasing from 0.4 to about 0.1. The bottom 40% of the LTV distribution have exactly zero debt in the model and essentially zero debt in the data, and both increase monotonically to about 0.5 in the model vs. 0.7 in the data.

Finally, the model matches reasonably well the rates of refinancing for the middle of the income distribution (quintiles 2 and 3, Panel E), where they are close to the average. For the bottom quintile of income, the model dramatically overshoots the fraction of household refinancing – over 25% in the model but just under 10% in the data, on average. In the top quintile, very few households in the model refinance, where as about 8% of those in the data do. This can be attributed to the fact that our model undershoots the magnitude of mortgage liabilities of the high-income households, especially relative to house value. When sorted on debt relative to income, the model matches the empirical refinancing rates fairly well, since households with little debt rarely refinance and a large fraction of refinance loans involves cash-out, which raises loan balances ex-post (in the data, we sort households based on current debt balance, while the refinancing indicator is naturally backward-looking).

The discrepancy between the rates of refinancing as a function of income in the model and in the data could also be driven by the fact that cognitive costs associated with understanding the refinancing process are decreasing with household income, which our model does not capture. Woodward and Hall (2010) report that many consumers overpay their mortgage brokers during their mortgage transactions, which effectively increases their cost of refinancing. If these costs are a function of financial sophistication, which likely rises with income, our model should overshoot refinancing among low income households, and undershoot it at the top of the distribution.

5.3 Historical time series

In order to evaluate the model's ability to match the observed history of household consumption behavior, we simulate a panel of 1000 households, who face random idiosyncratic labor income shocks generated within the model as well as the time series of realized shocks to the exogenous state variables in the data (discretized accordingly) for the period 1988–2012. We report the time-series aggregates of the model-generated variables along with their data counterparts in Figure 7. Panel A depicts the annual series for real consumption growth. The model-generated series of consumption growth tracks the data closely both in direction and in the magnitude of variations. The model overstates the fluctuations in consumption growth in 1990-1991 (both the recession-induced drop and the subsequent recovery), but matches closely the rapid and smooth growth in consumption boom in the late 1990s, somewhat exaggerates the "consumption boom" of mid-2000s, matches well the large consumption drop during the Great recession, with three consecutive years of consumption declines close to 2% per year (2007-2009), and somewhat overshoots the subsequent recovery.

What is driving these consumption patterns in the data? Clearly, the empirically observed processes for aggregate income and house prices that we feed into the model play a role. But the model provides households with opportunities to endogenously adjust their decisions on consumption, savings, homeownership vs. renting, as well as the decisions related to mortgage refinancing.

The role of refinancing in particular is apparent from Panel B of Figure 7, which depicts the median ratio of the mortgage rate obtained as a result of refinancing to the rate on the original (prepaid) loan. The model matches the dynamics of the median ratio of the new

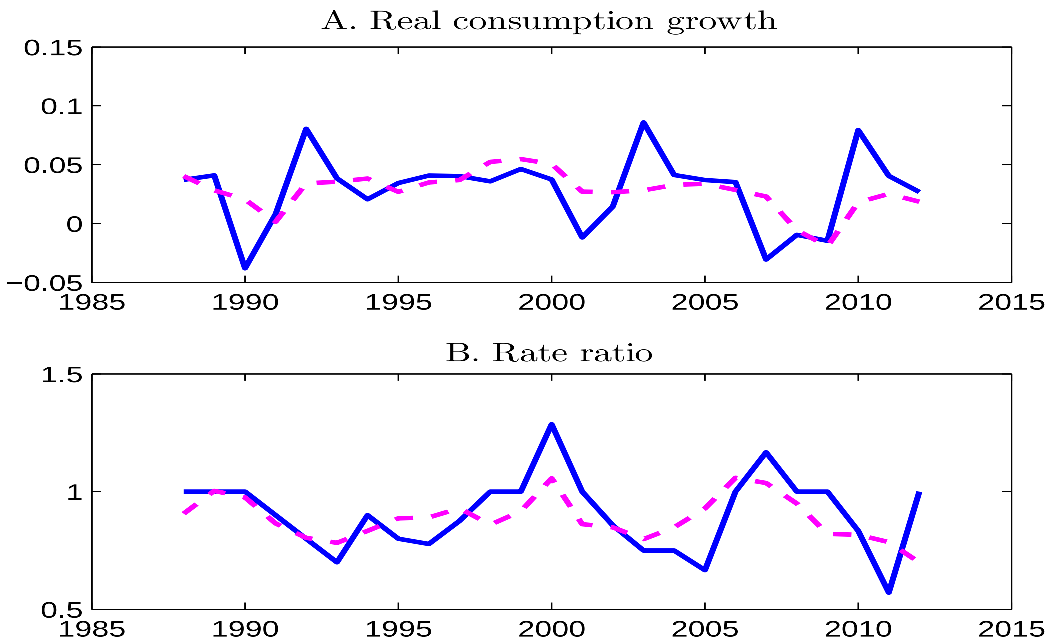

Figure 7: **Model-implied aggregate time series.** This figure plots the model-implied aggregate time series (solid lines) for real consumption growth (all households) and the median rate ratio of refinance loans, and their data counterparts (dashed lines), from 1988 to 2012.

mortgage rate to the old rate closely, including the peaks when the ratio goes above unity, capturing the effect of liquidity demand by constrained households at the onset of a recession. The rate ratio series appear to be moving in the opposite direction of the consumption growth plotted in Panel A, suggesting that absent the opportunity to refinance (and cash-out) consumption would fall even more in recessions. The rate ratio in the model is somewhat more variable than it is in the data.

In sum, our model successfully replicates the main dynamics in consumption, debt, and the cash-out share and rate ratio of refinance loans in the period 1998–2012. In particular, it captures the relaxation of liquidity constraints due to the rise in house prices in the 2000s, which allowed households to rationally withdraw home equity via cash-out refinancing (and second-lien borrowing), driving up household leverage and generating (in part) the consumption boom of the mid-2000s. The fall in house prices and income starting in 2007 following the dramatic expansion of leverage tightened households' balance sheets, causing a sharp and protracted consumption drop. Despite the fact that in the model households are given an opportunity to "ride out" bad times by only paying interest on long-maturity loans, the tightening of the collateral constraints, combined with an increased uncertainty about future labor income (and a lower expected growth rate) lead households to reduce their leverage and improve their asset position, which entails cutting consumption. This mechanism is consistent with the evidence of depressed consumption by highly-indebted households as documented by Dynan (2012) and Mian, Rao, and Sufi (2013).

5.4 Cross-sectional analysis of the housing boom and bust

In this section, we examine our model's predictions about the cross-sectional household behavior during the recent housing boom and bust. We focus on two types of heterogeneity. First, we compare households that have experienced different degrees of house price appreciation but otherwise similar macroeconomic conditions during the housing boom. Second, we compare how households with different amount of leverage in 2007 behave differently following the housing bust.

Mian and Sufi (2010) document an important piece of empirical evidence in support of the effect of house prices on household borrowing. They use a measure of elasticity of housing supply developed by Saiz (2010) to show that U.S. MSAs with relatively inelastic supply of housing, which experienced fast house price growth prior to the Great Recession, saw a dramatic increase in household leverage due to home equity withdrawal, while MSAs with more elastic housing supply that had not experienced such a run-up in prices did not.

Since there is no heterogeneity in house price dynamics built into our model, we approach this evidence by conducting a counterfactual experiment. Specifically, along with our baseline model we consider two scenarios that are broadly representative of the "inelastic" and the "elastic" areas. Specifically, we solve the model using the same set of parameters as in the baseline model but a different stochastic process of house prices. In particular, in the "inelastic" case we let the volatility of transitory innovations to house prices be twice as large as our baseline. In the "elastic" case we instead assume that the ratio of real house price to real income is constant, i.e. $p_t^H = 1$. This assumption captures the notion that in areas

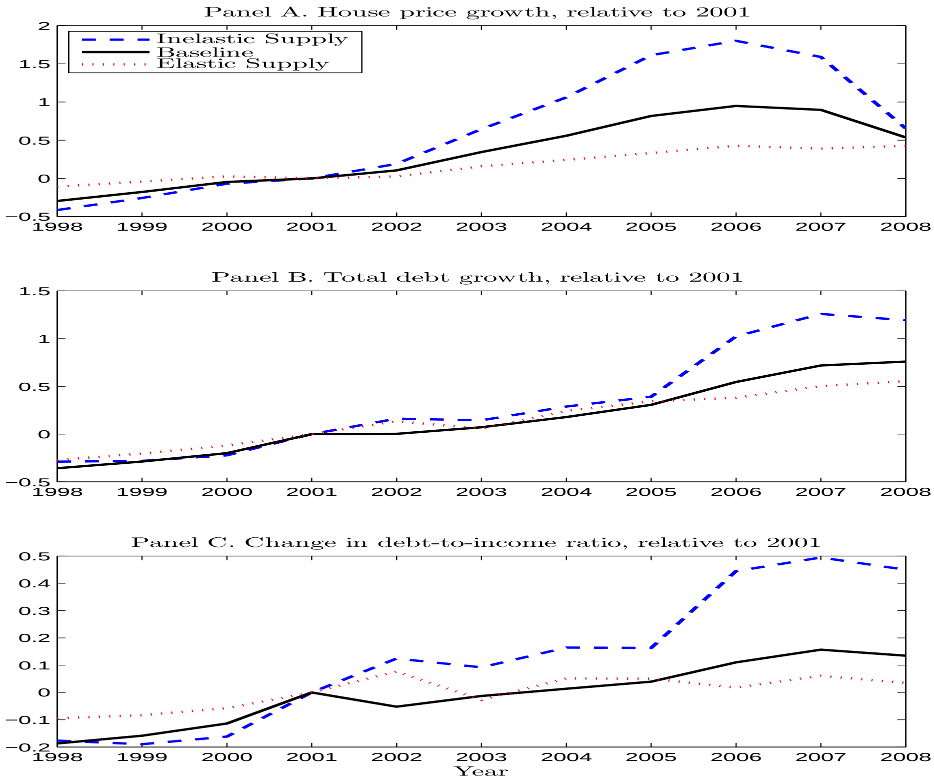

Figure 8: **Replicating Mian and Sufi (2010) evidence on household leverage.** The solid line represents the case with the house price path from the baseline model. The dash line represents the case with the ratio of real house price to real income being constant, which mimics the effect of elastic housing supply.

with elastically supplied housing prices are closely aligned with construction costs (e.g., see Glaeser, Gyourko, and Saiz (2008)). Since labor wages are a large component of these costs, we expect house prices to be roughly proportional to income in the elastic areas.

We plot the simulated total debt growth and changes in debt-to-income ratio over the decade 1998-2008 in Figure 8, analogous to Figure 1 in Mian and Sufi (2010). Panel A depicts the cumulative growth in house prices under the "inelastic" scenario and under the "elastic" scenario, as well as the baseline model. The inelastic case exhibits a much more rapid rise in house prices and a sharper drop than the baseline, where as the elastic case shows only moderate growth in house prices, driven by the increase in aggregate income, consistent with the Mian-Sufi data.

Panels B and C depict the evolution of the total housing debt and the debt-to-income ratio under the two scenarios. Under the inelastic scenario with significant house price appreciation, household debt grows dramatically, especially during the latter part of the period 2005-2008, both in total amount and relative to income, (although the model overstates the former and understates the latter increase compared to the Mian-Sufi data). In contrast, under the "elastic" scenario, total debt and debt-to-income ratio stay relatively flat over the entire period, broadly in line with the evidence documented by Mian and Sufi (2010). Therefore, according to our model, relaxation of the liquidity constraints as a result of house price run up can account for the observed increase in household leverage in a rational framework, insofar as it can be consistent with the observed path of house prices.

What about the cross-sectional evidence of household behavior following the housing bust of 2007 and the ensuing Great Recession? Mian, Rao, and Sufi (2013) document evidence of "debt overhang" whereby households whose leverage grew the most during the boom period experienced the sharpest declines in consumption subsequently.[20] We use the simulated artificial panel based on the aggregate historical time-series described in Section 5.3 above to analyze the model's cross-sectional implications in this period. Figure 9 plots several key variables aggregated over groups of households in the model: the top (dashed line) and bottom (dash-dotted line) quintile based on debt relative to income in 2006, and the average of all homeowners (solid line). We plot the simulated series for the years 2007-2012 to illustrate the heterogeneity in households' responses to aggregate economic conditions.

Panel A depicts the cumulative consumption growth (relative to 2006) for the three groups. The high-leverage households experience a sharper drop in consumption during the Great Recession than an average household, with a cumulative decline of about 10% by 2009 (vs. 5% for the average homeowner). In contrast, low leverage households experience essentially the same consumption drop than the average. This pattern is broadly consistent with evidence in Mian, Rao, and Sufi (2013). In the model, consumption recovers starting in 2010 for all groups. In fact the average household consumes 10% more by 2012 than in 2006 (in part because the highly levered households are those that experience particularly bad transitory income shocks, so that their income and consumption grows over time the most due to mean

[20] Cooper (2012) debates the direct role of leverage and argues that the evidence is more consistent with a standard wealth effect.

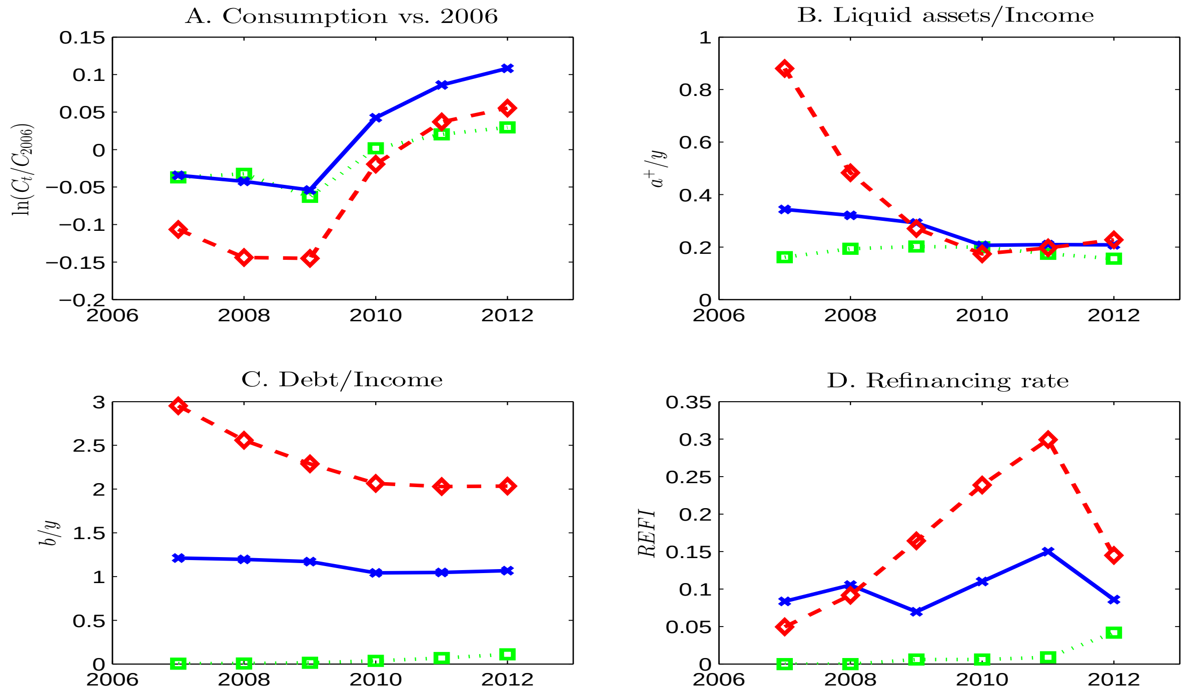

Figure 9: **Consumption, balance sheet, and refinancing behavior for households with different amount of leverage.** The dash-diamond line and the dot-square line represent the top and bottom quintile of the distribution of debt-to-income ratio in 2006, respectively. The solid-cross line represents the average homeowner.

reversion).

Panel B plots the liquid asset positions of the three groups. The high-leverage group enters the recession with substantial cash holdings, of about one year's worth of income on average: this is the result of the cash-out over the preceding boom period, which led to the high leverage in the first place. This endogenous link between leverage and liquid asset holding will be important for assessing the impact of income shocks on consumption. In contrast, the low leverage group has one tenth as much in assets relative to income at the beginning of the recession, whereas the average homeowner's asset holding is just under 40% of income. In the recession, the high- and average-leverage households draw down their liquid assets over time, while the low-leverage homeowners accumulate liquid assets due to elevated income uncertainty (and demand for precautionary savings). The high-leverage households also significantly reduce their leverage over 2007-2010 as a result of debt repayment and (in the later period) the rebound in income (Panel C).

The households' refinancing behaviors in this period are also quite revealing. In Panel D we plot the refinancing rates for the three groups. The high-leverage group initially experiences lower refinancing rates than average (essentially zero in 2007 and 2008), as the LTI and LTV constraints are binding for most of the households in this group. Refinancing activity rises significantly for this group after 2008, surpassing that of the average households and reaching 33% of loans in 2011, compared to the corresponding peak at 15% for the average household. This jump in refinancing is in part due to decline in debt, which relaxed the collateral constraints, but can be largely attributed to the prolonged period of lower mortgage rates. The model may be overstating refinancing by the constrained households, however, due to the tightening of lending standards following the subprime mortgage crisis.

Households in the low-leverage group have almost no mortgage debt. A few of these households "refinance"starting in 2010 by taking out a new loan with a 100% cash-out. However, such behavior is rare: even though liquidity is valuable, these households do not possess the interest rate option embedded in the mortgage (i.e., they do not benefit from lower mortgage payments by refinancing when interest rates are low), which makes it less worthwhile to incur the fixed costs of refinancing. In contrast, for households with non-zero mortgage balances, the exercising of the interest rate option complements the liquidity needs in their refinancing decisions. In fact, the wave of refinancing activity in the model contributes to the stronger recovery of consumption for levered households considered to those with little or no debt in 2006, since low interest rates represent a wealth effect that boosts consumption but only for those who can realize the savings by refinancing existing debt. The fact that empirically observed refinancing behavior among highly constrained households did not respond nearly as strongly to the refinancing incentives following the financial crisis, as documented by Fuster and Willen (2010), suggests that tightening of lending standards could play an important role in limiting the effectiveness of monetary policy on stimulating consumption.

6 Concluding Remarks

We present an estimated structural model of household mortgage debt and liquidity management that accounts for a range of key features of both the historical time-series and the cross-sectional facts on mortgage refinancing, household leverage, and consumption. The model can be useful for quantitative evaluation of economic policies aimed at supporting household balance sheets via the mortgage market.

Our model could be extended in a number of ways in order to investigate a set of closely related issues. While our focus is on understanding household decisions in response to the empirically observed prices of houses and financial assets, an evaluation of welfare and distributional implications would require closing the model by clearing both housing and asset markets. First, a fully specified model of the housing market would require not only a careful consideration of supply and its elasticity, but also a richer set of preferences over housing and the decision of whether to rent or own. Second, it would be useful to endogenize the interest rates on mortgages and HELOCs. One could endogenize mortgage rates within our framework using a partial equilibrium setting by introducing an exogenous stochastic discount factor, which would allow an evaluation of the welfare impact of refinancing costs by incorporating the equilibrium response of mortgage spreads to slower prepayment speeds.

Understanding the impact of securitization on mortgage borrowing, as well as its welfare implications, requires a general equilibrium analysis (e.g., as in Landvoigt (2013)). While Gerardi, Rosen, and Willen (2010) show empirically that mortgage securitization improved households' ability to smooth their housing consumption over time, the net effect on total consumption and welfare can only be ascertained in a structural model that captures all of the relevant frictions. Our framework should prove useful in pursuing this line of research.

Appendix

A State level evidence on counter-cyclical refinancing

To investigate the response of mortgage refinancing to economic activity further, we use data on the origination of home mortgage loans at the state level. This potentially allows us to separate the effect of low interest rates from that of deteriorating economic conditions, insofar as the local economic activity variables are less synchronized with the interest rates than are aggregate quantities, and that households cannot diversify away state-level shocks.

We use quarterly data on the mortgage loans (both refinance and purchase) for each of the 50 states and D.C., based on aggregated Home Mortgage Disclosure Act (HMDA) reporting. We regress the quarterly changes in the number of loans taken in order to refinance existing mortgages (adjusted by the state population) on measures of economic conditions. We use three such measures, specifically growth rates of nonfarm payroll employment, of the State Coincident Economic Activity Index (*CEAI*), which combines information contained in nonfarm payrolls, unemployment, hours worked and wages, and trends with the Gross State Product (GSP), and of the total personal income (*TPI*), deflated using the national consumer price index.[21] We use year-on-year (log) growth rates of quarterly levels of these measures as the main explanatory variables.

House prices determine both the motive to refinance due to a wealth effect and the ability of households to borrow against the value of their homes (perhaps for reasons unrelated to consumption smoothing). Since economic conditions are correlated with the level of house prices, refinancing activity could be high under good economic conditions due to high house prices. Thus, to better capture the effect of consumption smoothing on refinancing, it is important to control for house price appreciation in our regression. We use the FHFA house price indices for the 50 states and DC as our measure of house prices. As before, we also control for aggregate variables: the 30 year mortgage rate (contemporaneous and lagged by one year) and the short-term interest rate.

[21] Unlike the payroll employment and personal income measures, *CEAI* is not available for D.C.

We run pooled time series/cross-sectional regressions of the form:

$$REFI_t^{State} = \beta_{Cycle}^{REFI} Cycle_t^{State} + \beta_H^{REFI} \Delta HPI_t^{State} + \beta_{CH}^{REFI} Cycle_t^{State} \times HPI_t^{State} + \bar{R}_t^i + \beta_w^{REFI} WAC_t^{State} + \beta_r^{REFI} R_t^{3M} + \beta_R^{REFI} R_t^{M30} + \beta_{Rl}^{REFI} R_{t-4}^{M30} + \beta_t + \beta_{State} + \epsilon_t, \quad \text{(A.1)}$$

where $REFI_t^{State}$ is the number of refinance loans originated in state i over the quarter t, scaled by the state's population in the prior year. $Cycle^{State}$ is the variable that measures state-level aggregate economic conditions, ΔHPI_t measures house price appreciation using the 2-year growth in the FHFA state-level house price index that captures appreciation of the mortgaged properties, $\bar{R}_t^i$ is the average rate on newly originated conventional mortgages in state i over the past year,[22] WAC_t^{State} is the weighted average coupon on conforming mortgage loans outstanding in the state in the first month of the quarter that summarizes the rates currently paid by borrowers, $\mathbf{b}_t$ is the vector of quarter fixed effects that captures aggregate information not contained in other variables, and $\mathbf{b}_{State}$ a vector of state fixed effects. State fixed effects are important since there is substantial heterogeneity across states in the fixed costs associated with refinancing a mortgage (such as title insurance, taxes, etc.), which result in different average levels of refinancing as well as its sensitivity to aggregate variables. Given this specification, we are identifying the effect of within-state variation in economic conditions on refinancing. We include the lagged $Cycle$ variable to capture delayed response of households to economic conditions, and include an interaction term between $Cycle$ and the house price growth, orthogonalized with respect to both variables, to test whether higher level of house prices help relax the borrowing constraint especially in bad times.

Table A.1 presents the results of the state-level regressions for different specifications (two different economic activity measures). The coefficients on the state-level business cycle variables in the first column are all negative and statistically significant in all but one specification (TPI without time fixed effects), consistent with the view that households are more likely to refinance their mortgages in a downturn. The state-level cycle variable remains

[22] This variable is available from FHFA at annual frequency; we interpolate it linearly to generate quarterly observations.

significantly negatively related to refinancing when the quarter fixed effects are included, indicating that their presence does not simply proxy for variation in the aggregate term structure variables.

As expected, house price appreciation is positively related to refinancing. In fact, the effects of the business cycle variables become stronger (more negative) after house price appreciation is taken into account, which helps tease out the rise in refinancing in good times due to house value appreciation (results without house price index are not reported). Moreover, the interaction terms of house prices and the cycle variables are negative and typically statistically significant, suggesting that higher levels of house prices are particularly important for refinancing during economic downturns.

Both the 30-year mortgage rates and the short-term interest rate have a significant negative effect on refinancing, as expected. Similarly, the WAC has a significant positive coefficient, consistent with the fact that it captures the rates currently paid by borrowers, so that higher WAC translated into a greater incentive to refinance if current rates are low. In the specification with time fixed effects (where aggregate interest rates are not included) WAC has a negative coefficient, potentially due to the fact that it may capture persistent state-specific variation in mortgage spreads that we cannot control for separately without detailed state-level data on mortgage rates. Interestingly, the effect of current state-level mortgage rates is positive rather than negative, although not significant with time fixed effect, suggesting that it is capturing mostly aggregate variation in mortgage spreads (which are positively related to both default and prepayment risk).

Another measure of refinancing is the total volume of refinance loans. Table A.2 reports results of regressions (A.1) where $REFI_t^{State}$ is defined as the total dollar volume of newly originated refinance loans in state i over quarter t divided by the total personal income in the state over the previous quarter. The results are very similar: the *Cycle* variable comes in negatively (and significantly different from zero in all but one specification), house prices have a strongly positive effect, and the interaction is negative, albeit not significant when time fixed effects are present.

Table 1: Aggregate Refinancing Activity

ΔIP_t	-0.422	-0.253	-0.196	-0.268
	(0.161)	(0.087)	(0.097)	(0.091)
ΔHPI_t		0.148	0.156	0.155
		(0.098)	(0.095)	(0.095)
R_t^{M30}		-1.914	-1.982	-2.700
		(0.667)	(0.675)	(0.601)
$R_t^{M30} - R_{t-12}^{M30}$			-1.464	
			(0.845)	
$R_t^{M30} - R_{avg,t}^{M30}$				-2.609
				(1.247)
r_t^{1Y}		-1.156	-0.986	-0.278
		(0.611)	(0.566)	(0.496)
Adj. R^2	0.060	0.654	0.673	0.687

NOTE: Monthly data, January 1990 - December 2012. Numbers in parentheses are Newey-West standard errors with 12 lags. The left-hand-side variable is the MBA refi index scaled to match the average aggregate refi rate of 8%. ΔIP_t is the 12-month growth rate in industrial production. ΔHPI_t is the real 12-month growth rate in the Case-Shiller house price index. R^{M30} is the 30-year mortgage rate and R_{avg}^{M30} is the average 30-year mortgage rate in the past 3 years. r^{1Y} is the 1-year constant maturity treasury yield.

Table 2: Aggregate Home Equity Extraction

	Prime, first-lien mortgage			Home equity loans, lines of credit		
ΔPI_t	-0.003	-0.116	-0.132	0.056	-0.013	-0.027
	(0.051)	(0.041)	(0.042)	(0.041)	(0.032)	(0.031)
ΔHPI_t		0.061	0.063		0.062	0.064
		(0.023)	(0.021)		(0.018)	(0.016)
R_t^{M30}		-0.430	-0.431		-0.038	-0.039
		(0.146)	(0.133)		(0.112)	(0.099)
$R_t^{M30} - R_{t-1}^{M30}$			0.207			0.185
			(0.084)			(0.063)
r_t^{1Y}		0.279	0.262		0.045	0.030
		(0.099)	(0.087)		(0.076)	(0.065)
Adj. R^2	-0.055	0.487	0.545	0.111	0.611	0.679

NOTE: Annual data, 1993 – 2012. Numbers in parentheses are Hansen-Hodrick standard errors with 4 lags. The left-hand-side variable is the ratio of annual dollar amount of cash-out from prime, first-lien conventional mortgages or home-equity loans and lines of credit (HEL+HELOC) to previous-year personal income. ΔPI_t is the one-year real personal income growth. ΔHPI_t is the real one-year growth in the FHFA house price index. R^{M30} is the average 30-year conventional mortgage rate. r^{1Y} is the 1-year constant maturity treasury yield.

Table 3: Aggregate State Variables

Panel A: Descriptive Statistics

	GDP	p_t^H	r_t
Mean	0.025	0	0.040
Std	0.018	0.178	0.025
Autocorrelation	0.431	0.852	0.773
correlation:			
GDP		-0.037	0.449
h_t			0.190

Panel B: VAR Parameters

	μ	Φ_s			$\Sigma_s \times 10^{-3}$		
GDP	0.013	0.420	0	0	0.492	0.576	0.006
$\tilde{h}_t$	-0.015	0	0.888	0	0.576	6.525	0.440
r_t	0.002	0	0	0.844	0.006	0.440	0.192

Panel C: Mortgage Rate Parameters

κ_0	κ				R^2
	Z	p^H	r	$(p^H)^2$	
0.049	0.094	0.011	0.684	-0.270	0.949
(0.001)	(0.023)	(0.004)	(0.025)	(0.022)	

Table 4: Parameter Values

Panel A. Exogenously-fixed parameters

Dynamics	ρ_y	0.95	Autocorrelation of y
	$\sigma(Z_G)$	0.12	Volatility of y for Z^G
	$\sigma(Z_B)$	0.21	Volatility of y for Z^B
Institutional	τ	0.25	Income tax rate
	$\bar{H}$	4.00	Average house price to income ratio
	ξ_{LTV}	0.80	Collateral constraint
	ξ_{LTI}	3.50	Debt service constraint
	$-\underline{a}$	0.30	Maximum HELOC balance as fraction of aggregate income
	ω	0.15	Probability of return to credit market after default
	ζ	1.00	(1-ζ) confiscation rate of liquid assets upon default
	ϑ	0.04	Interest rate premium on HELOC

Panel B. Estimated parameters

Preferences	δ	0.920 (0.007)	Subjective discount rate
	γ	3.036 (0.347)	Risk aversion
	ψ	0.301 (0.020)	Intertemporal elasticity of substitution
	ν	0.134 (0.004)	Housing utility share
	$\bar{\eta}$	0.750 (0.006)	Disutility of renting versus home-ownership
Institutional	ϕ_0	0.154 (0.020)	Fixed cost of issuing new mortgage
	ϕ_1	0.014 (0.008)	Proportional cost of issuing new mortgage
	ϕ_h	0.135 (0.017)	Proportional cost of buying/selling a house

NOTE: This table reports the exogenously-fixed parameters and the estimated parameters of the model. For the estimated parameters, the values in parentheses are standard errors.

Table 5: Target Moments for the Estimation and Model Outputs

Moment	Variable	Data	Model	s.e.
	Panel A. Targeted Moments			
All Households:				
1. Consumption/Income	c_i/y_i	0.66	0.71	0.01
2. Consumption growth volatility, %	$\sigma(\Delta \log c_{i,t+1})$	12.0	16.4	0.01
3. Homeownership rate, %	$E[I^h]$	66.0	67.5	0.08
Homeowners:				
4. Liquid assets/Income	a_i^+/y_i	0.28	0.24	0.04
5. Mortgage/Income	b_i/y_i	0.98	0.96	0.08
6. HELOC/Income	$-a_i^-/y_i$	0.07	0.08	0.01
7. Refinancing rate, % of homeowners	$REFI$	8.0	11.3	0.02
8. Refi loan/Income	b_i'/y_i	1.41	2.74	0.14
9. Dollar cash-out/Refi loan	$(b_i' - b_i)^+/b_i'$	0.12	0.51	0.03
Renters:				
10. Liquid assets/Income	a_i^+/y_i	0.18	0.15	0.06
Refinancing Regression:				
11. Coefficient on Z	β_Z^{REFI}	-0.25	-0.24	0.41
12. Coefficient on $\Delta \log H$	β_H^{REFI}	0.15	0.08	0.14
Cashout Regression:				
13. Coefficient on Z	β_Z	-0.12	-0.23	0.43
14. Coefficient on $\Delta \log H$	β_H	0.06	0.11	0.15
	Panel B. Additional Moments			
Volatility of aggregate consumption growth, %	$\sigma(\Delta \log C_{t+1})$	2.7	3.9	0.01
Sensitivity of consumption to Z shocks	β_Z^C	0.46	1.30	0.20
Sensitivity of consumption to H shocks	β_H^C	0.06	0.09	0.05
Sensitivity of consumption to lagged r	β_r^C	0.07	0.09	0.43
Sensitivity of consumption to lagged R	β_R^C	0.09	0.10	0.65
Refinancing regression coefficient on R	β_R^{REFI}	-1.91	-1.09	0.67
Cashout regression coefficient on R	β_R	-0.43	-0.83	0.73

Table 6: Sensitivity Analysis

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	Baseline	δ		γ		ψ		ν		ϕ_0		ϕ_1	
		0.874	0.966	1.518	6.071	0.151	0.603	0.067	0.268	0.077	0.309	0.007	0.028
All Households:													
Consumption/Income	0.71	0.68	0.74	0.69	0.74	0.71	0.72	0.73	0.70	0.72	0.71	0.71	0.71
Cons. growth vol, %	16.5	17.2	15.7	17.6	15.2	15.5	19.3	15.8	19.2	16.9	16.3	16.6	16.4
Homeownership rate, %	67.4	43.6	96.3	51.6	88.0	58.5	86.2	53.6	100.0	76.0	64.3	68.3	66.0
Homeowners:													
Liquid assets/Income	0.24	0.20	0.31	0.20	0.35	0.30	0.20	0.24	0.28	0.26	0.15	0.25	0.22
Mortgage/Income	0.94	1.34	0.56	1.34	0.51	0.92	1.07	0.91	1.43	1.22	0.45	1.00	0.84
HELOC/Income	0.09	0.08	0.09	0.08	0.07	0.07	0.11	0.08	0.09	0.08	0.12	0.08	0.09
Refinancing rate, %	11.1	17.4	6.6	17.2	6.2	11.5	12.5	11.0	15.9	17.2	4.8	12.0	9.7
Refi loan/Income	2.73	2.39	2.97	2.47	2.91	2.57	2.81	2.64	2.83	2.51	2.97	2.71	2.76
Dollar cash-out/Refi loan	0.51	0.42	0.56	0.41	0.60	0.52	0.49	0.51	0.46	0.43	0.62	0.50	0.54
Renters:													
Liquid assets/Income	0.15	0.07	0.38	0.08	0.34	0.18	0.19	0.13	0.09	0.16	0.14	0.15	0.15
Refinancing Regression:													
Coefficient on R, β_R^{REFI}	-0.97	-1.40	-0.66	-1.46	-0.56	-0.61	-1.54	-0.80	-1.35	-1.57	-0.26	-1.03	-0.83
Cashout Regression:													
Coefficient on R, β_R	-0.57	-0.25	-0.84	-0.32	-0.71	-0.26	-1.14	-0.35	-1.08	-0.72	-0.24	-0.54	-0.59
Coefficient on Z, β_Z	-0.19	-0.09	-0.24	-0.09	-0.20	-0.12	-0.38	-0.25	0.13	-0.18	-0.38	-0.18	-0.25
Coefficient on H, β_H	0.10	0.14	0.01	0.15	0.04	0.06	0.17	0.10	0.05	0.08	0.06	0.11	0.08
Aggregate Consumption:													
Growth volatility, %	3.9	3.9	4.0	4.0	4.1	4.0	4.5	3.6	5.3	4.2	3.7	3.9	3.8
Sensitivity to Z, β_Z^C	1.30	1.25	1.37	1.28	1.36	1.34	1.40	1.22	1.72	1.41	1.26	1.30	1.28
Sensitivity to H, β_H^C	0.09	0.14	0.04	0.13	0.06	0.10	0.08	0.10	0.06	0.08	0.08	0.09	0.09
Sensitivity to lagged r, β_r^C	0.13	0.06	0.20	0.09	0.18	0.07	0.26	0.09	0.24	0.15	0.12	0.13	0.13
Sensitivity to lagged R, β_R^C	0.17	0.08	0.26	0.12	0.23	0.07	0.39	0.12	0.33	0.22	0.15	0.18	0.17

Table 7: Comparative Statics

	(1) Baseline	(2) $\sigma_B = \sigma_G$	(3) $\sigma_B = 30\%$	(4) $\xi_{LTI} = \infty$	(5) $\xi_{LTV} = 125\%$	(6) $\underline{a} = 0$
All Households:						
Consumption/Income	0.73	0.73	0.74	0.72	0.72	0.73
Cons. growth vol, %	16.6	16.8	15.6	16.9	17.2	16.6
Homeownership rate, %	67.4	67.1	71.7	81.9	77.4	61.6
Homeowners:						
Liquid assets/Income	0.24	0.23	0.31	0.27	0.28	0.34
Mortgage/Income	0.94	0.97	0.81	1.56	1.22	0.91
HELOC/Income	0.09	0.09	0.08	0.08	0.08	0.00
Refinancing rate, %	11.1	11.5	9.5	15.8	11.5	11.8
Refi loan/Income	2.73	2.71	2.82	3.19	2.94	2.71
Cash-out $/Refi loan	0.51	0.50	0.54	0.40	0.48	0.45
Default rate, %	0.0	0.0	0.0	0.6	1.9	0.0
Renters:						
Liquid assets/Income	0.15	0.15	0.22	0.09	0.20	0.15
Refinancing Regression:						
Coefficient on R, β_R^{REFI}	-0.97	-1.06	-0.80	-1.30	-1.19	-0.83
Cashout Regression:						
Coefficient on R, β_R	-0.57	-0.59	-0.61	-0.22	-1.67	-0.45
Coefficient on Z, β_Z	-0.19	-0.25	-0.18	-0.45	-0.31	-0.20
Coefficient on H, β_H	0.10	0.10	0.07	0.37	-0.27	0.10
Aggregate Consumption:						
Growth volatility, %	3.9	3.4	4.5	4.6	4.1	3.7
Sensitivity to Z, β_Z^C	1.30	1.21	1.41	1.36	1.39	1.24
Sensitivity to H, β_H^C	0.09	0.07	0.11	0.17	0.07	0.10
Sensitivity to lagged r, β_r^C	0.13	0.13	0.14	0.13	0.16	0.10
Sensitivity to lagged R, β_R^C	0.17	0.20	0.16	0.16	0.23	0.13

Table A.1: State-level refinancing activity

	$Cycle_t$	HPI_t	$C_t \times H_t$	WAC	$\bar{R}_t^i$	R_t^{M30}	R_t^{3M}	R_{t-4}^{M30}	$\bar{R}^2$
1	-0.29	0.17	-1.85	0.62	1.50	-1.70	-0.75	-0.20	0.61
Robust	(0.05)	(0.01)	(0.51)	(0.03)	(0.22)	(0.11)	(0.06)	(0.11)	
NW	(0.05)	(0.01)	(0.39)	(0.05)	(0.22)	(0.12)	(0.06)	(0.12)	
2	-0.24	0.10	-0.64	-2.74	0.32				0.89
Robust	(0.05)	(0.01)	(0.27)	(0.70)	(0.41)				
NW	(0.05)	(0.01)	(0.20)	(0.67)	(0.37)				
3	-0.10	0.16	-1.29	0.64	1.56	-1.79	-0.80	-0.23	0.60
Robust	(0.03)	(0.01)	(0.42)	(0.04)	(0.24)	(0.12)	(0.06)	(0.11)	
NW	(0.03)	(0.01)	(0.34)	(0.05)	(0.23)	(0.12)	(0.07)	(0.12)	
4	-0.14	0.10	-0.47	-2.62	0.36				0.89
Robust	(0.04)	(0.01)	(0.19)	(0.70)	(0.42)				
NW	(0.03)	(0.01)	(0.13)	(0.69)	(0.37)				
5	0.01	0.15	-1.89	0.61	1.84	-1.89	-1.00	-0.32	0.60
Robust	(0.03)	(0.01)	(0.54)	(0.04)	(0.27)	(0.14)	(0.06)	(0.11)	
NW	(0.03)	(0.01)	(0.37)	(0.05)	(0.26)	(0.13)	(0.07)	(0.13)	
6	-0.10	0.09	-0.36	-2.63	0.18				0.89
Robust	(0.03)	(0.01)	(0.25)	(0.70)	(0.44)				
NW	(0.03)	(0.01)	(0.22)	(0.70)	(0.39)				

NOTE: Quarterly data, 1993.III - 2009.IV (time subscript t is in monthly units). The dependent variable is the total number of newly originated refinance loans in the state over a quarter relative to the rescaled population of the state for the previous year (based on HMDA data). *Cycle* refers to the year-on-year growth in either the non-farm payroll employment index scaled by the state population (*Payroll*, specifications 1 - 2), State Coincident Economic Activity index in columns (*CEAI*, specifications 3 - 4), or the Total Personal Income (*TPI*, deflated using the CPI, specifications 5 - 6). HPI is the two-year growth rate of the state-level house price index. $C_t \times H_t$ is the orthogonalized interaction term, i.e. the residual from regressing the product of *Cycle* and HPI on a constant and both of these variables. WAC is weighted average coupon rate for conforming fixed-rate mortgages (equal-weighted average across FNMA and FHLMC loans) in a given state. $\bar{R}_t^i$ is the average coupon rate on all newly-originated conventional prime loans in the state over the quarter. Specifications 2, 4 and 6 have quarter fixed effects. Standard errors are in brackets (*Robust* are clustered by state, and *NW* are Newey-West with 20 lags).

Table A.2: Refinance loan volume relative to total income

	$Cycle_t$	HPI_t	$C_t \times H_t$	WAC	$\bar{R}^i_t$	R^{M30}_t	R^{3M}_t	R^{M30}_{t-4}	$\bar{R}^2$
1	-1.63	0.86	-6.78	2.30	7.77	-8.21	-3.69	-1.37	0.65
Robust	(0.26)	(0.05)	(2.52)	(0.16)	(1.17)	(0.58)	(0.28)	(0.53)	
NW	(0.25)	(0.05)	(1.77)	(0.20)	(1.07)	(0.59)	(0.31)	(0.57)	
2	-1.70	0.64	-2.52	-15.54	5.32				0.87
Robust	(0.35)	(0.08)	(1.83)	(5.19)	(2.45)				
NW	(0.30)	(0.06)	(1.43)	(4.57)	(2.21)				
3	-0.74	0.84	-4.92	2.39	7.93	-8.61	-3.80	-1.53	0.65
Robust	(0.16)	(0.05)	(1.94)	(0.17)	(1.22)	(0.62)	(0.31)	(0.53)	
NW	(0.16)	(0.05)	(1.41)	(0.21)	(1.13)	(0.61)	(0.33)	(0.59)	
4	-1.00	0.63	-1.92	-14.78	5.44				0.86
Robust	(0.21)	(0.07)	(1.17)	(5.41)	(2.47)				
NW	(0.19)	(0.06)	(0.83)	(4.74)	(2.23)				
5	-0.25	0.76	-7.14	2.30	8.98	-9.19	-4.69	-1.88	0.64
Robust	(0.14)	(0.05)	(2.72)	(0.18)	(1.28)	(0.69)	(0.29)	(0.54)	
NW	(0.15)	(0.04)	(1.81)	(0.20)	(1.21)	(0.64)	(0.32)	(0.63)	
6	-0.75	0.56	-1.17	-14.48	4.54				0.86
Robust	(0.17)	(0.07)	(1.84)	(5.26)	(2.46)				
NW	(0.15)	(0.06)	(1.50)	(4.77)	(2.27)				

NOTE: Quarterly data, 1993.III - 2009.IV (time subscript t is in monthly units). The dependent variable is the total dollar volume of newly originated refinance loans in the state over a quarter relative to the total personal income in the state for the previous quarter (based on HMDA data). *Cycle* refers to the year-on-year growth in either the non-farm payroll employment index scaled by the state population (*Payroll*, specifications 1 - 2), State Coincident Economic Activity index in columns (*CEAI*, specifications 3 - 4), or the Total Personal Income (*TPI*, deflated using the CPI, specifications 5 - 6). HPI is the two-year growth rate of the state-level house price index. $C_t \times H_t$ is the orthogonalized interaction term, i.e. the residual from regressing the product of *Cycle* and HPI on a constant and both of these variables. WAC is weighted average coupon rate for conforming fixed-rate mortgages (equal-weighted average across FNMA and FHLMC loans) in a given state. $\bar{R}^i_t$ is the average coupon rate on all newly-originated conventional prime loans in the state over the quarter. Specifications 2, 4 and 6 have quarter fixed effects. Standard errors are in brackets (*Robust* are clustered by state, and *NW* are Newey-West with 20 lags).

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