Is there a Puzzle in Underwater Mortgage Default?

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Abstract

A recurring question in the mortgage default literature is why underwater default is rare relative to model predictions. We find that one answer is model miscalibration of flow payoffs. We build a novel detailed quantitative model of mortgage default, and find realistic rent dynamics plus mild levels of default costs is sufficient to eliminate negative equity strategic default. We present some further empirical results supporting our model's focus on flow payoffs. Our model addresses the underwater mortgage default puzzle, offers more realistic interpretations of policy consequences, and reinforces the theoretical effectiveness of cash-flow based interventions.

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1 Introduction

In an influential paper, Foote et al. (2008) examined more than 100,000 homeowners in Massachusetts who had negative equity during the early 1990s and found that fewer than 10 percent of these owners eventually lost their home to foreclosure. Calculations done for the great financial crisis yield similarly low numbers. Economists have struggled to explain this low number.

It's not that economists can't explain why a rational borrower with negative equity might choose not to default. Using option theory, economists have argued that borrowers might rationally continue making payments even when underwater. The logic is that the default option effectively insures borrowers against the downside of future losses if prices fall further, while preserving the upside potential of regaining positive equity in the future. Therefore, defaulting immediately could actually make them poorer in the long run.

However, option-based models from the 1980s and 1990s based on this reasoning predicted far too many defaults. Kau et al. (1994) and Kau and Keenan (1999) suggested *all* borrowers would default at negative equity levels of 25% or less, contradicting real-world data showing that even borrowers with 50% negative equity typically continued making their mortgage payments.

More recently, economists have built dynamic models where borrowers receive stochastic labor income, face borrowing and collateral constraints, non-payment penalties, and many other realistic features that should be relevant to the default decision. These models can generate realistic default levels, but only by assuming borrowers face enormous psychological costs for defaulting. For example, the calibration of Campbell and Cocco (2015) in Ganong and Noel (2023) requires a utility cost that is worth 25% of lifetime consumption. Hembre (2018) and Laufer (2018) estimate this cost to be even higher, between 50-70%. These utility penalties are staggeringly high - equivalent to about $625,000 for a household spending $50,000 annually over 50 years.

We argue that this "strategic default puzzle" arises not necessarily because households fail to act optimally with respect to their financial interests, but because models have historically miscalibrated the core incentive behind mortgage default. Conceptually, existing theoretical analyses typically emphasize stock variables: house prices, mortgage balances, and home equity as the difference between them. But for households making decisions under uncertainty, the relevant tradeoff is inherently a flow problem, for which flow variables are central to households' strategic incentives and needs to be carefully calibrated. What is the utility of staying in the home versus exiting into the rental market, conditional on income and housing cost shocks? In other words, what is the flow cost of maintaining a call option on the home, where the flow cost is the user cost difference between owning and renting minus any flow utility differences between owning and renting? In this paper, we estimate a novel detailed model of mortgage default to evaluate household strategic default incentives given realistic calibrations of flow costs.

For intuition, suppose that as in the benchmark Campbell and Cocco (2015) model there is only a single type of housing, that homeowners are exogenously assigned their homeownership and mortgage, and that defaulters are forced to become permanent renters. Then, the financial incentive to default in fact depends entirely on the calibration of rent in the model, as the "punishment" of default is to rent permanently. However, while house prices declined significantly during the 2007–2008 housing crash, rent remained relatively flat (Loewenstein and Willen, 2023). Therefore, in the Campbell and Cocco (2015) model, owners may have limited incentives to defaulting on their mortgage and switching to renting even if they have negative equity.

We illustrate this effect in Figure 1. In particular, Panel (a) of Figure 1 shows the households' income change conditional on default in the Campbell and Cocco (2015) model's baseline calibration as compared with Ganong and Noel (2023)'s data by levels of loan-to-value (LTV) ratios. It shows that high LTV borrowers require significantly less income decline in order to default, in a way that is inconsistent with the data. Panel (b) of Figure 1 shows that adding a high non-pecuniary utility cost of default, on the order of 25 percent of lifetime consumption, allows the model to better match the data. These panels replicate the findings in Ganong and Noel (2023). However, panel (c) of Figure 1, which is novel to our paper, shows that the same fit to the data in terms of income declines given default can be achieved by holding real rent fixed at 2001 levels, consistent with Loewenstein and Willen (2023), but without any non-pecuniary utility cost of default.[1] Thus, the high implied value of strategic default in previous calibrations of the Campbell and Cocco (2015) model is largely due to their high assumed financial attractiveness of renting relative to owning during housing crashes, which no longer holds under a more realistic rent-to-price process.

[Figure 1 inserted here]

Why are rents more downward stable than house prices, especially during times of house prices declines? Several explanations are possible. First, during financial crises, household demand for rental units may increase relative to owner-occupied units due to the execution of income-driven foreclosures, which may generate upward pressure on rents. Indeed, Foote et al. (2018) find significant household inflows into rental units as well as a rise in the quantity of vacant units during the 2008 housing crisis, both of which could increase rents. Second, under a standard Rosen-Roback model, rents are related to utility of being in a location in space, which includes factors like wages and amenities, and these factors may be relatively stable in aggregate. On the other hand, house prices may be more prone to speculative dynamics (DeFusco et al., 2022) and may be responsive to credit supply shocks (Adelino et al., 2025), both of which would explain its greater volatility. Regardless of the reason for the lower volatility of rent, we take this empirical pattern, as reproduced in Figure 2, as a primitive in our model.

[Figure 2 inserted here]

[1] Appendix A discusses this model in more detail, and Appendix Figure A.1 shows that the income declines conditional on default is not different when we add back the non-pecuniary costs worth 25% of lifetime consumption, suggesting that such non-pecuniary costs have little additional explanatory power.

While our calibration of the benchmark Campbell and Cocco (2015) is revealing, it is possible that rent only plays an outsized role due to their specific assumptions. First, households cannot downsize their homes, yet if a household suffers a permanent income shock, one natural reason to default would be to move to a smaller, more affordable house. In fact, the model feature that households cannot downsize implies that as long as rent is higher than the household's user cost of owning (i.e., their mortgage payment plus taxes and maintenance), households would never default regardless of the severity of income shocks or the level of negative equity, making the model-implied default rates near zero and the model implied non-pecuniary default penalties *negative* with realistic rent processes. Second, defaulters are permanently excluded from homeownership, whereas in reality, they can regain access to mortgage credit after several years, which further artificially reduces the appeal of negative equity default.[2]

We build a novel, detailed model of mortgage default which may serve as a useful rational benchmark for future empirical analyses of mortgage default. First, we incorporate heterogeneous property sizes in our model following Kaplan et al. (2020), so that households have incentives to downsize following income shocks. While this significantly increases the computational complexity of our model by expanding the state space to include property sizes, mortgage sizes, and housing tenure choice, it is necessary for capturing the downsizing incentives of default. Our model matches the property size choices of owners and renters, LTVs, and the life-cycle rates of homeownership well. Second, we add realistic options that increase the attractiveness of default. In our model, we allow foreclosed households to re-buy a home after 7 years in expectation, when the foreclosure flag is removed from their credit

[2]In macroeconomic modelling, researchers may be able to get around these problems by assuming a counterfactually lower rent in the Campbell and Cocco (2015) model and having the lower rent proxy for the additional incentives to default such as being able to downsize, calibrating the counterfactually lower rent required to match actual default rates, and thus making Campbell and Cocco (2015) a useful and computationally efficient input into larger models. However, the lower rent necessary to fit default rates would capture both the additional incentives to default as well as any household reluctance from doing so, and a more detailed calibration of the value of the additional incentives to default is necessary for our purposes of understanding whether the underwater mortgage default puzzle exists.

profile.[3] Furthermore, we allow the household to live in their homes for free for one year while defaulting on their mortgage. Third, we give defaulters the realistic option to "cure" their default before foreclosure completion, thus making default in our model a two-stage problem. This increases default incentives for households with income shocks as a way to smooth consumption. With these realistic modifications, we fit the data on lifecycle moments, default rates, and large income losses conditional on default. We find that a positive non-pecuniary cost of default is in fact necessary in our calibration, but at only 0.7% of lifetime consumption compared to 25–50% of lifetime consumption found in the literature, suggesting positive though limited strategic default incentives.

We now describe our model in more detail. In order to allow for heterogeneous property sizes, our model significantly expands upon the canonical life-cycle models of mortgage default (Campbell et al., 2021; Campbell and Cocco, 2015) by endogenizing homeownership choice, choice of house sizes, and choice of mortgage size. The model features stochastic income, savings, housing tenure choice, and mortgage choice. In terms of income, we follow Campbell et al. (2021) in allowing the income process in the model to vary by business cycle recessions and expansions and calibrate to those found in Guvenen et al. (2014). We further conduct a novel calibration of the dynamics of house prices during recessions and expansions by using zipcode level price indices. We impose a restriction that the smallest houses can only be rented, which captures realistic differentiation and segmentation in the market following Kaplan et al. (2020). We note that this assumed market segmentation does not prevent strategic default in our model, as owners can still rent their preferred sizes, but is instead important for fitting the life-cycle profile of homeownership as in Kaplan et al. (2020).[4] Finally, we allow defaulters to cure their default instead of going into foreclosure.

[3]Such a transaction could be done earlier with cash for households who have the liquidity, but that is unlikely to be possible for most households. Furthermore, even households who have enough cash may have better alternative investment opportunities during the period of large house price declines and rising rental yields, relative to defaulting and re-buying their home which is a cash-intensive investment with zero immediate net worth gains.

[4]If some houses cannot be rented and some households have inelastic demand for those houses, that would further reduce the incentives to default from our 0.7% of lifetime consumption number, suggesting that correctly calibrating the rent process is sufficient for addressing the underwater mortgage default puzzle

We calibrate this model to match homeowership rates over the lifecycle and distributions of owner and renter house values in the American Community Survey (ACS) in 2001, the loan-to-value (LTV), payment-to-income (PTI), debt-to-income (DTI) ratios in the 2001 Survey of Consumer Finances (SCF), as well as delinquency rates by LTV in the 2005–2023 in the Equifax/McDash CRISM data set. Importantly, we hold real rent constant, which captures more realistic rent dynamics from Loewenstein and Willen (2023). Despite having only 7 free parameters, our model matches these distributions reasonably. In addition, our model matches non-target moments, PTI by LTV in the cross-section of mortgage borrowers as well as the house size distribution among owners and renters well. Notably, the required level of default penalty is much smaller in our model compared to the earlier literature, at 0.7% of lifetime consumption instead of 25–50%.

There are two ways to interpret our 0.7% of lifetime consumption mortgage default penalty. First, it can capture the non-monetary costs of mortgage default, including losses of reputation in the labor market, limits from renting certain properties, and other non-pecuniary costs. These costs may be heterogeneous and larger for households who face higher reputation costs. Second, it can be viewed as an upper bound on the rational incentives to default in our life-cycle model, irrespective of what the true non-pecuniary costs of default are which may indeed be higher than what we calibrate among many households.[5] This second interpretation does not require readers to accept our model as a positive description of what households do, in the sense of Campbell (2006), but rather as a normative description of what rational optimizing households should do. The second interpretation implies that the financial incentives to strategically default for the rational households, while still present, is in fact significantly more limited compared to what has been estimated in the earlier literature. This in turn allows for more realistic policy analysis and adds to the theoretical

in our model of mortgage default.

[5]There is some evidence that this cost is larger than the 0.7% number among homeowners who choose to repay their mortgages while moving, with Brueckner et al. (Forthcoming) finding a median lower bound of $28,871 to $52,448 depending on credit score quintile. Our model implies that these numbers are more than sufficient to largely eliminate strategic default incentives. Guiso et al. (2013) shows that many survey respondents feel a moral obligation not to default.

generalizability for cash-flow based interventions.

Ganong and Noel (2023) presents empirical evidence on the drivers of mortgage default which is important for our model to match. In particular, we find in our model the income change conditional on default is flat or declining in LTV, which is empirically realistic based on Ganong and Noel (2023), and suggests that few borrowers default purely because they have negative equity. We note that there is in fact declining income change conditional on default by LTV in our model, which is possible due to the positive correlation between income and house price growth. The fact that in our model, significant income declines are required for negative equity default implies that the financial benefits to defaulting is limited.

A key insight of our paper is that correctly calibrating flow payoffs is key to modelling household strategic behavior. Households may not be particularly incentivized to default when they are underwater if their alternative of renting has not fallen drastically in cost. On the other hand, if flow payoffs truly matter for household decision making, households may be more incentivized to default if their expected rent declines permanently. We illustrate this possibility via a model counterfactual analysis where real rents fall permanently by 10%. We show that this results in 0–5 percentage point higher default rates depending on the household's LTV, with the higher effects being concentrated in higher LTV households. We also show that this results in a 2 percentage point increase in foreclosure rates conditional on defaulting. While the earlier literature has focused on "double trigger" models of mortgage default driven by negative equity and income declines, our model is instead supportive of a "triple trigger" model of default where income decline, negative equity, and lower value of owning relative to renting together trigger default among some households as the natural benchmark for empirical analyses.[6]

We also present some suggestive empirical results supporting our model's emphasis on

[6] In addition to declining rent, the flow benefit of homeownership can also change due to factors such as climate catastrophes, which may increase the attractiveness of renting relative to owning, thus making the "triple trigger" benchmark model potentially relevant in face of rising climate risk as it becomes accompanied by house price declines. This possibility is discussed by Benjamin Keys in the NYTimes HERE.

the flow payoff differences between owning and defaulting. For identification of the effect of flow payoffs, we condition on borrowers who experience 90-day default, and examine differences in their foreclosure likelihoods as a function of the change in their nominal rent growth since mortgage origination. By conditioning on 90-day default, we isolate a sample of households who were likely hit with income shocks (Ganong and Noel, 2023), and then subsequently examine their foreclosure behavior as they relate to flow payoff changes. We find that, in agreement with our model, foreclosure probabilities conditional on default rises by 1.5 percentage points for every standard deviation decline in rent, where one standard deviation decline in rent is 8.5%, consistent with our model's predictions.

A potential confounder of this result is that rent growth may be correlated with economic conditions and therefore chances of income recovery of the defaulted household. We address this endogeneity in three ways. First, we note that this correlation is not necessarily positive, as worsening economic conditions drive both an increase in foreclosures and an increased in the demand for rental units leading to higher rents. Second, we add unemployment rate and local wage growth variables as controls, and find similar coefficients after controlling for these variables. Third, we use the instrument from Gete and Reher (2018), which they argue predicts rent growth independent of local economic conditions, and find larger effects in the instrumental variables analysis, which suggests that the correlation between rent growth and unobserved economic conditions may indeed be negative.

2 Existing Literature on Mortgage Default

On the theoretical front, early work relied on option theoretic models of mortgage default including Foster and Van Order (1984) and Riddiough (1991). More recent models of mortgage default, starting from the seminal work of Campbell and Cocco (2015), uses a life-cycle framework. We build heavily upon their model. Hembre (2018), Laufer (2018) and Li et al. (2022) require a similar or even larger non-pecuniary costs in their life-cycle models compared to the Campbell and Cocco (2015) model. Schelkle (2018) requires more reasonable non-pecuniary costs, but instead requires both an low discount factor ($\beta = 0.9$) and low elasticity of inter-temporal substitution ($\gamma = 5$), with the absence of either makes the model similar to earlier models.[7] Ganong and Noel (2023) provides a calibration of the Campbell and Cocco (2015) model.[8]

An important complementary contribution to the theory of mortgage default is Low (2023a), which introduces a model that fits the average level of abovewater and underwater default by introducing empirically motivated large and time-varying psychic moving costs, on the order of $200,000 on average. However, the model continues to predict unrealistically high levels of default for highly underwater households, and the paper reiterates that underwater default poses a "puzzle" for the literature. Low (2023a) emphasizes that it is important for a model of mortgage default to (1) fit both abovewater as well as underwater default rates and (2) generate reasonable moving rates, which we do in our model as shown in Figure 6a and Appendix Figure A.2. Nevertheless, our goal is not to produce an alternative definitive model of mortgage default or to take a position about the size and prevalence of non-pecuniary default costs. We use our model primarily to show in a rigorous quantitative framework that there is a lack of a strong theoretical incentive to strategically default by underwater households, which allows for more realistic interpretations of policy and suggest conditions under which cashflow-based interventions are more theoretically generalizable.

On the empirical side, a large prior literature reviewed in Foote and Willen (2018) finds low rates of underwater default even among those with negative equity. Bhutta et al. (2017) examines LTV cut-offs for defaulting over the financial crisis, finds that borrowers are unlikely to default on their mortgages until their LTVs becomes significantly higher than earlier

[7]In cutting-edge work, Kalikman and Scally (2022) introduce a model that fit the average cumulative default rates by cohort in the data through the use of heterogeneous default penalties, but does not discuss the magnitude of default penalties required. A large macro-finance literature, including Chatterjee and Eyigungor (2015), Corbae and Quintin (2015), Elenev et al. (2021), Diamond and Landvoigt (2022), Diamond et al. (2025), and Elenev and Liu (2025) incorporate models of mortgage default in their analyses, but do not focus on default costs.

[8]Available HERE.

models' predictions. They reasonably attribute the borrowers' high LTV cut-offs to "emotional and behavioral factors." We do not rule out the importance of such emotional and behavioral factors, but instead show that a modest amount for these factors at 0.7% of lifetime consumption is already sufficient to address the "strategic default puzzle" in a rational model of mortgage default, unlike the earlier literature which requires much larger.[9] Gupta and Hansman (2022) studies the role of adverse selection and moral hazard on explaining the correlation between leverage and mortgage default by using interest rate indexes as a source of exogenous variation, and finds that both forces are important. An important contribution that we rely heavily on is Ganong and Noel (2023), which finds that most defaults are driven by income loss or a combination of income loss and negative equity, rather than purely driven by negative equity. A regression kink design from Indarte (2023) suggests that liquidity is the primary driver of personal bankruptcy among mortgage borrowers. Survey evidence from Low (2023b) confirms the importance of liquidity shocks in household default. Hazard instrumental variables estimates from Palmer (2024) as well as evidence from large principal reductions from randomly assigned mortgage cramdowns holding fixed the monthly payment in Cespedes et al. (Forthcoming) suggests that negative equity is relevant for foreclosures. Generally, the literature identifies a central role for liquidity, with negative equity also being relevant particularly for foreclosures. Our model is consistent with these empirical findings.

3 Data

We use several data sources to calibrate our model. In particular, we obtain the PTI and LTV ratio from the 2001 Survey of Consumer Finances (SCF), and the homeownership rates over the life-cycle in the 2001 American Community Survey (ACS). We also calculate default and foreclosure rates as the share of loans that default or get foreclosed upon, respectively, in a given year using data on owner-occupied, first-lien mortgages between 2001 and 2023

[9] Brueckner et al. (Forthcoming) indeed finds a higher lower bound for default costs based on repaying homeowners than what is required by our model, at a median lower bound of $28,871 to $52,448 depending on credit score quintile, which based on our model is sufficient to largely eliminate strategic default.

in the Equifax/McDash CRISM data set. We define default as the first month a mortgage transitions to 90 day delinquency, following the literature in Ganong and Noel (2023).

For the rent to price ratio, we take the average of the rent to price ratio in 2001, and hold real rent constant as shown in Loewenstein and Willen (2023). Price to rent ratios used in this calibration as well as Figure 2a come from a dataset of property-level rent to price ratios derived from MLS data as described in Loewenstein and Willen (2023). This is a sample of renter-occupied single family homes and condos for which we observe contract rents and sale prices within a one year time span. Importantly, this allow us to obtain rents and prices for the same property, and thereby measure more realistic rent-to-price ratios compared to using average rent and average prices in a metro area.

To calibrate zip-code house price dynamics, we use the Corelogic zip code house price index, and deflate it with the CPI deflator. The Corelogic zip code index improves on the FHFA zip code price index by using a larger sample of properties than those tracked by the FHFA, which are limited to properties financed via conforming loans. We obtain monthly zipcode house price index values from January 1987–2008, and use it to estimate a mixture model of house price movements.

For our empirical analysis on the relationship between nominal rent growth and default, we use Credit Risk Insights McDash (CRISM), which is mortgage performance data matched with credit records from Equifax, along with market-level data on changes in effective asking rents (rents net of concessions) from CoStar. We take CRISM loans originated prior to 2008 with a 90-day delinquency between 2010 and 2019, and track them until the end of 2024. We include the summary statistics on this dataset in Table 2.

4 Model

In this section we describe our life-cycle model of mortgage default. Our model builds in more realistic features than Campbell and Cocco (2015) in several important ways, which allows us to more quantitatively benchmark the households' utility incentives to default. First, we endogenize housing tenure choice in terms of owning and renting, house sizes, as well as the choice of mortgage balances, which allow households to downsize after being hit by a liquidity shock. While this feature significantly expanding the state space of the model, it is essential for obtaining positive default costs once more realistic rent processes are calibrated. Second, we allow households to re-buy their homes after an expected 7 years. Third, we incorporate a default period prior to foreclosure, and allow households to cure their default before foreclosure. By incorporating these realistic features, we are able to more quantitatively assess the benefit of defaulting for underwater households. The options of different types of households are summarized in the Figure 3. We describe them in more detail below, with time parameters and preferences in Section 4.1, income and house prices in Section 4.2, mortgage contracts in Section 4.3. We also provide a full mathematical description of the households' recursive problem in Appendix Section D.

4.1 Time parameters and preferences

Household utility is CRRA over non-housing consumption c_{it} and housing consumption h_{it}:

$$\max E_1 \sum_{t=1}^{T} \beta^{t-1} \frac{((1-\eta)c_{it}^{1-\phi} + \eta h_{it}^{1-\phi})^{\frac{1-\sigma}{1-\phi}}}{1-\sigma} + \beta^T b_0 \left(\frac{(b_1 + w_{i,T+1})^{1-\sigma}}{1-\sigma} \right) \tag{1}$$

where β is the discount factor, σ is the coefficient of relative risk aversion, ϕ captures the substitutability between housing h_{it} and non-housing consumption c_{it}, and η is the relative importance of housing consumption. Housing service can be obtained by owning or renting. b_0, b_1 are parameters for the bequest motive. Specifically, b_0 measures the relative importance of utility derived from bequest and b_1 captures the extend to which bequest is a luxury good.

Households receive income y_{it} in each period and optimize over non-housing consumption c_{it}, housing consumption h_{it} and housing tenure choice o_{it} subject to buying and selling frictions, mortgage size m_{it} subject to cash-out refinancing frictions, and mortgage default.

These choices affect liquid savings $w_{it} \geq 0$.

Owning and rental markets are partially segregated. The size of houses available for rent is $\{h_1^R, h_2^R, h_3^R, ..., h_J^R\}$ and size of houses available for purchase is $\{h_1^O, h_2^O, h_3^O, ..., h_J^O\}$. We assume that $\exists j_R$ such that $h_j^R \leq h_1^O$ for all $j \leq j_R$. That is, some smaller units are only available for rent rather than purchase. This segregation allows us to fit the lifecycle ownership profile of households.

In each period, homeowners derive utility based on owned housing size h. On the other hand, they pay a real maintenance cost $\delta \bar{P} h$, and property insurance and tax $\tau_h \bar{P} h$, charged as a fraction of stationary house prices. Renters do not pay these costs but instead pays real rent $\bar{R}h$ in each period. For the initial $\frac{\bar{R}}{\bar{P}}$ we apply the 2001 rent-to-price ratio estimated at a unit level from Loewenstein and Willen (2023), and keep real rent fixed at their 2001 levels, consistent with the findings in Loewenstein and Willen (2023) for the evolution of rent over the 2001 to Great Recession period.

Entry into homeownership involves a buyer cost τ_b, while exit from homeownership involves a seller cost τ_s. Households can also adjust their owned housing size h while remaining owners by paying τ_b on their existing home and τ_s on their new home. Renters can freely adjust their housing size h^r.

4.2 Income and house prices

Our income process follows that of Guvenen et al. (2014) which features a mixed Normal distribution whose means differs during expansions and recessions, with the addition of a lifecycle age profile χ_j since we match on homeownership rates over the lifecycle. Specifically, household i of age j receives real labor income y_{ijt} at time t given by

$$\log(y_{ijt}) = z_{it} + \chi_j + \epsilon_{it}, \tag{2}$$

$$z_{it} = \rho z_{it-1} + \eta_{it}, \tag{3}$$

where η_{it} is given by a mixed normal distribution:

$$\eta_{it} = \begin{cases} \eta_{it}^1 \sim N(\mu_{1s(t)}, \sigma_1) \text{ with prob. } p_1, \\ \eta_{it}^2 \sim N(\mu_{2s(t)}, \sigma_2) \text{ with prob. } 1 - p_1 \end{cases}, \tag{4}$$

and aggregate $s(t) \in \{E, R\}$ indicates whether the economy is in an expansion (E) or recession (R) year. Following Kaplan et al. (2020), our life-cycle age profile χ_j is approximated as with a quadratic function of age. ϵ_{it} is a transitory shock that follows normal probability distribution with mean 0 and standard deviation σ_ϵ.

Labor income is taxed. Adopting the functional form Heathcote et al. (2017), our model features progressive income tax,

$$\tau(y_{ijt}) = \tau_0(y_{ijt})^{1-\tau_1}, \tag{5}$$

where, τ_0 captures the average level of taxation and τ_1 captures the degree of progressively of the tax system.

In our model, real house prices per unit of housing service h are decomposed into an average price $\bar{P}$ and a shock ζ, such that $P_t = \bar{P}\zeta_t$. Real house prices follow a random walk with drift of which depends on business cycles, whose shocks ϵ_s^p follow a mixed Normal distribution:

$$\begin{gathered} \log(P_t) - \log(P_{t-1}) = \underbrace{\log(\bar{P}) - \log(\bar{P})}_{=0} + \log(\zeta_t) - \log(\zeta_{t-1}) = \epsilon_s^p, \\ \epsilon_s^p = \begin{cases} \epsilon_{s1}^p \sim N(\mu_{1s(t)s(t-1)}^P, \sigma_{1s(t)s(t-1)}^P) \text{ with prob. } \pi_{s(t)s(t-1)} \\ \epsilon_{s2}^p \sim N(\mu_{2s(t)s(t-1)}^P, \sigma_{2s(t)s(t-1)}^P) \text{ with prob. } 1 - \pi_{s(t)s(t-1)} \end{cases}, \end{gathered} \tag{6}$$

and aggregate state $s(t) \in \{E, R\}$ which captures that the average price growth and price growth volatility may differ between whether the household is entering an expansion (E) or a recession (R). Note that the shared aggregate state $s(t)$ between income and house price processes imply a positive correlation between them.

4.3 Mortgage contracts, home equity extraction, and default

Our model features the most popular mortgage contracts: 30 year fixed rate contracts with interest rate r^m and term $N = 30$, which has constant nominal payments over time as given by the standard amortization formula. Note that real mortgage payments decay at the rate of inflation. At the time that the borrower originates or refinances the mortgage (i.e. mortgage age $n = 1$), they are subject to two constraints. First, the leverage is limited by a loan-to-value constraint:

$$D_{it} \leq (1 - d)P_t h, \tag{7}$$

where $\xi = 5\%$ implies a downpayment requirement of 5%. Second, there is a cap on scheduled payment to income ratio at mortgage origination, which is set to be 50% based on Greenwald (2018)'s analysis of the pre-2000 period.

Furthermore, mortgage origination and refinancing involves an origination cost of 1% of the loan amount plus $2000 2001 dollars, following Agarwal et al. (2013). Mortgage refinancing which allows households to extract their home equity in times of house price increases and thereby increasing their LTV.

At the beginning of each period t, mortgage borrowers can choose to default by stopping their mortgage payment for a year. They can subsequently decide to cure their mortgage and become current again, by paying their owed amounts and 5% late fee proportional to the mortgage payment they missed and becoming current, if they have sufficient liquidity. They can also choose to pay off the entire mortgage and the late fee, sell their home, and rent. If they choose neither of those options, they will get foreclosed upon. Defaulting incurs an immediate utility cost of, ψ, which captures the impact of default on the borrower's credit score, any impact on future credit access, and/or any moral or reputation concerns.

A foreclosed borrower loses all of their home equity, become renters and cannot buy a home as long as their foreclosure flag, Ω, is still on their record. In each period with probability q, their record of default will be removed in next period so they have the option to become owners. A mathematical description of our model features is shown in Appendix Section D.

5 Calibration and Implications

A key question for our model is what it implies about the utility incentives to default after its parameters are calibrated to key moments of the U.S. housing market. We describe the calibration process in Section 5.1, the model's fit to both targeted and untargeted moments in Section 5.2, the model's implications for income changes given default in Section 5.3, and the model's implications for a counterfactual drop in rent in Section 5.4.

5.1 Parameter calibration

We calibrate the model to match the age profile of homeownership rates, loan-to-value ratios, payment-to-income ratios, debt-to-income ratios, and default rates by loan-to-value ratios. We conduct the calibration in two stages. In the first stage, we determine the parameters which are directly estimated using the data or taken from the literature. In the second stage, key parameters are calibrated by minimizing the absolute distance between the model's moments and those in the data. Table 1 summarizes both sets of parameters.

5.1.1 Parameters determined outside of the model

Each period in our model corresponds to one year in the data.

Demographics: Households are born at age 23 and live up to age 85. Households retire at age 64.

Preference: Following Guren et al. (2021b), we set inter-temporal elasticity of substitution σ to 2. Discount rate β, housing share in the utility η, substitution between housing and non-housing consumption ϕ, bequest motives b_0, b_1, and the utility cost of default ψ are to be calibrated.

Asset: The risk-free interest r is set to be 2% per year. The average annual inflation rate has been stabled around 2 percent since late 1990s. the mortgage spread $\zeta_m = 1.5\%$, which is averaged difference between contract mortgage interest rate and the market yield on 30-year treasury bond using data from the Federal Housing Finance Agency and Federal Reserve Bank of St. Louis. Annual inflation π is 2% which gives us an annual nominal mortgage interest of $r_m = 5.5\%$.

The initial asset distribution is constructed using data from Survey of Consumer Survey (2001) for households aged from 20 to 22. We take the value of all their assets to construct the initial asset distribution.

Housing: We set the annual property tax and maintenance cost to 1.5% and 1%, respectively, which match the average property taxes and owner costs reported in the American Community Survey (2001). Transaction costs for buyers and sellers are $k_b = 6\%$ and $k_s = 2\%$ (see e.g. Sommer et al. (2013)). The variable mortgage mortgage closing cost is set to $\omega_1 = 1\%$, which matches the average initial fees reported by the Federal Housing Finance Agency. The constant mortgage closing cost is set to $\omega_0 = 2000$ 2001 dollars, following Agarwal et al. (2013).

For the baseline calibration in 2001, we set the downpayment requirement ξ to be 5%, which is standard in the literature. Meanwhile, the constraint on payment-to-income ratio (PTI) is set to be 50%.

Aggregate State: There are two aggregate states, recessions R and expansions E. The transition probabilities between recessions and expansions are taken from Campbell et al. (2021). The annual probability of transiting from an expansion to a recession is 0.18 and the probability of transiting from a recession to an expansion is 0.63. Both income and house prices depend on this aggregate state and therefore income and house price shocks are correlated in the model.

Income: Following Guvenen et al. (2014), we set annual autocorrelation of persistent earnings shocks ρ to 0.979, standard deviation of transitory shock σ_ϵ to 0.186. The mixed normal distribution has a first mixture probability $p_1 = 0.49$. The two mixture components have innovation term during expansions E and recessions R that are $\mu_{1E} = 0.119, \mu_{2E} = -0.026, \mu_{1R} = -0.102, \mu_{2R} = 0.094, \sigma_1 = 0.325, \sigma_2 = 0.001$ for the parameters in Equation 4, with subscripts E and R corresponding to the aggregate state subscript $s(t)$ in Equation 4. The deterministic age income profile $\bar{w}_j$ is calibrated to match the average household income for different age groups using data from the Panel Study of Income Dynamics (PSID). Parameters in the tax schedule $\tau_0 = 4.787$ and $\tau_1 = 0.151$ come from Kaplan et al. (2020).

Average House Prices and Rent: The average house price level $\bar{P} = \$162,169$ is the median house value reported by owners and the annual rent $\bar{R} = \bar{P} \times 0.1019$ is calibrated to the sample average rent to price ratio for a single-family home and condos that were both sold and rented on the MLS in 2001, following Loewenstein and Willen (2023). In the model, house prices are allowed to move dynamically while real rents are assumed to stay constant, capturing the 2001 to 2012 house price rise and housing crash period as shown in Figure 2a, where real rents are relatively flat between 2001 and 2012 while house prices are volatile.

Important to this calibration, rent to price ratios have fallen by about 30% relative to 2001 by the 2020s due to house price growth (Loewenstein and Willen, 2023), which made renting more financially attractive in terms of flow costs in recent years compared to our model period. Whether this implies more strategic incentives to default should another house price crash occur depends on the reason why households' reasons for choosing to own rather than rent despite a lower rent to price ratio. If households' reason for homeownership despite a lower rent to price ratio is due to an ownership premium or concerns about rent growth risk (Sinai and Souleles, 2005), and those factors relatively stable, then strategic default incentives may continue to be moderated. Our model can be adapted to include an ownership premium as well as rent growth risk concerns if used to evaluate another housing crash in the 2020s housing market.[10]

House Price Dynamics: We estimate the housing price dynamics using CoreLogic zip code house price index growth deflated via the CPI deflator between 1987 and 2008. When the economy stays in expansion (i.e., an aggregate state of E for in the last period and this period), we estimate that house price shocks has mean $\mu^P_{EE} = 0.02$ and standard deviation $\sigma^P_{EE} = 0.057$, and model it as a Normal distribution with $\pi_{EE} = 1$. When the economy stays in recession (i.e., an aggregate state of R for in the last period and this period), we estimate a mean $\mu^P_{RR} = -0.017$ and standard deviation $\sigma^P_{RR} = 0.09$, which we also model as a Normal distribution with $\pi_{RR} = 1$. We note that our estimated mean real house growth is larger during expansions compared to recessions, at 2% versus -1.7%, respectively, while the standard deviation of house price growth is smaller in expansions compared to recessions, at 5.7% and 9%, respectively.

When the economy falls from expansion to recession (i.e., an aggregate state that transitions from E for in the last period and to R this period), we use a mixed Normal distribution to fit house price shocks to capture the fact that some recessions are more likely to be associated with house price declines than others. We use a maximum likelihood approach to estimate these mixtures. We estimate the probability of first mixture as $\pi_{ER} = 0.2$, the mean and standard deviation of first mixture as $\mu^P_{1,ER} = -0.0925, \sigma_{1,ER} = 0.0758$, the mean and standard deviation of the second mixture as $\mu^P_{2,ER} = 0.021, \sigma_{1,ER} = 0.0708$. Similarly, the economy rises from recession to expansion (i.e., an aggregate state that transitions from R for in the last period and to E this period), we also use a mixed Normal distribution to calibrate house price shocks, and estimate the probability of first mixture $\pi_{RE} = 0.22$, mean and standard deviation of first mixture as $\mu^P_{1,RE} = 0.0013, \sigma_{1,RE} = 0.0293$, and mean and standard deviation of the second mixture as $\mu^P_{2,RE} = 0.021, \sigma_{2,RE} = 0.0611$. We note that the two mixtures are more different in mean, and the standard deviations are higher, during transitions from recession to expansions compared to transitions from expansions to

[10]Our model does not currently include an ownership premium, as it is not needed to fit ownership rates in our setting. Many models in the literature do include one and use it to fit homeownership rates.

recessions. This suggests that there is more dispersion in house price growth as households enter into a recession in our model. The relatively low levels of mean house price growth as the economy emerges from recessions to expansions $\mu^P_{1,RE}, \mu^P_{2,RE}$ also point to limited mean reversion in the house price dynamics.

In summary, our house price dynamics exhibit lower expected price growth within recessions as well as limited expected mean reversion within recessions. This estimated dynamic is mostly due to our estimation period being up to 2008, which does not include the period of house price increases as households emerge from the Great Recession. We chose this estimation period to be conservative. The limited mean reversion is likely to increase the financial incentives for negative equity default in our model, thus making our finding of limited financial incentives on negative equity default more stark. In addition, it may also correctly capture the expectations of negative equity households during the housing crash period if they were making similar inferences based on historical data.

[Table 1 inserted here]

5.1.2 Parameters calibrated inside the model

We calibrate the discount rate β, minimum house size h^{min}, housing share η, substitutability between housing and non-housing consumption,ϕ the two parameters that shape the bequest motive, b_0 and b_1, and the default utility cost ψ to the 2001 ACS age profile (for 58 age groups) of the homeownership rate, 2001 SCF loan-to-Value ratios, and mortgage payment-to-income ratios by age group. We also calibrate to default rates by LTV among owners from our Equifax/McDash CRISM data set. Importantly, when calibrating to Equifax/McDash CRISM default rates, we assume that their mark-to-market LTVs are measured with a 14% standard deviation error, which is consistent with Bogin et al. (2019)'s exploration of the accuracy of zipcode level price indices we use to calculate mark-to-market LTVs. We estimate these parameters using the Simulated Method of Moments. Specifically, we choose the parameters that minimize the distance between simulated moments in the stationary equilibrium and the data.

Although we jointly calibrate seven parameters, each parameter is most closely related to one moment. The minimum house size available to buy, h^{min}, is most sensitive to the homeownership rates of young and old households with relatively low wealth as these households are more likely to be constrained by the minimum house size. The housing share and the substitutability between housing and non-housing consumption in the utility function, η and ϕ, are most closely related to the payment to income ratios. The discount factor, β, influences how much households care about future consumption and is related to loan-to-value ratios. The parameters of the bequest motive, b_0 and b_1, are most impactful on the ownership rates and mortgage debts of older households. A stronger bequest motive leads to older households being more likely to continue owning and less likely to use mortgage refinancing to extract equity. In particular, b_1 mainly captures the extent to which a bequest is a luxury good. ψ is mainly relevant for the default rate.

The calibrated values of our parameters are also shown in Table 1. We calibrate an $h^{min} = 0.8$, which implies that house sizes above 80% of the median house size is available to buy. We calibrate a housing share in utility η of 0.2. The elasticity of substitution between housing and non-housing consumption $\frac{1}{\phi}$ is calibrated to $\frac{1}{1.5} = 0.67$, close to Li et al. (2016). Our calibrated discount factor β is 0.92, within the range provided by previous studies (see e.g. Guren et al. (2021b) and Athreya et al. (2018)). The two parameters for the bequest motive $b_0 = 20$ and $b_1 = 1$. Importantly, the calibrated value for the default utility cost is $\psi = 0.15$, which is equivalent to a 0.7% life time consumption loss. This number is low, compared to 25–50% of lifetime consumption estimated in the earlier literature.

5.2 Fit to life-cycle moments

Figure 4 examines the fit of our calibration in terms of life-cycle moments by comparing the model generated moments and compares it to data from the 2001 Survey of Consumer Finances (SCF). Panel (a) of Figure 4 plots lifecycle homeownership rates, defined as the share of homeowners as a share of all households in the model. Panel (b) of Figure 4 plots lifecycle loan-to-value ratios. Panel (c) of Figure 4 plots lifecycle payment-to-income ratios, defined as the ratio of mortgage plus property tax and insurance payments divided by the borrower's income in the model, and defined as the amount of mortgage payment (which for most households includes property taxes and insurance as escrow) divide by the borrower's income in the 2001 SCF data. Panel (d) Figure 4 plots lifecycle debt-to-income ratios, defined as the amount of mortgage balance divided by income. Given the limited number of free parameters, our model matches these lifecycle moments well. Importantly, it captures the increase in homeownership rate and decreasing mortgage balances by age, and tehreby capturing the joint household housing tenure choice and mortgage debt choice.

[Figure 4 inserted here]

We use moments that are not targeted in the calibration to further assess the performance of our baseline. Specifically, we compare the distribution of PTI by LTV at mortgage origination, house values, and annual rents simulated in our model to the data for all owners. As emphasized in Ganong and Noel (2023) and Low (2023b), income shocks play a major role in driving mortgage default, matching the payment-to-income ratio by LTV is important in terms of predicting mortgage default. Fitting the distribution of house values and annual rents is important for capturing the downsizing motive of default. Figure 5 plots model fit in terms of these non-targeted moments. Although not directly targeted in the calibration, our model matches the distribution of PTI by LTV, house values, and annual rents well.

[Figure 5 inserted here]

5.3 Implications for mortgage default

We use our model to examine its implications for mortgage default. Figure 6 presents the results. Panel (a) of Figure 6 plots the fit of the model in terms of default rates. We find that the model fits well in terms of default rates by loan-to-value (LTV) bins, for both abovewater and underwater households.

[Figure 6 inserted here]

Panel (b) of Figure 6 plots the average income change among defaulters as a fraction of mortgage payment. We find significant average income loss among the defaulters, comparable to the size of mortgage payment for all underwater borrowers, consistent with Ganong and Noel (2023) and consistent with limited strategic default behavior. Interestingly, Panel (b) of Figure 6 suggests that the income change prior to default decreases with LTV, in sharp contrast to pure negative-equity driven strategic default which would imply defaulter income changes that increase with LTV. The reason for this is the positive correlation between income and house prices induced by our aggregate state s: times of house price declines coincide with times of income declines, leading to greater observed income declines for defaulting underwater households.

Panel (c) of Figure 6 plots the foreclosure/sale/cure rates by LTV. Positive equity defaulters are more likely to sell or cure their mortgages, whereas negative equity defaulters are more likely to have their homes be foreclosed on. Therefore, while there is limited strategic default in the sense of pure negative-equity driven default in our model, the model still implies a relationship between negative equity and eventual foreclosure completion conditional on default, as is consistent with Palmer (2024) and Cespedes et al. (Forthcoming).

We also examine the model-implied average income change conditional on the type of default resolution (i.e. Foreclosure, Cure, or Sale) in the period following default in Appendix Figure A.3. Curing typically requires a positive income shock after defaulting, consistent with the borrowers being hit with an a negative income shock prior to default and being unable to afford their mortgages without an income recovery. Lower LTV households experience a larger variation in terms of income change relative to mortgage payments due to their lower mortgage payment. For below 60% LTV (positive equity) borrowers, borrowers hit with a further negative income shock after defaulting sell their homes, which is consistent with their potential demand to downsize. Above 60% LTV, the decision to sell or foreclose after defaulting is less related to income changes following default and more related to feasibility, whereas the decision to cure continues to rely on a large positive income shock, consistent with a central role for liquidity in driving the initial default decision.

5.4 Analysis of flow payoffs

5.4.1 Lower cost of renting

Our model suggests that negative equity by itself does not necessarily create large financial incentives to default if the alternative of renting remains unattractive, and that flow utility are central to the households' incentives to default. To examine this effect more closely in a counterfactual, we simulate a 10% one-time permanent decrease in real rent and examine the resulting default rate increases across the LTV distribution. Based on Figure 2 and Appendix Figure A.4, a 10% decline in real rent is roughly the maximum of what some borrowers experienced during the house price crash period of 2007–2012, though it was not permanent ex post.

Panel (a) of Figure 7 shows that in this counterfactual, default rates rise by about 5 percentage points for households with 130-140% LTV and for households with 140%+ LTV. The effect declines with LTV, and households with under 80% LTVs' default rates are unaffected by rent declines. This suggests that flow utility considerations may be more important for household default behavior when they are already underwater and potentially hit by an income shock, and is suggestive of a "triple trigger" model of default consisting of negative equity, income shocks, and flow utility shocks. As flow utility shocks become more common, for example due to climate catastrophes making the home less attractive as a place to live, this model of default may become more relevant.

[Figure 7 inserted here]

Panel (b) of Figure 7 shows that foreclosure rates conditional on default rise by about 2 percentage points when households expect real rents to have fallen by 10% permanently. This rise in foreclosure rates conditional on default is relatively uniform for households with 70% or higher LTV. As defaulting households in our time period typically face severe liquidity shocks (Ganong and Noel, 2023), the effort they subsequently exert in terms of preventing eventual foreclosure as it relates to rent declines is indicative of flow utility considerations being relevant to household decision making. We test this model prediction in Section 6.

5.4.2 Adjustment of housing size

An important component of the flow payoff comparison between continuing to own and defaulting is the ability to downsize after defaulting, thereby saving on rent. That is, the relevant counterfactual may not be renting the same size of house, but rather renting a smaller unit. This downsizing possibility may be optimal for households who experience an income shock and therefore have a lower demand for space. We examine this possibility in Figure 8, which plots the change in house size among households who underwent foreclosure.

[Figure 8 inserted here]

As Figure 8 shows, most households who undergo foreclosure in our model do downsize, which is consistent with the negative income shock they experienced. Approximately 74% of foreclosed households downsize to between -66% to -33% of their original house size, whereas 25% of foreclosed households downsize to less than or equal to -66% of their original house size. Only 1% has a house size that is more than -33% of their original house size. The significant downsizing following foreclosure is consistent with the negative income shock that was experienced by the defaulters in our model.

6 Further external validity

Our model implies that household foreclosure decisions should be correlated with the flow utility value of renting versus owning, and that there should be fewer foreclosures conditional on default in areas with higher rent growth. We study this prediction empirically using a CBSA-level measure of effective rents per square foot from CoStar, which are asking rents for new tenants net of concessions such as a free month of rent, and mortgage servicer data from CRISM, which includes information on mortgage performance matched with credit bureau data that contains information on any outstanding second liens. We limit our sample to first-lien, owner-occupied mortgages. Summary statistics for our main sample are in Table 2.

Since many loans with moderate and even severe delinquency eventually cure, we limit our sample to loans that experience 90-day default and test whether the local rent growth experienced by that borrower has any statistical effect on whether they eventually are foreclosed upon. The sample therefore contains one observation per loan, at the time of the 90-day default and the dependent variable is an indicator of foreclosure completion. This is a similar exercise to Figure 7b in the counterfactual exercise discussed above where rents fall by 10 percent. To facilitate the use of an instrument for rent growth discussed below, we also limit the sample to loans originated prior to 2008.

To this end, we run the following linear probability model:

$$D_i = \beta_1 \Delta \ln(\text{rent}_{ot(i)}) + \beta_2 LTV_i + \zeta \mathbf{X_i} + \gamma_{t(i)} + \psi_{o(i)} + \delta_i + \epsilon_i$$

where D_i is an indicator of whether loan i is eventually foreclosed upon multiplied by 100.[11] The main right-hand side variable ($\Delta \ln(Rent_{ot(i)})$) is the effective rent growth per square foot associated with loan i from that loan's origination date (o) to the date of 90-day default (t(i)). Our measure of the current LTV_i is created using the sum of the outstanding first-lien mortgage balance and any outstanding balances on second liens in the numerator and the purchase price updated using a county-level house price index. The $\mathbf{X_i}$ vector of additional characteristics includes the monthly mortgage payment at the time of default (including

[11] We consider a foreclosure completed if the loan status subsequently becomes "R" or "L", which stand for real-estate owned or liquidated respectively.

escrow payments for property taxes and insurance), an indicator for whether the loan is fixed rate, and two measures of local economic conditions: the average wages in that county and year and the county-level annual unemployment rate. Last, we include fixed effects for the year of default ($\gamma_{t(i)}$), the year the loan was originated ($\psi_{o(i)}$), and state (δ_i). The year fixed effects capture any countrywide macroeconomic events, the origination year fixed effects control for time since origination, and state fixed effects capture any fixed factors related to the state, such as state-level recourse laws. Standard errors are clustered by the year of 90-day default. Our main coefficient of interest is β_1, which captures the degree to which probability of eventual foreclosure is affected by changes in the cost of renting since loan origination. We expect β_1 to be negative, indicating that the more rental costs increased, the lower the probability of eventual foreclosure.

The results are in Table 3. All the regressors are normalized to be mean zero, standard deviation of one. In column (1), we only include loan-level covariates. In column (2) and (3) we add in measures of local economic conditions. The addition of these variables has little impact on the coefficient on rent growth, which is statistically significant and negative. The coefficient on rent growth implies that a one standard deviation increase in rent growth (which according to Table 2 is an increase of about 8.5 percentage points) results in a 1.5–1.7 percentage point decline in the probability of eventual foreclosure. In other words, a 10 percentage point decline in rent growth, would increase foreclosure rates by 1.7–2 percentage points. This is relative to an average foreclosure rate of 33.6 percent in this sample of defaulted loans. This is on par with the results from the model displayed in Figure 7b. The other coefficients with significant coefficients are LTV, whereby a higher LTV is positively correlated with the probability of eventual foreclosure conditional on default, also consistent with our model prediction in Figure 6c.

An important potential confounder to our results is that rent growth may be correlated with local economic conditions beyond those captured by our controls. To address this issue, we instrument for rent growth using a measure of the share of banks by CBSA that became subject to stress testing after the GFC created by Gete and Reher (2018). Gete and Reher (2018) show that as mortgage supply contracted in these markets, rent growth increased as demand for rental properties grew. They show that the change in rents due to this channel are unrelated to local economic conditions and unrelated to origination conditions for loans originated prior to 2008.

The result in column (4) indicates once we instrument for rent growth using the Gete and Reher (2018) instrument, our estimated effect of rent growth on foreclosure completion is larger. Specifically, a one standard deviation increase in rent growth lowers foreclosure completions by over 6 percentage points. This larger magnitude compared to our OLS estimates in columns (1) and (3) is suggestive evidence that rent growth may actually be negatively correlated with unobserved positive economic conditions, perhaps due to unobserved negative economic conditions increasing rental demand relative to owning over the time period (Foote et al., 2018), making our OLS estimates downwardly biased in terms of magnitude.

7 Discussion

Our paper emphasizes the central role of flow payoffs in evaluating models of household behavior. While the earlier literature tended to focus their discussion of strategic behavior on the role of negative equity and income, the combination of which gives rise to "double trigger" default that is caused by a combination of negative equity and income shocks, our analysis highlights that flow payoffs is also an important component of strategic behavior. This in turn suggests that "triple trigger" effects where income shocks, negative equity, and shocks to the flow utility of owning versus renting naturally emerges as a candidate benchmark model for mortgage default, relative to the "double trigger" model typically evaluated in the academic literature.

Our results also have implications for understanding the 2020s housing market. Rent to price ratios are comparable between 2001 and 2009 (Loewenstein and Willen, 2023), so our calibration accurately captures the housing crash period during which underwater default is most salient. In more recent years, rent to price ratios have fallen by about 30% relative to 2001 (Loewenstein and Willen, 2023). Whether there are more strategic incentives to default in recent years should there be another housing crash depends on the reason why households in more recent times choose to own despite a lower rent to price ratio. If households choose to own due to an ownership premium or to avoid the risk of rent growth (Sinai and Souleles, 2005), then strategic default incentives may continue to be moderated even with a low initial rent to price ratio as long as the reasons that households choose to own (e.g., ownership premium and rent growth risk) are unchanged.

8 Conclusion

The lack of strategic mortgage default during the financial crisis has long posed a challenge to the literature on mortgage default, with many commentators suggesting that non-pecuniary costs such as shame and social management as the reasons (White, 2010b). We show that factoring in a more realistic process for rent is sufficient to largely eliminate the household strategic default incentives in a detailed quantitative model of mortgage default. Therefore, in sharp contrast to the earlier literature, we estimate the strategic benefits of defaulting on their mortgage to be limited for underwater households when rents are downward stable in times of steep house price declines.

Our paper has two important policy implications. First, our estimate that there are dramatically lower ex ante financial benefits of the defaulting by underwater households compared to the earlier literature has implications for policy design. For example, differences in default behavior during the 2008 housing crash has been shown to be the primary driver of the racial gap in housing returns (Kermani and Wong, 2021). Prior models of mortgage default would imply that, at least during the Great Recession when many households are underwater on their homes, the minority borrowers' higher foreclosure propensities is ex ante financially beneficial even if they may have turned out to be ex post financially costly. This in turn implies that liquidity-based policies may be ex ante financially costly for households by further disincentivizing financially beneficial strategic default. Our model instead suggests that defaulting over the Great Recession period is ex ante costly, and that liquidity policies are ex ante financially beneficial, thus offering a more realistic interpretation of the effects of policy such as the Home Affordable Modification Program (HAMP).

Second, our paper adds to the theoretical case for the effectiveness of cashflow based policies, such as mortgage forbearance, for reducing household default. Empirically, these policies have been found to be more cost effective than policies targeting home equity, such as loan modifications, in terms of preventing default (Ganong and Noel, 2020). Our model adds to the generalizability of these results by suggesting that they do not have to rely on factors such as morality, emotional attachment, or other non-pecuniary costs, that may vary across cultures and over time, being very large. Indeed, White (2010a) prominently argued for a change in Americans' moral attitudes towards strategic default as the housing crisis unfolded.[12]

[12]See a description in the NYTimes HERE.

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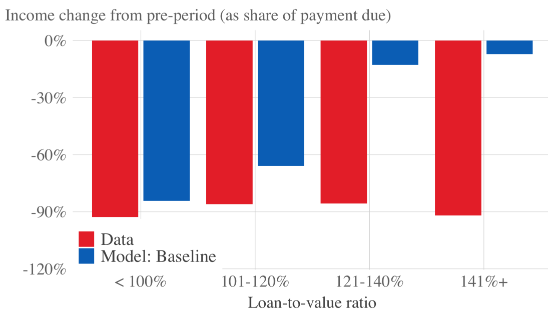
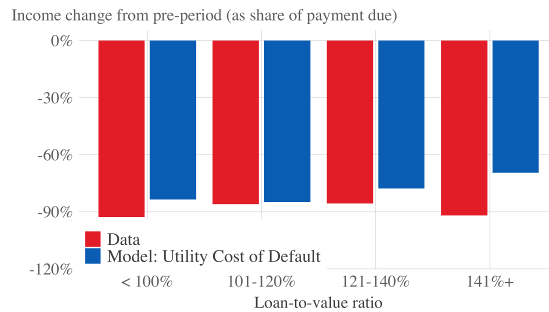
Figure 1: Income changes conditional on default implied by Campbell and Cocco (2015)'s model, compared with Ganong and Noel (2023) data

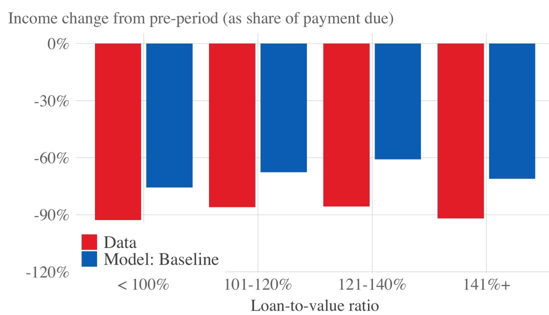
Note: This figure presents the results of the income change conditional on default implied by Campbell and Cocco (2015)'s model, as compared with the income declines in Ganong and Noel (2023)'s bank account data. Panel (a) presents the income changes conditional on default in the model without any non-pecuniary default stigmas in blue, as compared with the data in red. Panel (b) adds a high default stigma to the model worth 25% of life-time consumption, with results plotted in blue, compared to the same data in red. Panel (c) presents the results of the Campbell and Cocco (2015) model without any stigma, but fixes real rent at constant 2001 levels.



(a) Campbell and Cocco (2015)'s model



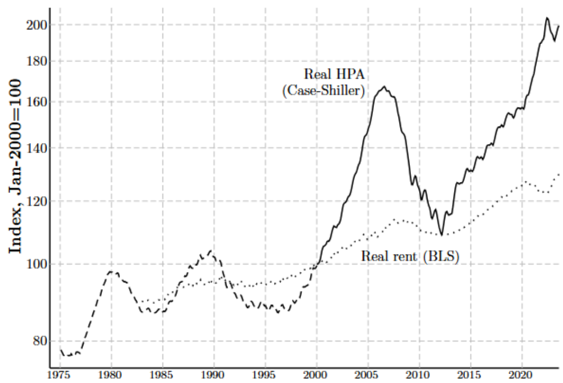
(b) Campbell and Cocco (2015)'s model with high default stigma



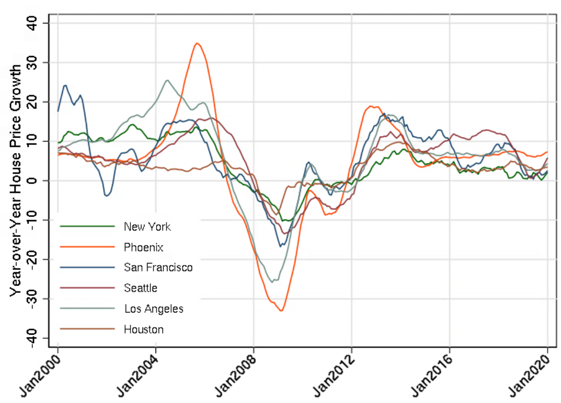
(c) Campbell and Cocco (2015)'s model with constant real rent

Figure 2: House prices, rents, and new tenant rents in a cross-section of cities

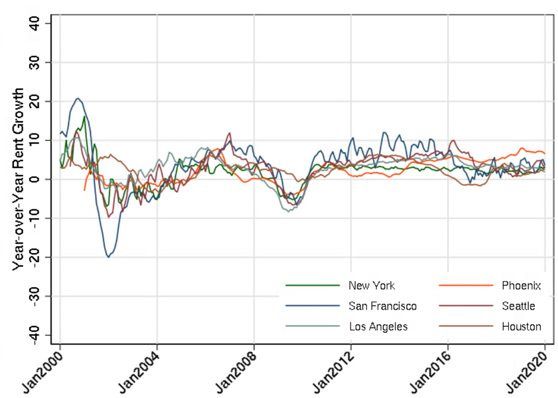
Note: Panel (a) of this figure is reproduced from (Loewenstein and Willen, 2023) and plots real house price indices (Case-Shiller) and rent (BLS) over time. Panel (b) of this figure presents nominal price growth from CoreLogic HPI and new tenant rent growth from CoreLogic SFRI for a selection of cities, where cities are included if they have a single-family rent index from 2024 going back to 2000. Adams et al. (2024) shows that CoreLogic SFRI inflation rates are a good approximation of new-tenant rent inflation from the BLS Housing Survey, which is representative sample of renter-occupied housing units. The percent of households with negative equity and more than 10% decline in rents are plotted in Appendix Figure A.4.



(a) Real House Prices and Rents (Loewenstein and Willen, 2023)



(b) Nominal House Price Growth in a Cross-section of Cities (CoreLogic HPI)



(c) Nominal New Tenant Rent Growth in a Cross-section of Cities (CoreLogic SFRI)

Figure 3: Dynamic Options of Households

Note: This figure summarizes the dynamic options of households as described in Section 4. Flagged Renters are renters with a foreclosure flag.

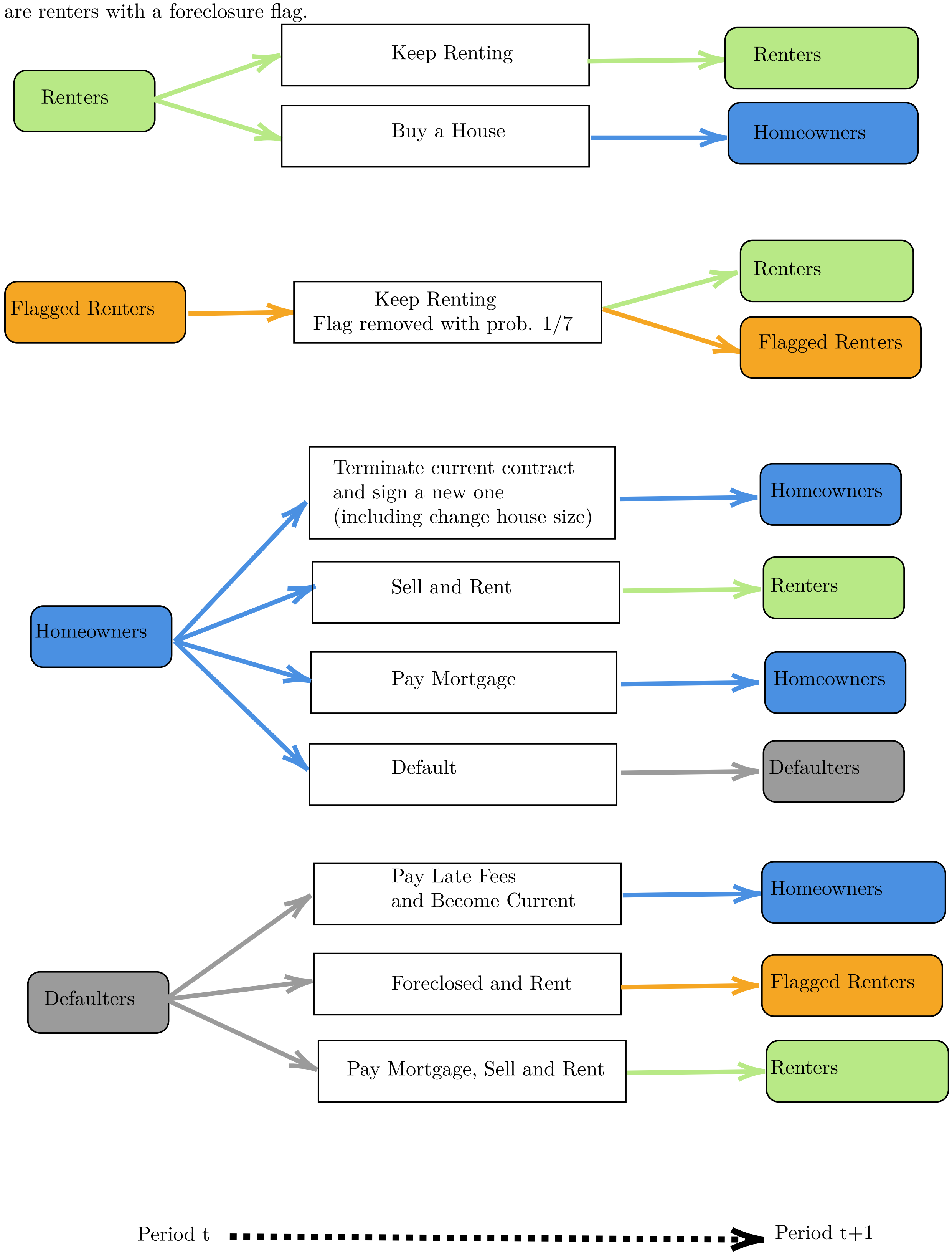
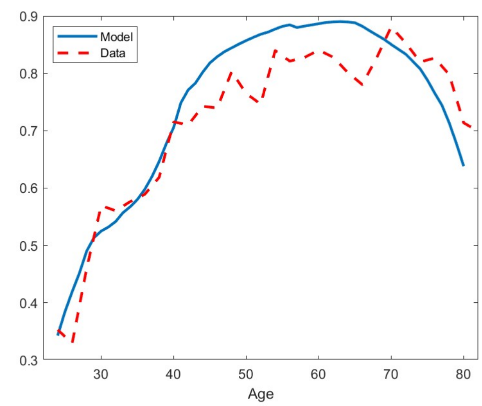
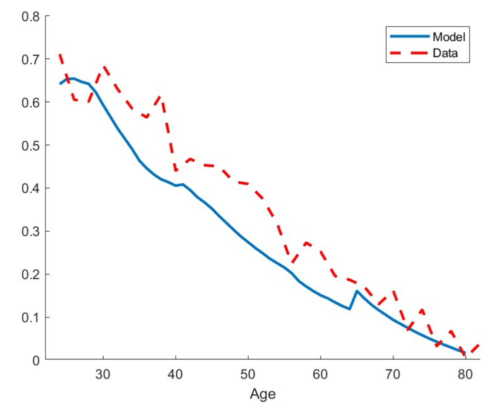


Figure 4: Calibration Results: Lifecycle Moments

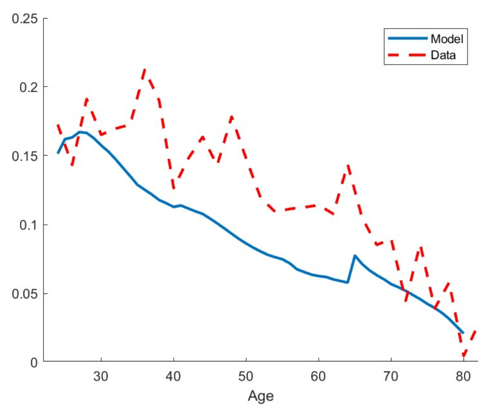
Note: This figure presents our model fit to the data given the parameters in Table 1 in terms of targeted moments. Panel (a) presents the homeownership rates by household age in the model (solid blue) and in the data (dashed red). Panel (b) presents the average LTV by borrower age. Panel (c) presents the average payment to income ratio by borrower age. Panel (d) presents the model-implied payment to income ratio and compares it to SCF data. Source: PTI and LTV are from the 2001 SCF; Homeownership rates from the 2001 ACS; Default rates are from CRISM.



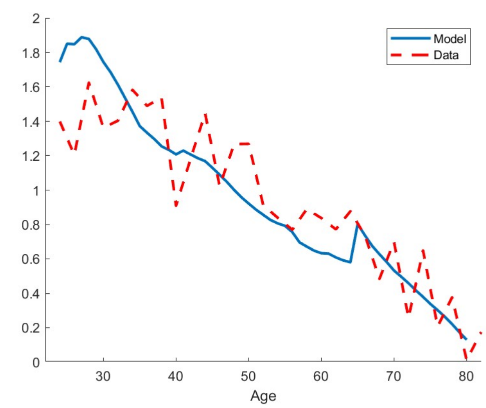
(a) Homeownership Rates



(b) Loan-to-Value Ratios



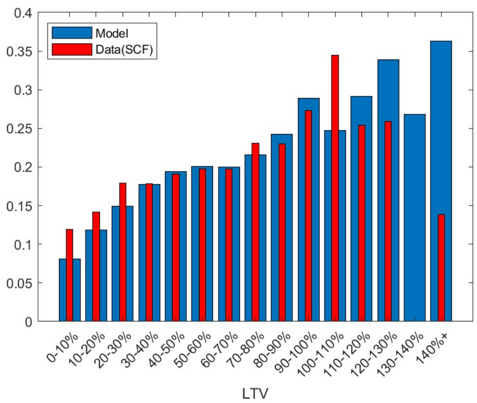
(c) Payment-to-Income Ratios



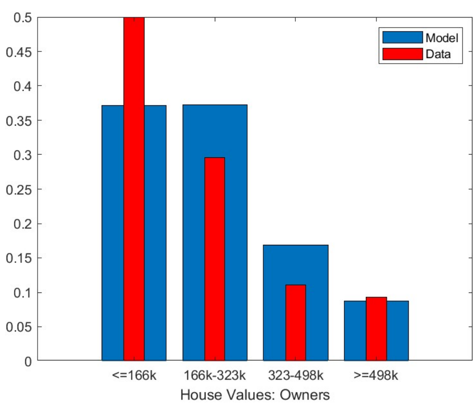
(d) Debt-to-Income Ratios

Figure 5: Model Fit in Non-targeted Moments

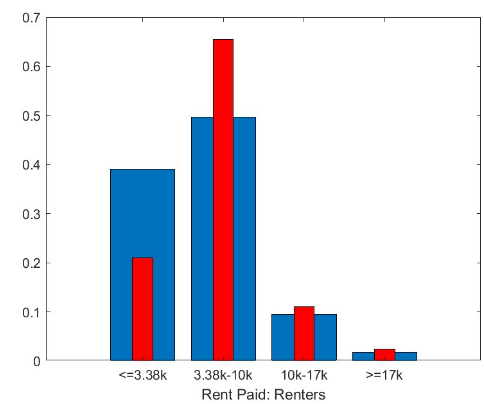
Note: This table presents the model fit in terms of distribution of house values among owners and annual rents among renters. Panel (a) presents the model-implied payment to income ratio and compares it to 2001 SCF data. Panel (b) presents the model implied distribution of home values among all the owners and compare it with 2001 SCF data. Panel (c) presents the model implied distribution of annual rents paid by renters and compares it with 2001 SCF data.



(a) Average Payment to Income Ratio by LTV



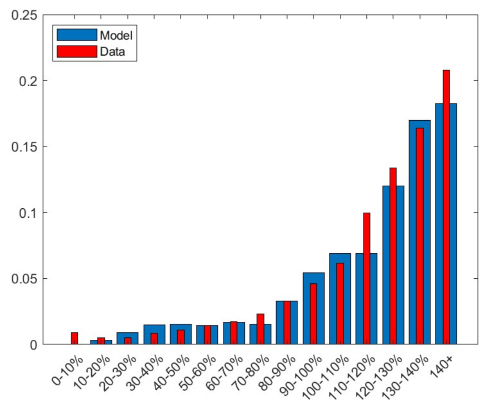
(b) Distribution of House Values Among Owners



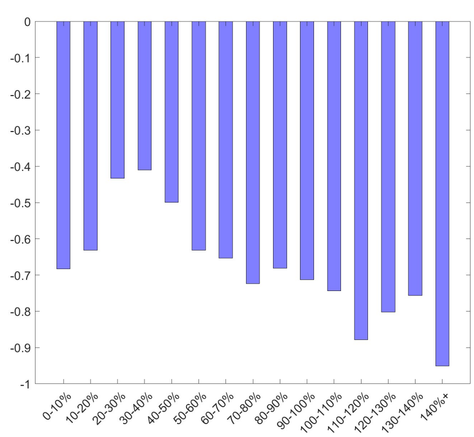
(c) Distribution of Annual Rents Among Renters

Figure 6: Model Implications for Mortgage Default

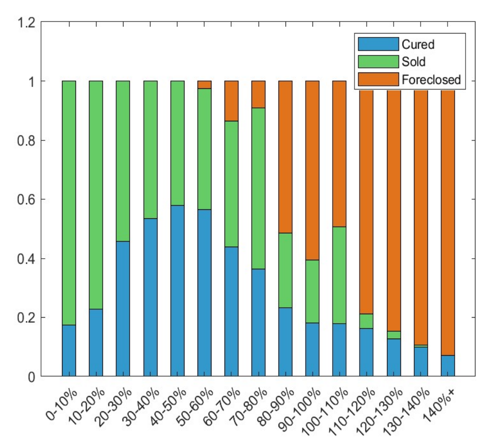
Note: These figures present the one-year income change among defaulters in our model, measured as a fraction of mortgage payment. Panel (a) presents the model-implied default rate by LTV and compares it to our CRISM data. Panel (b) plots the average one-year income change among defaulters relative to their mortgage payment. Panel (c) presents the foreclosure/sale/cure rates among defaulters by LTV. For Panel (a) to (c), model-implied LTVs are assumed to be measured with error with a standard deviation of 14%.



(a) Default Rate



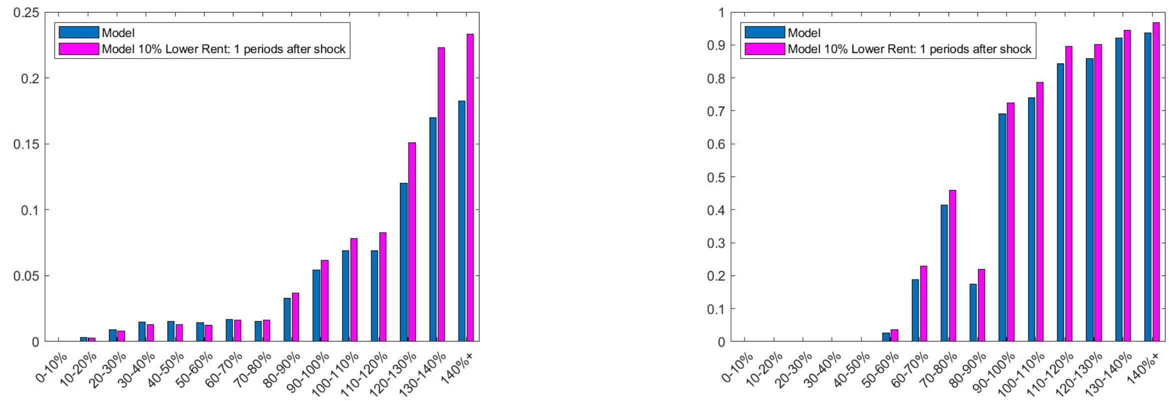
(b) Income Change Prior to Default as a Fraction of Mortgage Payment



(c) Foreclosure/Sale/Cure Rates by LTV among Defaulted Loans

Figure 7: Implication of a Permanent 10% Decline in Real Rent

Note: These figures present the short-run impact of a 10% decline in real rent on default and foreclosure one year after the rent shock. In Panel (a), default rate is defined as the number of households who become delinquent within the LTV bin by the total number of households within the LTV bin. In Panel (b), foreclosure rate among defaulters is defined as the fraction of delinquent households who undergo foreclosure by their mark-to-market LTV. For Panels (a) to (b), model-implied LTVs are assumed to be measured with error with a standard deviation of 14%.



(a) Default Rate by LTV

(b) Foreclosure Rate Conditional on Default

Figure 8: Housing Consumption Adjustment Among Foreclosed Households

Note: This figure presents the distribution of housing consumption adjustment among foreclosed households. Housing consumption adjustment is measured by the ratio difference of the size of the house they rent after foreclosure to that of the home they previously owned.

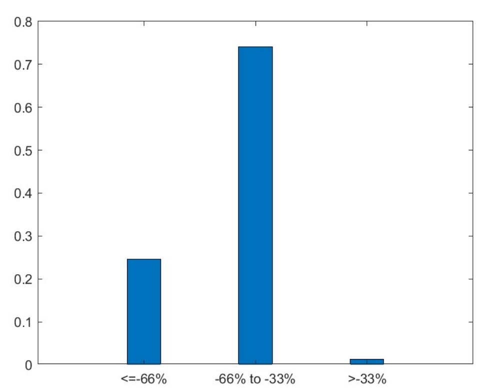


Table 1: List of Parameters

Note: This table presents the parameters we use in our model which are either directly calibrated by grid search via moment matching or taken from the literature. Calibrated parameters are described as "Calibrated," and a source is provided otherwise. Borrower birth, retirement, and exit ages are assumed and labelled as "Assumed."

Parameter	Value	Source
Demographics		
Household born age	23	Assumed
Household retirement	64	Assumed
Household exit age	85	Assumed
Preferences		
Inter-temporal elasiticty of substitution σ	2	Guren et al. (2021a)
Discount rate β	0.92	Calibrated
Housing share in utility η	0.2	Calibrated
Substitution between housing and non-housing consumption ϕ	1.5	Calibrated
Bequest motive b_0	20	Calibrated
Bequest motive constant term b_1	1	Calibrated
Utility cost of default ψ	0.15 (CEV 0.7%)	Calibrated
Asset		
Annual risk free interest rate	2%	Assumed
Annual inflation rate π	2%	Inflation target
Mortgage spread ζ_m	1.5%	FHFA & Federal Reserve Bank
Housing		
Annual property tax τ_h	1.5%	American Community Survey
Annual maintenance cost δ	1%	American Community Survey
Seller transaction cost k_s	6%	Sommer et al. (2013)
Buyer transaction cost k_b	2%	Sommer et al. (2013)
Mortgage origination cost (fixed) ω_0	$2000 2001 dollars	Agarwal et al. (2013)
Mortgage origination cost (variable) ω_1	1%	Agarwal et al. (2013)
Downpayment requirement χ	5%	LTV distribution
Cap on PTI PTI^{limit}	0.50	Pre-2000 standard
Term N	30	Assumed
Minimum purchase size $h^{\min}$	0.8	Calibrated
Foreclosure flag removal probability	1/7	Flag stays for 7 years in expectation
Average price $\bar{P}$ per unit of h	$162,169	Estimated
Annual rent $\bar{R}$ per unit of h^r	$16525	Estimated
Aggregate State		
$P(recession\|recession)$	0.37	Campbell et al. (2021)
$P(recession\|expansion)$	0.18	Campbell et al. (2021)
Income		
Income Profile $\bar{w}_j$		PSID
Tax schedule τ_0	4.787	Kaplan et al. (2020)
Tax schedule τ_1	0.151	Kaplan et al. (2020)
Income Process ρ	0.979	Guvenen et al. (2014)
Income Process p_1	0.49	Guvenen et al. (2014)
Income Process μ_{1E}, μ_{2E}	0.119, -0.026	Guvenen et al. (2014)
Income Process μ_{1R}, μ_{2R}	-1.02, 0.094	Guvenen et al. (2014)
Income Process $\sigma_1, \sigma_2, \sigma_\epsilon$	0.325, 0.001, 0.186	Guvenen et al. (2014)
House prices shocks		
Expansion to Expansion $\mu^P_{EE}, \sigma^P_{EE}$	0.02,0.057	Estimated
Recession to Recession $\mu^P_{RR}, \sigma^P_{RR}$	-0.017, 0.09	Estimated
Expansion to Recession $\pi_{ER}, \mu^P_{1,ER}, \sigma^P_{1,ER}, \mu^P_{2,ER}, \sigma^P_{2,ER}$	0.2, -0.0925, 0.0758, -0.021, 0.0708	Estimated
Recession to Expansion $\pi_{RE}, \mu^P_{1,RE}, \sigma^P_{1,RE}, \mu^P_{2,RE}, \sigma^P_{2,RE}$	0.22, 0.0013, 0.0293, 0.021, 0.061	Estimated

Table 2: Summary statistics

Note: This table summary statistics for our empirical analysis. The data is from the sample used for the regressions in Table 3, so is limited to loans that are originated before 2008 in CBSAs for which we have the IV from Gete and Reher (2018). Rent growth is from year of mortgage origination to year of first 90-day default. There is one observation per loan. *Source:* Authors' calculations using CRISM®; CoStar; BLS Local Area Unemployment Statistics; Census Annual County Population Estimates; and the Quarterly Census of Employment and Wages.

	Mean	Std
Foreclosure | 90-Day Default	33.6	47.2
Current LTV (%)	91.4	34.2
Monthly Mortgage Payment ($)	1560.2	1146.5
Fixed Rate (%)	0.7	0.4
$\Delta \ln(\text{Rent/Sq. Ft.})_{t,o}$	6.3	8.5
Unemployment Rate (%)	8.2	3.0
Average Wage ($,000)	46933.1	10228.5
N	250,435	

Table 3: Probability of Foreclosure Conditional on 90-day Default

Note: Dependent variable is an indicator of 90 day default conditional on future foreclosure completion multiplied by 100. The sample is limited to owner-occupied first-liens for which we have non-missing information for effective rents, wages, unemployment, and local population and that experienced a 90-day default. Each loan has one observation. Rent growth is the log change in the CBSA-level effective rent per square foot from CoStar at the time of loan origination relative to the time of the 90-day default. The monthly mortgage payment includes escrow payments for that loan. The average wage is for all covered employees in a given county and year and county employment is an annual count of total employees. Standard errors are clustered by year. All regressors are normalized to have mean zero and a standard deviation of one. Current LTV is a combined LTV measure calculated using the sum of the primary principal balance outstanding and any outstanding debt on home equity lines of credit and closed-end seconds as the numerator, and a house value updated using county-level house price indices in the denominator. The IV is from Gete and Reher (2018). *Source:* Authors' calculations using CRISM®; CoStar; BLS Local Area Unemployment Statistics; Census Annual County Population Estimates; and the Quarterly Census of Employment and Wages.

	Foreclosure (in percentage points)			
	(1)	(2)	(3)	(4)
Δ(Rent)	-1.72***	-1.60***	-1.52***	-6.13**
	(0.41)	(0.41)	(0.41)	(2.27)
Current LTV	5.25***	5.21***	5.17***	4.65***
	(0.29)	(0.29)	(0.28)	(0.43)
ln(Monthly Payment)	-0.44	-0.35	-0.32	-0.37
	(0.68)	(0.69)	(0.71)	(0.69)
ln(Average Wages)		-0.51***	-0.44***	-0.19
		(0.15)	(0.12)	(0.19)
Unemployment Rate			0.37	-0.82
			(0.42)	(0.74)
R^2_a	0.054	0.054	0.054	0.007
Observations	250,435	250,435	250,435	250,435
Year FEs	Y	Y	Y	Y
Close Year FEs	Y	Y	Y	Y
State FEs	Y	Y	Y	Y
FRM Dummy	Y	Y	Y	Y
Mean(Y)	33.6	33.6	33.6	33.6
Std Dev(Y)	47.2	47.2	47.2	47.2
Model	OLS	OLS	OLS	IV
F-Stat				1868

Internet Appendix

This appendix supplements the analysis of this paper. Below is a list of the sections contained in this appendix.

Table of Contents

A Details about the Campbell and Cocco (2015) model

The Campbell and Cocco (2015) assumes that rent-to-price ratios $\frac{R_{it}}{P_{it}}$ evolve as:

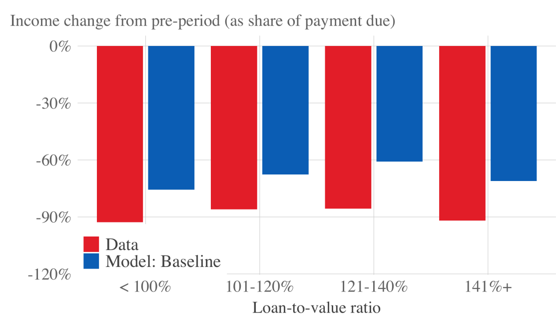
$$\frac{R_{it}}{P_{it}} = [\underbrace{i_{i,t}}_{\text{nominal rate}} - \underbrace{E_t(exp(\Delta p^H_{t+1} + \pi_t) - 1)}_{\text{expected nomial house price growth}} + \underbrace{\tau_p}_{\text{property tax}} + \underbrace{m_p}_{\text{maintenance}}], \tag{8}$$

which implies that, to the extent the nominal rate $i_{i,t}$ is pro-cyclical, $\frac{R_{it}}{P_{it}}$ is also pro-cyclical and falls during recessions. For example, a 4 percentage point decrease in $i_{i,t}$ between 2007 to 2010 implies that the $\frac{R_{it}}{P_{it}}$ fell from approximately 7% in 2007 to approximately 3% in 2010. In reality, rent-to-price rose from approximately 7% to about approximately 10% between 2007 and 2010 Loewenstein and Willen (2023), a three-fold difference relative to the model's assumption.

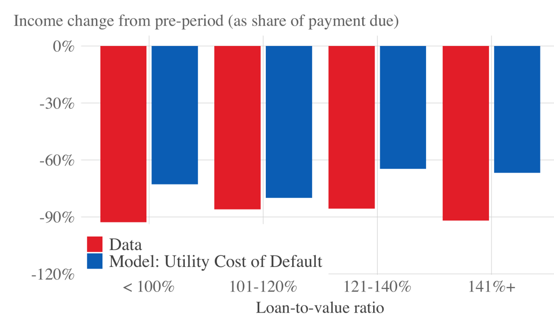
Panel (a) of Figure A.1 examines the Campbell and Cocco (2015)'s model with constant real rent, and finds that it largely fits the data in terms of income change conditional on default by borrower LTV. Panel (b) of Figure A.1 examines the Campbell and Cocco (2015)'s model with constant real rent as well as a high default stigma worth 25% of life-time consumption, which shows that relative to Panel (a) of Figure A.1 a high default stigma as little additional explanatory power.

Figure A.1: Income changes conditional on default implied by Campbell and Cocco (2015)'s model, compared with Ganong and Noel (2023) data, additional scenarios

Note: This figure presents the results of the income change conditional on default implied by Campbell and Cocco (2015)'s model, as compared with the income declines in Ganong and Noel (2023)'s bank account data. Panel (a) presents the results of the Campbell and Cocco (2015) model without any stigma, but fixes real rent at constant 2001 levels. Panel (b) adds a high default stigma to the model worth 25% of life-time consumption in addition to fixing real rent at 2001 level.



(a) Campbell and Cocco (2015)'s model with constant real rent



(b) Campbell and Cocco (2015)'s model with constant real rent and high default stigma

B Additional Model Results

Figure A.2: Model-Implied Moving Rates

Note: This figure presents our model's implied annual share of homeowners who move by their age. The model is as described in Section 4.

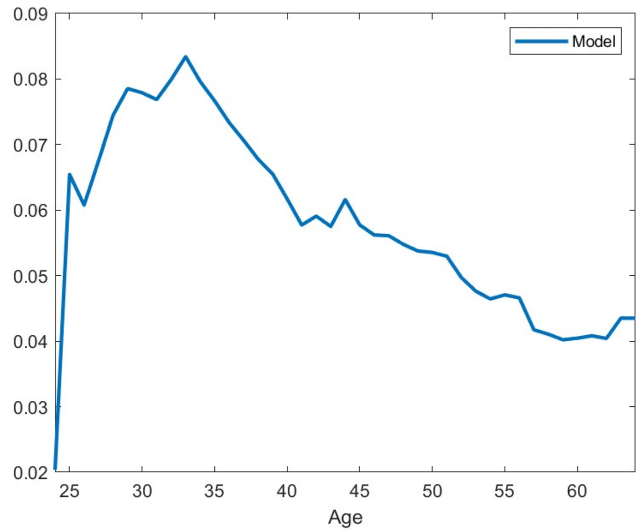
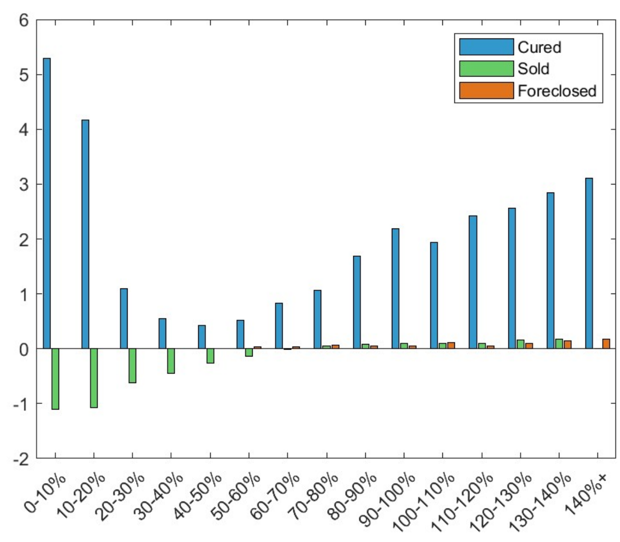


Figure A.3: Income Change Conditional on Default Resolution as a Fraction of Mortgage Payment

Note: This figure plots the average one-year income change among defaulters relative to their mortgage payment by type of default resolution (Foreclosed, Cured, or Sold). The model is as described in Section 4. Borrowers already experienced an average income drop during the defaulting period to making this decision, where the income change is as in Figure 6b, and are more likely to cure when their income recovers relative to a year prior. Model-implied LTVs are assumed to be measured with error with a standard deviation of 14%.

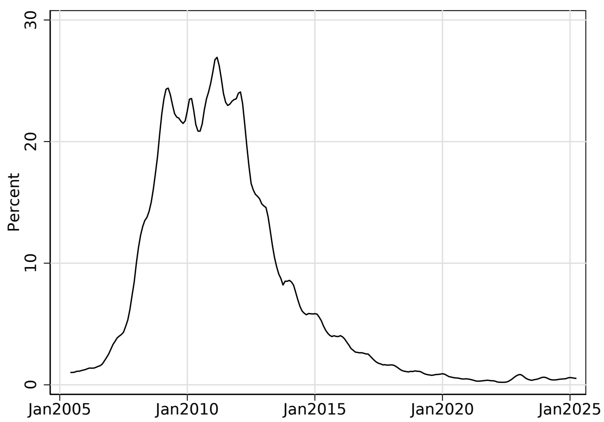


C Additional Exhibits

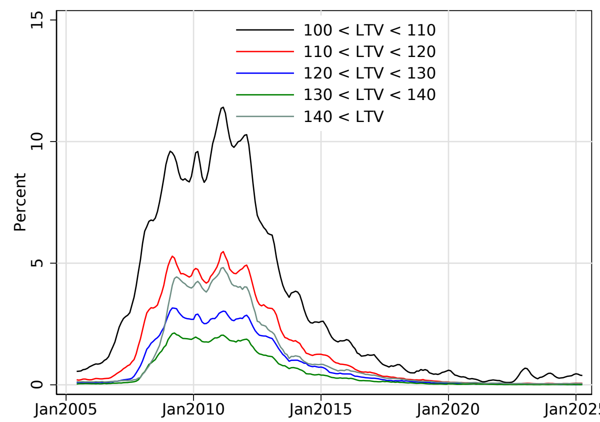
Figure A.4: Percent of Loans with Negative Equity and/or Rent Growth

Note: Figure A.4a is the percent of active loans with negative equity. Figure A.4b is the percent of loans with negative equity in the given LTV buckets. Figure A.4c is the percent of loans that have experienced at least a 10 percent decline in rents since origination. Figure A.4d is the percent of loans that have both negative equity and have experienced at least a 10 percent decline in rents since origination. Rents are measured using effective rents per square foot by CBSA from CoStar. Loan data is from CRISM, and LTVs are adjusted to account for second liens. Property values are updated using zip code house price indices from CoreLogic.

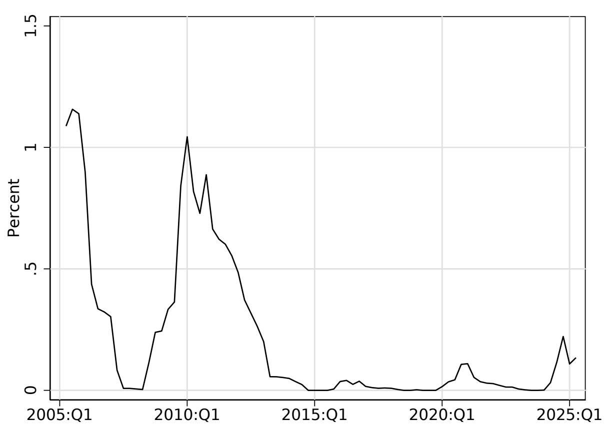
(a) Negative Equity



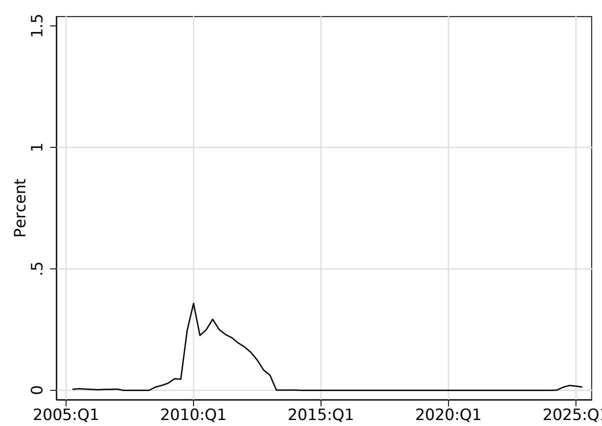
(b) Negative Equity by LTV



(c) Negative Rent Growth



(d) Negative Equity and Negative Rent Growth



D Household's recursive problem in our more detailed model of mortgage default

The state variables (Λ) of a household are their mortgage age n, owned house size h, mortgage payment m, saving in the risk-free asset k, current income shocks ϵ, current house price shocks ζ, current aggregate state $s \in \{E, R\}$, age j, and whether they have a default flag on file $\Omega \in \{0, 1\}$. To sum up, the household value function has nine states summarized by Λ:

$$\Lambda = (n, h, m, k, \epsilon, \zeta, s, j, \Omega). \tag{9}$$

At the beginning of each period, there are four types of households: (1) a renter with a clean foreclosure record $\Omega = 0$ and no owned house $h = 0$ makes decision on the size of house to rent and whether to become an owner starting from current period, (2) a homeowner with positive owned housing size $h > 0$ who makes the decision to change house size, sell and rent, pay mortgage, or default the next period, (3) a defaulted owner who is behind their mortgage payment who makes a decision to pay late fees and become current, get foreclosed on and rent, or pay mortgage, sell, and rent, and (4) a flagged renter with a foreclosure record on file $\Omega = 1$ makes decision on the size of house to rent. Figure 3 details the options of different types of households.

D.0.1 Renters' maximization problem

Households who enter the period with no owned housing ($h = 0$) choose between getting the service through the rental market by making decision on the size of house to rent, $h^r \in \{h_1^R, h_2^R, h_3^R, ..., h_J^R\}$ (option labeled as RR) and becoming owners by choose the size of house to buy h' and mortgage contract m' (option labeled as RO). The value of renters' maximization problem is:

$$V(n=0,h=0,m=0,k,\epsilon,z,\zeta,s,j,\Omega=0)=\max_{R,O}\{V^{RR}(.),V^{RO}(.)\}, \tag{10}$$

where $V^{RR}(.)$ is the value of continuing to be a renter, and $V^{RO}(.)$ is the value of becoming an owner, with the option labels RR and RO being in the superscripts. As renters do not have a mortgage, their mortgage age state n is in the missing state represented by zero. Their house size h, mortgage payment m, and default flag Ω are also zero. We mathematically define $V^{RR}(.), V^{RO}(.)$ next.

Continue to be renters

The value of continuing to be a renter is:

$$\begin{aligned} V^{RR}(0,0,0,k,\epsilon,\zeta,s,j,0) = \max_{h^r,k'}\{ & \frac{((1-\eta)c^{1-\phi}+\eta(h^r)^{1-\phi})^{\frac{1-\sigma}{1-\phi}}}{1-\sigma} \\ & + \beta E_{(\epsilon',\zeta',s')|(\epsilon,\zeta,s)}V(0,0,0,k',\epsilon',\zeta',s',j+1,0)\}, \\ s.t. \qquad c+k'+\bar{R}h^r = (1- & \tau(y(\epsilon,j)))y(\epsilon,j)+(1+r)k \end{aligned} \tag{11}$$

where the states in $V^{RR}(.)$ follow the same order as in Equations (9) and (10), $\bar{R}h^r$ is total rental payment, $(1-\tau(y(\epsilon,j)))y(\epsilon,j)$ is the after-tax income and rk is the return on risk free asset.

Become Owners The value of becoming an owner is:

$$V^{RO}(0,0,0,k,\epsilon,z,\zeta,s,j,0) = \max_{h',m',k'}\{\frac{((1-\eta)c^{1-\phi}+\eta(h')^{1-\phi})^{\frac{1-\sigma}{1-\phi}}}{1-\sigma}$$

$$+\beta E_{(\epsilon',\zeta',s')|(\epsilon,\zeta,s)}V(1,h',m',k',\epsilon',z',\zeta,s,j,0)\}$$

$$s.t.$$

$$\frac{m'(1-(1+r_m)^{-N})}{r_m P h'} < 1-\xi \qquad , \tag{12}$$

$$c+k'+(1+\tau_b)\bar{P}\zeta h'+(\delta+\tau_h)\bar{P}h' = (1-\tau(y(\epsilon,j))y(\epsilon,j)+(1+r)k$$

$$+(1-\omega_1)\frac{m'(1-(1+r_m)^{-N})}{r_m} - \omega_0 \mathbb{1}_{m>0}$$

$$\frac{m'}{y(\epsilon,j)} < PTI^{limit}$$

where the states in $V^{RO}(.)$ follow the same order as in Equations (9) and (10), $\frac{m'(1-(1+r_m)^{-N})}{r_m}$ is the amount of new mortgage loan, $(1+\tau_b)\bar{P}\zeta h'$ is the total cost of purchasing a new house, and $(\delta+\tau_h)\bar{P}h'$ is cost of maintenance and property tax. Downpayment requirement ξ and payment to income ratio cap PTI^{limit} both apply as the household gets a new mortgage loan. Following Boar et al. (2022), we assume that there is a constant mortgage closing cost ω_0 and a variable cost that is proportional to mortgage debt ω_1.

D.0.2 Homeowners' maximization problem

An homeowner, $h > 0$, with a mortgage contract m which was signed n years ago have four options: (1) continue with the current mortgage contract (option labeled as C), (2) get a new mortgage (refinance) without adjusting current house size or terminate the current mortgage by selling the house (and buying another house or not) (option labeled as N), (3) Sell the house and rent (option labeled as OR) (4) default on the mortgage (option labeled as D).

Thus, the value function V is given by the maximum value of these four options, with the option labels in superscripts:

$$V(n,h,m,k,\epsilon,\zeta,s,j,0)=\max_{C,N,OR,D}\{V^C(.),V^N(.),V^{OR}(.),V^D(.)\}. \tag{13}$$

For notation simplicity, in Equation (13) and in all subsequent value functions we write the states in the same order as in Equations (9). In Equation (13), the last state of $V(.)$, the foreclosure flag Ω, is set to zero because only defaulters can get foreclosed on and gain the foreclosure flag as flagged renters.

Continue with current mortgage contract

Owners who decide to continue with their current mortgage contract choose current consumption c and saving k'. The value of staying with the current mortgage contractis:

$$\begin{aligned}
&V^C(n,h,m,k,\epsilon,\zeta,s,j,0)=\max_{k'}\frac{((1-\eta)c^{1-\phi}+\eta(h)^{1-\phi})^{\frac{1-\sigma}{1-\phi}}}{1-\sigma}+\\
&\beta E_{(\epsilon',\zeta',s')|(\epsilon,\zeta,s)}[\mathbb{1}_{n<N}V(n+1,h,m,k',\epsilon',\zeta',s',j+1,0)+\mathbb{1}_{n=N}V(0,h,0,k',\epsilon',\zeta',s',j+1,0)],\\
&s.t.\;\; c+k'+(\delta+\tau_h)\bar{P}h=(1-\tau(y(\epsilon,j)))y(\epsilon,j)+(1+r)k-\frac{m}{(1+\pi)^n}
\end{aligned} \tag{14}$$

where $\mathbb{1}_{n=N}$ is an indicator function that takes 1 if this is the last period of the mortgage contract. In other words, starting from the next period, the household has no mortgage debt. $\bar{P}$ is the stationary house price which does not vary with business cycles and $\delta\bar{P}h$ is the maintenance cost and $\tau_h\bar{P}h$ and property tax which are assumed to be proportional to the average house price $\bar{P}$. In other words, maintenance costs and property tax do not vary with business cycles. $(1-\tau(y(\epsilon,j)))y(\epsilon,j)$ is the after tax income, rk is the return on the saving, and $\frac{m}{(1+\pi)^n}$ is the real mortgage payment for a mortgage contract that was signed n periods ago with an inflation rate of π. Note that our model features declining real mortgage payments over time due to inflation.

Refinance or change house size

Owners who decide to refinance or adjust house size will first terminate the current mortgage contract and then get a new mortgage contract (m') and a new house (h').The value of getting a new loan is:

$$
\begin{aligned}
V^N(n,h,m,k,z,\zeta,s,j,0) &= \max_{k',h',m'} \frac{((1-\eta)c^{1-\phi}+\eta(h')^{1-\phi})^{\frac{1-\sigma}{1-\phi}}}{1-\sigma} \\
&\quad + \beta E_{(\epsilon',\zeta',s')|(\epsilon,\zeta,s)} V(1,h',m',k',z',\zeta',s',j+1,0) \\
&\quad s.t. \\
\frac{m'(1-(1+r_m)^{-N})}{r_m \bar{P}\zeta h'} &< 1-\xi \\
\frac{m'}{y(z,\epsilon,j)} &< PTI^{limit} \\
c + k' + (\delta+\tau_h)Ph + (\tau_s \bar{P}\zeta h + \tau_b \bar{P}\zeta h')\mathbb{1}_{h\neq h'} &= (1-\tau(y(\epsilon,j))y(\epsilon,j) \\
&\quad + (1+r)k + \bar{P}\zeta h - D(m,n) - \bar{P}\zeta h' \\
&\quad + (1-\omega_1)\frac{m'(1-(1+r_m)^{-N})}{r_m} - \omega_0 \mathbb{1}_{m'>0}
\end{aligned}
, \qquad (15)
$$

where $\mathbb{1}_{h\neq h'}$ is an indicator function that takes value 1 if the household adjusts their house size (i.e. $h \neq h'$). Specifically, $\tau_s \bar{P}\zeta h$ is the cost of selling the current house and $\tau_b \bar{P}\zeta h'$ is the cost of purchasing a new one. $D(m,n)$ is the loan balance on the current mortgage contract which depends on the scheduled mortgage payment m and the number of payments households have made n, and $\bar{P}\zeta h - D(m,n)$ is the home equity. $\bar{P}\zeta h'$ is the value of the new house and $\frac{m'(1-(1+r_m)^{-N})}{r_m}$ is the amount of new mortgage loan. We assume that there is a mortgage origination cost which has a constant part ω_0 and a variable part proportional to the total loan amount, ω_1. There are two additional constraints at mortgage origination. First, loan to value ratio has to be lower than $1-\xi$ which is equivalent to a minimum downpayment of ξ. Second, the schedule mortgage to income ratio cannot exceed PTI^{limit}.

Sell and rent

Owners who decide to sell and become renters will first terminate the current mortgage contract and receive their housing service from the rental market. The value of selling and renting is:

$$
\begin{aligned}
V^{OR}(n,h,m,k,z,\zeta,s,j,0) &= \max_{k',h^r} \frac{((1-\eta)c^{1-\phi}+\eta(h^r)^{1-\phi})^{\frac{1-\sigma}{1-\phi}}}{1-\sigma} \\
&\quad + \beta E_{(\epsilon',\zeta',s')|(\epsilon,\zeta,s)} V(0,0,0,k',z',\zeta',s',j+1,0) \\
s.t.\quad c+k'+\bar{R}h^r &= (1-\tau(y(\epsilon,j))y(\epsilon,j)+(1+r)k \\
&\quad + (1-\tau_s)\bar{P}\zeta h - D(m,n)
\end{aligned}
, \qquad (16)
$$

where Rh^r is rental cost. Specifically, $(1-\tau_s)\bar{P}\zeta h - D(m,n)$ is profit of selling the house net of transaction cost τ_s and τ_b and outstanding debt $D(m,n)$.

Default

Owners who choose to default (become delinquent) do not pay the mortgage and incur a direct utility cost ψ, which captures the potential consequence of late payments such as a decline in credit score or a potential reputation concern.

The value of default on current mortgage contract is:

$$
\begin{aligned}
V^{D}(n,h,m,k,\epsilon,\zeta,s,j,0) &= \max_{k'} \frac{((1-\eta)c^{1-\phi}+\eta(h)^{1-\phi})^{\frac{1-\sigma}{1-\phi}}}{1-\sigma} - \psi \\
&\quad + \beta E_{(\epsilon',\zeta',s')|(\epsilon,\zeta,s)} VQ(n,h,m,k',\epsilon',\zeta',s',j+1,0) \\
s.t.\quad c+k'+(\delta+\tau_h)\bar{P}h &= (1-\tau(y(\epsilon,j)))y(\epsilon,j)+(1+r)k
\end{aligned}
, \qquad (17)
$$

where $VQ(.)$ is the value of starting the next period as delinquent owners.

Note that while we assume defaulting homeowners do not pay their mortgage for a year, we still assume they pay the property tax and maintenance $(\delta+\tau_h)\bar{P}h$. This makes the possibility of curing their mortgage more natural in the subsequent period. To the extent that households anticipating foreclosure also do not pay property taxes and maintenance, our default penalty may be understated by the amount $(\delta+\tau_h)\bar{P}h$, which with our calibrated $\delta = 1.5\%$ and $\tau_h = 1\%$ is a financial cost of \$4,054 for our median house size of \$162,169.[1]

D.0.3 Defaulted owners' maximization problem

Defaulted owners have three options: (1) become current on their debt by paying all outstanding dues (missed payment and current payment), late fees, and applicable interest on the late payment (option labeled as U); (2) pay the outstanding dues, sell the house and rent (option labeled as S); (3) get foreclosed on and start next period as rents with foreclosure flag (option labeled as F).

The value of default owners Vq is given by the maximum value of these three options, with the option labels in superscripts:

$$VQ(n,h,m,k,\epsilon,\zeta,s,j,0) = \max_{U,S,F}\{VQ^U(.), VQ^S(.), VQ^F(.)\}. \tag{18}$$

Become current

The value of becoming current on mortgage debt is:

$$\begin{aligned} VQ^U(n,h,m,k,\epsilon,\zeta,s,j,0) = \max_{k'} & \frac{((1-\eta)c^{1-\phi}+\eta(h)^{1-\phi})^{\frac{1-\sigma}{1-\phi}}}{1-\sigma} + \\ & \beta E_{(\epsilon',\zeta',s')|(\epsilon,\zeta,s)}[\mathbb{1}_{n<N-2}V(n+2,h,m,k',\epsilon',\zeta',s',j+1,0) \\ & + \mathbb{1}_{n>=N-2}V(0,h,0,k',\epsilon',\zeta',s',j+1,0)] \\ & s.t. \\ c+k'+(\delta+\tau_h)\bar{P}h + \frac{m}{(1+\pi)^{n+1}} + (1+r_m+\kappa)\frac{m}{(1+\pi)^{n+1}} = & (1-\tau(y(\epsilon,j)))y(\epsilon,j) \\ & + (1+r)k \end{aligned}, \tag{19}$$

[1] This can be calculated as \$162,169*$(\delta+\tau_h)$ = \$162,169*0.025 = \$4,054.

where $(1+r_m+\kappa)\frac{m}{(1+\pi)^{n+1}}$ is the interest (r_m) and penalty (κ) for the late mortgage payment and $\frac{m}{(1+\pi)^{n+1}}$ is the amount due in the current period.

Pay, sell and rent

It is possible for delinquent households to sell the house, pay the outstanding dues, and rent. Note that underwater households may prefer this option to getting foreclosed as it allows them to get another house in the near future. The value of this option is:

$$\begin{aligned} VQ^S(n,h,m,k,\epsilon,\zeta,s,j,0) = \max_{k',h^r} & \frac{((1-\eta)c^{1-\phi}+\eta(h^r)^{1-\phi})^{\frac{1-\sigma}{1-\phi}}}{1-\sigma} \\ & + \beta E_{(\epsilon',\zeta',s')|(\epsilon,\zeta,s)} V(0,0,0,k',\epsilon',\zeta',s',j+1,0) \\ & s.t. \\ c+k'+(1+r_m+\kappa)\frac{m}{(1+\pi)^{n+1}}+\bar{R}h^r = & (1-\tau(y(\epsilon,j)))y(\epsilon,j) \\ & + (1+r)k + (1-\tau_s)\bar{P}\zeta h - D(m,n+1) \end{aligned}, \quad (20)$$

where $(1+r_m+\kappa)\frac{m}{(1+\pi)^{n+1}}$ is the interest (r_m) and penalty (κ) for the outstanding mortgage payment carried from last period and $(1-\tau_s)\bar{P}\zeta h - D(m,n+1)$ profit of selling the house net of transaction cost and mortgage debt. Note that after households pay the outstanding due, the remaining debt becomes $D(m,n+1)$.

Foreclosed and rent If delinquent households decide to walk away from their debt, their household get foreclosed on and they will start next period with a foreclosure flag which prevents them from becoming owner. The value of this option is:

$$\begin{aligned} VQ^F(n,h,m,k,\epsilon,\zeta,s,j,0) = \max_{k',h^r} & \frac{((1-\eta)c^{1-\phi}+\eta(h^r)^{1-\phi})^{\frac{1-\sigma}{1-\phi}}}{1-\sigma} \\ & + \beta E_{(\epsilon',\zeta',s')|(\epsilon,\zeta,s)} VF(0,0,0,k',\epsilon',\zeta',s',j+1,1) \\ & s.t. \\ c+k'+\bar{R}h^r = & (1-\tau(y(\epsilon,j)))y(\epsilon,j)+(1+r)k \end{aligned}, \quad (21)$$

where $VF(.)$ is the value of being renters with a foreclosure flag. Foreclosed households become renters, get housing service from the rental market, and pay rent $\bar{R}h^r$.

D.0.4 Flagged Renters

Renters with a foreclosure flag cannot become owners in current period. However, at the end of the period, with probability q, their flag will be removed and they can start the next period as regular renters. The value of being a renter with a foreclosure flag is:

$$
\begin{aligned}
&VF(0,0,0,k,\epsilon,\zeta,s,j,1) = \max_{k',h^r} \frac{((1-\eta)c^{1-\phi}+\eta(h^r)^{1-\phi})^{\frac{1-\sigma}{1-\phi}}}{1-\sigma} + \\
&\beta E_{(\epsilon',\zeta',s')|(\epsilon,\zeta,s)}[(1-q)VF(0,0,0,k',\epsilon',\zeta',s',j+1,1)+qV(0,0,0,k',\epsilon',\zeta',s',j+1,0)]. \\
&s.t. \;\; c+k'+\bar{R}h^r = (1-\tau(y(\epsilon,j)))y(\epsilon,j)+(1+r)k
\end{aligned} \tag{22}
$$