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HOUSES AS ATMS? MORTGAGE REFINANCING AND MACROECONOMIC UNCERTAINTY

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ABSTRACT

We estimate a structural model of household liquidity management in the presence of long-term mortgages. 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 mild recovery following the Great Recession, especially among the most constrained households.

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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. 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 on the structural forces driving both the borrowing boom and the consumption slump that followed. 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. Our analysis focuses on households' optimal choices of leverage, pre-

cautionary 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]

[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.

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 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

[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.

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 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

[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.

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 refi-

[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 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).

nancing 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.

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 vari-

ation 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 (Section 3), as well as helps with the identification of the structural parameters (Section 4) and the assessment of model performance (Section 5).

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

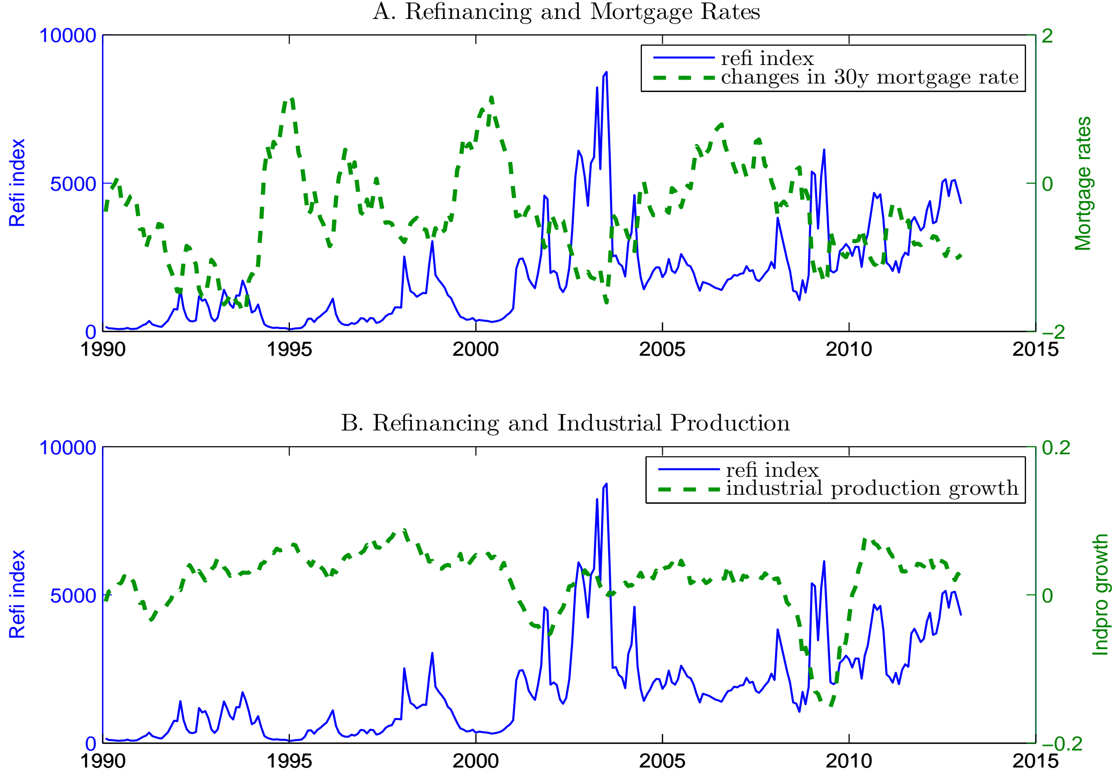

Figure 1: **Refinancing, Interest Rates, and Macroeconomic Conditions.** The refi index is from the Mortgage Bankers Association. The change in 30-year mortgage rate is defined as the difference between the 30-year conventional mortgage rate and its past 3-year moving average. The industrial production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

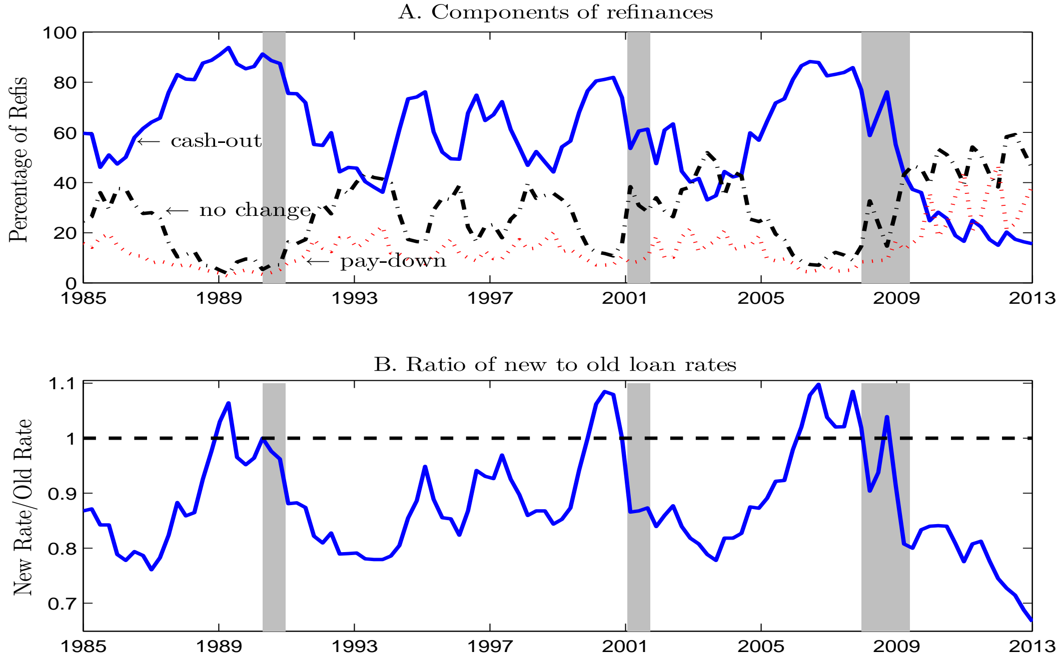

Figure 2: **Fraction of cash-out and the median rate ratio for refinance loans.** Panel A plots the percentage of refinancing resulting in 5% higher loan amount (cash-out), no change, or lower loan amount (pay-down). Panel B plots the median ratio of new to old loan rates upon refinance. The data is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

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

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),

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

where

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

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. 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 process y_{it} for household i has an aggregate component, Y_t, as well as an idiosyncratic component, $\tilde{y}_{it}$. That is,

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

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 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.[7]

Finally, the income tax rate is τ.

3.2 Household assets and liabilities

Liquid Assets Households have access to a savings account that pays 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 houses in the model. We make the assumption that nominal house prices H_t have 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 house price is

$$H_t = \bar{H}\ p_t\ Y_t\ h_t, \tag{6}$$

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

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

[7]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.

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 riskfree 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 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_{it}^{RF}, with $I_{it}^{RF} = 1$ if the home loan is refinanced at time t and $I_{it}^{RF} = 0$ otherwise, so that dynamics of the mortgage rate k_{it} are given by the law of motion:

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

For tractability, we specify the mortgage rate R_t as an exogenous function of all the aggregate state variables (r_t, Z_t, h_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 as well as direct fees associated with issuing a new mortgage. 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:

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

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:

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

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.[8]

Home sales A home sale incurs a proportional transaction cost ϕ_h. 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 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 must pay rent every period. For tractability, we assume that renter households will allocate a constant fraction $\eta/(1 + \eta)$ of their (after tax) labor income toward the rent expense every period. This assumption is a short-hand representation of a model with Cobb-Douglas preferences over nondurable consumption and housing services, which imply a constant expenditure share of housing.[9] 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

[8] 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.

[9] 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.

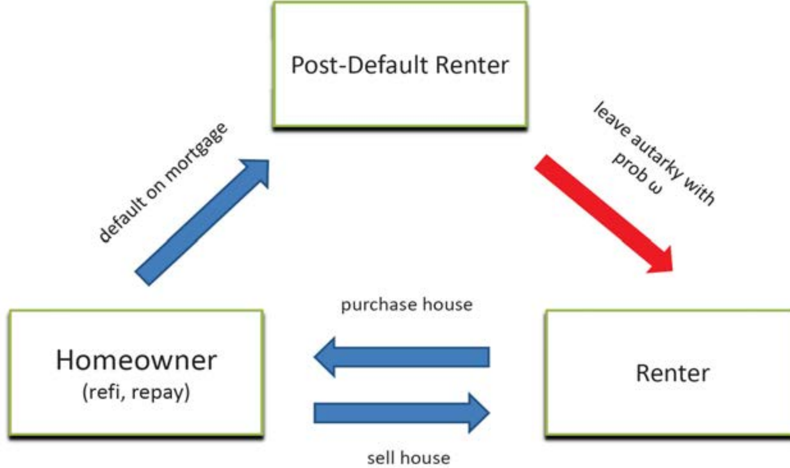

Figure 3: **Homeowner, renter, and post-default renter diagram.**

$\phi(b_{i,t+1}; S_t)$ 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 $S_t \equiv (Z_t, h_t, r_t)$. We assume that S_t follows a first-order vector autoregressive process (VAR) in logarithms:

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

For tractability, 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):

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

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 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,

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

subject to

$$c_i + \frac{a_i^{+\prime}}{1+(1-\tau)r} + \frac{a_i^{-\prime}}{1+r^{HL}} + b_i = (1-\tau)(y_i - k_i b_i) + a_i + b_i' - \phi(b_i'; S)\ I_i^{RF}, \tag{18}$$

$$(b_i' - b_i)\ (1 - I_i^{RF}) \leq 0,$$

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

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 $U_i^h(a_i, b_i, k_i, s_i)$, by $U_i^{hr}(a_i, b_i, k_i, s_i)$ in a state of transition from homeowner to renter by selling the home, and by $U_i^{hd}(a_i, b_i, k_i, s_i)$ 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 $(1 - \phi_h)H$ 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

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

subject to

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

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

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

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.

The problem for an unrestricted renter is to choose liquid assets such that

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

subject to the positivity of consumption, and

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

The parameter η determines that fraction $\eta/(1+\eta)$ of total labor income is paid out as rent.

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

$$U_i^{rh}(a_i, s_i) = \max_{a_i', b_i'} \left[(1-\delta)(c_i/p)^{\frac{1-\gamma}{\theta}} + \delta \, \mathbb{E} \left[U_i^h(a_i', b_i', R, s_i')^{1-\gamma} \right]^{\frac{1}{\theta}} \right]^{\frac{\theta}{1-\gamma}}, \tag{25}$$

subject to

$$c_i = (1-\tau)\frac{y_i}{1+\eta} + a_i - \frac{a_i'}{1+(1-\tau)r} + b_i' - \phi(b_i'; S) - (1+\phi_h)H, \tag{26}$$

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

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

The problem of a restricted renter post default is given by

$$U_i^d(a_i, s_i) = \max_{a_i' \geq 0} \left[(1-\delta)(c_i/p)^{\frac{1-\gamma}{\theta}} + \delta \mathbb{E}\left[(1-\omega) \left(U_i^d(a_i', s_i') \right)^{1-\gamma} \right]^{\frac{1}{\theta}} + \delta \mathbb{E}\left[\omega \max\left(U_i^{rh}(a_i', s_i'), U_i^r(a_i', s_i') \right)^{1-\gamma} \right]^{\frac{1}{\theta}} \right]^{\frac{\theta}{1-\gamma}}, \quad (27)$$

subject to the positivity of consumption as well as the renter budget constraint (24).

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 on household assets and mortgage refinancing (computed from the simulation of a large panel of households) 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.[10]

[10]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.

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, h, r) are discretized using 2, 10, and 4 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, except that it understates the severity of the drop during the Great Recession and overstates the extent of the recovery thereafter somewhat. Panel B shows the highly persistent but transitory deviations of house prices from the trend of real economic growth, which our grid 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, h_t, r_t, h_t^2), suggesting that this exogenous function $R(S)$ captures most of the time 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 5 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

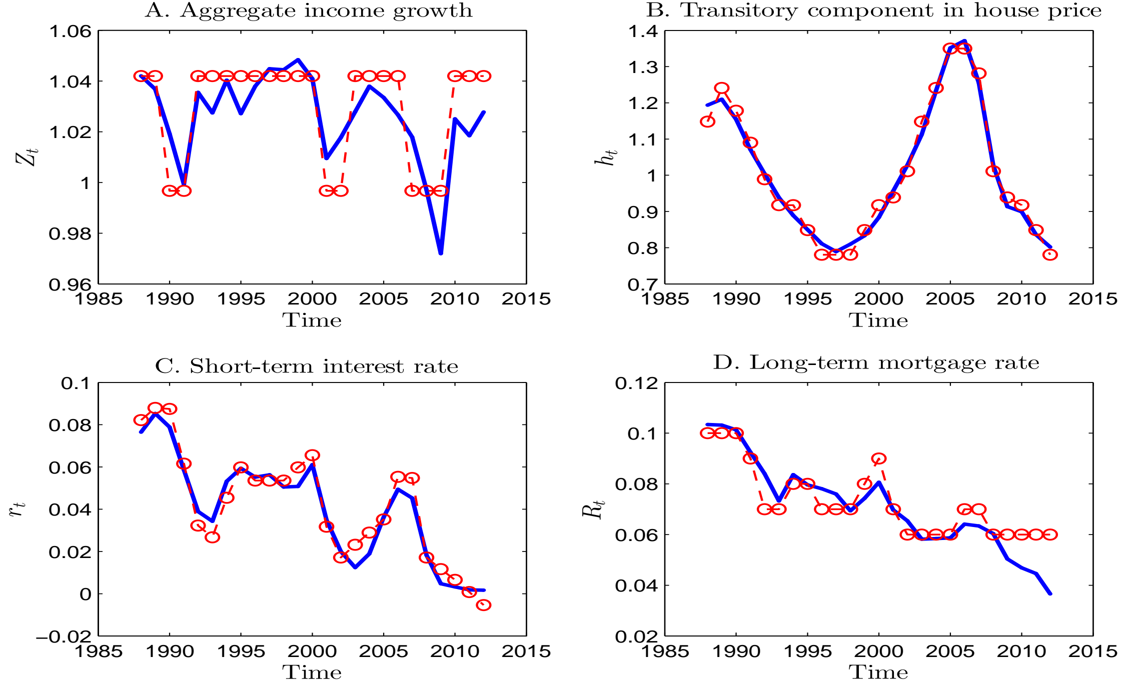

Figure 4: **Time series of exogenous state variables.**

history of the mortgage rates well before 2008 but not afterwards, as the lower bound of the approximation is set at 6% while the observed mortgage rates over this period dip below 4%.

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 24 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). 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 $\sigma(Z_B) = 21\%$. These values are on the higher end of the estimates of Storesletten, Telmer, and Yaron (2007).

The autocorrelation parameter is $\rho_y = 0.95$, which is also consistent with Storesletten, Telmer, and Yaron (2007).

Institutional parameters We follow Campbell and Cocco (2010) in specifying the main institutional features of the U.S. economy for homeowners and renters. First, personal income tax rate is $\tau = 25\%$. 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.

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 $\Theta \equiv (\delta, \gamma, \psi, \eta, \phi_0, \phi_1, \phi_h)$, taking as given the set of prespecified parameters $\Theta_0 \equiv (\mu_S, \Phi_S, \Sigma_S, \pi, \mu_y, \rho_y, \sigma_y(.), \bar{H}, \tau, \kappa_0, \kappa_1, \kappa_2, \xi_{LTI}, \xi_{LTV}, \underline{a}, \zeta, \omega, \vartheta)$, 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).[11] 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).[12] In the data, the wealth distribution is 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

[11] 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).

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

the bottom 80% of the distribution is close to the median of the entire sample.[13]

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 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,

[13]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).

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 feed the historical time-series of the aggregate state-variables S_t, appropriately discretized, into the model, and generate a panel of N 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. 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 uncertainty about the moments measured 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 approach, 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 0.6 is slightly below 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 0.001, which implies that statistically this difference is significant, even though it is economically small. The model-implied annual household-level consumption growth volatility of 18% is much higher than the 9% target estimated by Wachter and Yogo (2010), which is constructed to reduce measurement error, but it is broadly 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). This moment also has a fairly tight standard error of 0.9%, which implies that only some of the latter set of empirical estimates could have been produced by the model.

Notice that the 18% household-level consumption growth volatility is essentially the same as the unconditional labor income growth volatility, implying very little 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).

The model also does a good job matching the average liquid asset holding and mortgage balance for homeowners in the data. Mortgage debt is a fraction 0.98 of household income on average, exactly matching our estimate in the SCF data. 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 (0.07 of household income in the data vs. 0.06 in the model, insignificantly different statistically given the standard error of 0.02).

Despite the low return on liquid assets, households still hold liquid assets equal to 23%

of income in the model, which is close to the amount observed in the SCF data (28%, and statistically different given a small standard error of 1%). 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) binds.[14]

About 12.8% of homeowners per year refinance their mortgages in the model, compared to 8% in the data. This difference is not statistically different from zero given the standard error of 3.3%. The average loan-to-income ratio for the new loans originated from refinancing in the model (2.60) is significantly higher than the average value in the 2001 SCF (1.41) and the HMDA data for 1993-2009 (1.90). In addition, the amount cashed out equals to 48% 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.

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.

The model fails to match the share of homeowners in the population, with only 22.5% in the model vs. 60% in the data, well outside the reasonable confidence interval (standard

[14]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 ma be necessary to explain quantitatively the extent of the puzzle.

error is 8.7%). This is due to the tension between homeownership and the key moments on mortgages. Making households more patient, more risk averse, or increasing the rental costs will help raise homeownership. However, all of these changes will cause the households to reduce mortgage balance and the frequency of refinancing. In order to address this issue, we could model the benefits of homeownership in richer ways, for example by allowing homeowners to choose the size of the house that fits their budget. The model also understates the liquid asset holdings of renters at 7% of annual household income vs. 18% in the SCF data. An extension of the model to allow for the choice of house size and a more realistic rental market should help the model's performance on these dimensions.

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 $\delta = 0.929$, the coefficient of relative risk aversion $\gamma = 2.383$, and the intertemporal elasticity of substitution $\psi = 0.610$. 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 between the estimates obtained by Vissing-Jørgensen (2002) using household-consumption data from the CEX using subsamples of stock- and bond-holders (below 0.3 and above 0.8, respectively).[15]

While a number of studies estimating the IES using the aggregate log-linearized Euler equation following Hall (1988) find values very close to zero (we estimate a coefficient of 0.068 in the data), such an approach would not be valid in an economy that conforms to

[15]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 bottow 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).

our model, given the substantial heterogeneity and frictions.[16] 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 0.03. The coefficient is somewhat higher if the long-term mortgage rate R is used in the regression, but at 0.06 it is still only one-tenth of the true value.

The rental expense parameter $\eta = 0.359$ implies that just over a quarter of renter's labor income ($\eta/(1+\eta)$) are related to housing services, which is empirically sensible. This parameter is identified jointly by the average consumption-income ratio and the share of homeowners, since the benefit of homeownership is in large part the avoidance of rental expenses (as well as the collateral value of housing).

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 9.3% of permanent income (or 2.3% of the house value on average) and a proportional cost of 2.6%, which is comparable to the costs calibrated by Campbell and Cocco (2003).[17]

The model implies that the cost of buying (or selling) a house ϕ_h is 13.8% 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

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

[17] 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 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 imprecisely in the sense that the sampling uncertainty about the data moments, under the null of the model, translates into wide confidence bands for the point estimates. The implied 95% confidence intervals include zero for all of the parameters except the discount factor δ, which is also statistically significantly lower than unity. Such wide confidence bands are a consequence of a very short aggregate time series sample of 25 annual observations (the cross-sectional moments are in fact estimated very precisely). However, this does not imply that the point estimates of the structural parameters are not meaningful, only that the small sample makes statistical inference about these parameters difficult.[18] 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 3.1%, compared to 2.7% in the data; while this difference is economically small, it is statistically significant due to the small standard error of 0.06%. Finally, the model also matches 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 -1.19 in the model, compared to -1.91 in the data. In the cash-out regression, $\beta_R = -0.46$ in the model vs. -0.43 in the data. This close fit is especially remarkable since we do not target these particular coefficients in our estimation. The huge

[18]One way to assess whether a particular parameter of the model is statistically significantly different from, say, zero, would be to solve the model under the null hypothesis that the latter is true, and use simulated data to compute the probability of observing the empirical values of the target moments.

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 their homeownership, and increases their savings in the form of liquid asset holdings and home equity (lower the 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, they can be cheaper to access when liquidity is needed). As mortgage balances decline, so does the frequency of refinancing and the sensitivity of refinancing to interest rates (β_R^{REFI} closer to 0): since 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, while households cashout 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 (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 sharply in risk aversion and the sensitivity of refinancing to mortgage rate β_R^{REFI} moves close to 0. Like the patient households, risk-averse households also cashout more following negative aggregate consumption shocks (more negative β_Z), but unlike the patient households, they use the money to raise consumption today rather than saving it, as is evident in a lower β_Z^C. As a result, aggregate consumption is less volatile (in particular, less cyclical) with higher risk aversion, even though consumption is more volatile at the household level.

Intertemporal elasticity of substitution ψ A higher IES lowers liquid asset holdings and increases mortgage balances. These effects are qualitatively similar to but quantitatively not as strong as those of a lower risk aversion. The IES has virtually no effect on the homeownership rate or the frequency and magnitude of refinancing. Crucially, however, the IES is 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. The latter is in stark contrast to the effect of a lower risk aversion.

Rent share η The effect of the share of rent in labor income is intuitive: high cost of renting leads to a high rate of homeownership. The effect of η on other quantities operates through the homeownership channel as well, and is not always monotonic. In particular, while both asset holdings and mortgage balances are lower on average when η is lower than the baseline case, they are also dramatically lower when $\eta = 1.437$ (implies that 58% of consumption expenditures are attributed to housing). The former is because with lower rental costs higher-income households dominate the ranks of homeowners. In the latter case, it is the opposite: since renting is very costly, most households prefer homeownership, including the low-income ones, but maintain very low debt levels to reduce the risk of being forced to sell the house (when the interest payments become unaffordable to them as a result of persistent negative income shocks). This composition effect also explains why cash-out is more responsive to aggregate income shocks when η is high. Other implications of high η include lower liquid asset holdings and more HELOC borrowing, and more savings by renters

to buy a house.

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 -0.34 with high ϕ_1, compared to -1.19 in baseline case) and more likely to refinance to cash out home equity.

Cost of housing transactions ϕ_h Finally, the housing transaction cost parameter ϕ_h naturally lowers homeownership. For homeowners, a high ϕ_h has an effect similar to high rental cost η, whereby leverage is lower on average in order to reduce the probability of having to sell the house when income falls below required interest payment. The more liquid HELOC partially substituting for the illiquid mortgage borrowing when needed. Given the lower mortgage balances, lower refinancing frequency and higher loan/value ratios follow due to the fixed costs of refinancing. One significant difference from the case of high η is that households cashout less, not more, following negative aggregate income shocks. This is again due to the composition of homeowners. Whereas a higher rental cost drives more low-income people into homeownership, a higher housing transaction cost drives this part of the population away. The remaining high-income homeowners have less need to use cashout to smooth consumption.

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 counter-cyclical variation in income uncertainty leads households to choose higher leverage than in the baseline (mortgage-to-income ratio rises from 0.98 to 1.05), while the consumption growth volatilities at both the individual and aggregate level change very little.

With higher mortgage balances, homeowners also refinance their mortgages more frequently, with the average refinancing rate rising from 12.8% to 14.2% per year. In particular, refinance becomes more sensitive to changes in mortgage rates (β_R^{REFI} changing from -1.19 to -1.36). However, households cashout less following negative aggregate income shocks (β_Z changing from -0.17 to -0.11). One reason is that there is less cross-sectional dispersion in realized income, thus fewer distressed households. The other reason is that there is also less preemptive cashout by those households whose income have not dropped yet but are concerned that the LTI constraint might prevent them from cashing out in the future. As a result, consumption becomes more responsive to aggregate incomes shocks contemporaneously (β_Z^C is higher), while consumption growth becomes more responsive to lagged interest rate changes. Still, both β_r^C and β_R^C are well below the actual value of the intertemporal elasticity of substitution (the highest value is 0.21 for β_R^C).

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, households dramatically reduce their leverage (mortgage debt to income ratio drops to 0.62) and hold more liquid assets (asset to income ratio rises from 0.23 to 0.31), yet the consumption volatility at both the household and aggregate level are higher on average. Refinancing is less frequent, at 8.08%, but households withdraw more equity upon refinancing, with the ratio of cash-out amount to new loan balance increasing from 0.48 to 0.58. 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 -1.19 to -0.5), while cashout becomes significantly more responsive to aggregate income shocks (β_Z changes from -0.17 to -0.28). These results are consistent with households preserving their home equity for the bad state as well as cashing out preemptively when income uncertainty rises.

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 40% higher, at 1.38 (relative to income), compared to 0.98 in the baseline. Refinancing becomes more frequent (15.4% per year) and more sensitive to interest rate changes ($\beta_R^{REFI} = -1.79$). Removing the LTI constraint also enables households to cashout more following aggregate income shocks, as β_Z becomes nearly twice as high as in the baseline case. 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 under one tenth of 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 more frequent, and cashout is more sensitive to shocks to aggregate income and interest rates.

Interestingly, households now cashout more, not less, following drops in house prices (β_H changes from 0.06 in the baseline case to -0.35). Two effects are at work in determining how cashout 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 cashout and house price changes. On the other hand, because house price shocks are persistent, households will want to cashout 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 7.83% 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.

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. 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 affected.

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. In the model, liquidity needs drive much of the refinancing behavior. Consequently, the rate of refinancing is declining in income (see Panel A). In the bottom quintile, 27% of the households refinance in a given year, against about 2.5% in the fourth quintile, and close to zero in the top quintile. Conditional on refinancing, the average dollar cash-out to income ratio is also decreasing in income (Panel B), from close to 1.5 in the bottom quintile to about 0.25 in the top.

The average refinancing households in all the income quintiles have nonzero HELOC balances before refinancing, suggesting that liquidity-constrained households first borrow using short-term HELOCs, which have no transaction costs, and then switch to cashing out home equity when the liquidity needs become sufficiently strong. The HELOC-to-income ratio is decreasing in income, 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 60% for the fourth quintile. 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 (Panel D) is above unity for the bottom three quintiles, and significantly below

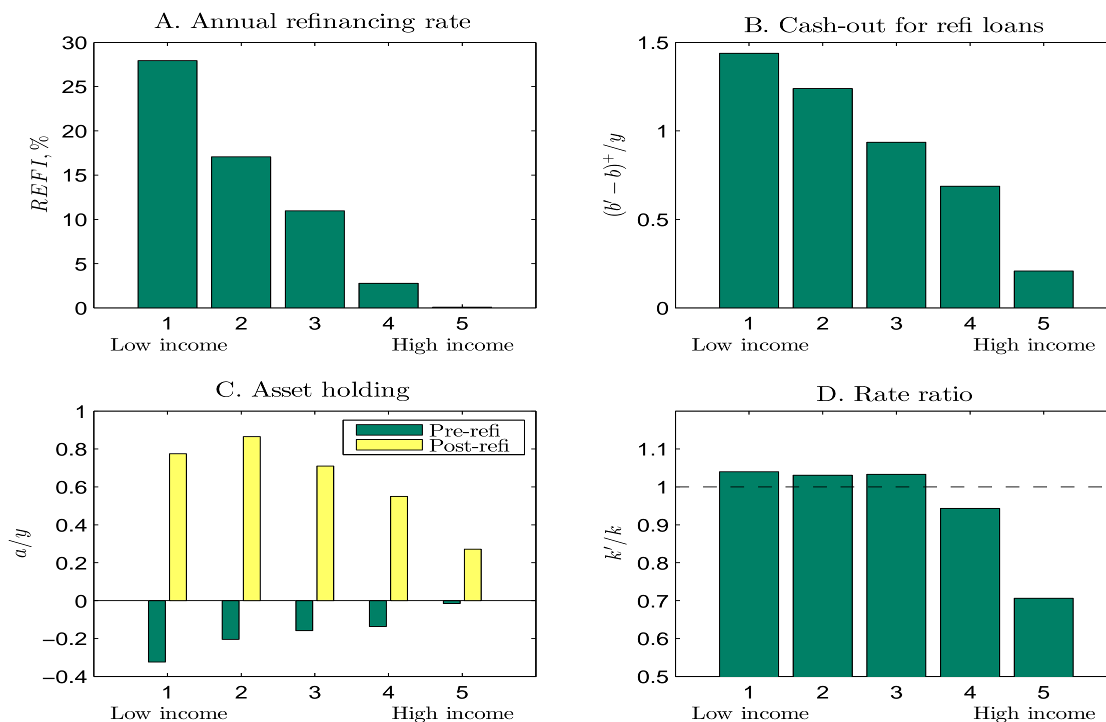

Figure 5: **Cross-sectional implication for homeowners sorted on income.**

unity (at 0.7) for the top income quintile. The low income households are willing to *increase* their average debt service cost in order to access liquidity. On the other hand, the high income households tend to have low mortgage balances, which means that they will require a significant drop in mortgage rate to be willing to incur the fixed cost for refinancing.

Figure 6 plots the same set of quantities for quintiles sorted on mortgage debt relative to income. Here the results are more nuanced. While the households with high debt-to-income ratio may have a stronger incentive to refinance either to access liquidity (if income is low) or to lower the cost of borrowing when rates decline (if debt is high), the pattern of refinancing rates is not monotonic. In the bottom two quintiles, the refinancing rate is only about 3%, in the third and fourth quintiles the rate rises to above 20%, but in the top quintile the refinancing rate drops to about 10%. This result is driven by the fact that for the high debt-to-income ratio cases the LTI constraint is likely to be binding, preventing many of the households who would like to refinance from doing so.

Panel B shows that, conditional on refinancing, the ability of households to withdraw

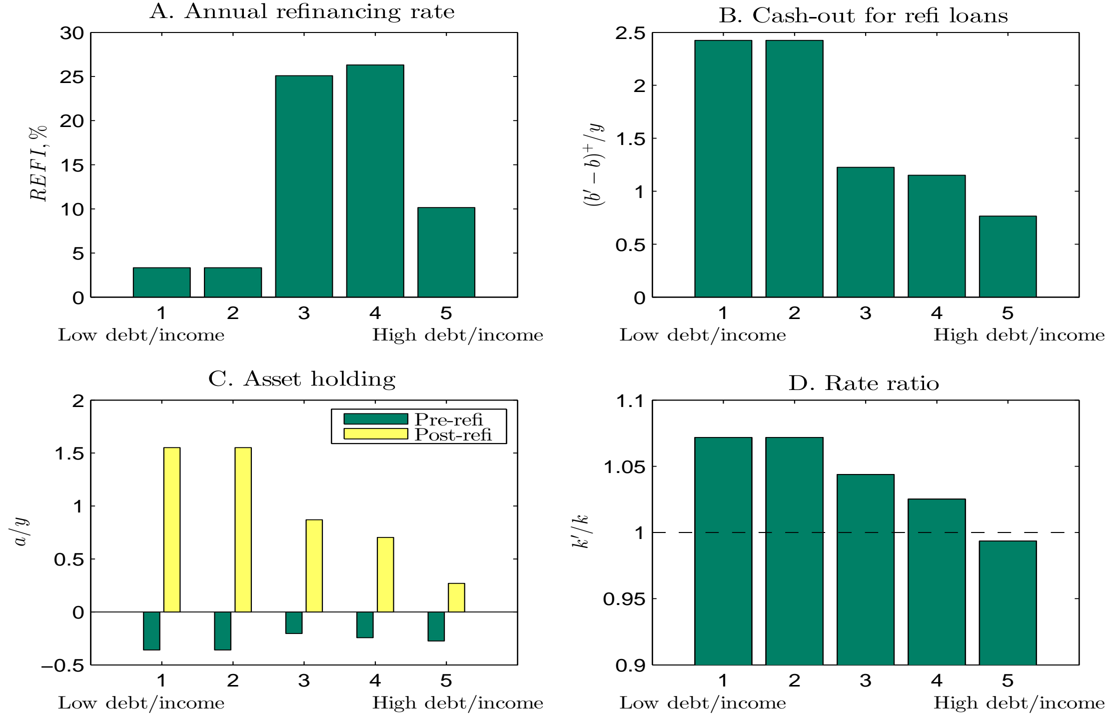

Figure 6: **Cross-sectional implication for homeowners sorted on mortgage debt-to-income ratio.**

home equity upon refinancing declines with debt-to-income ratios, with the bottom two quintiles cashing out almost 2.5 times their annual income, the third and fourth quintile about 1.1 times, and the top quintile only about three quarters. Indeed, for the bottom two quintiles, accessing liquidity is the only reason to refinance (or even originate a new loan if current balance is zero). They come into the period with HELOC balances equal to 0.36 times annual income, and leave the period with about 1.5 times income on average (Panel C), or 65% of the amount cashed out. About 21% of the cashed-out equity is used on consumption, allowing them to consume roughly 1.5 times their annual income this period. For the middle quintile, 17% of the cashed-out equity is used for paying off the HELOCs, 12% consumed, with the remaining 71% saved as liquid assets (0.87 times annual income). These households with low or medium leverage typically refinance at disadvantageous rates, as shown in Panel D. In contrast, the high-leverage households have limited ability to cash out. Thus, the incentive to reduce the cost of borrowing dominates, and their average rate ratio falls below one (albeit slightly). For the high-leverage households, the average fraction

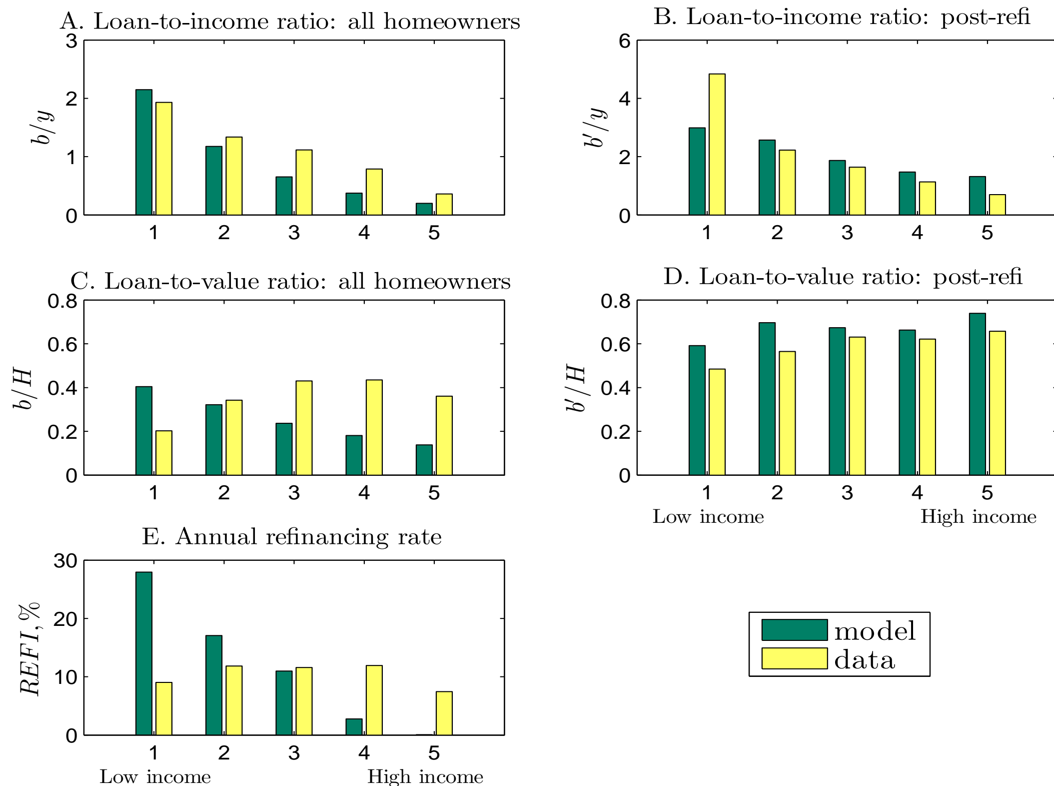

Figure 7: **Comparing the cross-sectional implication for homeowners sorted on income with the data.**

of the cashed-out equity used to pay off HELOCs, consumed, and saved are 36%, 29%, and 35%, respectively. The savings amount to just 0.27 times annual income.

Next, we confront the model's cross-sectional predictions with empirical evidence in Figure 7. 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 as before (conditional on homeownership); in the data, we sort households based on income relative to the value of their primary residence, since in the model we do not allow for heterogeneity in home value; 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 (Panel A): the bottom quintile 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). For the households in the data who report refinancing their mortgage over the previous year (or the year of the survey), we compare their mortgage loan-to-value ratios with the LTI for homeowners who choose to refinance in the model, b'/y (Panel B). The loan-to-income ratios also match very closely, especially for the middle quintiles. For the bottom quintile, the model-implied LTI undershoots the value in the data, which is in part because the ratio is by assumption capped at 3.5 for new loans in the model, while in the data the average is close to 5 times income.[19]

The model's ability to match the unconditionally distribution of loan-to-value ratios (i.e., for all homeowners) is weaker (Panel C). 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 likely reason for this discrepancy is our stark modeling of housing that allows for no cross-sectional variation in the home value. Indeed, as indicated in Panel D, *conditional* on refinancing the LTV patterns in the model are very close to those in the data: they almost monotonically increase with income from about 0.5 in the bottom quintile to above 0.6 in the top according to the data, with the model values overshooting by about 0.05 to 0.1 throughout. Overall, there is much less variation in LTV ratios upon refinancing relative to the LTI ratios.

Finally, the model matches reasonably well the rates of refinancing for the middle of the income distribution (quintiles 2 and 3), where they are close to the average. For the bottom quintile, 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 discrepancy may 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

[19]While conventional mortgage loans are typically restricted to allow for debt service ratios that are consistent with our assumption of $\xi_{LTI} = 3.5$, household do have access to alternative mortgage products that allow higher LTIs, e.g. Federal Housing Administration (FHA) loans, as well as subprime and alternative documentation loans that were popular prior to the financial crisis of 2008.

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 explain the observed history of consumption, debt, and refinancing 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 8. 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. In particular, the model matches reasonably well the low consumption growth in 1990-1991 and the 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, owning a house vs. renting, as well as the decisions related to mortgage refinancing. The degree to which households take advantage of these opportunities in the model can be assessed by studying the dynamics of their balance sheets.

Panel B of Figure 8 depicts the average stock of (housing) debt relative to household income. We construct two empirical measures to compare to the average debt-to-income ratio in the model. The first one is the ratio of total housing debt from the U.S. Flow of Funds Accounts (FFA) to aggregate personal income. The disadvantage of this measure is that it ignores the fact that almost 40% of households are renters and therefore do not have access

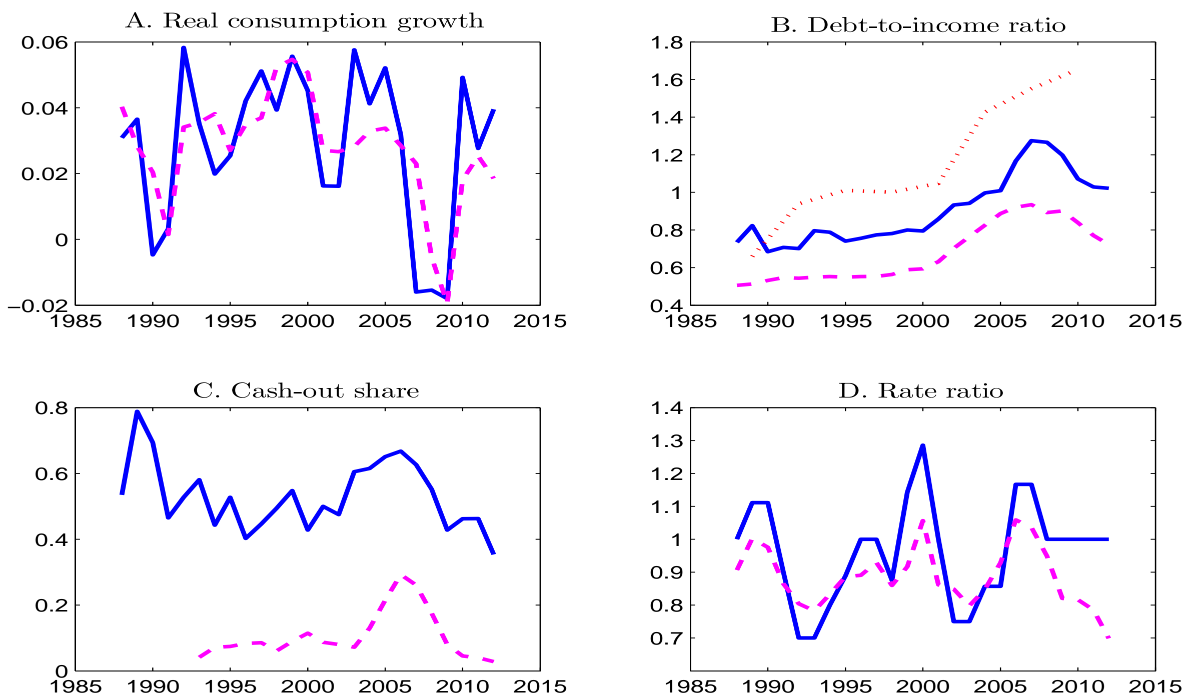

Figure 8: **Model-implied aggregate time series.** This figure plots the model-implied aggregate time series (solid lines) for real consumption growth (all households), debt-to-income ratio (all homeowners), and the cash-out share and rate ratio of refinance loans from 1988 to 2012. The dash lines in Panels A, C, D represent the data counterpart. The dash line and dotted line in Panel B represent two alternative measures of debt-to-income ratio based on the data from the Flow of Funds and the SCF, respectively.

to mortgage debt, which will make it understate the debt-to-income ratio for homeowners. Its advantage is that it is available at an annual frequency. The second empirical measure uses the triennial Surveys of Consumer Finances for years 1989, 1992, 1995, 1998, 2001, 2004, 2007, and 2010. We compute the average ratio of total debt collateralized by the household's primary residence (including both first mortgage and second-lien borrowing, such as home-equity loans and HELOCs) to total household income across all households in the bottom 80% of the wealth distribution that we targeted in estimation. The model is able to replicate the dramatic run-up in debt-to-income ratios starting in the mid-1990's and through the later 2000's: the ratio peaks at about 1.2 in the model in year 2007, before cresting in 2008-2009 and declining roughly back to it's 2005 value of approximately one by 2012. This is somewhat lower than the average in the SCF data, which peaks at 1.6 in 2010 (the most recent survey available). The FFA series follows similar dynamics as the

model-generated series but at a lower level.

The model also predicts a sharp drop in the debt ratio in 2011. While there is no SCF data available past 2010, other data sources (such as the Flow of Funds) indicate a decline in debt ratios over the recent period, consistent with the model's predictions (e.g. see Midrigan and Philippon (2011), Mian, Rao, and Sufi (2013), and Justiniano, Primiceri, and Tambalotti (2013)). While the decline in total debt begins as early as 2008, sharply falling aggregate income keeps the debt-to-income ratio high during the Great Recession, so that the "deleveraging" effect only becomes apparent once incomes begin to recover.

The rise and fall in household debt clearly mimics the coincident rise and subsequent decline in house prices, as households' liquidity constraints first become relaxed, and then tighten. The fastest increases in the debt-to-income ratios occur during the 2001 recession and the subsequent "jobless recovery" (through 2003), and at the onset of the Great Recession (2007-2008). However, the increase in home equity cash-out precedes the peak of the debt-to-income ratio, as demonstrated in Panel C: the share of refinance loan dollar volume attributed to cash-out peaks in 2006 in the data and the model. Panel C also reflects the fact that our model generates too much cash-out on average relative to the data, as it is already shown in Table 5.

The model matches the dynamics of the median ratio of the new mortgage rate to the old rate upon refinancing (Panel D) 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 ratio in the model is somewhat more variable. It does not match the dramatic decline in the rate ratio after 2008 due to the fact that the discretized mortgage rate time series that we feed into the model does not capture the effect of the extraordinary monetary policy measures undertaken by the Federal Reserve following the global financial crisis (see Panel D, Figure 4).

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 heterogeneities. 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 the measure of elasticity of housing supply developed by Saiz (2010) to show that U.S. MSAs with relatively inelastic supply of housing that 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, we consider the baseline model as broadly representative of the "inelastic" areas, since it matches the general dynamics of the boom and bust in house prices. In order to construct a theoretical proxy for the house prices in the "elastic" areas, we solve the model using the same set of

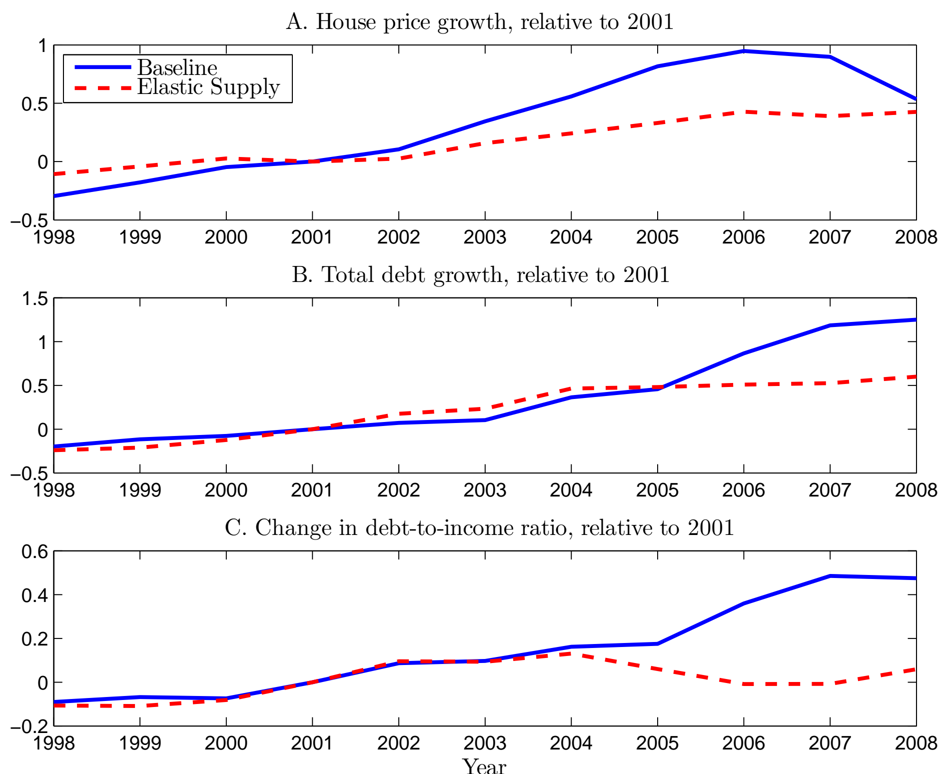

Figure 9: **Replicating Mian and Sufi (2010) evidence on leverage patterns.** The solid line represents the case with the house price path from the baseline model. The dash line represents the case with the ratio of real house price to real income being constant, which mimics the effect of elastic housing supply.

parameters as in the baseline model but a different stochastic process of house prices. In particular, we assume that the ratio of real house price to real income is constant, i.e. $h_t = 1$. This assumption captures the notion that in areas 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 9, analogous to Figure 1 in Mian and Sufi (2010). Panel A depicts the cumulative growth in house prices under the "inelastic" scenario (i.e., the baseline model) as well as under the "elastic" scenario (i.e., the counterfactual experiment). The latter shows only moderate growth in house prices, driven by the increase in aggregate income, consistent with the Mian-Sufi data. Panel B and C depict the evolution of the total housing debt and the

debt-to-income ratio under the two scenarios. Under the baseline 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. 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 10 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 much sharper drop in consumption during the Great Recession than an average household, with a cumulative decline of 20% by 2008 (vs. 10% by 2009 for the average homeowner). In contrast, low leverage households experience a smaller consumption drop than the average. This pattern is broadly consistent with evidence in Mian, Rao, and Sufi (2013).

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

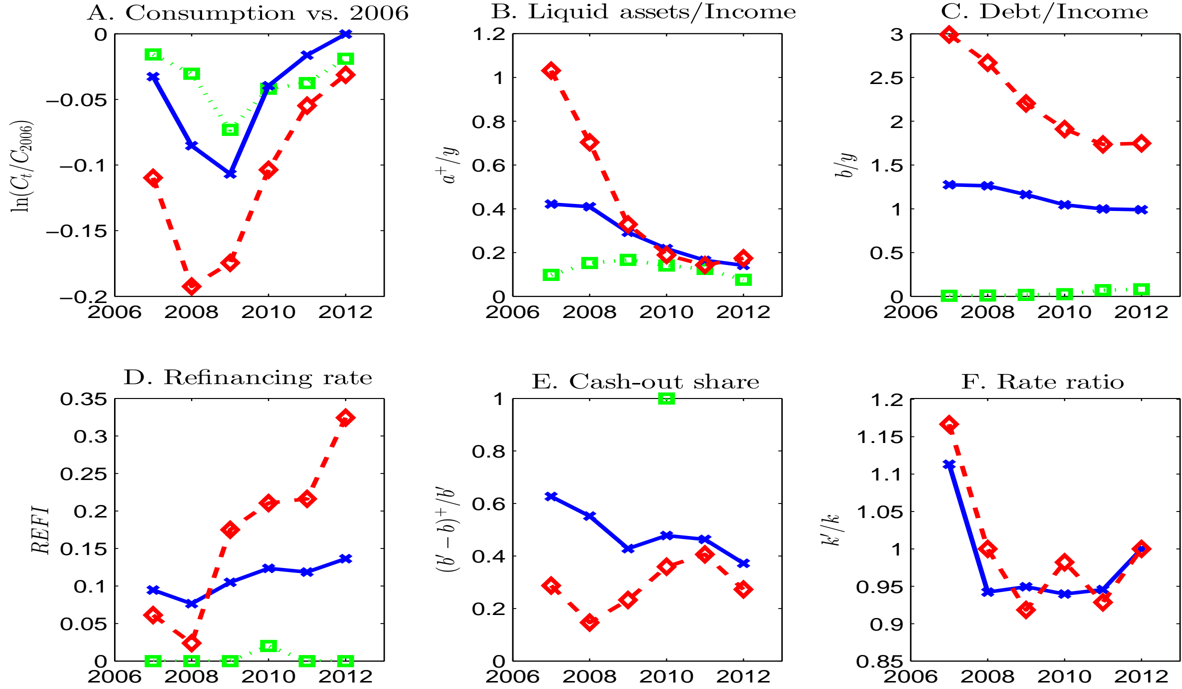

Figure 10: **Consumption, balance sheet, and refinancing behavior for households with different amount of leverage.** The dash-diamond line and the dot-square line represent the top and bottom quintile of the distribution of debt-to-income ratio in 2006, respectively. The solid-cross line represents the average homeowner.

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 about 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, as the LTI and LTV constraints are binding for some of the households in this group. Refinancing activity rises significantly for this group after 2008, from 2% in 2008 to 18% in 2009. This jump in refinancing is part due to decline

in debt which relaxed the collateral constraints, and in part due to the lower mortgage rates. This prediction is likely to be counterfactual, however, due to the banks tightening their lending standards following the subprime mortgage crisis. Conditional on refinancing, the model predicts that the high leverage households cashout at a lower rate than average (see Panel E), as they likely have less home equity and are closer to the collateral constraints. Also, in 2007, the rate ratio for refinance loans is 1.11 on average and 1.17 for the high-leverage households (see Panel F), as liquidity-constrained households cash out to smooth consumption despite higher mortgage rates.

Households in the low-leverage group have almost no mortgage debt. A few of these households "refinance" in 2010 by taking out a new loan with a 100% cash-out. However, such behavior is rare (the refinancing rate is 0 for this group in all other years), because 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.

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.[20] 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.

[20] 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,[21] 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

[21] 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	h_t	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
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	h	r	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	Average house price to income ratio
	ξ_{LTV}	0.8	Collateral constraint
	ξ_{LTI}	3.5	Debt service constraint
	$-\underline{a}$	30%	Maximum HELOC balance as fraction of aggregate income
	ω	0.15	Probability of return to credit market after default
	ζ	1	1-ζ = confiscation rate of liquid assets upon default
	ϑ	0.04	Interest rate premium on HELOC

Panel B. Estimated parameters

Preferences	δ	0.929	Subjective discount rate
		(0.038)	
	γ	2.383	Risk aversion
		(3.963)	
	ψ	0.610	Intertemporal elasticity of substitution
		(0.988)	
	η	0.359	Rent as a share of labor income
		(0.362)	
Institutional	ϕ_0	0.093	Fixed cost of issuing new mortgage
		(0.088)	
	ϕ_1	0.026	Proportional cost of issuing new mortgage
		(0.078)	
	ϕ_h	0.138	Proportional cost of buying/selling a house
		(0.222)	

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/pY	0.66	0.60	0.001
2. Consumption growth volatility, %	$\sigma(\Delta \log c^i_{t+1})$	9	18.0	0.9
3. Homeownership rate, %	$E[I^h]$	60	22.5	8.7
Homeowners:				
4. Liquid assets/Income	a/pY	0.28	0.23	0.01
5. Mortgage/Income	b/pY	0.98	0.98	0.18
6. HELOC/Income	$-a^-/pY$	0.07	0.06	0.02
7. Refinancing rate, % of homeowners	$REFI$	8.0	12.8	3.3
8. Refinance loan/Income	b'/pY	1.41	2.60	0.28
9. Dollar cash-out/Refinance loan	$(b'-b)^+/b'$	0.12	0.48	0.08
Renters:				
10. Liquid assets/Income	a/pY	0.18	0.07	0.02
Refinancing Regression:				
11. Coefficient on Z	β_Z^{REFI}	-0.25	-0.46	1.33
12. Coefficient on $\Delta \log H$	β_H^{REFI}	0.15	0.14	0.35
Cashout Regression:				
13. Coefficient on Z	β_Z	-0.13	-0.17	0.34
14. Coefficient on $\Delta \log H$	β_H	0.06	0.06	0.14
	Panel B. Additional Moments			
Volatility of aggregate consumption growth, %	$\sigma(\Delta \log C_{t+1})$	2.7	3.1	0.06
Sensitivity of consumption to Z shocks	β_Z^C	0.46	1.00	0.64
Sensitivity of consumption to H shocks	β_H^C	0.06	0.11	0.12
Sensitivity of consumption to lagged r	β_r^C	0.068	0.03	7.58
Sensitivity of consumption to lagged R	β_R^C	0.091	0.06	1.55
Refinancing regression coefficient on R	β_R^{REFI}	-1.91	-1.19	1.13
Cashout regression coefficient on R	β_R	-0.43	-0.46	0.53

Table 6: Sensitivity Analysis

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
	Baseline	δ		γ		ψ		η		ϕ_0		ϕ_1		ϕ_h	
		0.837	0.976	0.596	9.532	0.153	2.441	0.090	1.437	0.023	0.372	0.007	0.105	0.035	0.554
All Households:															
Consumpion/Income	0.60	0.56	0.73	0.59	0.69	0.61	0.60	0.70	0.61	0.61	0.60	0.61	0.60	0.62	0.58
Cons. growth vol, %	17.98	18.15	18.32	18.49	19.10	17.22	19.78	17.48	20.06	18.00	17.99	18.06	17.87	18.63	17.69
Homeownership rate, %	22.51	3.44	75.13	16.58	52.40	23.53	23.21	4.04	66.21	25.79	17.19	24.59	18.06	29.46	10.39
Homeowners:															
Liquid assets/Income	0.23	0.10	0.31	0.18	0.74	0.32	0.18	0.20	0.07	0.21	0.12	0.25	0.14	0.22	0.19
HELOC/Income	0.06	0.06	0.07	0.07	0.03	0.05	0.07	0.04	0.20	0.06	0.10	0.06	0.09	0.07	0.09
Mortgage/Income	0.98	1.41	0.11	1.49	0.14	0.87	1.15	0.59	0.16	1.19	0.24	1.20	0.35	1.19	0.48
Refinancing rate, %	12.84	30.32	1.54	23.08	1.92	12.35	14.32	9.53	2.39	21.45	1.99	17.12	3.75	15.58	6.73
Refi loan/Income	2.60	1.80	2.94	2.31	2.93	2.57	2.58	1.87	2.93	2.20	3.06	2.52	2.80	2.49	2.97
Cash-out $/Refi loan	0.48	0.27	0.59	0.34	0.73	0.48	0.47	0.61	0.56	0.38	0.83	0.42	0.74	0.43	0.51
Default rate, %	0.01	0.06	0.00	0.03	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.59
Renters:															
Liquid assets/Income	0.07	0.00	0.45	0.03	0.90	0.10	0.05	0.04	0.18	0.08	0.07	0.07	0.07	0.13	0.03
Refinancing Regression:															
Coefficient on R, β_R^{REFI}	-1.19	-3.15	-0.05	-2.39	-0.09	-0.66	-2.22	-1.30	0.12	-1.49	-0.11	-1.63	-0.34	-2.12	-0.18
Cashout Regression:															
Coefficient on R, β_Z	-0.46	-0.05	-0.08	-0.29	-0.25	-0.30	-0.73	-0.15	0.15	-0.56	-0.09	-0.51	-0.22	-0.62	-0.04
Coefficient on Z, β_Z	-0.17	-0.01	-0.28	-0.07	-0.19	-0.11	-0.23	-0.02	-0.24	-0.16	-0.11	-0.16	-0.19	-0.35	-0.07
Coefficient on H, β_H	0.06	0.02	0.02	0.07	0.01	0.03	0.09	0.00	0.04	0.04	0.04	0.07	0.04	0.01	0.01
Aggregate Consumption:															
Volatility , %	3.12	2.43	3.21	3.05	2.71	3.07	3.39	2.62	3.39	3.28	2.82	3.26	2.86	3.63	2.69
Sensitivity to Z, β_Z^C	1.00	0.86	1.11	0.94	0.81	1.06	0.89	1.01	1.17	1.03	0.99	1.02	0.99	0.98	1.03
Sensitivity to H, β_H^C	0.11	0.06	0.02	0.12	0.09	0.08	0.17	0.03	0.02	0.12	0.07	0.13	0.08	0.18	0.03
Sensitivity to r, β_r^C	0.03	-0.01	0.23	0.00	0.12	0.02	0.02	0.08	0.20	0.03	0.06	0.03	0.06	-0.02	0.09
Sensitivity to R, β_R^C	0.06	0.05	0.28	0.06	0.18	0.02	0.13	0.15	0.24	0.07	0.09	0.07	0.09	0.01	0.15

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:						
Consumpion/Income	0.60	0.60	0.64	0.61	0.62	0.60
Consumption growth vol, %	17.98	17.91	21.77	18.02	18.92	17.93
Homeownership rate, %	22.50	23.10	32.10	27.10	32.50	19.80
Homeowners:						
Liquid assets/Income	0.23	0.22	0.31	0.28	0.25	0.30
HELOC/Income	0.06	0.07	0.06	0.07	0.06	–
Mortgage/Income	0.98	1.05	0.62	1.38	1.56	0.94
Refinancing rate, % of homeowners	12.84	14.22	8.08	15.41	14.59	13.29
Refinance loan/Income	2.60	2.56	2.76	3.07	2.93	2.61
Dollar cash-out/Refinance loan	0.48	0.47	0.58	0.44	0.37	0.44
Default rate, % of homeowners	0.01	0.01	0.01	0.09	7.83	0.01
Renters:						
Liquid assets/Income	0.07	0.06	0.20	0.06	0.09	0.07
Refinancing Regression:						
Coefficient on R, β_R^{REFI}	-1.19	-1.36	-0.50	-1.79	-1.81	-1.48
Cashout Regression:						
Coefficient on R, β_R	-0.46	-0.40	-0.40	-0.74	-1.57	-0.38
Coefficient on Z, β_Z	-0.17	-0.11	-0.28	-0.32	-0.62	-0.15
Coefficient on $\Delta \log H$, β_H	0.06	0.05	0.04	0.13	-0.35	0.05
Aggregate Consumption Growth:						
Volatility, %	3.12	3.04	3.74	3.34	3.42	3.00
Sensitivity to Z, β_Z^C	1.00	1.03	1.06	1.01	1.10	0.99
Sensitivity to H, β_H^C	0.11	0.10	0.14	0.14	0.08	0.10
Sensitivity to lag r, β_r^C	0.03	0.07	0.08	0.03	0.08	0.04
Sensitivity to lag R, β_R^C	0.06	0.21	0.09	0.07	0.15	0.07

Table A.1: State-level refinancing activity

	$Cycle_t$	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	-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. $\bar{R}^i_t$ 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).

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

	$Cycle_t$	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	-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. $\bar{R}_t^i$ 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).

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