Houses as ATMs?
Mortgage Refinancing and Macroeconomic Uncertainty*

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Abstract

Mortgage refinancing waves tend to coincide with economic downturns. Using both aggregate and state-level data we show that refinancing activity increases when economic conditions deteriorate, even after controlling for the cyclical behavior of interest rates, with a larger fraction of loans involving cash-out (equity extraction) around recessions. We develop a quantitative model in order to investigate the role of mortgage refinancing as a mechanism for smoothing consumption by liquidity constrained households, focusing on the interaction of the aggregate economic conditions, interest rates, and idiosyncratic labor income risk. Calibrating the model to the data we show that counter-cyclical labor income risk is important for generating the cyclical behavior of refinancing. The calibrated model can closely replicate the dynamics of empirically observed cash-out refinancing, in particular during the housing boom of 2003-2006.

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1 Introduction

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. This paper investigates the role of mortgage refinancing as a mechanism through which households can relax liquidity constraints in response to aggregate and idiosyncratic shocks by borrowing against their home equity. Fluctuations in interest rates that determine the strength of the financial incentive to refinance alone are not sufficient to capture all of the movement in the aggregate prepayment/refinancing activity in the data (e.g., Boudoukh, Richardson, Stanton, and Whitelaw (1997)). We focus on the interaction between the interest rate variation and macroeconomic conditions in affecting household decisions. The decision to refinance a mortgage either to take advantage of the lower interest rates or to take out home equity for consumption-smoothing purposes trades off the benefits of refinancing against the costs of originating a new loan, both financial and non-pecuniary. The interaction of the two motives for refinancing that underscores its potential importance for the effectiveness of monetary policy.[1]

Empirically, interest rates are pro-cyclical, falling in economic downturns, when both aggregate income falls and its cross-sectional dispersion rises. Consequently, the option to prepay an existing fixed-rate mortgage (FRM) is more likely to be in the money at a time when households are constrained and experiencing a need to tap their home equity (if it exists), in effect providing a form of insurance. Indeed, we show that in the data, mortgage refinancing activity appears to respond to macroeconomic conditions, even after controlling for the cyclicality of mortgage rates, using both aggregate and state-level data. Refinancing activity spikes with measures of macroeconomic uncertainty such as the implied stock market volatility and unemployment claims, and is lower in states that experience higher rates of economic growth. Refinancing is positively

[1] 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).

related to growth in house prices, which drives the tightness of the collateral constraint, while more refinancing households extract home equity ("cash-out") as the economy enters into recessions, even before interest rates fall.

We build a dynamic model of household mortgage financing that replicates these stylized facts. The model also helps quantify the degree to which refinancing costs as well as the lack of home equity constrain the ability of households to smooth consumption in the face of macroeconomic uncertainty.

In our model, households face uninsurable idiosyncratic and aggregate labor income risk, and their only means of borrowing is via a home mortgage. The mortgage repayment and refinancing behavior is driven by both the purely financial motive of minimizing the borrowing costs (as in Campbell and Cocco (2003)) and by the consumption-smoothing motive of using home equity to alleviate the liquidity constraint (as in Hurst and Stafford (2004)). An important feature of our model is the counter-cyclical volatility of idiosyncratic labor income growth, documented by Storesletten, Telmer, and Yaron (2004). This property of the labor income process combined with the pro-cyclical interest rates implies that a macroeconomic downturn should coincide with a spike in refinancing activity both due a decline in mortgage rates and because more households become liquidity constrained, provided that the cost of refinancing is low enough and households still have enough home equity.

In a quantitative calibration of the model that targets the main features of income, consumption, and mortgage data we show that the dynamics of labor income are key for generating counter-cyclical refinancing and cash-out behavior. On the one hand, counter-cyclical idiosyncratic labor income risk is important for cyclical behavior of refinancing. On the other hand, riskier idiosyncratic income implied greater precautionary saving, i.e. greater liquid asset holdings and lower mortgage balances on average. Further, highly persistent labor income processes advocated in the recent literature imply that idiosyncratic shocks are very difficult to smooth, and therefore dampen the effect of economic cycles on refinancing behavior. Thus observed refinancing behavior contains useful information for understanding the dynamics of individual labor income.

We use the quantitative model to provide a benchmark for understanding the dramatic expansion of household leverage over the house price boom period documented by Mian and Sufi (2010) and others. This empirical evidence is qualitatively consistent with liquidity-constrained households taking advantage of relaxed housing collateral constraints in the face of (current or anticipated) temporarily depressed labor income. It could also be due to self-control problems on the part of consumers (e.g., Laibson (1997)) and/or moral hazard on the part of mortgage originators (e.g. Keys, Mukherjee, Seru, and Vig (2010)). We show that a calibrated model can replicate the dynamic behavior of the time series of home equity cash-out for prime conventional loans over the period 1997-2011. Thus, our model can potentially quantify the contribution of liquidity constraints to household leverage expansion relative to the other channels.

The second benefit of our approach is that it would allow us to conduct policy experiments to evaluate the dynamic impact of changes to the mortgage market environment on household consumption behavior. For example, a structural model allows one to deduce welfare implications of loan origination costs and loan-to-value ratio constraints in a rich economic setting, which can help assess the effectiveness of policy proposals of stimulating the economy through relaxing refinancing constraints. The effects of changes in the costs of refinancing a mortgage, prepayment penalties, or loan-to-value and debt-to-income constraints can be studied without reliance on extrapolating household behavior from past experiences that may differ along other dimensions. In addition, we could evaluate the costs of existing policies (such as the government guarantee of agency-backed mortgages) and of their distributional consequences (such as the improved access to credit by a marginal borrower).

A better understanding of the links between mortgage refinancing and macroeconomic conditions is important for several reasons. First, while previous models have predominantly focused on refinancing as exercise of an interest rate option, our results show that the liquidity-driven motive can significantly amplify the demand for refinancing under certain macroeconomic conditions. This is important for pricing prepayment risk in mortgage-related assets (e.g., Duarte, Longstaff, and Yu (2007) show that agency-backed mortgage backed securities are subject to macroeconomic risk captured by stock returns), as well as for understanding the relation between refinancing activity in the mortgage markets and volatility in other fixed income markets (see, e.g., Duarte (2008)). Second, our model can quantify the welfare implications of refinancing costs in a rather rich economic setting, which can help evaluate policy proposals of stimulating the economy through relaxing refinancing constraints.

1.1 Literature

There is a large literature on mortgage refinancing decision, with different strands focusing on different facets of the optimal solution to the problem faced by the household.

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)). The wide divergence of prepayment behavior across households has been modeled by attributing it to implicit heterogeneity in the costs of refinancing (e.g. Stanton (1995), Deng, Quigley, and Van Order (2000)), both explicit and implicit, in particular those arising from behavioral biases (e.g. Agarwal, Driscoll, and Laibson (2002)). 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. Downing, Stanton, and Wallace (2005) consider the interaction between the mortgage prepayment and default decision and the explicit role of house prices.

The 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)). Some evidence supporting the importance of housing collateral has been documented using variation in consumption responses to income at the regional level (Caplin, Freeman, and Tracy (1997), Lustig and Van Nieuwerburgh (2010)). Hurst and Stafford (2004) explicitly consider the role of mortgage refinancing as a mechanism of accessing home equity for the purpose of smoothing consumption over time and provide household-level evidence. Gan (2010) reports similar evidence using data on households in Hong Kong. Gerardi, Rosen, and Willen (2010) also use micro-level data to show that the mortgage securitization improved households' ability to smooth their housing consumption over time, while Campbell and Hercowitz (2005) use a structural model to argue that the increased accessibility of housing collateral due to such financial innovations contributed to the "Great Moderation" of the business cycles in the recent decades.

A large literature aims to understand the importance of housing wealth for determining consumption (e.g., Carroll, Otsuka, and Slacalek (2011), Case, Quigley, and Shiller (2011)). Our model is closely related to that in 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 Rios-Rull and Sanchez-Marcos (2008) endogenize house prices in a similar environment. Piazzesi and Schneider (2009) study the interaction of housing and uninsurable inflation risk in household wealth portfolios within a temporary equilibrium framework.

2 Empirical evidence

2.1 Aggregate level evidence

In this section, we discuss empirical evidence on how refinancing activity at the aggregate level relates to interest rates and macroeconomic conditions. The key variable capturing mortgage refinancing by households that we use is the index of mortgage applications compiled by the Mortgage Bankers Association (MBA Refi Index), which is available from 1990 to 2011. In addition, we also examine the quarterly cash-out data from Freddie Mac for the period from 1985 to 2011.

Figure 1 Panel A plots the Refi index (weekly) along with the 30-year mortgage rates. Not surprisingly, refinancing increased in the early 90s and especially around 2003, both of which are times with 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 with the VIX index, a measure of the implied volatility of the $S\&P$ 500 stock market index. The spikes in Refi in 1998, 2001, 2008, and 2009 all appear to coincide with spikes in the VIX. Panel C plots the Refi index with the year-on-year growth rate in industrial production. The Refi index rose significantly during the 2001 recession, and again in early 2008, the onset of the Great Recession. Panels B and C are suggestive evidence that households borrow against home equity (while they are not yet "under water") when experiencing bad income shocks or in anticipation of worsening economic conditions in the future.

We regress the (monthly average) Refi Index on a host of financial and macroeconomic variables:

$$REFI_t = b_0 + b_{IP} IP_t + b_{hpi} HPI_t + b_r R_t^{3m} + b_{r30} R_t^{M30} + b_{r30l}(R_t^{M30} - R_{t-12}^{M30}) + \epsilon_t, \tag{1}$$

where R_t^{3M} is the 3-month Treasury Bill rate, R_t^{30Y} the 30-year fixed mortgage rate, R_{t-12}^{30Y} the 30-year fixed mortgage rate lagged by one year, HPI_t the year-on-year growth in the Case-Shiller

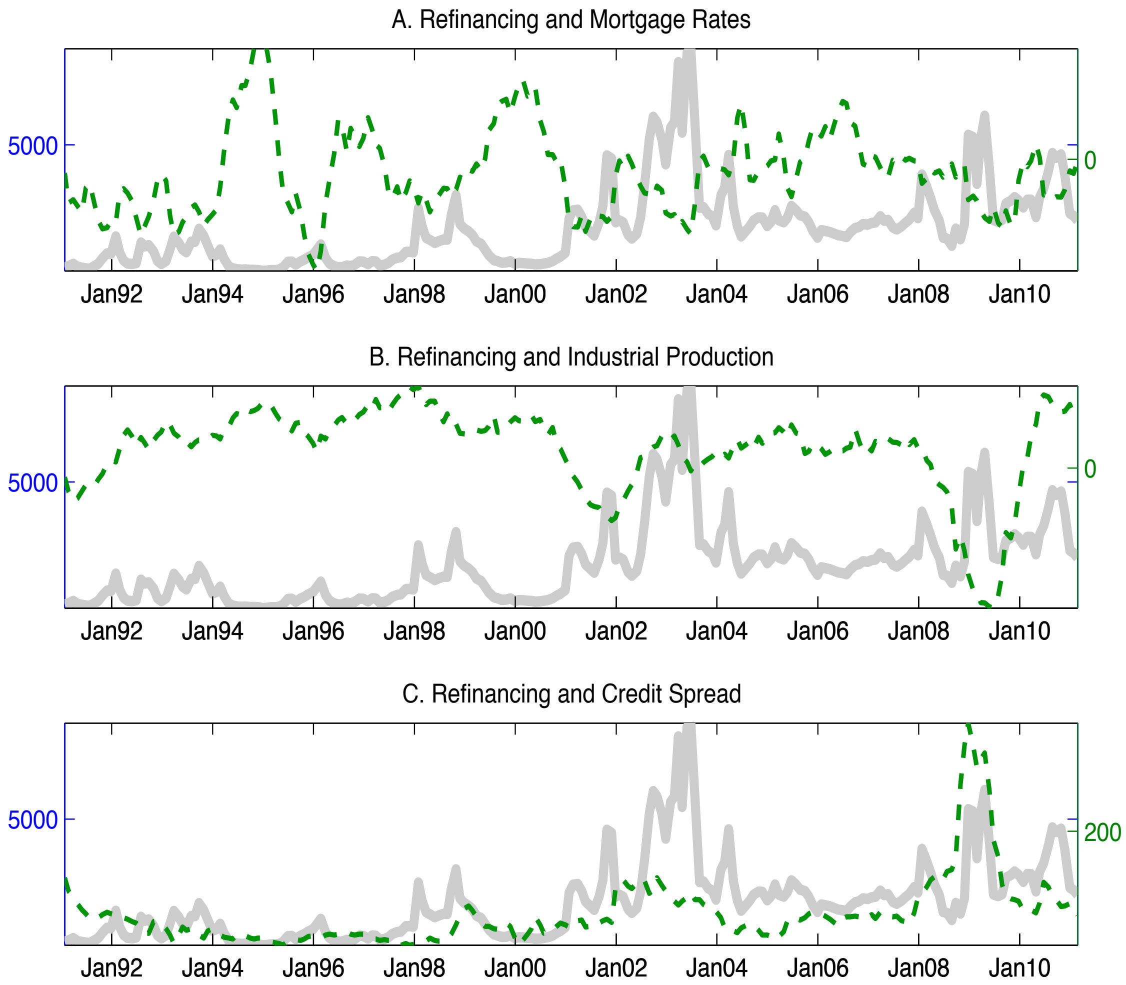

Figure 1: Refinancing, Interest Rates, and Macroeconomic Uncertainty

housing price index, and IP_t the year-on-year change in the Industrial Production index (IP). Besides IP_t, other proxies for macroeconomic conditions we consider include lead industrial production growth (IP_{t+1}) and the Baa-Aaa credit spread ($SPRD_t$).

Table 1 reports the results. The most important driver of mortgage refinancing are the current 30-year mortgage rate and the one-year change in the 30-year rate, both of which come in with a negative and robustly significant coefficient in all of the regressions. This is natural, as one of the primary reasons to refinance a mortgage is to take advantage of lower interest rates and thus lower interest payments, and a proxy for the potential interest saving is the gap between the current and lagged mortgage rates. It is also intuitive that past house price growth affects refinancing positively,

Table 1: Explaining the MBA Refinancing Index - Monthly

	1	2	3	4
IP_t	-0.60	-0.38	0.54	0.44
	(0.22)	(0.22)	(0.40)	(0.35)
$IP_t \times HPI_t$				-0.08
				(0.03)
$SPRD_t$			16.02	22.69
			(5.11)	(6.14)
HPI_t		0.36	0.58	0.64
		(0.21)	(0.24)	(0.22)
R_t^{M30}	-7.98	-5.79	-4.74	-5.24
	(1.25)	(1.18)	(1.36)	(1.16)
R_t^{3M}		-2.06	-1.37	-0.83
		(1.09)	(0.87)	(0.75)
$R_t^{M30} - R_{t-12}^{M30}$		-3.53	-4.84	-4.45
		(2.09)	(2.17)	(2.07)
Adj. R^2	0.56	0.62	0.68	0.70

NOTE: Monthly data, January 1990 - February 2011. Numbers in parentheses are Newey-West standard errors with 12 lags. The left-hand-side variable is the MBA refi index. IP_t is the one-year growth rate in industrial production. HPI_t is the real one-year growth in the FHFA house price index. $SPRD_t$ is the Baa-Aaa credit spread. R^{M30} is the average 30-year mortgage rate. R^{3M} is the 3-month t-bill rate.

as the wealth effect induces households to consume from home equity.

The other right-hand side variables are meant to capture the sensitivity of refinancing to the economic conditions. The Industrial Production growth, a direct measure of economic activity, has a significant and negative coefficient after controlling for current mortgage rate, but the significance becomes marginal after controlling for the short rate, changes in mortgage rates, and house price growth. The short rate captures the attractiveness short-duration borrowing options, such as adjustable rate mortgages (ARMs), which could partly explain the weaker effects of IP. Interestingly, leading industrial production growth by one month makes the effect stronger, consistent with the interpretation that households make their refinancing decisions in anticipation of future economic conditions. Once we include Baa-Aaa spread in the regression, the coefficient on industrial production growth turns positive and insignificant, while the coefficient on credit spread is positive and significant, again capturing the countercyclicality of refi. This result is consistent with a large body of evidence that financial variables such as the credit spread (the VIX index is another example) contain relevant information about the future state of the economy.

Finally, even in the presence of credit spread, the interaction of industrial production growth and past house price growth has a negative and significant coefficient. It suggests that households are more likely to refinance when economic condition weakens but the amount of home equity they have is large.

The aggregate refinancing index 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 cash-outs react to macroeconomic conditions, which provide a more direct measure of household borrowing.

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, (ii) remains the same, or (iii) is reduced by 5% or more. The data is from Freddie Mac for the period of Q1 of 1985 to Q1 of 2011. On average, 61% of refinancing over this period are cash-outs, which highlights the importance of cash-outs in mortgage refinancing. The share of cash-outs is visibly higher towards the end of each expansion, and it becomes lower after a recession. In contrast, the fraction of refinancing that do not result in a higher loan balance does not appear to have a clear business cycle pattern. The waves in the mid-90s and early 2000s instead correspond to periods of declines in mortgage rates, which is intuitive since the goal of such refinancing should be to reduce interest payments. Finally, the fraction of pay-down refinancing, those that result in a reduction in loan balance, typically rises following a recession, as households repay the loans they take out entering the recession. These pay-downs should also be associated with lower rates, for otherwise households could prepay rather than refinance their mortgages.

Like other types of refinancing, cash-outs can also be due to low interest rates. Thus, it is informative to examine under what conditions refinancing tends to lower loan rates. Panel B of Figure 2 plots the ratio of the median new mortgage rates on refinance loans to the old mortgage coupon rates k. Households tend to refinance despite higher rates towards the end of economic expansions, but at lower rates coming out of recessions. The correlation between this rate ratio and the cash-out share in Panel A is 78%. Together, they suggest that macroeconomic factors other than interest rates play an important role in determining the aggregate amount of cash-out refinancing.

Why do households refinance their mortgages at higher rates? One possibility is that they are borrowing against future income (consumption smoothing), either because their expected future

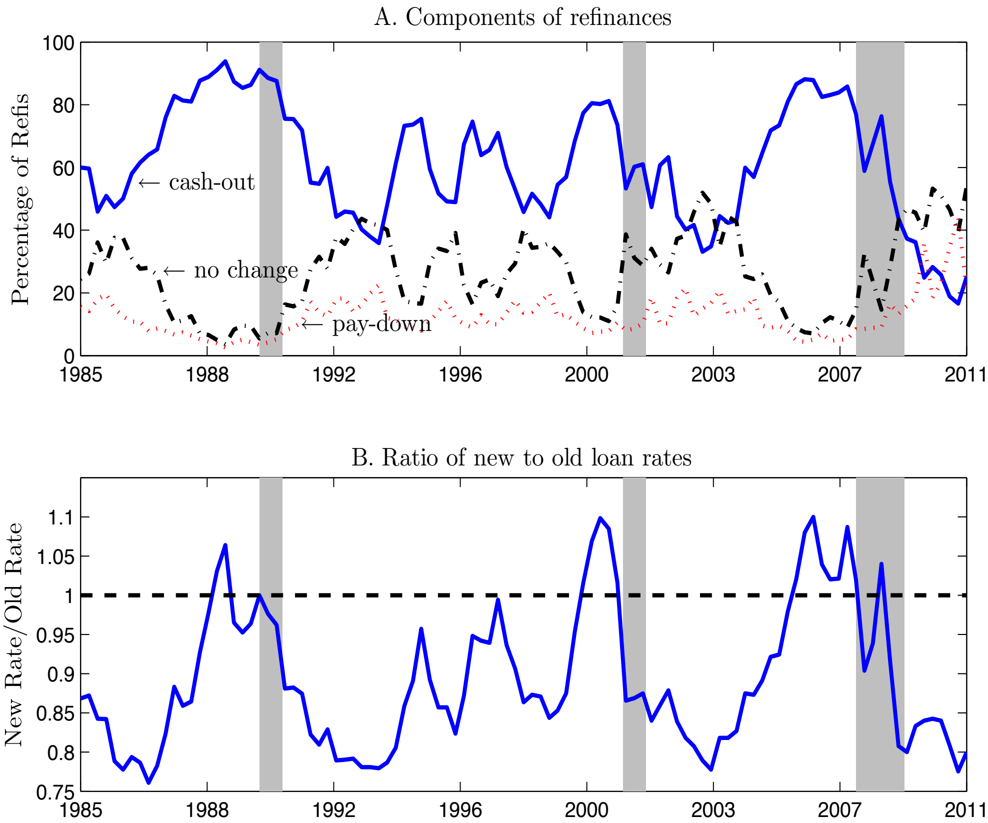

Figure 2: Panel A plots the percentage of refinancing resulting in 5% higher loan amount (cash-out), no change in loan amount, or lower loan amount (pay-down). Panel B plots the median ratio of new to old loan rates upon refinance.

income has become higher, or they are currently hit by a temporary drop in income. Given that labor income is not tradable and other non-collateralized personal loans (e.g., credit card loans) are expensive, the house can become a major source of credit for liquidity constrained households. A second, and related, reason is that households borrow preemptively when they expect future income to drop. Frictions such as loan-to-income ratio restriction, and more severe adverse selection due to higher income volatility in the cross section can make it more difficult (costly) to borrow in bad times, which will generate precautionary demand for borrowing before income has fallen. Third, households who need to borrow from the house might expect long term mortgage rates to rise in the future, so they may be attempting to "time the market" by taking out larger mortgages in anticipation and locking in the low rate. Fourth, households might expect house value to fall, which affects their future borrowing capacity through the loan-to-value ratio restriction.[2] Finally, if households expect higher returns from other types of investment (e.g., from the stock market or the housing market), they might borrow against the house in spite of high rates.

Finally, we examine to what extent do households rely on cash-out to smooth shocks to income. We normalize the dollar amount of total home equity cashed outs by year-ago personal income, and then regress it on real personal income growth, house price growth, and several interest rate variables:

$$CASHOUT_t = c_0 + c_{pi}PI_t + c_{hpi}HPI_t + c_r R_t^{3m} + c_{r30}R_t^{M30} + c_{r30l}(R_t^{M30} - R_{t-12}^{M30}) + \epsilon_t, \qquad (2)$$

where PI is past one-year real income growth, and the other variables are the same as defined in (1).

The results are shown in Table 2. Over the sample, growth in real personal income is only weakly negatively correlated with the cash-out to income ratio. However, after controlling for house price and interest rate information, the coefficient on personal income growth becomes significantly negative, again consistent with the interpretation that households use cash-out to smooth temporary negative income shocks. The magnitude of the coefficient can be interpreted as follows. If real income drops by 1%, households on average increase cash-out by 0.15-0.17% of income to offset this effect. Obviously, there will be significant heterogeneity across households in their cash-out responses to income shocks which we do not capture here. We explore these effects in our model.

While cash-out is still negatively related to the level of 30-year mortgage rate, it is negatively related to the term spread ($R^{M30} - R^{3M}$), and positively related to the one-year change in mortgage rate, the opposite of the case for refi (see Table 1). This is due to the fact that different components of refinancing depend on interest rates differently. When households refinance to lower their interest payments, the difference between the current mortgage rate and lagged mortgage rate is a proxy for the potential size of interest savings, which ought to be negatively related to the likelihood to refi. When households decide when to cash out, the level of current mortgage rate compared to the costs of other sources of financing as well as the expectation of future rates also matter. Thus, the fact that cash-out tends to rise with mortgage rates could be due to the costs of other sources

[2] Higher house price might also lead to more cash-out due to the wealth effect, or if they own investment properties.

Table 2: Cashout and Personal Income

	1	2	3	4	5
PI_t	-0.015	-0.152	-0.143	-0.169	-0.167
	(0.112)	(0.050)	(0.039)	(0.048)	(0.054)
$PI_t \times HPI_t$					-0.345
					(1.819)
$SPRD_t$				0.403	0.389
				(0.294)	(0.340)
HPI_t		0.120		0.132	0.132
		(0.032)		(0.032)	(0.033)
HPI_t^{2Y}			0.086		
			(0.013)		
R_t^{M30}		-0.009	-0.007	-0.009	-0.009
		(0.003)	(0.002)	(0.003)	(0.003)
R_t^{3M}		0.003	0.002	0.003	0.003
		(0.002)	(0.001)	(0.002)	(0.002)
$R_t^{M30} - R_{t-12}^{M30}$		0.004	0.003	0.004	0.004
		(0.001)	(0.001)	(0.001)	(0.001)
Adj. R^2	-0.014	0.568	0.704	0.582	0.576

NOTE: Quarterly data, Q1 1993 - Q1 2011. Numbers in parentheses are Newey-West standard errors with 4 lags. The left-hand-side variable is the ratio of annualized dollar cash-out to personal income lagged by 4 quarters. PI_t is one-year real personal income growth. HPI_t is the real one-year growth in the FHFA house price index. HPI_t^{2Y} is the real two-year growth in the FHFA house price index. $SPRD_t$ is the Baa-Aaa credit spread. R^{M30} is the average 30-year mortgage rate. R^{3M} is the 3-month t-bill rate.

of credit (e.g., credit card) rising faster than mortgage rates or expectation of an increase in future mortgage rates. Finally, similar to the case of refinancing, house price growth is positively related to cash-out, both because of the wealth effect of higher home value and the fact that the availability of home equity is required for cash-out. Credit spread is positively related to cash-out, but the effect is not significant.

2.2 State level evidence

To investigate the response of mortgage refinancing to economic activity further, we use state-level 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 there is heterogeneity in business conditions across states so that 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.[3] 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.

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

$$REFI_t^{State} = b_{Cycle}Cycle_t^{State} + b_{HPI}\Delta HPI_t^{State} + b_{CH}Cycle_t^{State} \times HPI_t^{State} + \bar{R}_t^i + b_w WAC_t^{State} + b_r R_t^{3M} + b_{r30}R_t^{M30} + b_{r30l}R_{t-4}^{M30} + \mathbf{b}_t + \mathbf{b}_{State} + \epsilon_t, \quad (3)$$

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,[4]

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

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

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 3 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 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

Table 3: 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}	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).

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 4 reports results of regressions (3) where $REFI^{State}_t$ 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

Table 4: Refinance loan volume relative to total income

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

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

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.

3 The Model

This section presents a dynamic model of household decisions. This model will focus on understanding households' decisions on how much to consume, save and finance a house over time, as a function of idiosyncratic shocks to income and aggregate shocks to short-term interest rates, real growth, house value, and inflation.

3.1 Households

The economy is populated by ex-ante identical, infinitely lived households. Household are indexed by i. We assume households have time-separable utility over consumption, $u(c_i)$. Each household is endowed with a house with time-varying market price H_t, and one unit of labor supplied inelastically that receives an after-tax wage $(1-\tau)y_{it}$. The idiosyncratic income process is stochastic and will be key in the optimal behavior.

Households can save using a one-period liquid asset a_{it} that pays a stochastic nominal short rate in the economy, denoted by $r_t^{\$}$. The households are prevented from borrowing (except for through their mortgages), that is $a_{it} \geq 0$ for all t. All variables are nominal, and the price level at time t is denoted by p_t. The model will thus feature inflation risk, where the (gross) inflation rate is defined as $\pi_{t+1} = p_{t+1}/p_t$.

House price 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), as well as a 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

$$H_t = p_t \ Y_t \ \bar{H} \ \tilde{h}_t, \tag{4}$$

where $\bar{H}$ is the house price level (in terms of the consumption good), and the shocks $\tilde{h}_t$ are assumed to be stationary, so that real house price level is cointegrated with real aggregate income.

Labor income 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,

$$y_{it} = p_t \ Y_t \ \tilde{y}_{it}, \tag{5}$$

The growth rate of the aggregate real income Y_t is $Z_{t+1} = Y_{t+1}/Y_t$. The idiosyncratic labor income component $\tilde{y}_{it}$ follow an autoregressive process with state-dependent conditional volatility, i.e., heteroscedastic innovations, given by,

$$\log \tilde{y}_{it} = \log \mu_y(Z_t) + \rho_y \log \tilde{y}_{i,t-1} + \sigma(Z_t)\epsilon_{it}^y, \quad \epsilon_{it}^y \sim \mathcal{N}(0,1). \tag{6}$$

The counter-cyclical nature of the idiosyncratic labor income risk is emphasized by Storesletten, Telmer, and Yaron (2004). We calibrate $\mu_y(Z_t)$ 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: $\log \mu_y(Z) = -\frac{1}{2}\frac{\sigma^2(Z)}{1+\rho_y}$

Summary of exogenous shocks In total, there are four aggregate state variables, summarized in the aggregate state vector $S_t \equiv (r_t^{\$}, Z_t, H_t, \pi_t)$. We assume that S_t follows a first-order vector autoregressive process (VAR) in logarithms:

$$\log S_{t+1} = \mu_S + \Phi_S \log S_t + \sqrt{\Sigma_S}\epsilon_{t+1}^S. \tag{7}$$

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" households 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 - e.g., Parker and Vissing-Jorgensen (2009)).

3.2 Mortgages

For simplicity, mortgages in this economy are assumed to be perpetual interest-only mortgages. Households have to meet a mortgage payment every period, defined as the (fixed) mortgage coupon rate k_{it} times the mortgage balance due on the house b_{it}. Note that 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}.

We assume that each household is initially endowed with a mortgage balance of b_{i0}, a mortgage rate equal to k_{i0}, and a house of value H_0. In other words, each household is endowed with home equity equal to $H_0 - b_{i0}$, and has to pay a mortgage annuity payment equal to $k_{i0}b_{i0}$. Households are only allowed to borrow a fraction of the full value of their home, that is they face the following constraint in mortgage financing,

$$b_{i,t+1} \leq \xi \ H_t, \tag{8}$$

where $\xi \in [0,1]$ is the parameter that controls the tightness of the *loan-to-value constraint*. In addition, there is also a *loan-to-income constraint*:

$$b_{i,t+1} \leq \kappa \ y_{i,t}, \tag{9}$$

which mimics the debt-to-income constraint widely used in practice (there are no other forms of borrowing besides mortgage in our model).

As a home-owner, 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 simply default on the mortgage and rent. As a renter, a household can choose to remain a renter or buy a house.

Figure 3 shows a diagram that represents the households' homeownership decisions. This approach broadly follows Campbell and Cocco (2010) in the treatment of the homeownership and default decision.

Repayment Households can always repay their mortgage by reducing the outstanding loan balance on their home, that is when $b_{i,t+1} < b_{it}$. The repayment decision is denoted by the indicator $I_{it}^{RP} = 1$ if home loan balance is reduced and $I_{it}^{RP} = 0$ otherwise.

Refinancing Households also have the option to refinance their homes by increasing or reducing the outstanding loan balance, that is when $b_{i,t+1} \neq b_{it}$. The refinancing decision is denoted by the indicator $I_{it}^{RF} = 1$ if the home loan is refinanced and $I_{it}^{RF} = 0$ otherwise. When households decide to refinance, they will incur a cost captured by the function ϕ. For example, if a household "pulls out" an amount $(b_{i,t+1} - b_{it})$ from their home equity, they will incur a refinancing cost equal to $\phi(b_{i,t+1})$. Therefore the net proceeds from refinancing will in fact be equal to $b_{i,t+1} - b_{it} - \phi(b_{i,t+1})$, which is the loan increase/decrease net of refinancing cost. These refinancing costs can be thought of the time cost spent on the refinancing process as well as direct finance fees associated with issuing

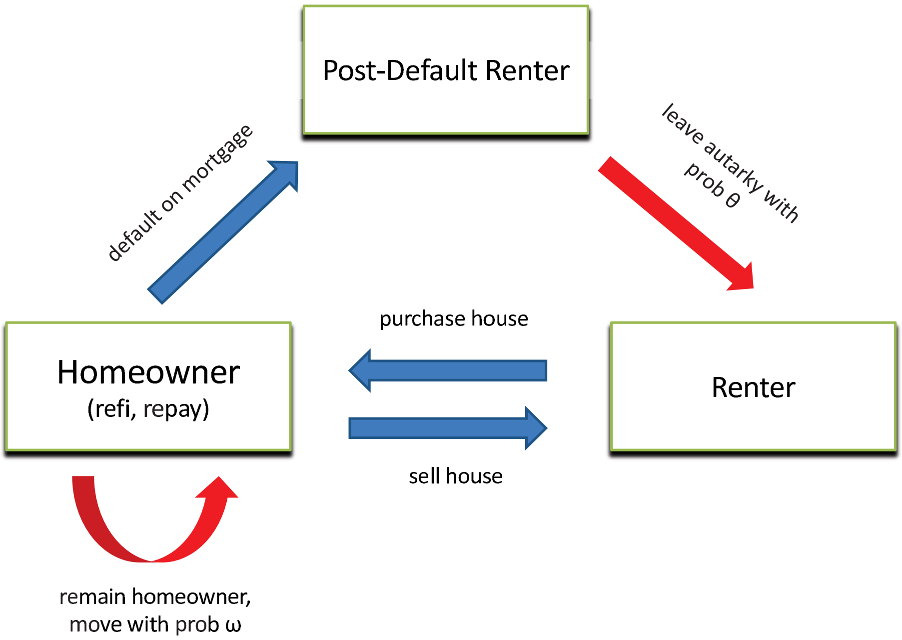

Figure 3: Home-owner, renter, and post-default renter diagram.

a new mortgage. In this paper, we assume that refinancing costs have a fixed and proportional component.

When a household refinances, the old outstanding mortgage b_{it} is repaid in full using the proceeds of the new mortgage and the available assets. The new home loan is $b_{i,t+1}$, which is subject to the loan-to-value constraint (8), and the new mortgage coupon rate $k_{i,t+1}$ that is used to calculate future annuity payments is equal to the mortgage rate available to the household $R(s_{it})$. Therefore by refinancing a household commits to repay an infinite stream of constant annuity payments equal to $R(s_{it})b_{i,t+1}$, unless the mortgage is refinanced again in the future. The dynamics of the mortgage rate k_{it} will be

$$k_{i,t+1} = k_{it}\ (1 - I_{it}^{RF}) + R(s_{it})\ I_{it}^{RF}. \tag{10}$$

Households can choose to merely pay their mortgage and neither refinance nor repay their home loan. This decision is denoted by the indicator $I_{it}^{NR} = 1$ if home loan and the mortgage rate are unchanged, and $I_{it}^{NR} = 0$ otherwise.

Default Home-owners have the option to default on their mortgages and become a renter. When a household defaults on its mortgage obligation b, 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 ζ could be seen as a way to capture full or partial recourse as well as other costs of default, such as their effect on credit history, in reduced form. Furthermore, the household that defaulted on its mortgage will be excluded from the housing market for a stochastic period of time. With probability θ each period, it will regain eligibility for becoming a home-owner, at which point the household can choose to buy or remain a renter.

Moving Every period, there is a probability ω that the household will be forced to move for exogenous reasons (e.g., geographic relocation). In such an event, we assume that the household has to sell its house, repay the existing loan outstanding, and use the proceeds along with its liquid assets and possibly a new mortgage loan to buy a new house. Equivalently, households are forced to refinance their home at the prevailing rate in the economy with a probability ω each period.

Renting As a renter, a household must pay rent every period. For tractability, we assume that households will allocate a constant fraction of their consumption toward that rent expense every period.[5] In addition, we assume that households suffer a utility loss of not being home-owners. This simply states that households will prefer, all else equal, to live in a house they own rather than rent, and that a higher rent will afford a higher quality home, which in turn lower the loss of utility of renting versus owning. The next step is to extend the model to incorporate housing in the utility function as well as rental costs to capture the costs of renting more realistically.

3.3 Household Recursive Problem

In order to simplify notation, we drop subscripts t and use primes to denote next period variables. The problem for household i is to choose consumption c_i, the position in the liquid asset a_i', and whether to refinance I_i^{RF}, repay early I_i^{RP} (yielding new mortgage balance b_i'), or default on the mortgage, so as to maximize the expected lifetime utility of real consumption.

[5]This assumption can be micro-founded by assuming that households choose the level of rent each period as a static choice and that they have a power utility over real rent payment and that it is additive to the utility over real consumption.

3.3.1 Home-owner Problem

As a home-owner, a household chooses consumption and stock of liquid assets, but also has access to borrowing against his house.

The household problem in the home-owner state can be formalized as follows,

$$U_i^h = \max_{a_i', b_i', I_i^{RF}} \quad u(c_i/p) + \beta \mathbb{E}\left[\omega \max\left(U_i^{hh'}, U_i^{hr'}, U_i^{hd'}\right) + (1-\omega)\max\left(U_i^{h'}, U_i^{hr'}, U_i^{hd'}\right)\right], \quad (11)$$

subject to

$$\begin{aligned}
c_i + \frac{a_i'}{1+(1-\tau)r^{\$}} + b_i &= (1-\tau)(y_i - k_i b_i) + a_i + b_i' - (pY\phi_0 + \phi_1 b_i') I_i^{RF}, && (12a)\\
k_i' &= k_i\ (1 - I_i^{RF}) + R\ I_i^{RF}, && (12b)\\
(b_i' - b_i)\ (1 - I_i^{RF}) &\leq 0, && (12c)\\
(b_i' - \xi\ H)\ I_i^{RF} &\leq 0, && (12d)\\
(b_i' - \kappa\ y_i)\ I_i^{RF} &\leq 0, && (12e)\\
a_i', c_i, b_i' &\geq 0. && (12f)
\end{aligned}$$

where we denote the value function of the household in the home-owner state by $U_i^h(a_i, b_i, k_i, s_i)$, by $U_i^{hh}(a_i, b_i, k_i, s_i)$ in a state of refinancing the mortgage loan at current rate and remaining a home-owner, by $U_i^{hr}(a_i, b_i, k_i, s_i)$ in a state of transition from home-owner 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 home-owner to renter by defaulting on the mortgage. Notice the difference in the continuation values for households that are forced to move (with probability ω) and those who are not in Equation (11). For movers, the value function $U_i^{h'}$ in the max operator is replaced by $U_i^{hh'}$ because movers do not have the option to keep their current mortgage contract.

We assume that the cost of refinancing is the sum of a fixed component and a proportional component. However, given that the economy is growing over time, the fixed cost of refinancing is assumed to be scaled with the nominal growth rate in the economy, that is, we assume the following functional form,

$$\phi(b_i') = pY\phi_0 + \phi_1 b_i'. \quad (13)$$

When a home-owner is moving, it is forced to refinance its current mortgage. Thus, the moving household's value function is U_i^{hh}, which solves the same problem in (11-12), except that $I_i^{RF} = 1$.

Home-owners have the option to sell their home at any time. When they do so, they repay the outstanding mortgage –including current mortgage coupon payment– using the proceeds, minus the transaction cost ϕ_2, and their stock of liquid assets. As a result, they become renters with savings equal to $H(1-\phi_2) - (1+(1-\tau)k)b + a$. The transition problem for the household from the home-owner to the renter state by selling its home is given by,

$$U_i^{hr}(a_i, b_i, k_i, s_i) = \max_{a_i'} \quad u(c_i/p) + \beta \mathbb{E}\left[U_i^r(a_i', s_i')\right], \tag{14}$$

subject to

$$\begin{aligned} c_i + \frac{a_i'}{1+(1-\tau)r^{\$}} &= (1-\tau)(y_i - k_i b_i) + a_i + H(1-\phi_2) - b_i, & \text{(15a)} \\ a_i', c_i &\geq 0. & \text{(15b)} \end{aligned}$$

The transition problem for the household from the home-owner to the renter state by defaulting on its mortgage is given by,

$$U_i^{hd}(a_i, b_i, k_i, s_i) = \max_{a_i'} \quad u(c_i/p) + \beta \mathbb{E}\left[U_i^d(a_i', s_i')\right], \tag{16}$$

subject to the positivity of consumption and liquid wealth, and

$$\begin{aligned} c_i + \frac{a_i'}{1+(1-\tau)r^{\$}} &= (1-\tau)y_i + \zeta a_i, & \text{(17a)} \\ a_i', c_i &\geq 0. & \text{(17b)} \end{aligned}$$

3.3.2 Renter Problem

The household problem in the post selling renter state – without being excluded from accessing home-ownership – is given by

$$U_i^r = \max_{a_i'} \quad (1+\psi)\ u(c_i/p) + \beta \mathbb{E}\left[\max\left(U_i^{rh'}, U_i^{r'}\right)\right], \tag{18}$$

subject to the positivity of consumption and liquid wealth, and

$$(1+\psi)\ c_i + \frac{a_i'}{1+(1-\tau)r^{\$}} = (1-\tau)y_i + a_i. \tag{19}$$

The parameter ψ determines both the fraction of consumption expense used as rents and the utility loss of renting.

The transition problem for the household from the renter to the home-owner state is

$$U_i^{rh}(a_i, s_i) = \max_{a_i', b_i'} \quad (1+\psi)\ u(c_i/p) + \beta\ \mathbb{E}\left[U_i^h(a_i', b_i', R, s_i')\right], \tag{20}$$

subject to

$$\begin{aligned} (1+\psi)\ c_i + \frac{a_i'}{1+(1-\tau)r^{\$}} + H(1-\phi_2) &= (1-\tau)y_i + a_i + b_i' - (pY\phi_0 + \phi_1 b_i'), && \text{(21a)} \\ b_i' &\leq \xi\ H, && \text{(21b)} \\ b_i' &\leq \kappa\ y_i, && \text{(21c)} \\ a_i', c_i, b_i' &\geq 0. && \text{(21d)} \end{aligned}$$

3.3.3 Post Default Renter Problem

The household problem in the post default renter state is given by,

$$U_i^d = \max_{a_i'} \quad (1+\psi)\ u(c_i/p) + \beta\mathbb{E}\left[(1-\theta)U_i^{d'} + \theta \max\left(U_i^{rh'}, U_i^{r'}\right)\right], \tag{22}$$

subject to the positivity of consumption and liquid wealth, as well as the renter budget constraint (19), where we denote the value function of the household in transition between the renter state and the home-owner state by $U_i^{rh}(a_i, s_i)$.

3.4 Stationary Reformulation of the Household Recursive Problem

Let the household utility be CRRA, $u(c) = \frac{c^{1-\gamma}}{1-\gamma}$, then we can rescale the problem with respect to the permanent aggregate income Y_t and the price level p_t in order to make it stationary. We can rescale the variables, as well as the state vector such that the rescaled household problem is stationary. The algebraic details are given in the Appendix.

3.5 Household Optimal Policies

The optimal policies for liquid asset holdings, home loan, and mortgage rate are denoted by $a'_i = g_{i,a}(a, b, k, s)$, $b'_i = g_{i,b}(a, b, k, s)$, and $k'_i = g_{i,k}(a, b, k, s)$. In addition, the discrete refinancing policy is denoted by $I_i^{RF} = g_{i,RF}(a, b, k, s)$. The optimal repayment policy denoted by $I_i^{RP} = g_{i,RP}(a, b, k, s)$ can be constructed out of the optimal loan and refinancing policies,

$$I_i^{RP} = \mathbb{I}_{b'_i \neq b_i} \ (1 - I_i^{RF}).$$

Similarly the optimal no refinancing/repayment policy denoted by $I_i^{NR} = g_{i,NR}(a, b, k, s)$ can be constructed out of the optimal refinancing and repayment policies,

$$I_i^{NR} = 1 - I_i^{RP} - I_i^{RF}.$$

3.6 Key Endogenous Aggregate Variables

For the purposes of analyzing the aggregate implications of households' optimal mortgage choices, we consider a cross-section of N households that follow optimal policies. The households are ex ante identical and are subject to an identical time series of aggregate shocks, that is all households face the same interest rates and macroeconomic shocks in the economy. However households are subject to different realizations of their idiosyncratic income shocks over time. We are interested in the behavior of aggregated household variables along the paths of aggregate state vector S_t. The consumption and financial policies of interest are given by,

$$\begin{aligned}
\text{Aggregate consumption: } C_t &= \frac{1}{N}\sum_{i=1}^{N} c_{it}, \\
\text{Aggregate liquid assets: } A_t &= \frac{1}{N}\sum_{i=1}^{N} a_{it}, \\
\text{Aggregate mortgage balance: } B_t &= \frac{1}{N}\sum_{i=1}^{N} b_{it}, \\
\text{Average mortgage coupon rate: } K_t &= \frac{1}{N}\sum_{i=1}^{N} k_{it}, \\
\text{Weighted average loan age: } WALA_t &= \frac{\sum_{i=1}^{N} b_{it} n_i}{\sum_{i=1}^{N} b_{it}},
\end{aligned}$$

where n_i is the number of periods since household i's current loan was originated. The refinancing and cash-out policies of interest are defined as follows:

$$\begin{aligned}
\text{Aggregate refinancing rate: } REFI_t &= \frac{1}{N}\sum_{i=1}^{N} I_{it}^{RF}, \\
\text{Conditional dollar refinancing: } REFI_t^{\$} &= \frac{\sum_{i=1}^{N} b_{it+1} I_{it}^{RF}}{\sum_{i=1}^{N} I_{it}^{RF}}, \\
\text{Conditional dollar cash-out: } CASHOUT_t^{\$} &= \frac{\sum_{i=1}^{N} (b_{it+1} - b_{it}) I_{it}^{RF}}{\sum_{i=1}^{N} I_{it}^{RF}}.
\end{aligned}$$

4 Calibration Results

This section describes the implications of the model in Section 3. There is no closed-form solution for this model, therefore we use numerical techniques to approximate it. Specifically, we discretize the state space and apply standard numerical dynamic programming and then simulate the optimal policies for a large panel of households. We explain the choice of the key parameters of the model and characterize the solution.

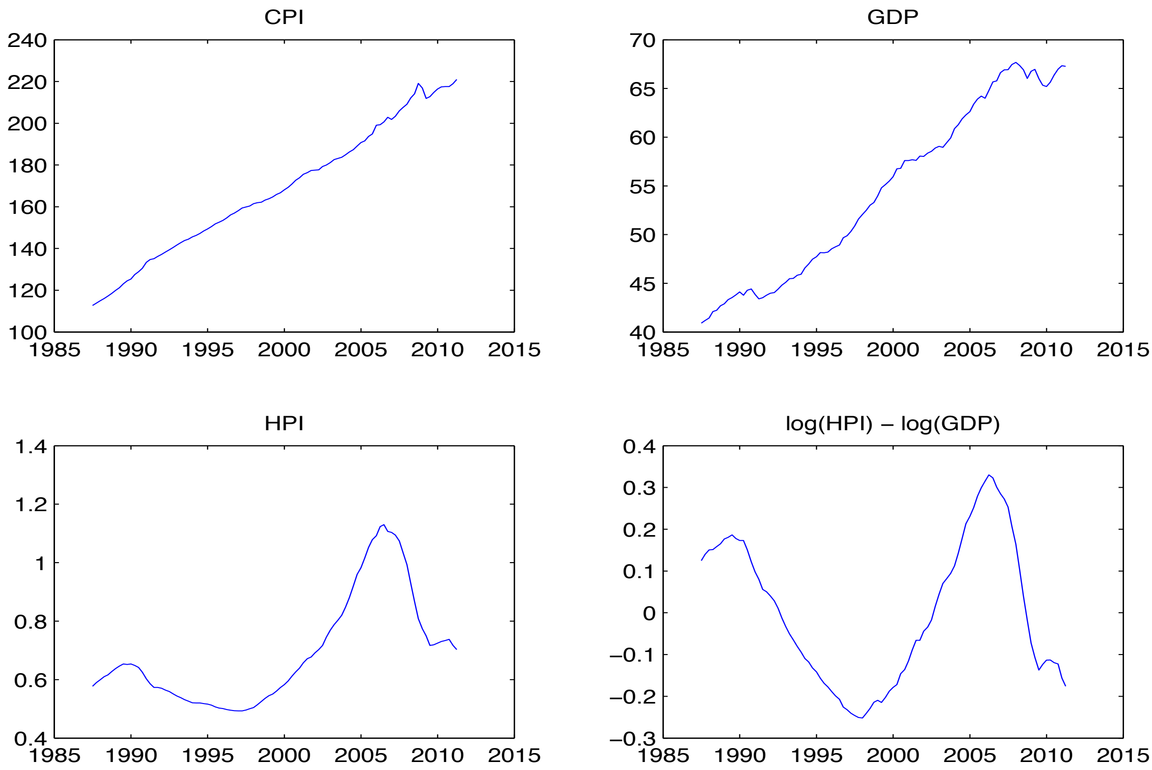

Figure 4: Inflation, real growth, and real house prices

4.1 Parameter Choice

The model is calibrated at the yearly frequency. We estimate a VAR(1) for the aggregate state variables using annual data:

$$\log S_{t+1} = \mu_S + \Phi_S \log S_t + \sqrt{\Sigma_S}\epsilon^S_{t+1}. \tag{23}$$

The variables we use are the U.S. GDP growth rate adjusted for CPI inflation (our proxy for the real growth variable Z in the model), the one-year Treasury bill rate as the nominal short rate $r^\$_t$, CPI growth rate (a measure of inflation π), and demeaned log house price-GDP ratio computed using the S&P Case-Shiller house price index (HPI) deflated using the CPI. The macroeconomic variables used - the CPI, the real GDP, the real HPI, and the HPI/GDP ratio are plotted in Figure 4. The last variable captures the notion of highly persistent but transitory deviations of house prices from the trend of real economic growth represented in the model by the state variable h.

The descriptive statistics for these variables (as well as the 30-year conforming mortgage rate – our empirical proxy for R) and the estimated parameters of the VAR are reported in Table 5. We then approximate the VAR with a discrete-state Markov chain using the method of Tauchen and Hussey (1991). The real growth rate of the economy Z is discretized using 2 points to capture two macroeconomic states for growth. The 'bad' state of the economy is denoted by Z^B and is defined as the cases when the economy grows at the low rate and, conversely, the 'good' state is denoted Z^G and corresponds to the high growth rate. The short rate $r^{\$}$, the house price process $\tilde{h}$, and the inflation rate process π are discretized each as a 3-state Markov chain. Thus the aggregate state is discretized using a total of 54 grid points. 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).

For tractability, we specify the mortgage rate R as an exogenous function of all the aggregate state variables. We choose the following specification,

$$\log R(S) = \kappa_0 + \kappa' \log S. \tag{24}$$

Panel C of Table 5 reports the regression estimates of the coefficients of this relation using the empirical proxies for the state vector S and the mortgage rate R, with the corresponding standard errors. While only the constant and the interest-rate sensitivity are statistically significantly different from zero, we use all of the estimated coefficients in order to capture as much of potential comovement of the mortgage rate with the macroeconomic variables as possible.

The idiosyncratic component of the income process $\tilde{y}_{it}$ is discretized as a Markov chain with 64 grid points. The conditional volatility depends on whether the economy is in the good or bad state, that is we choose a two-state representation of the macroeconomic conditions, following Storesletten, Telmer, and Yaron (2007). We use volatility parameters that are on the higher end of their estimates in order to emphasize the effect of heteroscedasticity on refinancing. In our benchmark calibration, the conditional volatility of the log idiosyncratic income component in the good states (when it is low) is $\sigma_{y,G} = 12\%$, whereas in the bad state, the conditional volatility is

Table 5: Aggregate State Variables

Panel A: Descriptive Statistics

	GDP	$r_t^\$$	CPI	HPI/GDP	R
Mean	2.085	4.414	2.855	0.000	7.308
Std	1.646	2.272	1.275	17.310	1.605
Autocorrelation	0.419	0.724	0.149	0.866	0.828
correlations:					
GDP		0.064	-0.144	-0.153	0.060
$r_t^\$$			0.614	0.104	0.892
CPI				0.429	0.596
HPI/GDP					0.089

Panel B: VAR Parameters

	μ	Φ_s				$\Sigma_s \times 10^{-3}$			
GDP	0.006	0.442	-0.476	0.892	-0.075	0.307	-0.014	-0.019	0.297
r	-0.004	0.337	0.660	0.432	-0.003	-0.014	0.111	0.075	0.100
CPI	0.022	0.127	0.240	-0.219	0.030	-0.019	0.075	0.108	0.304
HPI/GDP	-0.028	1.458	-2.000	3.114	0.838	0.297	0.100	0.304	4.182

Panel C: Mortgage Rate Parameters

κ_0	κ			
	Z	r	π	$\tilde{h}$
0.043	0.011	0.586	0.134	-0.004
(0.002)	(0.034)	(0.051)	(0.092)	(0.012)

high $\sigma_{y,B} = 21\%$. The autocorrelation parameter $\rho_Y = 0.85$ is in the middle of the estimates in the literature (see discussion in section 4.4 below).

Table 7 summarizes the parameters we use for the numerical analysis. The preference parameters (the subjective discount factor $\beta = 0.95$ and the curvature of the utility function $\gamma = 2$) are chosen so that the mean and standard deviation of aggregate consumption growth are close to those in the NIPA data, and the average ratios of mortgage balances to income and house value approximately match those in the data. In our simulated data (Table 8, described in detail below), the average aggregate consumption growth is essential equal to the mean aggregate income growth at 1.9% per annum, with volatility of about 3.5% (slightly higher than roughly 2% in the NIPA data. Given the amount of both aggregate and idiosyncratic risk in the model, household-level

Table 6: Aggregate State Variables - Quarterly

Panel A: Descriptive Statistics

	GDP	$r_t^\$$	CPI	HPI/GDP	R
Mean	0.473	0.990	0.714	0.000	1.795
Std	0.945	0.555	0.561	17.056	0.394
Autocorrelation	0.261	0.957	0.230	0.984	0.944
correlations:					
GDP		0.112	-0.388	-0.054	0.086
$r_t^\$$			0.386	0.130	0.853
CPI				0.277	0.374
HPI/GDP					0.112

Panel B: VAR Parameters

	μ	Φ_s				$\Sigma_s \times 10^{-3}$			
GDP	0.001	0.406	-0.209	0.606	-0.008	0.000	0.000	-0.000	0.000
r	-0.000	0.045	0.972	0.016	0.001	0.000	0.000	0.000	0.000
CPI	0.004	0.020	0.294	0.066	0.007	-0.000	0.000	0.000	0.000
HPI/GDP	-0.004	0.750	-0.701	0.589	0.995	0.000	0.000	0.000	0.000

Panel C: Mortgage Rate Parameters

κ_0	κ				
	Z	r	π	$\tilde{h}$	$\tilde{h}^2$
0.013	0.055	0.639	0.044	0.002	-0.065
(0.000)	(0.018)	(0.031)	(0.030)	(0.001)	(0.008)

average consumption volatility is much higher, at about 22% in the benchmark case. Average ratio of consumption to income at around 0.69 essentially the same as in the NIPA data (using both nondurable and durable goods expenditures, as well as non-housing services).

The mortgage rates are higher than the subjective rate of time preference, so that mortgages are a costly form of borrowing and households prefer to pay down their balances. Still, the balances are repaid slowly enough that on average mortgage debt is 1.1 times household income, matching exactly the average ratio of household debt to income in 2001 SCF. The average ratio of mortgage balance to house value is just under 0.3, close to the long-run average ratio of mortgage debt to housing assets in the U.S. Flow of Funds data of about 0.35. Households use debt primarily as a way of smoothing consumption, as well as a way of financing new home purchases. Existing debt

Table 7: Parameter Values.

	Parameter	Model	Description
	β	0.95	Subjective discount rate
Preference	γ	2	Risk aversion
	ψ	1.00	Rent relative to consumption
	τ	25%	Average tax rate
	ξ	80%	House collateral requirement
	$\bar{H}$	4	House price relative to permanent income
	ϕ_0	15%	Fixed cost of issuing new mortgage
Institution	ϕ_1	5%	Proportional cost of issuing new mortgage
	ϕ_2	5%	Proportional cost of buying/selling a house
	ω	5%	Exogenous rate of relocation
	θ	15%	Rate of access back to home-ownership after default
	ζ	50%	Default penalty
	ρ_y	0.85	Autocorrelation of idiosyncratic income component y
Income Process	$\sigma_{y,B}$	21%	Volatility of y for Z^B
	$\sigma_{y,G}$	12%	Volatility of y for Z^G

NOTE: The model is calibrated at the yearly frequency.

balances are refinances either to reduce the coupon rate k, or to cash-out equity for consumption purposes. The cost of refinancing is set so as to generate empirically reasonable average refinancing rates, in terms of both frequency and loan size. Anecdotal evidence suggests that explicit costs of roughly $2-5\%$ 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 model we choose a fixed cost of 15% and a proportional cost of 5% (which is somewhat higher than the costs calibrated by Campbell and Cocco (2003)). These costs imply refinancing rates of about 11% (loans per year), compared to roughly 8% per year in the data (the latter number is based on the average number of refinance loans originated per year according to HMDA data, relative to the number of homeowner households according to the U.S. Census). The average ratio of loan size to house value on refinance loans is 0.62 (its analog in the data is around 0.7). The weighted average loan age is close to that in the data for agency pools (around 3.3 years), suggesting that the mortgage repayment and refinancing occur in the model at empirically reasonable rates.

4.2 Simulations

The household problem is solved numerically and simulated data are generated using the optimal policies. A cross-section of $N = 1000$ households is considered and the various aggregate quantities defined above are calculated along the time path of $T = 2500$ (annual) periods.

Our simulation strategy is as follows. We start the simulations by randomly drawing triplets (a_i, b_i, m_i) over the state space for all N households in the cross-section. At every time period, we draw a pair (ω_i, θ_i) for each household in the cross-section. This will allow us to know whether a particular home-owner is subject to an exogenous move, or if a particular post default renter is allowed back into the home-ownership market. In other words, these random draws will tell us the feasible set of choices for all households at all times.

We replicate the regressions that we ran in the data by running a number of regressions of the aggregate refinancing rate $REFI_t$ on the rates R_t, r_t, the macroeconomic growth rate Z_t, and the house price h_t. We use several model specifications in order to isolate the various effects at work. The benchmark calibration features a baseline level of stochastic volatility of income shocks. The second and third specifications have higher conditional volatilities in the bad state, at 0.315% and 0.42%, respectively. The fourth specification features homoscedasticity in income shocks, i.e. $\sigma_{y,B} = \sigma_{y,G} = 17\%$, set to the average volatility in the benchmark case. The fifth also features homoscedastic income shocks, but the average volatility is set to the (higher) level of average volatility of specification three ($\sigma_{y,B} = \sigma_{y,G} = 20\%$). Specifications four and five of labor income process are closest to that estimated by Heaton and Lucas (1996) in that they feature high but constant volatility of labor income risk (but higher persistence). These specifications will allow us to understand the difference between the effect of the overall level of volatility and the effect of high volatility in the bad state alone.

4.3 Refinancing Behavior

4.3.1 Aggregate Behavior

Table 8 reports averages of the aggregated variables computed using the simulated data for the various specifications of the model, as well as the corresponding quantities in the data. The table shows that households in the benchmark case (1) experience more frequent refinancing and repayment and slightly higher mortgage balances than in the riskier specifications (2) and (3), but essentially the same as in the homoscedastic specification (4). This appears to be largely due to differences in loan sizes at origination. The corresponding average loan to income ratio for refinance loan originations in the riskier scenarios are essentially the same as the average estimated from HMDA data at 1.9, while the average loan to value ratio is somewhat lower, at just under 50% (compared to 70% in the data). When the household in the model refinance or repay the principal, they do so in similar magnitudes across specifications, with cash-outs equal on average to 35% of home value and just between 115% and 140% of annual income. The model thus predicts too much cash-out, as in the data it is responsible for about 11.5% of refinance loan volume, implying the average ratio to home value of about 8%.

Another distinguishing feature is that households tend to carry slightly higher liquid assets, consistent with a precautionary motive, when conditional volatility of idiosyncratic labor income risk is higher. In a riskier world, households will tend to accumulate more cash on hand as a precautionary buffer stock, and thus be less likely to have to resort to refinancing in order to self-insure against adverse idiosyncratic labor income shocks. Given the spread between the borrowing and lending rates, carrying both cash balances and mortgage debt is costly, and therefore a stronger precautionary saving motive implies that households keep lower mortgage balances by repaying their debt more quickly. The strength of the precautionary saving motive is therefore key for understanding quantitative features of the model, in the sense that it determines the ex-ante behavior of mortgage borrowers. This is corroborated by the result for the riskier specifications (2) and (3) in which households maintain larger holdings of liquid assets (80% of annual income in case (3) vs. under 40% in the benchmark case (1)), but also have to resort to refinancing to smooth consumption more often, yielding roughly the same refinancing activity as in the benchmark case.

Note that the model cannot simultaneously match the average magnitudes of household indebtedness and liquid asset holdings, since note of these specifications are close to producing the asset holdings of over 1.3 times income as observed in the data. As shown in table 9, higher coefficients of risk aversion strengthen the precautionary motive to the extent that allows us to match such a high number (e.g., $\gamma = 9$), but only at the expense of reducing mortgage borrowing dramatically (albeit still producing empirically reasonable dollar share of cash-out). Increasing the coefficient of relative risk aversion from 2 to 6 almost doubles the average stock of liquid assets relative to permanent income, from just above 38% to 70%. At the same time, average mortgage balances are lower. Resolving this tension requires relaxing some of the key assumptions of the model. It is likely that adding life-cycle to the model would help reconcile the averages of asset holdings and debt levels, potentially with the help from preferences in which bequests have luxury-good properties (e.g. Carroll (2000), DeNardi (2004), Roussanov (2010)).

Table 8: Summary Statistics.

Model Specification	Data	(1)	(2)	(3)	(4)	(5)
Comparative Statics on $\sigma_{y,G}$		0.12	0.12	0.12	0.17	0.20
Comparative Statics on $\sigma_{y,B}$		0.21	0.315	0.42	0.17	0.20
Aggregate Real Variables:						
Mean Income Growth	2.1%	1.9%	1.8%	1.9%	1.9%	1.9%
Std. Dev. Income Growth	1.8%	2.5%	2.5%	2.6%	2.6%	2.6%
Mean Consumption Growth	2.0%	1.9%	1.8%	1.9%	1.9%	1.9%
Std. Dev. Consumption Growth	1.6%	3.5%	3.0%	3.2%	3.5%	3.6%
Consumption and Financial Policies:						
Consumption to Income c/pY	0.66	0.69	0.70	0.68	0.69	0.69
Consumption Growth $\mu(\Delta \log c)$		1.9%	1.8%	1.9%	1.9%	1.9%
Consumption Growth $\sigma(\Delta \log c)$		22.4%	23.4%	26.0%	25.7%	26.5%
Liquid Asset Holdings to Income a/pY	1.33	0.38	0.52	0.81	0.43	0.49
Mortgage Balance to Income b/pY	1.12	1.11	0.66	0.67	1.12	0.98
Mortgage Balance to House Value b/H	0.35	0.28	0.16	0.17	0.28	0.24
Average Mortgage Coupon Rate k	6.99%	7.10%	7.22%	7.15%	7.10%	7.14%
Weighted Average Loan Age (years)	3.37	3.24	3.21	3.22	3.16	3.32
Refinancing:						
$REFI$	8.01%	10.71%	8.31%	8.66%	11.10%	10.28%
Conditional \$ $REFI$ to Income	1.90	2.49	1.95	1.92	2.48	2.34
Conditional \$ $REFI$ to House Value	0.70	0.62	0.49	0.48	0.62	0.58
Conditional \$ Cash-out to Income	0.22	1.40	1.20	1.15	1.35	1.32
Conditional \$ Cash-out to House Value 0.08	0.35	0.30	0.29	0.34	0.33	
Repayment:						
REP		50.92%	33.01%	31.52%	49.54%	44.29%
Conditional \$ REP to Income		0.20	0.22	0.23	0.21	0.21
Conditional \$ REP to House Value		0.05	0.06	0.06	0.05	0.05

NOTE: Summary statistics of the simulated data, for different model specifications.

4.3.2 Behavior in the Cross-Section

In order to understand the refinancing behavior in the aggregate, it is important to understand the refinancing and repayment behavior at the household level. To accomplish this, we need to

Table 9: Comparative Statics - Risk Aversion

Model Specification	Data	(10)	(1)	(11)	(12)	(13)
Comparative Statics on γ		1.5	2	3	6	9
Aggregate Real Consumption:						
Mean Consumption Growth	2.0%	1.9%	1.9%	1.9%	1.9%	1.9%
Std. Dev. Consumption Growth	1.6%	3.7%	3.5%	3.3%	2.7%	2.3%
Consumption and Financial Policies:						
Consumption to Income c/pY	0.66	0.69	0.69	0.69	0.70	0.70
Consumption Growth $\mu(\Delta \log c)$		1.9%	1.9%	1.9%	1.9%	1.9%
Consumption Growth $\sigma(\Delta \log c)$		23.8%	22.4%	20.5%	17.9%	17.2%
Liquid Asset Holdings to Income a/pY	1.33	0.34	0.38	0.44	0.70	1.37
Mortgage Balance to Income b/pY	1.12	1.10	1.11	1.00	0.44	0.10
Mortgage Balance to House Value b/H	0.35	0.28	0.28	0.25	0.11	0.03
Mortgage Rate k	6.99%	7.09%	7.10%	7.11%	7.18%	7.22%
WALA (years)	3.37	3.23	3.24	3.32	3.41	2.91
Refinancing:						
$REFI$	8.01%	10.42%	10.71%	10.48%	7.46%	5.44%
Conditional \$ $REFI$ to Income	1.90	2.52	2.49	2.35	1.49	0.50
Conditional \$ $REFI$ to House Value	0.70	0.63	0.62	0.59	0.37	0.13
Conditional \$ Cash-out to Income	0.22	1.41	1.40	1.34	0.96	0.36
Conditional \$ Cash-out to House Value	0.08	0.35	0.35	0.33	0.24	0.09
Repayment:						
REP		50.25%	50.92%	47.31%	23.79%	6.33%
Conditional \$ REP to Income		0.20	0.20	0.21	0.23	0.27
Conditional \$ REP to House Value		0.05	0.05	0.05	0.06	0.07

understand which households refinance and repay their mortgage. Because all households are ex-ante identical, they differ by their history of shocks, which in turn affect their level of liquid assets and mortgage balance. We use the simulated data to compute average refinancing and repayment rates, as well as the dollar amounts, across two dimensions: (i) level of period income relative to aggregate income (y_i/pY), and (ii) liquid assets to income ratio (a_i/pY).

Figure 5 plots averages by households sorted and grouped into four bins. The upper panel shows the results for the sort over income, while the lower panel shows the results for the sort over liquid assets. It is clear from these graphs that the households who refinance are those who experience very low income and have very low level of liquid assets. In contrast, households repay their mortgage at a higher rate when they are achieve high levels of income. Similarly households repay higher dollar amounts when their have higher stock of liquid assets. All of these qualitative results are consistent with the consumption smoothing motive: households repay their costly mortgage balance in good times -high level of income and assets- and refinance to pull out home equity in order to increase consumption in bad times -low level of income and assets-.

4.3.3 Aggregate Refinancing Activity

Table 10 reports the results for the regressions ran in the simulated data for each of the model specifications for the aggregate levels of refinancing (average number of refi loans) on the aggregate state variables. The key empirical relationship holds in the model: lower mortgage rates R imply more refinancing. Since in the model the mortgage rate is driven primarily by the short rate r, when the latter variable is included in the regressions it drives out the mortgage rate, unlike in the data where the variation in the mortgage rate is less well captured by the short rate.

As in the data, refinancing activity in the model is weakly counter-cyclical, as it is negatively related to the aggregate labor income, captured by the negative coefficient on the rate of economic growth Z (after controlling for the mortgage rate or the short rate). Also, the coefficient of refi on the house price growth variable ΔH is positive as it is in the data, consistent with the fact that higher levels of house prices help relax the collateral constraint. However, the relationship between aggregate refinancing activity and the aggregate income growth is difficult to establish statistically, as the standard errors are large relative to the magnitude of the coefficient, and in fact it turns positive if we do not control for house prices (as, in fact, it does in the data). This confirms that

Table 10: Regressions - simulated data.

Model Specification	R	r	Z	$\Delta h/h$	R^2
(1) Benchmark: Heteroscedastic	-1.39				0.15
	(0.07)				
	-1.39		0.07		0.15
	(0.07)		(0.02)		
	-1.24		-0.05	0.07	0.18
	(0.07)		(0.03)	(0.01)	
	1.18	-1.69	-0.04	0.07	0.19
	(0.50)	(0.35)	(0.03)	(0.01)	
(2) Heteroscedastic + High Volatility	-0.60				0.09
	(0.04)				
	-0.59		0.10		0.11
	(0.04)		(0.01)		
	-0.53		0.05	0.03	0.12
	(0.04)		(0.02)	(0.00)	
	0.42	-0.66	0.06	0.03	0.13
	(0.30)	(0.21)	(0.02)	(0.00)	
(3) Heteroscedastic + Very High Volatility	-0.68				0.13
	(0.03)				
	-0.67		0.11		0.16
	(0.03)		(0.01)		
	-0.60		0.05	0.04	0.19
	(0.03)		(0.01)	(0.00)	
	0.01	-0.42	0.05	0.04	0.19
	(0.27)	(0.19)	(0.01)	(0.00)	
(4) Homoscedastic	-1.16				0.13
	(0.06)				
	-1.15		0.13		0.14
	(0.06)		(0.02)		
	-1.03		0.02	0.07	0.17
	(0.06)		(0.02)	(0.01)	
	1.08	-1.47	0.04	0.06	0.18
	(0.45)	(0.31)	(0.02)	(0.01)	
(5) Homoscedastic + High Volatility	-1.02				0.13
	(0.05)				
	-1.00		0.15		0.15
	(0.05)		(0.02)		
	-0.88		0.05	0.06	0.19
	(0.05)		(0.02)	(0.01)	
	0.33	-0.85	0.06	0.06	0.19
	(0.40)	(0.28)	(0.02)	(0.01)	

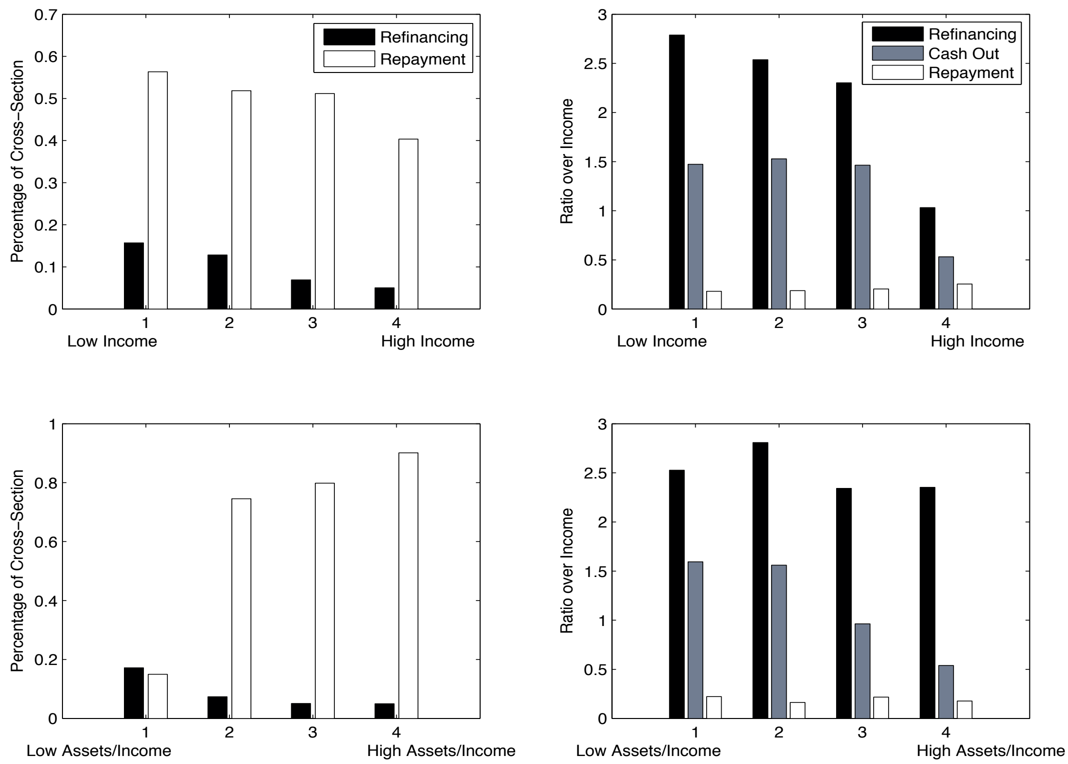

Figure 5: Refinancing and repayment rates (on the left panels), and dollar refinancing, cashout and repayment (on the right panels).

even when consumption smoothing is an important motive for refinancing, in the aggregate the cyclical effect is dominated by the interest rate movements.

As demonstrated in Table 8, refinancing activity is higher in the benchmark case, and the lowest in the model specification that is the most risky (i.e. where income is heteroscedastic and most volatile). This is consistent with the precautionary motive: there is less refinancing activity when mortgage rates are falling when the world is very risky, since in such a world household pay down mortgages quickly and accumulate a buffer stock of liquid assets. Indeed, the model produces less sensitivity of refi to interest rates and the other macro variables in the riskier specifications (2) and (3). At the same time, the homoscedastic specification (5) with the same average level of idiosyncratic risk as the benchmark also generates positive sensitivity to the macroeconomic shock Z. This is presumably due to the permanent income effect, since the aggregate income growth is slightly positively autocorrelated, so a positive shock to Z raises agents' expectations about future income.

These quantitative experiments have enabled us to understand the effect of state-dependent conditional mean and volatility on households aggregate refinancing activity. An increase in the riskiness of idiosyncratic income leads risk averse households to use their home equity with more caution. When the world is more uncertain, households will tend to hold more liquid assets and reduce their mortgage balance. This behavior also leads them to be less responsive to a decrease in mortgage rates. At the same time, the counter-cyclical volatility of idiosyncratic labor income risk is key for generating counter-cyclical refinancing.

4.4 The role of persistence in idiosyncratic shocks

There is some debate in the literature on the degree of persistence of idiosyncratic labor income shocks and its implications for asset pricing and macroeconomics. Persistence is key for consumption smoothing: e.g., Constantinides and Duffie (1996) postulate a process for idiosyncratic labor income that features only permanent (and heteroscedastic) shocks that implies no smoothing at all. In contrast, Heaton and Lucas (1996) estimate the autocorrelation of idiosyncratic labor income as low as 0.5 implying that households are able to self-insure almost perfectly by accumulating buffer stocks of liquid assets in good times, then drawing them down and borrowing in bad times, repaying the loans when good times return. We investigate the implications of different persistence estimates for refinancing behavior.

We consider a range of persistence parameters ρ_y between zero (entirely transitory shocks) and 0.95 (extremely persistent shocks, as estimated by Storesletten, Telmer, and Yaron (2004)). Table 11 displays the summary statistics for these alternative parameterizations, holding all other parameters constant as in the benchmark calibration. It is much easier for households to smooth transitory shocks than persistent shocks by borrowing against future income using housing as collateral. Consequently, there is much less refinancing when shocks are persistent, since cash-out loans need to be repaid, which is harder when adverse shocks are permanent. When shocks are entirely or largely transitory, mortgage debt is on average twice the size of annual income; however, when shocks are persistent, average debt to income ratio is below one. Refinancing is also less frequent, and magnitude of refinancing are slightly smaller, when ρ_Y is above the benchmark level.

Table 11: Summary Statistics - Varying Persistence

Model Specification	Data	(6)	(7)	(1)	(8)	(9)
Comparative Statics on ρ_y		0	0.5	0.85	0.9	0.95
Aggregate Real Consumption:						
Mean Consumption Growth	2.0%	1.9%	1.9%	1.9%	2.0%	1.9%
Std. Dev. Consumption Growth	1.6%	6.5%	6.0%	3.5%	3.1%	2.7%
Consumption and Financial Policies:						
Consumption to Income c/pY	0.66	0.65	0.66	0.69	0.70	0.70
Consumption Growth $\mu(\Delta \log c)$		1.9%	1.9%	1.9%	2.0%	1.9%
Consumption Growth $\sigma(\Delta \log c)$		24.4%	24.4%	22.4%	22.2%	23.7%
Liquid Asset Holdings to Income a/pY	1.33	0.46	0.50	0.38	0.34	0.33
Mortgage Balance to Income b/pY	1.12	2.26	2.12	1.11	0.82	0.61
Mortgage Balance to House Value b/H	0.35	0.57	0.53	0.28	0.21	0.15
Mortgage Rate k	6.99%	7.11%	7.11%	7.10%	7.19%	7.11%
WALA (years)	3.37	3.04	3.12	3.24	3.25	3.71
Refinancing:						
$REFI$	8.01%	19.44%	18.08%	10.71%	9.08%	7.71%
Conditional \$ $REFI$ to Income	1.90	2.98	2.93	2.49	2.22	1.92
Conditional \$ $REFI$ to House Value	0.70	0.74	0.73	0.62	0.55	0.48
Conditional \$ Cash-out to Income	0.22	1.26	1.33	1.40	1.33	1.16
Conditional \$ Cash-out to House Value	0.08	0.31	0.33	0.35	0.33	0.29

Thus, with transitory shocks households self-insure by accessing housing collateral more often and cashing out more home equity in relation to their income, which leads to higher average mortgage balances and higher rates of loan repayment.

We also repeat the regression experiments on the simulated data for different persistence parameters. There results are reported in Table 12. As persistence increases from fully transitory shocks - specification (6) - to very persistent shocks - specification (9) - the sensitivity of refinancing to aggregate economic growth rate Z decreases substantially in magnitude, consistently with the fact that persistent shocks that have greater dispersion in bad times are also more difficult to self-insure against.[6] There is a decreasing pattern of interest rate sensitivities, while in general it could be non-monotonic however, as low interest rates are less important both when shocks are transient (so that borrowing for consumption-smoothing reasons can be repaid quickly and a higher interest rate is less thus costly) and when they are very persistent (and there is less refinancing overall).

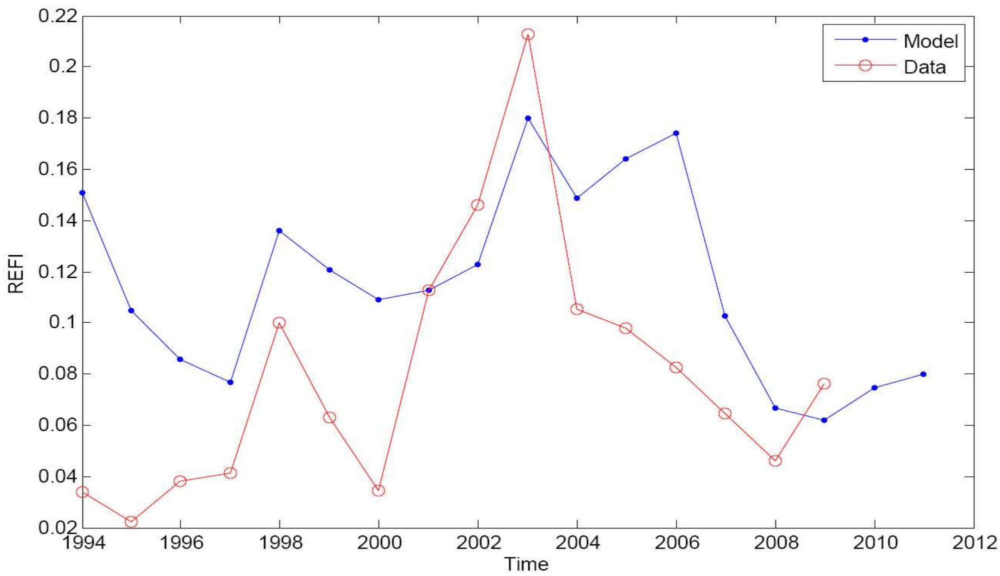

Figure 6: Model-implied and empirical refinancing.

[6]In some of our calibrations, as persistence rises, the sensitivity of refinancing to house prices increases slightly, indicating that households are more willing to borrow if they have a large enough cushion of home equity remaining, possibly for the fear of having to default if income payments become too onerous and house prices fall, as analyzed by Campbell and Cocco (2010). These patterns are not robust across calibrations, however, and are not reported here.

Table 12: Regressions - simulated data (varying persistence).

Model Specification	R	r	Z	$\Delta h/h$	R^2
(6)	-3.25				0.13
	(0.17)				
	-3.23		0.11		0.13
	(0.17)		(0.06)		
	-2.87		-0.24	0.21	0.17
	(0.17)		(0.07)	(0.02)	
	4.37	-5.05	-0.18	0.20	0.18
	(1.30)	(0.90)	(0.07)	(0.02)	
(7)	-3.11				0.16
	(0.14)				
	-3.11		-0.04		0.16
	(0.14)		(0.05)		
	-2.90		-0.24	0.12	0.19
	(0.14)		(0.06)	(0.02)	
	4.83	-5.36	-0.20	0.11	0.20
	(1.06)	(0.73)	(0.06)	(0.02)	
(8)	-0.84				0.12
	(0.05)				
	-0.84		0.03		0.12
	(0.05)		(0.02)		
	-0.75		-0.04	0.04	0.15
	(0.05)		(0.02)	(0.01)	
	0.25	-0.70	-0.04	0.04	0.15
	(0.35)	(0.24)	(0.02)	(0.01)	
(9)	-0.54				0.09
	(0.03)				
	-0.54		0.04		0.09
	(0.03)		(0.01)		
	-0.49		-0.00	0.03	0.11
	(0.03)		(0.01)	(0.00)	
	-0.75	0.18	-0.00	0.03	0.11
	(0.26)	(0.18)	(0.01)	(0.00)	

NOTE: Regressions results for refinancing activity on interest rates and state of the economy, using simulated data, for different model specifications.

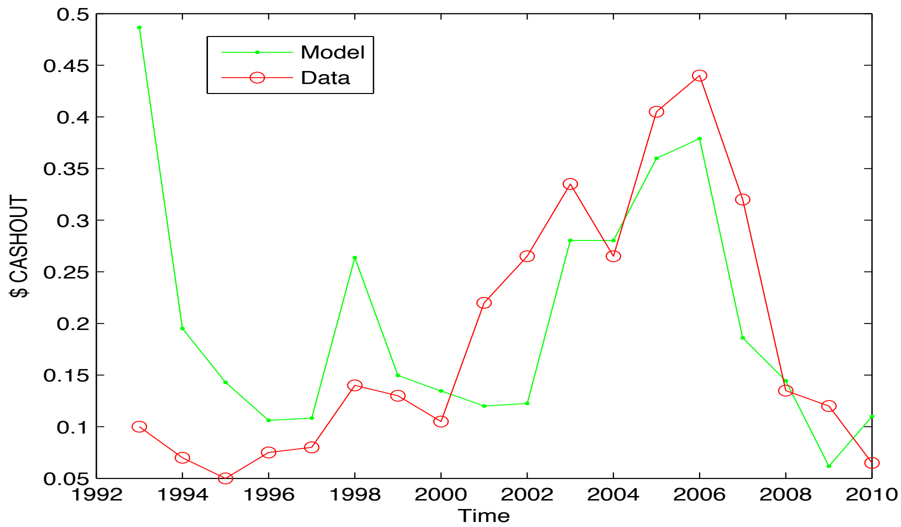

Figure 7: Model-implied and empirical (normalized) dollar cash-out.

4.5 Model-Implied Refinancing and Cash-out Behavior: 1993-2010

We can utilize the model further by feeding the last 17 years of data as inputs for the aggregate shocks (i.e. short rate, inflation, growth, and house price), approximated appropriately. We verify that this particular history of aggregate shocks translates into a time series of implied mortgage rates that is very close to the observed historical series.

After solving the model and using this specific path of aggregate shocks as simulation inputs, we compute the household policies and aggregate them across households. Figure 6 plots the refinancing rate, in the units of number of originated loans relative to the number of homeowner households, in the data (using HMDA aggregates) and in the model. We also compute aggregate dollar cash-out by households and compare it to the data on home equity cash-out estimates for prime conventional loans from Freddie Mac, each normalized using the appropriate measures of aggregate income. These time series are plotted in Figure 7.

Both figures indicate that this calibration of the model is able to account for the dynamics of aggregate refinancing and cash-out behavior in the data to a large extent. In the early part of the period the model overshoots substantially the amount of refinancing and cash-out, which is consistent with the fact that the increased mortgage market competition and financial innovation reduced the cost of refinancing over time, so that the overall level of refinancing activity reached by the late 1990's was substantially greater than experienced earlier, e.g. in the early 1990's (e.g. see Bennett, Peach, and Peristiani (2001)). Beginning in the mid-1990's the model-implied aggregates closely track their empirically observed. In particular, the refinancing measures peak at around 20 percent per year in 2003, both in the data and in the simulation, with the model implying a more gradual decline than observed in the data. Interestingly, the timing of the cash-out wave does not coincide exactly with that of the refinancing, since the former is more sensitive to the macroeconomic conditions and house prices than the latter. Aggregate cash-out does not peak until 2006, the height of the house price boom, both in the model and in the data, before dropping sharply in 2007-2008.

5 Conclusion

We document counter-cyclical variation of aggregate mortgage refinancing and explore a model of household behavior in which mortgage refinancing is driven by both time-varying interest rates and by consumption-smoothing in the face of idiosyncratic labor income risk. The model is able to replicate the main features of the counter-cyclical refinancing activity. It also highlights the importance for understanding the cyclical dynamics of idiosyncratic labor income risk for evaluating the quantitative features of refinancing behavior.

Our model can also be used to study the aggregate consumption implications of the impediments to refinancing. Refinancing is difficult when house prices fall, or when banks are in distress. These tend to coincide with bad income/productivity shocks. When markets are incomplete, this can severely hinder households' ability to smooth consumption or hedge against deflation risk, and exacerbate recessions.

In order to evaluate the equilibrium effect of the counter-cyclical refinancing we could endogenize mortgage rates by introducing an exogenous stochastic discount factor calibrated to match the term-structure interest rates. It could be used to price a menu of mortgage contracts (consisting of coupon rates and loan-to-value ratios) conditional on household characteristics. In that we could build on the analysis of Dunn and Spatt (2005) and Longstaff (2004) to the setting where borrower's decisions are explicitly affected by labor income fluctuations. This would allow us to evaluate the welfare impact of refinancing costs by incorporating the equilibrium response of mortgage spreads to slower prepayment speeds.

Potential questions that could be addressed within this framework include: was 2001 recession mild because high house prices allow households to smooth consumption, given the low interest rate environment? Can the refinancing boom of early 2000's, widely seen as contributing to the financial crisis (e.g. Khandani, Lo, and Merton (2009), Mian and Sufi (2010)) be attributed to the persistent dispersion of labor income and its slow aggregate growth following the recession - the "jobless recovery"? Our results on the dynamics of cash-out suggest that it may be.

Appendix A – Stationary Reformulation of the Household Recursive Problems

Let the household utility be CRRA, $u\,(c) = \frac{c^{1-\gamma}}{1-\gamma}$, then we can rescale the problem with respect to the permanent aggregate income Y_t and the price level p_t in order to make it stationary. Define the rescaled variables as follows,

$$a_{i,t+1} = p_t \; Y_t \; \tilde{a}_{i,t+1}, \quad b_{i,t+1} = p_t \; Y_t \; \tilde{b}_{i,t+1}, \quad \text{and} \quad c_{it} = p_{t-1} \; Y_{t-1} \; \tilde{c}_{it},$$

and the value functions as,

$$U^j_{it} = \left(\frac{Y_{t-1} \; p_{t-1}}{p_t} \right)^{1-\gamma} \tilde{U}^j_{it}, \quad \text{with } j \in \{h, r, d, hh, hr, hd, rh\}.$$

Then by taking advantage of homogeneity of the utility function, the original problem in the home-owner state can be restated as,

$$\begin{aligned} \tilde{U}^h_i(\tilde{a}_i, \tilde{b}_i, k_i, \tilde{s}_i) \;&=\; \max_{\tilde{a}'_i, \tilde{b}'_i, I^{RF}_i} \quad u(\tilde{c}_i) \\ &+\beta \mathbb{E} \left[\left(\frac{\pi Z}{\pi'} \right)^{1-\gamma} \left(\omega \max \left(\tilde{U}^{h'}_i, \tilde{U}^{hr'}_i, \tilde{U}^{hd'}_i \right) + (1-\omega) \max \left(\tilde{U}^{hh'}_i, \tilde{U}^{hr'}_i, \tilde{U}^{hd'}_i \right) \right) \right], \end{aligned} \tag{25}$$

subject to,

$$\begin{aligned} \tilde{c}_i + \frac{\pi Z \tilde{a}'_i}{1 + (1-\tau) r^{\$}} + \tilde{b}_i \;&=\; (1-\tau)(\pi Z \tilde{y}_i - k_i \tilde{b}_i) + \tilde{a}_i + \pi Z \tilde{b}'_i - \pi Z(\phi_0 + \phi_1 \tilde{b}'_i) I^{RF}_i, \\ k'_i \;&=\; k_i \; (1 - I^{RF}_i) + R \; I^{RF}_i, \\ (\pi Z \tilde{b}'_i - \tilde{b}_i) \; (1 - I^{RF}_i) \;&\leq\; 0, \\ (\tilde{b}'_i - \xi \; \bar{H} \; \tilde{h}) \; I^{RF}_i \;&\leq\; 0, \\ \tilde{a}_i, \tilde{c}_i, \tilde{b}'_i \;&\geq\; 0. \end{aligned}$$

When the household is not moving, the rescaled value function is defined as,

$$\tilde{V}^h_i(\tilde{a}_i, \tilde{b}_i, k_i, \tilde{s}_i) = \max \left(\tilde{U}^h_i(\tilde{a}_i, \tilde{b}_i, k_i, \tilde{s}_i), \tilde{U}^{hr}_i(\tilde{a}_i, \tilde{b}_i, k_i, \tilde{s}_i), \tilde{U}^{hd}_i(\tilde{a}_i, \tilde{b}_i, k_i, \tilde{s}_i) \right), \tag{26}$$

when the household is moving, the rescaled value function is defined as,

$$\tilde{V}_i^h(\tilde{a}_i, \tilde{b}_i, k_i, \tilde{s}_i) = \max\left(\tilde{U}_i^{hh}(\tilde{a}_i, \tilde{b}_i, k_i, \tilde{s}_i), \tilde{U}_i^{hr}(\tilde{a}_i, \tilde{b}_i, k_i, \tilde{s}_i), \tilde{U}_i^{hd}(\tilde{a}_i, \tilde{b}_i, k_i, \tilde{s}_i)\right), \tag{27}$$

The rescaled household problem in the post default renter state is given by,

$$\tilde{V}_i^d(\tilde{a}_i, \tilde{s}_i) = \max_{\tilde{a}_i'} \quad (1+\psi)\, u(\tilde{c}_i) + \beta\, \mathbb{E}\left[\left(\frac{\pi Z}{\pi'}\right)^{1-\gamma} \left((1-\theta)\tilde{U}_i^{re}(\tilde{a}_i', \tilde{s}_i') + \theta \max\left(\tilde{U}_i^{rh}(\tilde{a}_i', \tilde{s}_i'), \tilde{U}_i^{r}(\tilde{a}_i', \tilde{s}_i')\right)\right)\right], \tag{28}$$

subject to,

$$\begin{aligned} (1+\psi)\ \tilde{c}_i + \frac{\pi Z \tilde{a}_i'}{1+(1-\tau)r_t^{\$}} &= (1-\tau)\pi Z \tilde{y}_i + \tilde{a}_i, \\ \tilde{a}_i, \tilde{c}_i &\geq 0. \end{aligned}$$

When in the post default renter state, the rescaled value function if becoming a home-owner is available is given by,

$$\tilde{V}_i^d(\tilde{a}_i, \tilde{b}_i, k_i, \tilde{s}_i) = \max\left(\tilde{U}_i^{rh}(\tilde{a}_i, \tilde{s}_i), \tilde{U}_i^{r}(\tilde{a}_i, \tilde{s}_i)\right), \tag{29}$$

or if the home-owner-ship option is unavailable,

$$\tilde{V}_i^d(\tilde{a}_i, \tilde{b}_i, k_i, \tilde{s}_i) = \tilde{U}_i^d(\tilde{a}_i, \tilde{s}_i). \tag{30}$$

The rescaled household problem in the post selling renter state is given by,

$$\tilde{U}_i^r(\tilde{a}_i, \tilde{s}_i) = \max_{\tilde{a}_i'} \quad (1+\psi)\ u(\tilde{c}_i) + \beta\ \mathbb{E}\left[\left(\frac{\pi Z}{\pi'}\right)^{1-\gamma} \max\left(\tilde{U}_i^{rh}(\tilde{a}_i', \tilde{s}_i'), \tilde{U}_i^{r}(\tilde{a}_i', \tilde{s}_i')\right)\right], \tag{31}$$

subject to,

$$\begin{aligned} (1+\psi)\ \tilde{c}_i + \frac{\pi Z \tilde{a}_i'}{1+(1-\tau)r^{\$}} &= (1-\tau)\pi Z \tilde{y}_i + \tilde{a}_i, \\ \tilde{a}_i, \tilde{c}_i &\geq 0. \end{aligned}$$

When in the post selling renter state, the rescaled value function is given by,

$$\tilde{V}_i^r(\tilde{a}_i, \tilde{b}_i, k_i, \tilde{s}_i) = \max\left(\tilde{U}_i^{rh}(\tilde{a}_i, \tilde{s}_i), \tilde{U}_i^r(\tilde{a}_i, \tilde{s}_i)\right). \tag{32}$$

The rescaled transition problem for the household from the renter to the home-owner state is given by,

$$\tilde{U}_i^{rh}(\tilde{a}_i, \tilde{s}_i) = \max_{\tilde{a}_i', \tilde{b}_i'} \quad (1+\psi)\ u(\tilde{c}_i) + \beta\ \mathbb{E}\left[\left(\frac{\pi Z}{\pi'}\right)^{1-\gamma} \tilde{U}_i^h(\tilde{a}_i', \tilde{b}_i', R, \tilde{s}_i')\right], \tag{33}$$

subject to,

$$\begin{aligned}
(1+\psi)\ \tilde{c}_i + \frac{\pi Z \tilde{a}_i'}{1+(1-\tau)r^{\$}} + \pi Z \bar{H}\ \tilde{h} &= (1-\tau)\pi Z \tilde{y}_i + \tilde{a}_i + \pi Z \tilde{b}_i' - \pi Z(\phi_0 + \phi_1 \tilde{b}_i'), \\
\tilde{b}_i' &\leq \xi\ \bar{H}\ \tilde{h}, \\
\tilde{a}_i, \tilde{c}_i, \tilde{b}_i' &\geq 0.
\end{aligned}$$

The new state vector $\tilde{s}_i \equiv (\tilde{y}_i, r^{\$}, Z, \tilde{h}, \pi)$. In contrast to the original (nominal) formulation of the problem where the processes y_i and H are growing over time, the processes $\tilde{y}_i$ and $\tilde{h}$ in the rescaled problems are stationary.

References

Agarwal, Sumit, John C. Driscoll, and David I. Laibson, 2002, When should borrowers refinance their mortgages?, working paper, available at *http://www.nber.org/ confer/2002/si2002/laibson.pdf.*

Attanasio, Orazio, Andrew Leicester, and Matthew Wakefield, 2011, Do house prices drive consumption growth? The coincident cycles of house prices and consumption in the UK, *Journal of the European Economic Association* 9, 399–435.

Bennett, Paul, Richard Peach, and Stavros Peristiani, 2001, Structural change in the mortgage market and the propensity to refinance, *Journal of Money, Credit and Banking* 33, pp. 955–975.

Boudoukh, Jacob, Matthew P. Richardson, Richard H. Stanton, and Robert Whitelaw, 1997, Pricing mortgage-backed securities in a multifactor interest rate environment: A multivariate density estimation approach, *Review of Financial Studies* 10, 405–46.

Campbell, Jeffrey C., and Zvi Hercowitz, 2005, The role of collateralized household debt in macroeconomic stabilization, NBER Working Paper Series No. 11330.

Campbell, John Y., and Joao F. Cocco, 2003, Household risk management and optimal mortgage choice, *The Quarterly Journal of Economics* 118, 1449–1494.

——— , 2010, A model of mortgage default, working paper, Harvard University.

Caplin, Andrew, Charles Freeman, and Joseph Tracy, 1997, Collateral damage: How refinancing constraints exacerbate regional recessions, *Journal of Money, Credit and Banking* 29, 496–516.

Carroll, Christopher D., 2000, Why do the rich save so much?, in Joel Slemrod, ed.: *Does Atlas Shrug? The Economic Consequences of Taxing the Rich* (Harvard University Press: Cambridge, MA).

——— , Misuzu Otsuka, and Jiri Slacalek, 2011, How large are housing and financial wealth effects? A new approach, *Journal of Money, Credit and Banking* 43, 55–79.

Case, Karl E., John M. Quigley, and Robert J. Shiller, 2011, Wealth effects revisited 1978-2009, NBER Working Paper Series No. 16848.

Constantinides, George M., and Darrell Duffie, 1996, Asset pricing with heterogeneous consumers, *Journal of Political Economy* 104, 219–240.

DeNardi, Mariacristina, 2004, Wealth inequality and intergenerational links, *Review of Economic Studies* 71, 743–768.

Deng, Yongheng, John M. Quigley, and Robert Van Order, 2000, Mortgage terminations, heterogeneity and the exercise of mortgage options, *Econometrica* 68, 275–307.

Downing, Chris, Richard Stanton, and Nancy Wallace, 2005, An empirical test of a two-factor mortgage valuation model: How much do house prices matter?, *Real Estate Economics* 33, 681–710.

Duarte, Jefferson, 2008, The causal effect of mortgage refinancing on interest rate volatility: Empirical evidence and theoretical implications, *Review of Financial Studies* 21, 1689–1731.

———, Francis A. Longstaff, and Fan Yu, 2007, Risk and return in fixed-income arbitrage: Nickels in front of a steamroller?, *Review of Financial Studies* 20, 769–811.

Dunn, Kenneth B., and John McConnell, 1981, Valuation of GNMA mortgage-backed securities, *Journal of Finance* 36, 599–616.

Dunn, Kenneth B., and Chester S. Spatt, 2005, The effect of refinancing costs and market imperfections on the optimal call strategy and the pricing of debt contracts, *Real Estate Economics* 33, 595–617.

Favilukis, Jack, Sydney C. Ludvigson, and Stijn Van Nieuwerburgh, 2011, The Macroeconomic Effects of Housing Wealth, Housing Finance, and Limited Risk-Sharing in General Equilibrium, NBER Working Paper Series No. 15988.

Gan, Jie, 2010, Housing wealth and consumption growth: Evidence from a large panel of households, *Review of Financial Studies* 23, 2229–2267.

Gerardi, Kristopher, Harvey Rosen, and Paul Willen, 2010, The impact of deregulation and financial innovation on consumers: The case of the mortgage market, *Journal of Finance* 65, 333–360.

Heaton, John C., and Deborah J. Lucas, 1996, Evaluating the effects of incomplete markets on risk-sharing and asset pricing, *Journal of Political Economy* 104, 443–487.

Hurst, Erik, and Frank Stafford, 2004, Home is where the equity is: Mortgage refinancing and household consumption, *Journal of Money, Credit and Banking* 36, 985–1014.

Keys, Benjamin J., Tanmoy Mukherjee, Amit Seru, and Vikrant Vig, 2010, Did securitization lead to lax screening? Evidence from subprime loans, *Quarterly Journal of Economics* 125, 307–362.

Khandani, Amir E., Andrew W. Lo, and Robert C. Merton, 2009, Systemic Risk and the Refinancing Ratchet Effect, *MIT Sloan Working Paper.*

Koijen, Ralph S.J., Otto Van Hemert, and Stijn Van Nieuwerburgh, 2009, Mortgage timing, *Journal of Financial Economics* 93, 292–324.

Laibson, David, 1997, Golden eggs and hyperbolic discounting, *Quarterly Journal of Economics* 112, 443–477.

Longstaff, Francis A., 2004, Optimal recursive refinancing and the valuation of mortgage-backed securities, NBER Working Paper Series No. 10422.

Lustig, Hanno, and Stijn Van Nieuwerburgh, 2005, Housing collateral, consumption insurance, and risk premia: An empirical perspective, *Journal of Finance* 60, 1167–1219.

——— , 2010, How much does household collateral constrain regional risk sharing?, *Review of Economic Dynamics* 13, 265–294.

Mayer, Christopher J., Tomasz Piskorski, and Alexei Tchistyi, 2010, The inefficiency of refinancing: Why prepayment penalties are good for risky borrowers, NBER Working Paper Series No. 16586.

Mian, Atif R., and Amir Sufi, 2010, House Prices, Home Equity-Based Borrowing, and the U.S. Household Leverage Crisis, *American Economic Review, forthcoming,* avaliable at http://ideas.repec.org/p/nbr/nberwo/15283.html.

Parker, Jonathan A., and Annette Vissing-Jorgensen, 2009, Who bears aggregate fluctuations and how?, *American Economic Review* 99, 399–405.

Piazzesi, Monika, and Martin Schneider, 2009, Inflation and the price of real assets, Federal Reserve Bank of Minneapolis Staff Report 423, available at http://ideas.repec.org/p/fip/fedmsr/423.html.

Rios-Rull, Jose-Victor, and Virginia Sanchez-Marcos, 2008, An aggregate economy with different size houses, *Journal of the European Economic Association* 6, 705–714.

Roussanov, Nikolai, 2010, Diversification and its discontents: Idiosyncratic and entrepreneurial risk in the quest for social status, *Journal of Finance* 65, 1755–1788.

Stanton, Richard, 1995, Rational prepayment and the valuation of mortgage-backed securities, *Review of Financial Studies* 8, 677–708.

Storesletten, Kjetil, Chris Telmer, and Amir Yaron, 2004, Cyclical dynamics in idiosyncratic labor market risk, *Journal of Political Economy* 112, 695–717.

———, 2007, Asset pricing with idiosyncratic risk and overlapping generations, *Review of Economic Dynamics* 10, 519–548.

Tauchen, George, and Robert Hussey, 1991, Quadrature based methods for obtaining approximate solutions to nonlinear asset pricing models, *Econometrica* 59, 371–396.