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. In sharp contrast to the literature, we find that the financial incentives of negative-equity strategic default are significantly lower than previously understood once we incorporate realistic rent dynamics and detailed choice sets of borrowers in a novel quantitative model of mortgage default. We present further empirical results consistent with the unique implications of our model. Our model offers a novel benchmark for interpreting the empirical evidence on mortgage default and reinforces the effectiveness of cash-flow-based interventions.

Keywords: Mortgage Default, Strategic Default, Household Balance Sheets, Household Decision Making.

JEL Codes: D15, G51, R30.

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1 Introduction

What benchmark should be used to interpret the empirical evidence on mortgage default? According to prominent papers in previous literature, households have a strong financial incentive to default on an underwater mortgage, and that a non-pecuniary utility penalty of default of between 25 to 70 percent of lifetime consumption is needed to fit the data.[1] The models that are used in the literature also predict a limited role for changes in flow utilities between renting and owning in impacting the default decision. These results shape our understanding of household finance and are used for policy analyses.

In this paper, we develop a new model of mortgage default that provides a more realistic benchmark for interpreting the data on mortgage default and reinforces the effectiveness of cash-flow based interventions. Our resulting calibration implies that the financial incentives for underwater default are much lower than previously understood. Our model still requires a significant non-pecuniary default penalty, but at 0.7 percent of lifetime consumption, it is substantially smaller than the 25 to 70 percent of lifetime income found in the previous literature. Our estimate is also significantly closer in magnitude to the limited available empirical estimates of default costs, which we review at the end of Section 2. Finally, our model makes the unique prediction that changes in rent can affect foreclosure rates, which we test.

An important difference between our model and the previous literature is in our calibration of the tradeoffs between maintaining mortgage payments versus losing the home to foreclosure and entering the rental market. For example, historically researchers have assumed a static or counter-cyclical price-rent ratio, meaning that declining house prices coincide with declining rents, lowering the cost of renting (and therefore defaulting) when house prices fall. However, during the Great Recession rents remained stable despite the falling house prices (Loewenstein and Willen, 2023). As mortgage payments are also rel-

[1] More specifically, the Campbell and Cocco (2015) requires a utility cost of default worth 25 percent of lifetime consumption to fit the Ganong and Noel (2023) data on income declines conditional on underwater default. Hembre (2018) and Laufer (2018) estimate this cost to be even higher, at 50 to 70 percent.

atively constant over time, the stability of rents meant that the benefit of defaulting was mitigated. Consistent with simplifying assumptions about rent being a factor in driving the prior default cost estimates, Appendix A shows that the Campbell and Cocco (2015) model actually do not require a utility penalty of default to fit the Ganong and Noel (2023) data when real rents are held constant in the model as they are in the aggregate data (Loewenstein and Willen, 2023).

Our model also captures several other realistic details of household choice sets that are important for the household's incentive to default. For example, if a household suffers a permanent income shock, one natural reason to default would be to move to a smaller, more affordable house. The ability of a household to do this is affected by the sizes of homes available for rent. However, many mortgage default models assume only one house size, limiting the benefit of default. Many models also assume that 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. Furthermore, in reality, many households miss mortgage payments but "cure" their mortgage (make up their missed payments) before foreclosure occurs. In our model, we allow for the possibility of downsizing and allow borrowers to cure their delinquent mortgages and to buy a home again after foreclosure.

There are two unique implications of our model relative to a model with large non-pecuniary costs. First, our model implies that the changes to the flow payoffs of renting and owning can matter for the default decision. This is in stark contrast to both the classic "double trigger" model, where default is determined by the combination of income declines and negative equity, with no role for flow payoffs, and to the Campbell and Cocco (2015) model with large default costs as shown in Appendix Table A.1. We test this prediction in Section 7. Our model and empirical results imply that the triple combination of income declines, negative equity, and changes in the flow payoffs of renting and owning can matter for the default decision, which supports a "triple trigger" theory of mortgage default that

could serve as a benchmark for future research.

Second, our model specifies a set of measurable conditions under which strategic default is financially unattractive regardless of households' psychic attitudes towards default, which is a unique implication of our model. This is useful because non-pecuniary default costs are difficult to measure in real time. As an example, a change in attitudes towards mortgage default has been proposed by commentators towards the end of the financial crisis period.[2] Yet, a precise measurement of strategic default in real time requires data that can be difficult to obtain. By reducing the reliance of the model on non-measurable costs, our paper reinforces the effectiveness of liquidity based policies for preventing default (Ganong and Noel, 2020).

Why are rents more downwardly stable than house prices, especially during times of house-price declines? There are several possible explanations. First, during financial crises, household demand for rental units may increase relative to the demand for 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 number 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 the utility of being in a location, including factors such as wages and amenities, and these factors may be relatively stable in the aggregate (Roback, 1982; Rosen, 1979). On the other hand, house prices may be more prone to speculative dynamics (DeFusco et al., 2022) and may respond to credit supply shocks (Adelino et al., 2025), both of which would explain their greater volatility. Regardless of the reason for the lower volatility of rent, we take this empirical pattern, as reproduced in Figure 1 in a cross-section of cities, as a primitive in our model. Figure 2 shows that while there is a sizable fraction of households experience negative equity, fewer of them experience negative rent growth, and fewer still have a combination of negative equity and negative rent growth.

[2]See, e.g., Roger Lowenstein, "Walk Away from Your Mortgage!" *New York Times*, January 7, 2010, available here.

[Figures 1 and 2 inserted here]

We calibrate our model to match homeownership rates over the life cycle and distributions of owner and renter house values in the 2001 American Community Survey (ACS); the LTV, payment-to-income (PTI), and debt-to-income (DTI) ratios in the 2001 Survey of Consumer Finances (SCF); and delinquency rates by LTV during the 2005–2023 period in the Equifax Credit Risk Insights McDash (CRISM) data set. We chose the base year of 2001 because it is right before the large house price run-up and decline over the Great Recession, when underwater default is most relevant. Importantly, we hold real rent constant, which captures the more realistic rent dynamics described in Loewenstein and Willen (2023) over this time period. Regarding 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 zip code–level price indexes.[3] Despite having only seven free parameters, our model reasonably matches our targeted distributions. In addition, our model closely matches nontarget moments in terms of the PTI by LTV in the cross section of mortgage borrowers and the house-size distribution among owners and renters.

Importantly, our model implies income changes conditional on default that are consistent with the empirical finding in Ganong and Noel (2023), who found that severely underwater defaulters had the same income decline in percentage terms as defaulters with lower LTVs. This empirical fact is inconsistent with equity being the main driver of default, as one would expect income declines to be smaller for strategic defaulters who are severely underwater. In fact, we find declining (as opposed to flat) income change conditional on default by LTV in our model, which is possible due to the positive correlation between income and house-price growth. That significant income declines in our model are required for negative-equity

[3]While our estimated house price process is estimated using pre-2008 data and therefore implies limited mean-reversion, such limited mean-reversion is consistent with house price expectations data as reviewed in Kuchler et al. (2023).

default implies that the financial benefits to defaulting are limited and that few borrowers default purely because they have negative equity. Furthermore, in our model, households downsize to smaller homes after foreclosure, which is indicative of their liquidity constraints.

We conduct several counterfactual analyses using our model. First, we examine the effect of allowing households to obtain mortgage forbearance for a one-year period if their payment to income ratio is above 31%. In stationary equilibrium, we find that this policy reduces default rates by 38 percent, from 2.34 to 1.44, and foreclosure rates by around one third. Furthermore, introducing this policy when house prices decline significantly mitigates the increase in default rates and therefore has macro-prudential benefits. Importantly, our stationary equilibrium results assumes forward-looking consumers who increase their LTV, DTI, and PTI, all of which increases their default incentives, in the forbearance counterfactual. This assumption may be conservative, given that consumers may not always rationally anticipate income loss and forbearance when deciding on their mortgage choice. Even with such rational households, forbearance significantly reduces default rates in stationary equilibrium. Thus, our model reinforces the theoretical effectiveness of cash-flow based policies.

Second, we examine the effect of increasing rental market stigma following foreclosure. While over half of renters have credit scores below 650,[4] certain high-quality rental units may not be available to renters with a low credit score. We simulate the effect that this may have on our model by restricting foreclosed households to only the smallest rental unit. We find that this restriction reduces default rates, though not by as much as the forbearance policy. Furthermore, we find that this restriction cannot fully explain our 0.7% of lifetime consumption default stigma: in a hypothetical exercise where we enforce the rental unit restriction following default but remove the estimated default stigma, default rates in the model rise to above what is in data, suggesting that there are other components driving default stigma in our model beyond the rental unit restriction.

Third, we conduct a model counterfactual analysis in which real rents fall permanently by

[4]See Urban Institute Report HERE.

10 percent. This could result from an unexpected supply shock to the number of apartment units, which could permanently reduce rent in an area since rental and owned markets are close to being fully segmented (Greenwald and Guren, 2025). We show that this results in default rates by up to 5 percentage points higher depending on households' LTV, with stronger effects concentrated in higher LTV households. We also show that such a permanent decline in rent results in a 2 percentage point increase in foreclosure rates conditional on defaulting. While the earlier literature focuses on "double trigger" models of mortgage default driven by negative equity and income declines, our model instead supports a "triple trigger" model of default in which income declines, negative equity, and changes to the relative costs of owning versus renting together trigger default.[5]

Finally, we present empirical results supporting our model's prediction regarding flow payoffs. Specifically, 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. We find that, in agreement with our model, foreclosure probabilities conditional on default rise by 1.5 percentage points for every standard deviation decline in rent, where a one standard deviation decline in rent is 8.5 percent, consistent with our model's predictions in both direction and magnitude.

A potential confounder of our empirical result is that rent growth may be correlated with economic conditions and therefore with the likelihood of income recovery by 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 increase in the demand for rental units, leading to higher rents. Second, we find similar coefficients when controlling for local unemployment rate and wage-growth. Third, we conduct an instrumental variables (IV) analysis using the instrument from Gete

[5]In addition to declining rent, the flow benefit of homeownership can 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 the face of rising climate risk if accompanied by significant house price declines. For a discussion of how climate risk can affect the value of homeownership, see Benjamin Keys, "Climate Change Should Make You Rethink Homeownership," *New York Times*, October 29, 2024, available here.

and Reher (2018), which, the authors argue, predicts rent growth independent of local economic conditions, and find larger effects in the instrumental variables analysis, suggesting 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 research, including Foster and Van Order (1984) and Riddiough (1991), develops option-theoretic models of mortgage default. In the same vein, Kau et al. (1994) and Kau and Keenan (1999) suggested that *all* borrowers who are underwater by at least 25 percent would default. More recent models of mortgage default adopt life-cycle frameworks that incorporate household income risk and borrowing constraints, starting from the seminal contribution of Campbell and Cocco (2015). Ganong and Noel (2023) provide a calibration of the Campbell and Cocco (2015) model to fit their data on income changes conditional on default, and demonstrate that a 25 percent of lifetime consumption penalty is needed to fit the data.[6] A number of subsequent life-cycle models build on this framework and require similarly large nonpecuniary costs of default. For example, Hembre (2018) and Laufer (2018) require nonpecuniary costs larger than those implied by the Campbell and Cocco (2015) model. Schelkle (2018) obtains smaller required penalties, but only under parameterizations with both a low discount factor ($\beta = 0.9$) and a low elasticity of intertemporal substitution ($\gamma = 5$). The absence of either makes the model similar to earlier models.[7]

An important complementary contribution to the theory of mortgage default is Low (2025a), who introduces a model that fits the average level of above-water and underwater

[6] Available here.

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

default by introducing empirically motivated large and time-varying psychic moving costs on the order of 36.7% of lifetime consumption.[8] Thus, this model also implies a large financial benefit of defaulting which is counteracted by the large moving costs. Low (2025a) emphasizes that it is important for a mortgage default model to (1) fit both above-water and 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. In contrast, our model shows, in a rigorous quantitative framework, that the financial incentives to strategically default are more limited than previously understood, which allows for more realistic interpretations of policy and suggests conditions under which cash-flow-based interventions are more theoretically generalizable.

On the empirical side, a large earlier literature reviewed in Foote and Willen (2018) finds low rates of underwater default even among households with negative equity. Guiso et al. (2013) show that many survey respondents feel a moral obligation not to default. Bhutta et al. (2017) examine LTV cutoffs for defaulting during the Great Recession using a novel methodology, and finds that borrowers are unlikely to default on their mortgages until their LTVs become significantly higher than earlier models' predictions. The authors reasonably attribute the borrowers' high LTV cutoffs to "emotional and behavioral factors." Noteably, we do not rule out the importance of emotional and behavioral factors but instead show that a modest value for these factors that is relatively in line with other estimates in the empirical literature sufficiently addresses the "strategic default puzzle" in a model of mortgage default, unlike the earlier literature, which requires much larger values.

A key empirical contribution that motivates our approach is Ganong and Noel (2023), who show that most defaults are driven by income loss or by a combination of income loss and negative equity rather than by negative equity alone. Consistent with this view, a

[8]This moving cost number is motivated by both stated choice surveys and structural estimation by other papers in the literature. However, there is substantial uncertainty in the literature surrounding this number. Koşar et al. (2022) interprets their stated choice survey-elicited moving costs in much smaller dollar value terms based on a single year of income rather than permanent income, and Howard (2026) shows that the estimated magnitude of moving costs in structural models of migration depend strongly on model specification.

regression kink design by Indarte (2023) suggests that liquidity constraints are a primary driver of personal bankruptcy among mortgage borrowers. Hazard instrumental variable estimates from Palmer (Forthcoming), as well as evidence from large principal reductions in randomly assigned mortgage cramdowns in Cespedes et al. (2025), indicate that negative equity still plays an important role in foreclosure decisions. Survey evidence from Low (2025b) similarly confirms the importance of liquidity shocks in household default. Other papers in this literature include Kruger (2018), which finds that loan modification reduces foreclosures particularly in loans with less securitization frictions, and Gupta and Hansman (2022), which studies the role of adverse selection and moral hazard in explaining the correlation between leverage and mortgage default. Taken together, the literature identifies a central role for liquidity in driving mortgage default, some role for emotional and behavioral factors in driving the default decision, and it finds that large negative equity is also relevant for foreclosures. Our model is consistent with these empirical findings.

Several empirical papers provide numerical estimates of how consumers actually perceive default costs. Brueckner et al. (2025) estimates a lower bound for default costs among the selected sample of repaying homeowners, at a median lower bound of $28,871 to $52,448 depending on the credit score quintile. Their numbers are relatively close to our model's implied default cost. Specifically, a range of $28,871 to $52,448 represents approximately 0.8 to 1.5 percent of lifetime consumption for homeowners, which is in the same order of magnitude as our estimate of 0.7 percent of lifetime consumption.[9] Using data from the Federal Disaster Loan Program, Collier et al. (2025) estimates a median attachment of households to their homes of $11,000, which can be considered one component of default costs, with others being moral and stigma considerations. This number is lower than, but in the same magnitude as, our 0.7 percent of lifetime consumption estimate. Our paper reconciles default costs of this magnitude with the empirical data on default rates by LTV and income changes conditional on default through capturing the detailed choice sets of

[9]This is calculated for a household consuming $55,000 over 62 years. In the 2001 SCF, the median income of homeowners is $55,500, which is generally either consumed directly or through bequests in our model.

households, and explores the novel implications of such a model for household behavior.

3 Data

We use several data sources to calibrate our model. In particular, we obtain the PTI and LTV ratios from the 2001 SCF and the homeownership rates over the life cycle from the 2001 ACS. We also calculate default and foreclosure rates as the share of loans that go into default or foreclose, respectively, in a given year using data on owner-occupied, first-lien mortgages from 2001 through 2023 in the Equifax/McDash CRISM data set. We define default as the first month a mortgage transitions to 90-day delinquency, following the definition in Ganong and Noel (2023).

For the rent-to-price ratio, we take the average of that 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 in Figure 1a come from a data set of property-level rent-to-price ratios derived from Multiple Listing Service (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 span. Importantly, this allows us to obtain rents and prices for the same property and thereby measure rent-to-price ratios that are more realistic compared with using average rent and average sale prices in a metro area.

To calibrate zip code–level 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 Federal Housing Finance Agency (FHFA) zip code price index by using a larger sample of properties; the FHFA index tracks only properties financed via conforming loans. We obtain monthly zip code–level house-price index values from January 1987 through January 2008 and use them to estimate a mixture model of house-price movements.

For our empirical analysis of the relationship between nominal rent growth and default, we use the Equifax/McDash CRISM data set, which is mortgage performance data matched with

anonymous 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 before 2008 that had a 90-day delinquency at some point during the 2010–2019 period and track them until the end of 2024. We include the summary statistics on this data set in Table 4.

4 Model

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

[Figure 3 inserted here]

4.1 Time parameters and preferences

Household utility is constant relative risk aversion (CRRA) over nonhousing 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 nonhousing 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 extent to which bequest is a luxury good.

Households receive income y_{it} in each period and optimize over nonhousing 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 $w_{it} \geq 0$.

The homeownership 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 the 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 $h_j^R \leq h_1^O \equiv h^{\min}$ for all $j \leq j_R$. That is, some smaller units are available only for rent rather than purchase, following Kaplan et al. (2020). This segmentation allows us to fit the life-cycle ownership profile of households, where the smaller units may represent living with roommates or in specialized apartments. This segmentation does not prevent strategic default in our model, as all unit sizes are available to rent.

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 pay 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 rents fixed at their 2001 levels, consistent with the findings in Loewenstein and Willen (2023) for the evolution of rent over the period from 2001 to the Great Recession.

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 differ during expansions and recessions. Our process includes the addition of a life-cycle age profile χ_j, since we match on homeownership rates over the life cycle. 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 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 in Heathcote et al. (2017), our

model features a progressive income tax,

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

where τ_0 captures the average level and τ_1 captures the degree of progressivity of the income tax.

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 that depends on business cycles whose shocks ϵ_s^p follow a mixed normal distribution:

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

and aggregate state $s(t) \in \{E, R\}$, which captures how average price growth and price growth volatility may differ depending on whether the economy is entering an expansion (E) or a recession (R). Note that the shared aggregate state $s(t)$ between income and house-price processes implies that they are positively correlated.

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 involves constant nominal payments over time as given by the standard amortization formula. Note that real mortgage payments are deflated by the rate of inflation. The borrower is subject to two constraints when originating or refinancing a mortgage (that is, when mortgage age $n = 1$). 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 down-payment requirement of 5 percent. Second, there is a cap on the scheduled payment-to-income ratio at mortgage origination, which is set at 50 percent based on the analysis in Greenwald (2018) of the pre-2000 period.

Furthermore, mortgage origination and refinancing involve an origination cost of 1 percent of the loan amount plus $2,000 in 2001 dollars, following Guren et al. (2021a). Mortgage refinancing allows households to extract their home equity in times of house-price increases and thereby increase their LTV.

At the beginning of each period t, mortgage borrowers can choose to default by stopping their mortgage payments for a year. If they have sufficient liquidity, borrowers in default can cure their mortgage and become current again by paying the amount they owe plus a late fee of 5 percent of the payments they missed. They can also pay off the entire mortgage and the late fee, sell their home, and rent. If they choose neither of these options, they will fall into foreclosure. 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 reputational concerns.

A foreclosed borrower loses all their home equity, becomes a renter, and cannot buy a home as long as their foreclosure flag, Ω, remains on their record. In each period, there is probability q that their record of default will be removed in the following period, giving them the option to become owners again. Appendix Section C provides a mathematical description of our model's features.

5 Calibration and Implications

A key question for our model involves the implications for the utility incentives to default after the model's parameters are calibrated to key moments of the US housing market. We describe the calibration process in Section 5.1, the model's fit to both targeted and nontargeted 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 6.

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 LTV ratios. We conduct the calibration in two stages. In the first stage, we determine the parameters that are directly estimated using the data or taken from the literature. In the second stage, we calibrate key parameters 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 the model

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

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

Preference: Following Guren et al. (2021b), we set intertemporal elasticity of substitution σ to 2. Discount rate β, housing share in the utility η, substitution between housing and nonhousing 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 as 2 percent per year. The average annual inflation rate has been stable at about 2 percent since the late 1990s. The mortgage spread is $\zeta_m =$

1.5%, which is the average difference between contract mortgage interest rates and the market yield on 30-year Treasury bonds based on data from the Federal Housing Finance Agency and Federal Reserve Bank of St. Louis. Annual inflation π is 2 percent, which gives us an annual nominal mortgage interest of $r_m = 5.5\%$. We use the nominal rate to calculate mortgage payments, but appropriately divide by inflation throughout to keep our model in real terms.

We construct the initial asset distribution using data from the 2001 Survey of Consumer Finances for households aged 20 to 22. We use the value of all their assets to construct the initial asset distribution.

Housing: We set the annual property tax and maintenance cost at 1.5 percent and 1 percent, respectively, which match the average property taxes and owner costs reported in the 2001 American Community Survey. Transaction costs for buyers and sellers are $k_s = 6\%$ and $k_b = 2\%$ (see, for example, Sommer et al. (2013)). The variable mortgage closing cost is set as $\omega_1 = 1\%$, and the constant mortgage closing cost is set as $\omega_0 = 2000$ in 2001 dollars, following Guren et al. (2021a).

For the baseline calibration in 2001, we set the down-payment requirement ξ as 5 percent, which is standard in the literature. The constraint on the payment-to-income ratio is set as 50 percent. We picked the year 2001 to capture the period before the run up and decline in house prices during the Great Recession that is most relevant for underwater default.

Foreclosure Flag: Since foreclosures stay on households' credit report for 7 years, we set the probabillity of foreclosure flag removal q to $1/7$. This allows us to capture the foreclosure flag removal time in expectation while not expanding the state space of the model.

Aggregate Shocks and Business Cycles: 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 transitioning from an expansion to a recession is 0.18, and the probability of transitioning 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. The inclusion of the aggregate states capture the fact that the processes that drive income and house prices change during periods with more negative equity.

Income: Following Guvenen et al. (2014), we set the annual autocorrelation of persistent earnings shocks ρ as 0.979 and the standard deviation of transitory shock σ_ϵ as 0.186. The mixed normal distribution has a first mixture probability of $p_1 = 0.49$. The two mixture components have innovation terms 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).

Income Taxes: 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 in the 2000 Census, and the annual rent, $\bar{R} = \bar{P} \times 0.1019$, is calibrated to the sample's average rent-to-price ratio for a single-family home or condo that was both sold and rented on the MLS in 2001, following Loewenstein and Willen (2023).[10] As shown in Figure 1a, real rents were relatively flat from 2001 through 2012, while house prices were volatile. This period is also the most relevant period for underwater mortgage default, as shown in Figure 2.

Another aspect of this calibration is that rent-to-price ratios fell about 30 percent from 2001 to the 2020s due to house-price growth (Loewenstein and Willen, 2023), which made renting more financially attractive in recent years compared with our model period, with some regional heterogeneity. This decline in rent-to-price ratios can be viewed as a positive realization of the house price shocks, which we allow for in the model. Whether the strategic

[10]This number is also consistent with a median rental receipt as a percent of value of 10% among mortgaged properties, reported in the 2001 Census Bureau Residential Finance Survey Table 4-2, available here.

incentive to default is greater in lower initial rent-to-price markets depends on households' reasons for choosing to own rather than rent despite a lower rent-to-price ratio. If households choose to own a home despite a lower rent-to-price ratio due to an ownership premium or concerns about rent-growth risk (Sinai and Souleles, 2005), and if those factors are relatively stable, then strategic default incentives may continue to be moderated.

House-Price Dynamics: We estimate the house-price dynamics using CoreLogic zip code house-price index growth for the 1987–2008 period deflated with the CPI deflator. When the economy stays in expansion (that is, an aggregate state of E in the preceding period and the current period), we estimate that house-price shocks have mean $\mu^P_{EE} = 0.02$ and standard deviation $\sigma^P_{EE} = 0.057$ and model these shocks as a normal distribution with $\pi_{EE} = 1$. When the economy stays in recession (that is, an aggregate state of R in the preceding period and the current 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-price growth is larger during expansions than during recessions, at 2 percent versus –1.7 percent, respectively, while the standard deviation of house-price growth is smaller in expansions than in recessions, at 5.7 percent and 9 percent, respectively.

When the economy falls from expansion to recession (that is, an aggregate state that transitions from E in the preceding period to R in the current period), we use a mixed normal distribution to fit house-price shocks and capture the fact that some recessions are more likely than others to be associated with house-price declines. We use a maximum likelihood approach to estimate these mixtures. We estimate the probability of the first mixture as $\pi_{ER} = 0.2$, the mean and standard deviation of the first mixture as $\mu^P_{1,ER} = -0.0925, \sigma_{1,ER} = 0.0758$, and the mean and standard deviation of the second mixture as $\mu^P_{2,ER} = -0.021, \sigma_{1,ER} = 0.0708$. Similarly, when the economy rises from recession to expansion (that is, an aggregate state that transitions from R in the preceding period to E this period), we use a mixed normal distribution to calibrate house-price shocks and

estimate the probability of the first mixture as $\pi_{RE} = 0.22$, the mean and standard deviation of the first mixture as $\mu^P_{1,RE} = 0.0013, \sigma_{1,RE} = 0.0293$, and the mean and standard deviation of the second mixture as $\mu^P_{2,RE} = 0.021, \sigma_{2,RE} = 0.0611$. We note that the means of the two mixtures are more different and the standard deviations are higher during transitions from recession to expansion than during transitions from expansion to recession. This suggests that in our model, there is more dispersion in house-price growth as the economy enters into a recession.

In summary, our house-price dynamics exhibit negative expected price growth and no expected mean reversion during recessions, and low but positive expected price growth during expansions. This estimated dynamic results mostly from our estimation period ending in 2008, before the period of house-price rebound that followed the Great Recession. We chose this estimation period to capture the information set of a borrower in 2008, which is when underwater default is most relevant in the data. In terms of post-2008 data, house prices continued to decline for some years, with the rebound occurring between 2012 and 2013, which suggests that the negative expected house price growth in recessions fit the post-2008 data for some time, as can be seen in Figure 1a. The estimation period may correctly capture the expectations of negative-equity households during the housing-crash period if they were making similar inferences based on historical data. In household surveys, there is limited evidence that households expect mean reversion in house prices, and more evidence that households tend to project their recent experience forward even during recessions (Kuchler et al., 2023).

Implied User Costs Over the Business Cycle: The user costs implied in our model, defined as the sum of the mortgage rate r_m, property tax τ_h, maintenance cost δ, and minus the expected real house price growth, varies over the business cycle. During expansion states E, it is 7.1 percent. During recessions states R, it is 7.7 percent. Therefore, there is a greater user cost incentive to default in recession states compared to expansion states. Furthermore, the "effective" user costs in the model are about 4 to 5 percentage point higher for an

underwater household with an LTV of 140%, whose mortgage interest would be paid on more than the current value of the home and whose principal payment no longer contributes to their immediate net worth until the house price recovers to be abovewater. The incentives of defaulting in the model further include the possibility of downsizing following default as well as the possibility of re-purchasing the house after the foreclosure flag expires.

Ownership Premium: Our model does not include an ownership premium. Many models in the literature do include such an ownership premium, but an important difference between our calibration and theirs is that we use a more precise measure of rent-to-price, based on units that are both sold and rented on the MLS, from Loewenstein and Willen (2023). The earlier literature tends to calibrate to a lower annual rent-to-price ratio that does not adjust for housing unit size (for example, taking the ratio of average rents and average house prices in a city, despite the stock of rented housing being very different than the stock of owned housing), and instead use a positive constant ownership premium to both fit homeownership rates and to capture the unobserved differences in the desirability of rental and owned units.

[Table 1 inserted here]

5.1.2 Parameters calibrated within the model

We calibrate the discount rate β, minimum house size available to buy h^{min}, housing share η, substitutability between housing and nonhousing consumptionϕ, 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 percent standard deviation error, which is consistent with the exploration in Bogin et al. (2019) of the accuracy of the zip code–level price indexes 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 home-ownership 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 nonhousing 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, have the largest impact on the ownership rates and mortgage debts of older households. A stronger bequest motive increases older households' likelihood of continuing to own their home and reduces their likelihood of using mortgage refinancing to extract equity. In particular, b_1 mainly captures the extent to which a bequest is a luxury good, and 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 houses larger than 80 percent of the median house size are available to buy. We calibrate a housing share in utility η of 0.2. The elasticity of substitution between housing and nonhousing consumption $\frac{1}{\phi}$ is calibrated to $\frac{1}{1.5} = 0.67$, close to Li et al. (2016); Yogo (2006). Our calibrated discount factor β is 0.92, within the range provided by previous studies (see, for example, Guren et al. (2021b) and Athreya et al. (2018)). The two parameters for the bequest motive are $b_0 = 20$ and $b_1 = 1$. Importantly, the calibrated value for the default utility cost is $\psi = 0.15$, which is equivalent to a 0.7 percent lifetime consumption loss. This number is low compared with the 25 to 70 percent loss of lifetime consumption estimated in the earlier literature.

5.2 Fit to life-cycle moments

Figure 4 examines the fit of our calibration regarding life-cycle moments by comparing the model-generated moments to data from the 2001 Survey of Consumer Finances. Panel (a) of Figure 4 plots life-cycle homeownership rates, defined as the share of all households in the model that are homeowners. Panel (b) of Figure 4 plots life-cycle loan-to-value ratios. Panel (c) of Figure 4 plots life-cycle payment-to-income ratios. The payment-to-income ratios are defined as the ratio of the sum of a borrower's mortgage, property tax, and insurance payments divided by their income in the model. When comparing them to the 2021 SCF data, we define these ratios as the amount of a borrower's mortgage payment (which, for most households, includes property taxes and insurance as escrow) divided by their reported household income. Panel (d) of Figure 4 plots life-cycle debt-to-income ratios, defined as a borrower's mortgage balance divided by their income. Given the limited number of free parameters, our model matches these life-cycle moments well. Importantly, it captures the increase in the homeownership rate and decreasing mortgage balances by age, thereby 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 (2025b), income shocks play a major role in driving mortgage default; matching the payment-to-income ratio by LTV is important in predicting mortgage default; and fitting the distribution of house values and annual rents is important for capturing the downsizing motive of default. Figure 5 plots model fit in relation to these nontargeted 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 regarding default rates. We find that the model fits well in terms of default rates by LTV bins for both above-water and underwater households.

[Figure 6 inserted here]

Panel (b) of Figure 6 plots the average income change among defaulters as a fraction of their mortgage payments. We find significant average income loss among the defaulters, comparable to the size of mortgage payments for all underwater borrowers, consistent with Ganong and Noel (2023) and with limited strategic default behavior. Notably, Panel (b) of Figure 6 suggests that the income change before default decreases with the LTV, which is in sharp contrast to pure negative-equity-driven strategic default. This implies that defaulter income changes increase with the LTV. The reason for this is the positive correlation between income and house prices induced by our aggregate state s: periods with house-price declines coincide with periods 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 fall into foreclosure. 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, which is consistent with Palmer (Forthcoming) and Cespedes et al. (2025).

We also examine the model-implied average income change conditional on the type of default resolution (that is, 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 a borrower being hit with a negative income shock before default and being unable to

afford their mortgage payment without an income recovery. Lower LTV households experience a larger variation in income change relative to mortgage payments due to their lower mortgage payments. When borrowers whose LTV is lower than 60 percent (positive equity) are hit with a further negative income shock after defaulting, they sell their homes, which is consistent with their potential demand to downsize. For borrowers whose LTV is higher than 60 percent, the decision to sell or foreclose after defaulting is related less to income changes following default and more to feasibility, whereas the decision to cure continues to rely on a large positive income shock, consistent with the central role of liquidity in driving the initial default decision.

5.4 Adjustment of house size after foreclosure

An important component of the flow payoff comparison between continuing to own and defaulting that our model captures is the ability to downsize after foreclosure, thereby saving on rent. That is, the relevant counterfactual may not be renting the same size house, but rather renting a smaller unit. This downsizing possibility may be optimal for households that experience an income shock and therefore have a lower demand for space. We examine this possibility in Figure 7, which plots the change in house size among households that underwent foreclosure.

[Figure 7 inserted here]

As Figure 7 shows, most households that undergo foreclosure in our model do downsize, which is consistent with the negative income shock they experienced. Approximately 74 percent of foreclosed households downsize to 66 to 33 percent of their original house size, whereas 25 percent of foreclosed households downsize to less than or equal to 66 percent of their original house size. Only 1 percent has a house size that is more than 33 percent 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 Counterfactual Analyses

6.1 Forbearance

We begin by examining the implications of mortgage forbearance programs. Specifically, we consider a forbearance option that is available to non-delinquent borrowers experiencing financial distress, defined as having a payment-to-after-tax income ratio above 31 percent and having made at least one prior mortgage payment. The program allows eligible borrowers to postpone their mortgage payments for one year. During the forbearance spell, unpaid principal continues to accrue interest and is capitalized into the outstanding balance. Upon exiting forbearance, households face three choices: (i) resume making mortgage payments, in which case the accrued interest increases the remaining term on their mortgage; (ii) repay the outstanding balance and sell the house; or (iii) become delinquent. We evaluate the impact of mortgage forbearance programs both in stationary equilibrium where households anticipate forbearance option when they purchase a home and in a transition where forbearance is introduced to baseline stationary equilibrium without forbearance. The mathematical description of the model with forbearance is in Appendix Section C.2.

We begin by evaluating the effects of introducing a mortgage forbearance program in stationary equilibrium. Table 2 summarizes the abovewater and underwater default rates in the data, our baseline model, and our counterfactual analyses. Panel A of Table 2 shows that default rates in our CRISM data is 2 percent among abovewater borrowers and 10 percent for underwater borrowers. In terms of share of borrowers, 88.9% of borrowers are abovewater in the data, compared to 11.12% that are underwater. Panel B of Table 2 shows that the baseline model closely matches the data, with a 2 percent default rate among abovewater borrowers and 8 percent default rate among underwater borrowers, and 92.5% of borrowers being abovewater in the data.

Panel C of Table 2 shows that, in a model with a forbearance option, the steady state default rate falls to 1.1 percent for abovewater households and 4.0 percent for underwater

households, a nearly 50% decline relative to the baseline model in Panel B of Table 2. In aggregate, Table 3 shows that default rates fall from 2.3 percent in the baseline model to 1.4 percent in the model with forbearance, and foreclosure rates fall from 0.97 percent in the baseline model to 0.66 in the model with forbearance. Table 3 also shows that the introduction of forbearance reduces default and foreclosure rates in the year of introduction and one year after, with a larger effect for foreclosures in the one year after because of the one year delay from default to foreclosure.

[Table 2 and 3 inserted here]

Our analysis of the steady state in the model with forbearance necessarily assumes that households are rational and anticipates the forbearance action when they take out a mortgage. This causes them to take out mortgages with higher loan-to-value (LTV) ratios, which is naturally correlated with higher default rates. This may be a conservative assumption for modelling the effect of mortgage forbearance on default, because households may not in reality anticipate defaulting at the time of origination, in which case the effect of forbearance on LTV choice may be more muted than what the model predicts. Nevertheless, some households appear to be strategic with respect to mortgage modifications and home improvements, as shown in Mayer et al. (2014), Melzer (2017), making our model where households increase their leverage in response to the forbearance option a potentially useful benchmark. Even with such a conservative assumption and higher borrower LTVs in response to the forbearance option, forbearance ends up reducing default and foreclosure rates in the steady state. Appendix Figure A.4 shows the mortgage forbearance steady state in more detail, including the default rates by LTV, foreclosure conditional on default rates by LTV, the LTV distribution, and lifecycle ownership, LTV, DTI, and PTI rates.

Next, we study the effect of introducing mortgage forbearance to the non-forbearance steady-state in terms of financial stability outcomes. For this analysis, we start the model in steady-state without forbearance, introduce a house price crash where house prices fall to their lowest state, and compare the path of default and foreclosure rates as well as forbearance

take-up rates with and without simultaneously introducing the forbearance option. We show the results in Figure 8, which suggests that default and foreclosure rates rise much less sharply following the house price shock under the forbearance regime, with default rates shown in Panel A of Figure 8 and foreclosure rates shown in Panel B of Figure 8. Forbearance take-up rate increase to 8% at the peak before falling to around 5%.

[Figure 8 inserted here]

We end by discussing the cost of forbearance policy in the model. In our model, forbearance results in an extension of the effective amortization period of the mortgage. It is not costly to risk-neutral lenders in steady state, as they receive their required mortgage premia and face reduced default and foreclosure rates. If lenders are instead risk-averse in the sense that their marginal utility of consumption rises during recessions and periods with house price crashes (Campbell et al., 2021), they would further benefit from forbearance due to its financial stability benefits as shown in Figure 8. This private cost-effectiveness of forbearance is consistent with lenders' willingness to modify mortgages during periods of house price crashes absent securitization frictions, as documented in Kruger (2018).

6.2 Limiting rental options after foreclosure

An additional factor that may influence mortgage default behavior is the presence of rental market stigma following foreclosure. Households with a foreclosure flag on their credit profiles may face restricted access to higher-quality rental housing, either through credit screening or reputation effects in the rental market.

To examine the potential magnitude of this mechanism in our model, we extend the baseline model to incorporate rental constraints. Specifically, we consider two model variants: a model in which foreclosed households are limited to only the lowest-size rental units, and a further version where default stigma is further removed.

Table 2, Panel D introduces limited rental options after foreclosure. In this scenario, default rates decline from 1.97 in the baseline model to 1.54 in the version with limited

rental options in the abovewater case, and from 7.95 in the baseline model to 4.93 in the version with limited rental options in the abovewater case. These suggest that the inability to rent higher-quality units lowers the incentive to default, though not by as much as the forbearance case in Section 6.1.

Finally, Panel E of Table 2 explores the case with limited rental options but no default stigma, which tests if limited rental options can fully substitute for default stigma in the model. Here, the default rate rises substantially above the data in Panel A. These results suggest that limiting rental options alone does not allow us to fit the data in terms of default rates. A default penalty is necessary to reproduce real-world default rates, though the level of the penalty that is needed in our model is lower than in the earlier literature.

6.3 Lower cost of renting

Our model suggests that negative equity by itself does not necessarily create a large financial incentive to default if the alternative to renting remains unattractive and that flow utility is central to a household's incentive to default. To examine this effect more closely in a counterfactual, we simulate a one-time 10 percent permanent decrease in real rent and examine the resulting increases in default rates across the LTV distribution. The decline in real rent could result from an unexpected supply shock to the number of apartment units, which could permanently reduce rent in an area since rental and owned markets are close to being fully segmented (Greenwald and Guren, 2025). As shown in Figure 1c and Figure 2, a 10 percent decline in real rent is roughly the maximum that borrowers experienced when house prices crashed during the 2007–2012 period, though as we know ex post, those declines were not permanent.

Panel (a) of Figure 9 shows that in this counterfactual, default rates rise by about 5 percentage points for households with an LTV of 130 to 140 percent and for households with an LTV that is higher than 140 percent. The effect declines with the LTV, and the default rates of households with an LTV under 80 percent are unaffected by rent declines. This

suggests that flow utility considerations may be more important for default behavior when households are already underwater and potentially hit by an income shock. It also suggests a "triple trigger" model of default consisting of negative equity, income shocks, and flow utility shocks. As flow utility shocks become more common—due, for example, to climate catastrophes making homes less attractive places to live—this model of default may become more relevant.

[Figure 9 inserted here]

Panel (b) of Figure 9 shows that foreclosure rates conditional on default rise about 2 percentage points when households expect real rents to have fallen 10 percent permanently. This rise in foreclosure rates conditional on default is relatively uniform for households with a 70 percent or higher LTV. As defaulting households in our time period typically face severe liquidity shocks (Ganong and Noel, 2023), the model-implied relationship between rent declines and eventual foreclosure is indicative of flow utility considerations being relevant to household decision-making conditional on liquidity shocks. We test this model prediction in Section 7.

7 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 greater rent growth. We study this prediction empirically using a measure, at the core-based statistical area (CBSA) level from CoStar, of effective rents per square foot, which are asking rents for new tenants net of concessions such as a free month of rent. We also use mortgage servicer data from CRISM, which include information on mortgage performance matched with credit bureau data that contain 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 4.

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 those borrowers has any statistical effect on whether they eventually fall into foreclosure. Liquidity concerns have been identified as a driver of mortgage default both in the double trigger literature and in the more recent literature on positive equity defaults (Ganong and Noel, 2023; Low, 2025a). Limiting the sample to 90-day defaults therefore restricts the sample to households with liquidity concerns. The question is whether the cost of renting influences the subsequent decision to cure or lose the home to foreclosure.

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 exercise is similar to the counterfactual exercise discussed earlier (and shown in Figure 9b) in which rents fall 10 percent. To facilitate the use of an instrument for rent growth, which we discuss later, we also limit the sample to loans originated before 2008.

For our baseline analyses, 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 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

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

year and the county-level annual unemployment rate. Lastly, we include fixed effects for the year of default ($\gamma_{t(i)}$), the year the loan was originated ($\psi_{o(i)}$), and state where the property is located (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 the probability of eventual foreclosure is affected by changes in the cost of renting following loan origination. We expect β_1 to be negative, indicating that the more rental costs increase, the lower the probability of eventual foreclosure.

This empirical setup allows us to capture changes in the relative flow costs of renting versus owning across this group of loans. At origination, these borrowers chose ownership over renting, revealing their preference at that point in time. However, the trade-off between those flow costs changed over time and the log growth in asking rents since loan origination to 90-day default is our proxy for this change. Individual mortgage payments, especially for fixed rate borrowers, are slow moving and relatively static over time as even property taxes are relatively unresponsive to house prices (Lutz, 2008). The inclusion of mortgage payments mainly captures information about borrowers that we do not observe in our data such as income. Borrowers may also have different expectations for how much house prices in their areas will recover (the option value of their mortgage), which we proxy for using their current LTV.

The results are presented in Table 5. All the regressors are normalized to be mean zero, standard deviation of one. In column (1), we include only loan-level covariates. In columns (2) and (3), we add 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 4, is an increase of about 8.5 percentage points) results in a 1.5 to 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 to 2 percentage points. This is relative to an average foreclosure rate of 33.6 percent in this sample of defaulted loans. This increase is on par with the results from the model displayed in Figure 9b. The other significant coefficient is on 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, created by Gete and Reher (2018), of the share of banks by CBSA that became subject to stress testing after the Great Recession. Gete and Reher (2018) show that as mortgage supply contracted in these markets, rent growth increased while demand for rental properties grew. The paper also shows that the change in rents due to this channel are unrelated to local economic conditions and unrelated to origination conditions for loans originated before 2008.

The result in column (4) of Table 5 indicates that once we instrument for rent growth using the Gete and Reher (2018) instrument, our estimated effect of rent growth on foreclosure completion is larger, though our standard errors do not allow us to reject a difference in the point estimate between specifications (3) and (4) at the 95% level. Specifically, a one standard deviation increase in rent growth reduces foreclosure completions by more than 6 percentage points in the IV specification. That this point estimate is larger in magnitude than our OLS estimate in column (3) suggests 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.

8 Discussion

Our paper emphasizes the central role of flow payoffs in evaluating models of household behavior. While the earlier literature tends to focus the discussion of strategic behavior on the role of negative equity and income, the combination of which gives rise to "double trigger" default caused by a combination of negative equity and income shocks, our analysis highlights that flow payoffs are also an important component of strategic behavior. This suggests a "triple trigger" framework in which home equity, income shocks, and changes to the flow costs of owning versus renting all need to be considered when evaluating empirical evidence on mortgage default.

Our results also have implications for understanding housing markets with low initial rent-to-price ratios. Rent-to-price ratios for 2001 are comparable to those for 2009 (Loewenstein and Willen, 2023), so our calibration accurately captures the housing-crash period, during which underwater default was most salient. In more recent years, rent-to-price ratios have fallen about 30 percent relative to the 2001 level (Loewenstein and Willen, 2023), with some heterogeneity across markets. Whether a housing crash will result in greater strategic incentives to default in low initial rent-to-price ratio markets will depend on why households continue to choose to own despite 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 households choose to own (for example, ownership premium and rent growth risk) are unchanged. On the other hand, if some households choose to own in low rent-to-price markets to speculate on the house price, and those house price expectations has changed following a housing crash, then they may indeed have greater strategic incentives to default when they are underwater. The existence of a small fraction such speculative households who ended up defaulting may explain why in our baseline model the income change gradient with respect to LTV among defaulters is more negative than the data in Ganong and Noel (2023), as can be seen by comparing Figure 6 and the red bars of

Appendix Figure A.1a.

9 Conclusion

The lack of ubiquitous strategic mortgage default during the mid-2000s house-price declines has posed a challenge to those studying mortgage default, with many commentators suggesting nonpecuniary costs, such as shame and social management, as reasons (White, 2010b). Using a detailed quantitative model of mortgage default, we show that factoring in a more realistic process for rent largely eliminates the household strategic default incentives. Therefore, in sharp contrast to the earlier literature, we estimate the strategic benefits of defaulting on a mortgage to be limited for underwater households when rents are downwardly stable in times of steep house-price declines.

Our paper has two important policy implications. Our finding that the financial benefits of defaulting to underwater households are dramatically lower than previously estimated for the Great Recession period has implications for policy design. If the financial benefits of defaulting was as high as previously thought, then we would have expected a foreclosure to improve a household's financial position. In fact, such high benefits would imply a potential conflict of interest for policy-makers aiming to reduce foreclosures in financial terms.[12] Our model instead suggests that defaulting over the Great Recession period was ex ante costly for households, and that liquidity policies meant to prevent foreclosure were ex ante beneficial, thus offering a more realistic interpretation of the effects of policy such as the Home Affordable Modification Program (HAMP).[13]

Second, our research contributes to the theoretical foundation supporting the efficacy of cash-flow-based policies, such as mortgage forbearance, in reducing household defaults. Empirical evidence from Ganong and Noel (2020) suggests that these policies may be more

[12]Consistent with this implication, Roger Lowenstein, "Walk Away from Your Mortgage!" *New York Times*, January 7, 2010, available here, notes the issue in having the HUD-approved counselors "counseling people to throw away money."

[13]In fact, higher foreclosure rates by minority borrowers during the 2008 housing crash is an important driver of their lower housing returns ex post (Kermani and Wong, 2021).

cost-effective than alternatives focused on home equity in preventing defaults. Our model enhances the generalizability of their findings by indicating that their effectiveness does not necessarily depend on significant non-measurable and potentially behavioral factors. In fact, concerns that moral considerations might lead households to act against their financial interests have prompted discussions on the acceptability of strategic default. White (2010a) argued prominently that strategic default is morally acceptable during the 2008 housing crisis. Our study suggests that by accurately assessing the ongoing costs associated with renting versus homeownership, the debate over the moral acceptability of strategic default becomes unnecessary.

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Table 1: List of Parameters

Note: These are the model parameters that 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 labeled as "Assumed."

Parameter	Value	Source
Demographics		
Household born age	23	Assumed
Household retirement	64	Assumed
Household exit age	85	Assumed
Preferences		
Intertemporal elasiticty of substitution σ	2	Guren et al. (2021b)
Discount rate β	0.92	Calibrated
Housing share in utility η	0.2	Calibrated
Substitution between housing and nonhousing 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	Guren et al. (2021a)
Mortgage origination cost (variable) ω_1	1%	Guren et al. (2021a)
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	\$16,525	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}	-0.102, 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-price 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, 0.0611	Estimated

Table 2: Default and Foreclosure Outcomes: Abovewater vs. Underwater Borrowers

Note: This table compares observed and simulated mortgage performance outcomes across borrower equity positions. "Abovewater" borrowers have measured LTV less than or equal to 100%, "Underwater" borrowers have measured LTV above 100%. Each panel presents the Default Rate and the Proportion of Borrowers in each equity category under different model assumptions. Panel A is computed based on our CRISM data. Panel B is from the stationary equilibrium of the baseline model as described in Section 5.1. Panel C is from the stationary equilibrium of the model with forbearance, where forbearance is available to mortgagors who have made at least one payment and whose mortgage-payment-to-after-tax-income ratio exceeds 31%. Panel D and E are from the alternative version of the model where renters can only rent the smallest unit after foreclosure as described in Section 6.2.

	Abovewater (%)	**Underwater (%)**
Panel A: Data		
Default rate	2.03	10.12
Share of borrowers	88.88	11.12
Panel B: Baseline Model		
Default rate	1.97	7.95
Share of borrowers	92.47	7.53
Panel C: Model with Forbearance		
Default rate	1.10	4.01
Share of borrowers	89.01	10.99
Panel D: Model Limiting Rental Option After Foreclosure		
Default rate	1.54	4.93
Share of borrowers	93.14	6.86
Panel E: Model Limiting Rental Option After Foreclosure and No Default Stigma		
Default rate	9.66	17.43
Share of borrowers	92.70	7.30

Table 3: Default and Foreclosure Outcomes: Mortgage Forbearance

Note: This table summarizes simulated mortgage performance outcomes across alternative model environments. We compare (i) the baseline stationary equilibrium without a mortgage forbearance option, (ii) the stationary equilibrium in which forbearance is available, and (iii) the dynamic effects of introducing a forbearance program into the baseline economy—both immediately upon introduction and one year afterward. Under the program, any mortgagor who has made at least one payment and whose mortgage payment-to-after-tax-income (PTI) ratio exceeds 31% is eligible to postpone mortgage payments for one year.

	Default Rate	Foreclosure Rate
Baseline	2.34	0.97
Stationary Equilibrium with FB	1.44	0.66
Intro of FB	0.89	0.86
Intro of FB: 1 year after	0.97	0.27

Table 4: Summary Statistics

Note: These are summary statistics for our empirical analysis. The data are from the sample used for the regressions in Table 5, so they are limited to loans originated before 2008 in CBSAs for which we have the independent variable from Gete and Reher (2018). Rent growth is from the year of mortgage origination to the year of the first 90-day default. There is one observation per loan. *Sources:* Authors' calculations using Equifax Credit Risks Insight Servicing" and ICE, McDash; 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 (%)	73.4	44.2
$\Delta \ln(\text{Rent/Sq. Ft.})_{t,o}$	6.3	8.5
Unemployment Rate (%)	8.2	3.0
Average Wage ($,000)	46.9	10.2
N	250,435	

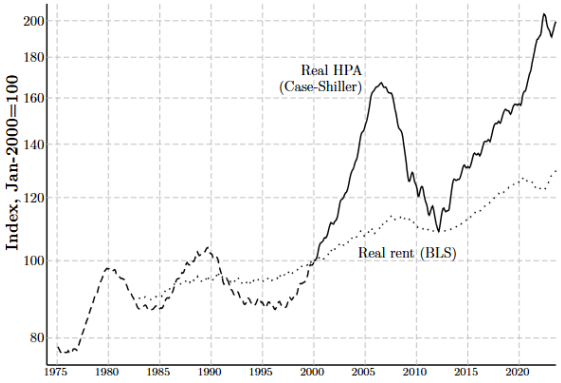
Table 5: Probability of Foreclosure Conditional on 90-day Default

Note: The dependent variable is an indicator of foreclosure completion multiplied by 100. The sample is limited to owner-occupied first-lien mortgages 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 in parentheses and 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 indexes in the denominator. The independent variable is from Gete and Reher (2018). *Sources:* Authors' calculations using Equifax Credit Risks Insight Servicing" and ICE, McDash; CoStar; BLS Local Area Unemployment Statistics; Census Annual County Population Estimates; and the Quarterly Census of Employment and Wages.

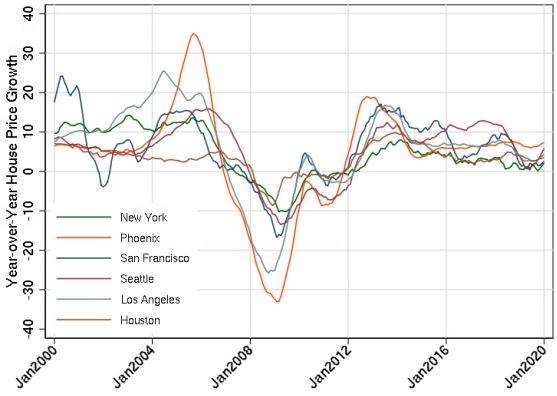
	Foreclosure (in percentage points)			
	(1)	(2)	(3)	(4)
	OLS	OLS	OLS	IV
Δ(Rent)	-1.72***	-1.60***	-1.52***	-6.13**
	(0.41)	(0.41)	(0.41)	(2.27)
Current LTV	5.25***	5.21***	5.17***	4.65***
	(0.29)	(0.29)	(0.28)	(0.43)
ln(Monthly Payment)	-0.44	-0.35	-0.32	-0.37
	(0.68)	(0.69)	(0.71)	(0.69)
ln(Average Wages)		-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
F-Stat				1868

Figure 1: House Prices, Rents, and New-tenant Rents in a Cross Section of Cities

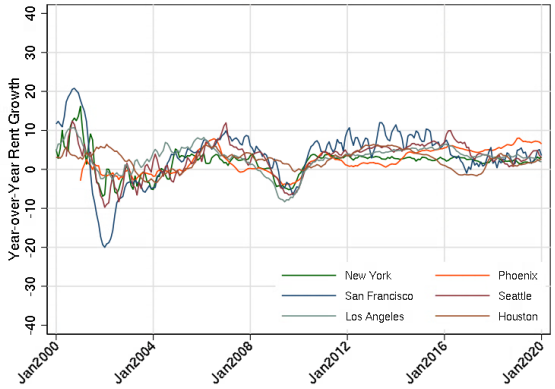
Note: Panel 1a of this figure is reproduced from Loewenstein and Willen (2023). It is a depiction of real house-price indexes (Case–Shiller) and rent (BLS) over time. Panels 1b and 1c are plots of nominal year-over-year house price and rent growth, respectively, for a selection of cities. House-price growth is measured using the CoreLogic HPIs and rent growth is measured using the CoreLogic Single-Family Rent Index. The cities included were chosen because they have a single-family rent index from 2024 going back to 2000. Adams et al. (2024) show that CoreLogic SFRI inflation rates are a good approximation of new-tenant rent inflation from the BLS Housing Survey, which is a representative sample of renter-occupied housing units. The percentage of households with negative equity and more than 10 percent decline in rents is plotted in Figure 2.



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



(b) Nominal House-price Growth in a Cross Section of Cities (CoreLogic HPI)

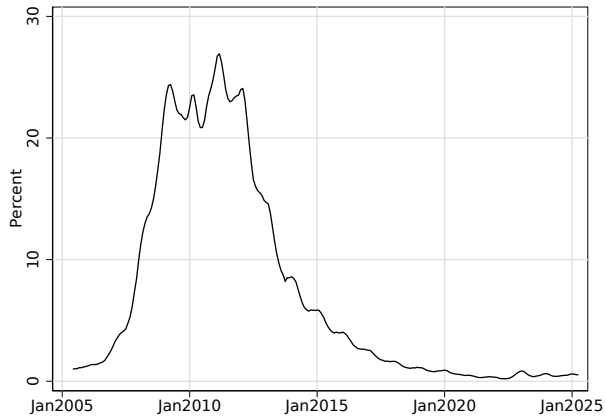


(c) Nominal New-tenant Rent Growth in a Cross Section of Cities (CoreLogic SFRI)

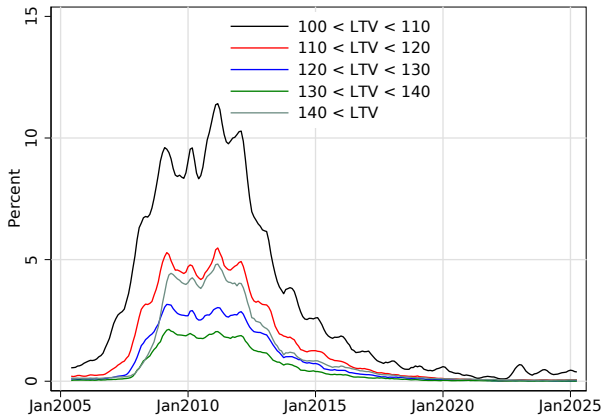
Figure 2: Percentage of Loans with Negative Equity and/or Rent Growth

Note: Figure 2a shows the percentage of active loans with negative equity. Figure 2b is the percentage of loans with negative equity in the given LTV buckets. Figure 2c is the percentage of loans that have experienced at least a 10 percent decline in rents since origination. Figure 2d shows the percentage of loans that have 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 are from CRISM, and LTVs are adjusted to account for second liens. Property values are updated using zip code house-price indexes from CoreLogic.

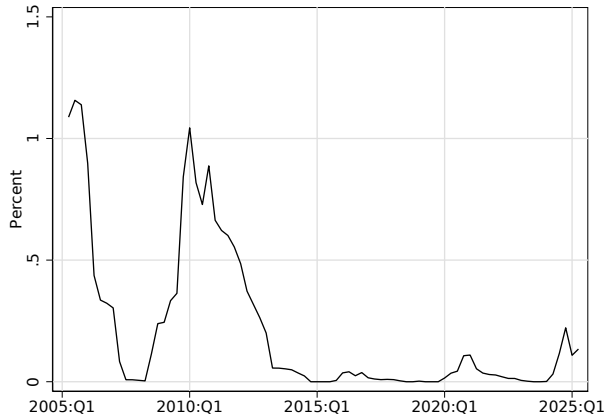
(a) Negative Equity



(b) Negative Equity by LTV



(c) Negative Rent Growth



(d) Negative Equity and Negative Rent Growth

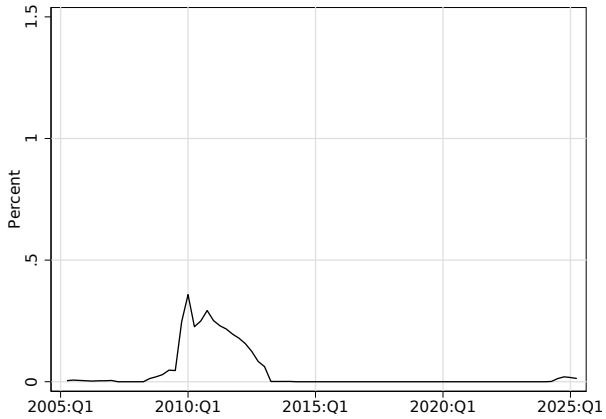


Figure 3: Dynamic Options of Households

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

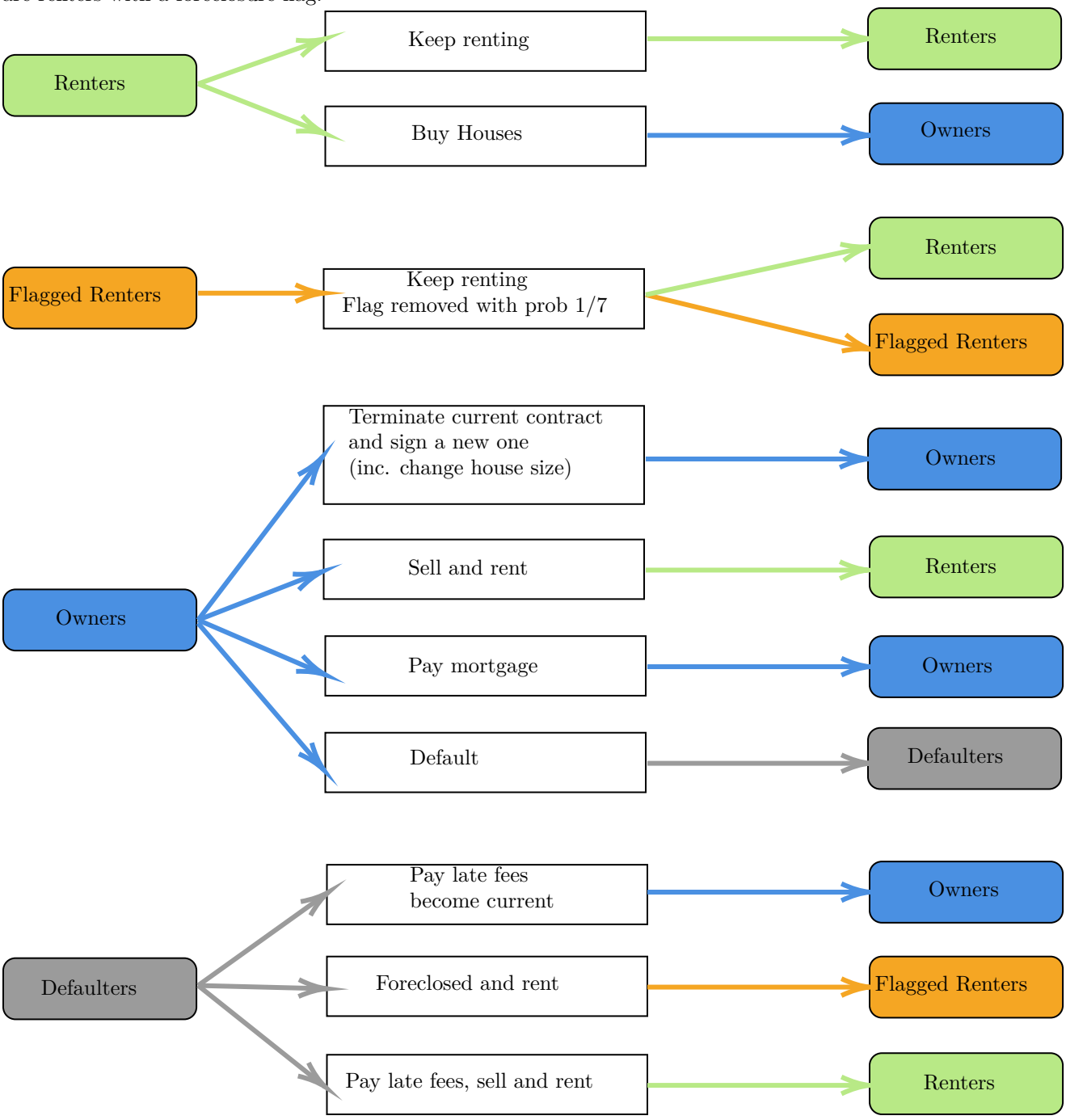
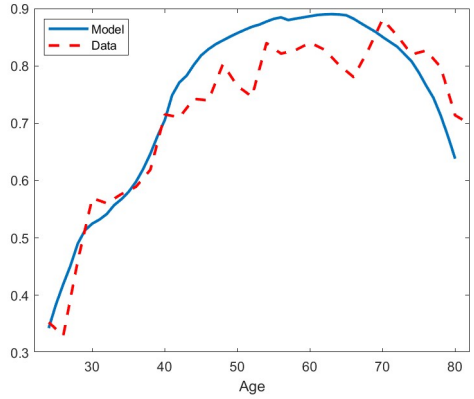
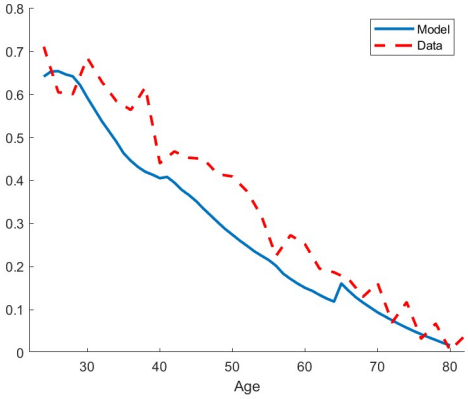


Figure 4: Calibration Results: Life-cycle Moments

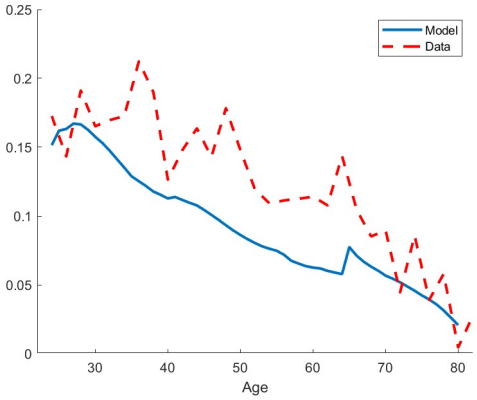
Note: In this figure, we present the model fit of our targeted moments to the data given the parameters in Table 1. Homeownership rates are in Panel 4a; LTVs by borrower age are in Panel 4b; average PTIs by borrower are are in Panel 4c; and average DTIs by borrower age are in Panel 4d. Sources: PTIs and LTVs are from the 2001 SCF; homeownership rates are from the 2001 ACS; default rates are from CRISM.



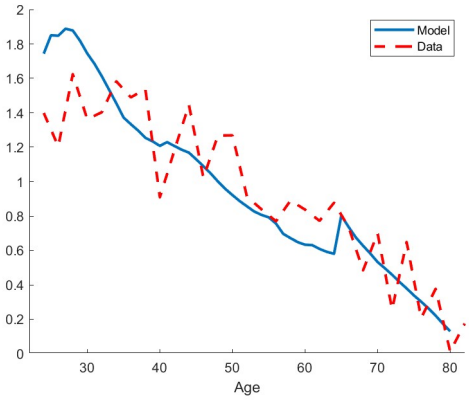
(a) Homeownership Rates



(b) Loan-to-Value Ratios



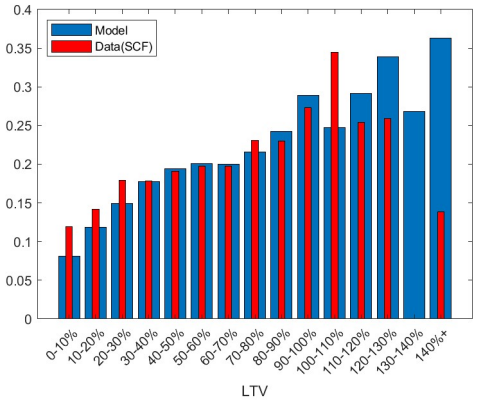
(c) Payment-to-Income Ratios



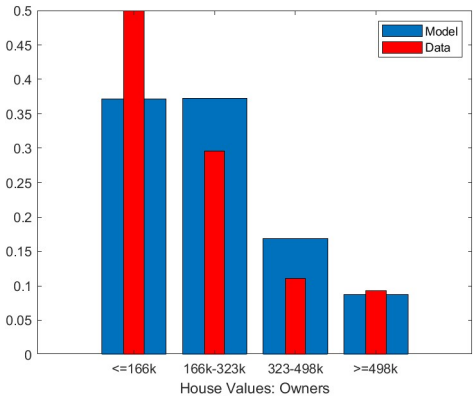
(d) Debt-to-Income Ratios

Figure 5: Model Fit in Nontargeted Moments

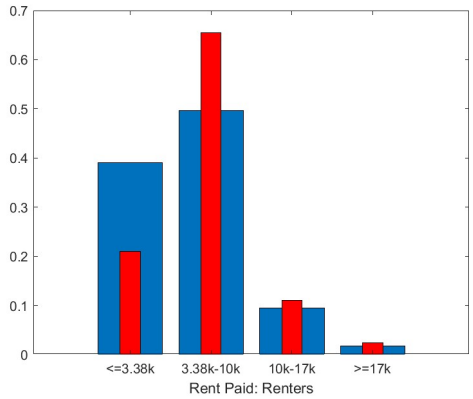
Note: We compare nontargeted model moments to empirical estimates from the 2001 SCF. Panel 5a is a comparison of payment-to-income ratios; Panel 5b is a comparison of the distribution of home values among homeowners; and Panel 5c is a comparison of annual rents paid by renters.



(a) Average Payment-to-Income Ratio by LTV



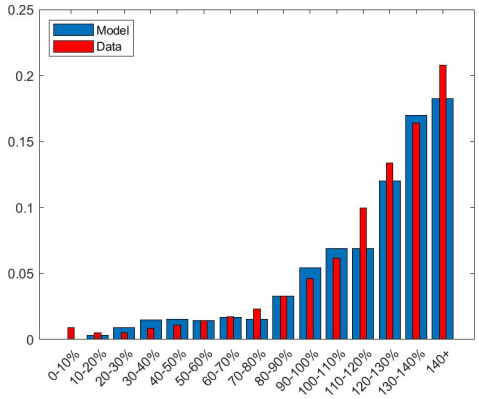
(b) Distribution of House Values among Owners



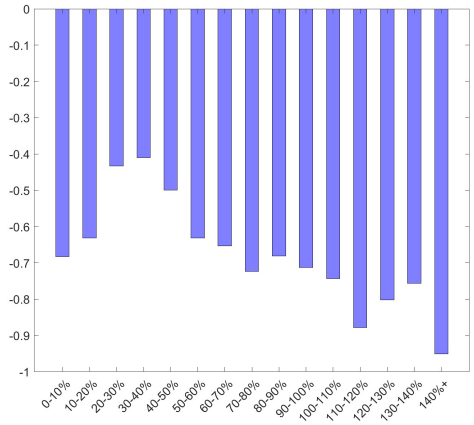
(c) Distribution of Annual Rents among Renters

Figure 6: Model Implications for Mortgage Default

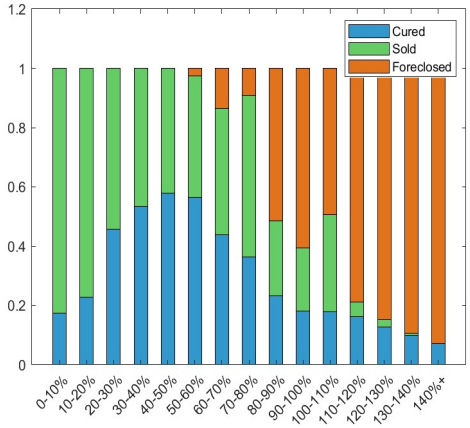
Note: Panel 6a is a depiction of the model-implied default rate by LTV and compared with our CRISM data. In Panel 6b, we plot the average one-year income change among defaulters relative to their mortgage payment. In Panel 6c, we present the foreclosure/sale/cure rates among defaulters by LTV. In all panels, the model-implied LTVs are assumed to be measured with error with a standard deviation of 14 percent.



(a) Default Rate



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



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

Figure 7: Housing Consumption Adjustment among Foreclosed Households

Note: This is a plot of the distribution of housing consumption adjustment among foreclosed households. Housing consumption adjustment is measured by the ratio of the difference of the size of the house that a household rents after foreclosure to that of the home it previously owned.

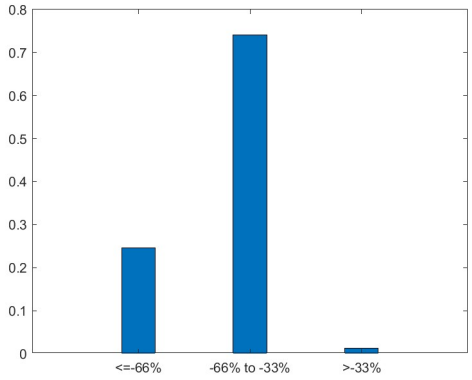
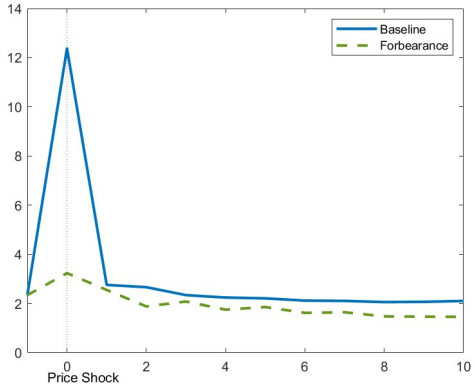
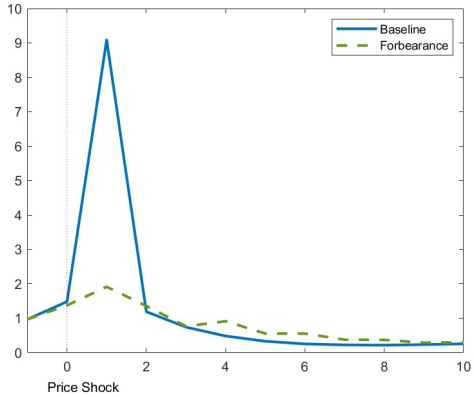


Figure 8: House Price Shock and the Introduction of Mortgage Forbearance

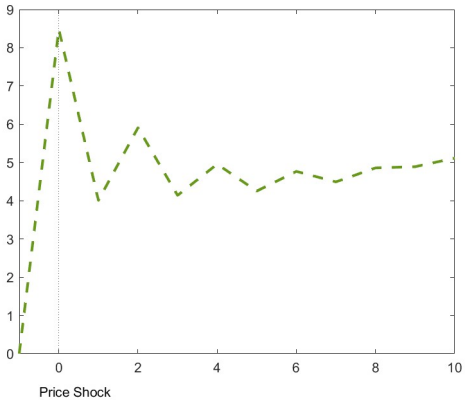
Note: This figure shows the evolution of delinquency and forbearance rates among mortgagors following a house price shock. In the counterfactual experiment, a mortgage forbearance program becomes available to all mortgagors who have made at least one payment and whose mortgage-payment-to-after-tax-income ratio exceeds 31%.



(a) Delinquency Rates



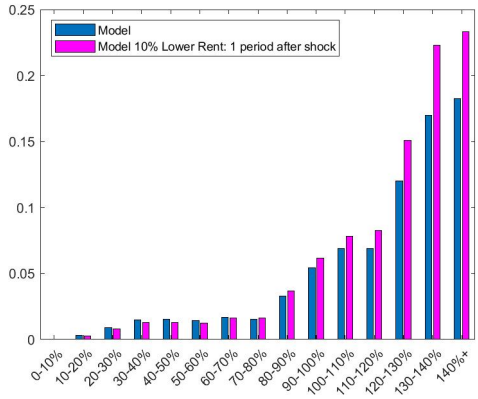
(b) Foreclosure Rates



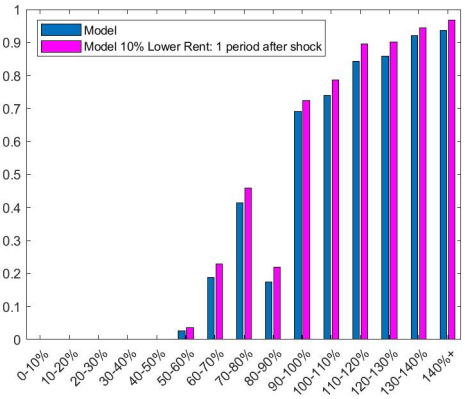
(c) Forbearance Take-Up Rate

Figure 9: Implication of a Permanent 10 Percent Decline in Real Rent

Note: All panels are a depiction of the short-run impact of a 10 percent decline in real rent on default and foreclosure one year after the rent shock. In Panel 9a, the default rate is defined as the number of households that become delinquent within the LTV bin by the total number of households within the LTV bin. In Panel 9b, the foreclosure rate among defaulters is defined as the fraction of delinquent households that undergo foreclosure by their mark-to-market LTV. For Panels 9a and 9b, model-implied LTVs are assumed to be measured with error with a standard deviation of 14 percent.



(a) Default Rate by LTV



(b) Foreclosure Rate Conditional on Default

Internet Appendix

This appendix supplements the analysis in this paper. The following is a list of the appendix sections.

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A Details about the Campbell and Cocco (2015) Model

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

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

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 $i_{i,t}$ from 2007 to 2010 implies that the $\frac{R_{it}}{P_{it}}$ fell from approximately 7 percent in 2007 to approximately 3 percent in 2010. In reality,the rent-to-price ratio rose from approximately 7 percent to approximately 10 percent from 2007 to 2010 (Loewenstein and Willen, 2023), a three-fold difference relative to the model's assumption.

In Figure A.1, we compare output from different calibrations of the Campbell and Cocco (2015) model to empirical estimates of the change in household income for defaulters from Ganong and Noel (2023) by levels of loan-to-value ratios (LTVs). If equity is the main driver of default, then we would expect that income declines become less vital to the default decision for more underwater households. However, Ganong and Noel (2023) find that households that are substantially underwater require an equally large decline in income as households with lower LTVs, implying that household liquidity concerns are more salient to default decisions than previously appreciated.

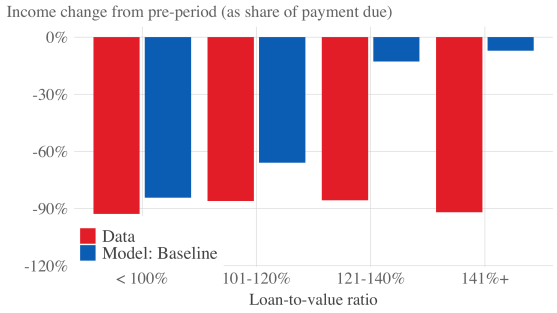
In Panel A.1a we plot household income change conditional on default in the Campbell and Cocco (2015) model's baseline calibration next to the estimates from Ganong and Noel (2023). In the model, high-LTV borrowers require a significantly smaller decline in income to default relative to the data because negative equity is the main driver of default in the baseline calibration, which assumes that rents move in parallel with house prices. In

Panel A.1b we show that adding a high nonpecuniary utility cost of default, on the order of 25 percent of lifetime consumption, enables the model to better match the data. These panels replicate the findings in Ganong and Noel (2023).

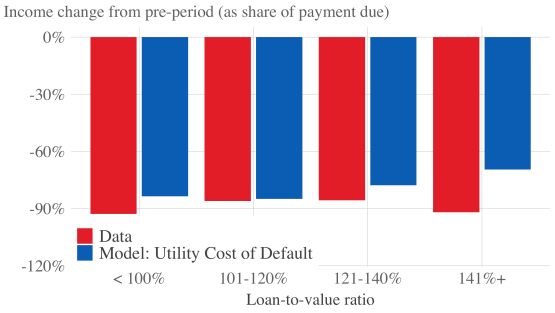
Panel A.1c illustrates the novel contribution of our paper. We show that the same fit can be achieved by holding real rent fixed at 2001 levels, consistent with the aggregate patterns in Loewenstein and Willen (2023), but without any nonpecuniary utility cost of default. Thus, the high implied value of strategic default in previous calibrations of the Campbell and Cocco (2015) model is largely due to the high assumed financial attractiveness of renting relative to owning during housing crashes, an assumption that no longer holds under a more realistic rent-to-price process. Panel A.1d examines the Campbell and Cocco (2015) model with constant real rent as well as a high default stigma worth 25 percent of lifetime consumption, which shows that, relative to Panel A.1c, a high default stigma has 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)'s Data

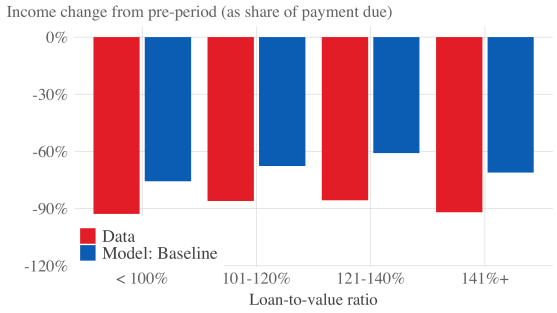
Note: In this figure, we present the results of the income change conditional on default implied by Campbell and Cocco (2015)'s model, as compared with the income declines in Ganong and Noel (2023)'s bank account data. In Panel A.1a, we plot the income changes conditional on default from the model without any non-pecuniary default stigmas in blue, as compared with the data in red. In Panel A.1b, we add a high default stigma to the model worth 25 percent of lifetime consumption, with results plotted in blue, compared with the same data in red. In Panel A.1c we plot the results of the Campbell and Cocco (2015) model without any stigma but with real rent fixed at constant 2001 levels.



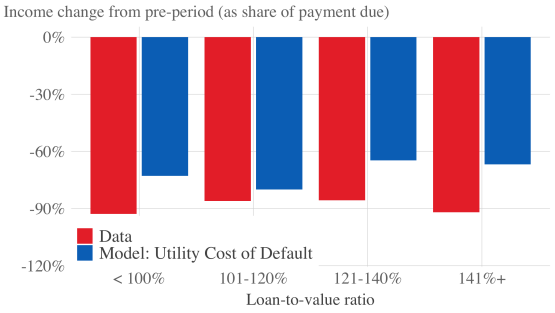
(a) Campbell and Cocco (2015)'s Model



(b) Campbell and Cocco (2015)'s Model with High Default Stigma



(c) Campbell and Cocco (2015)'s Model with Constant Real Rent



(d) Campbell and Cocco (2015)'s Model with Constant Real Rent and High Default Stigma

Table A.1: Effect of a permanent 10% decrease in rent in the Campbell and Cocco (2015) model with a high default stigma

Note: In this table, we present the effect of a permanent 10% decrease in rent in the Campbell and Cocco (2015) with a high default stigma. The baseline model is one with a default stigma worth 25% of lifetime consumption, as in Figure A.1b. The lower rent counterfactual represents the baseline model with a 10% lower rent. As the Campbell and Cocco (2015) model features no intermediate step between default and foreclosure, the default rate presented in this table may also be interpreted as the foreclosure rate.

	Default Rate
Baseline	0.19%
Lower Rent Counterfactual	0.19%

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.

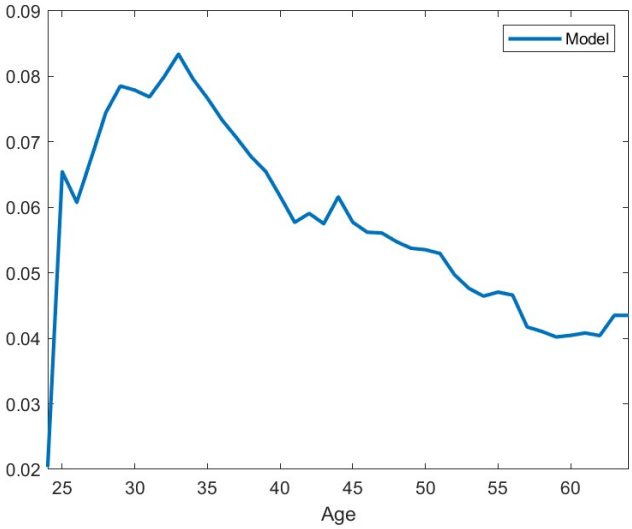


Figure A.3: Income Change Conditional on Default Resolution

Note: In this figure, we plot 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 described in Section 4. These borrowers had already experienced an average income drop when deciding to default (depicted in Figure 6b). In this figure, we plot their subsequent income change and shows that borrowers 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 percent.

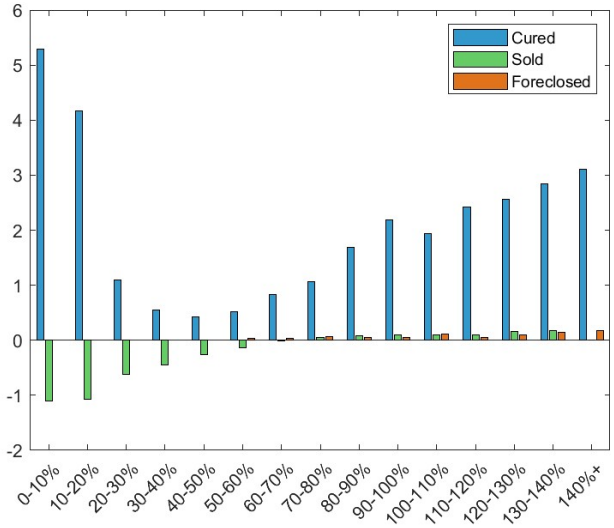
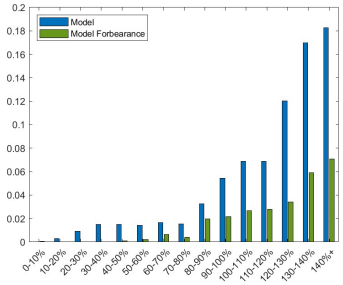
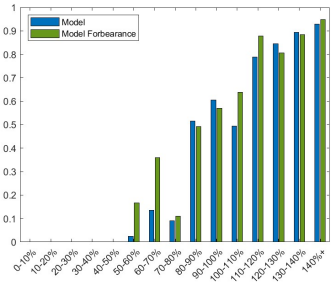


Figure A.4: Mortgage Forbearance in Stationary Equilibrium

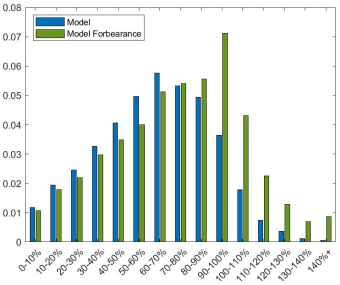
Note: This figure compares the stationary equilibrium economies with and without mortgage forbearance.



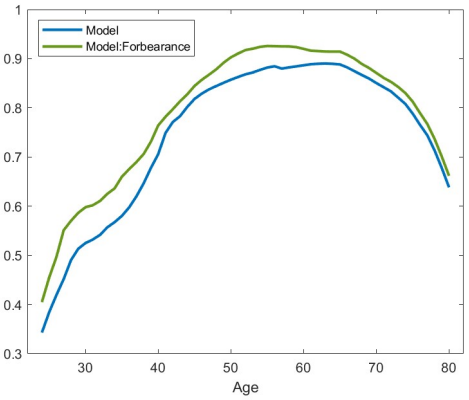
(a) Default Rate



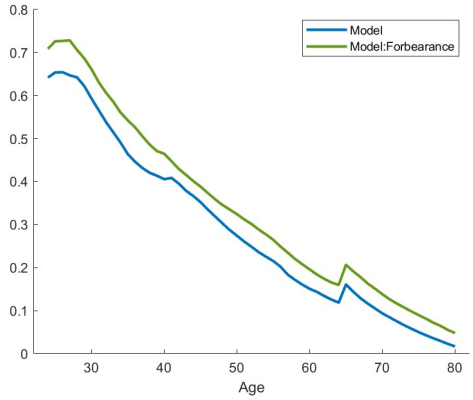
(b) Foreclosure|Default



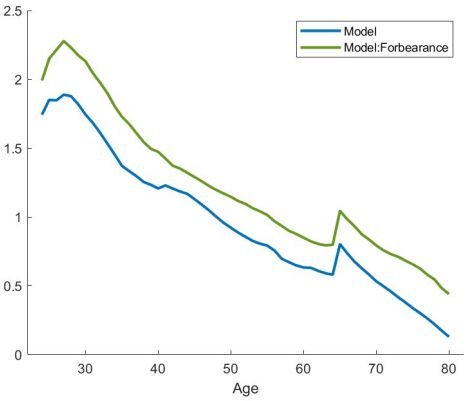
(c) LTV Distribution



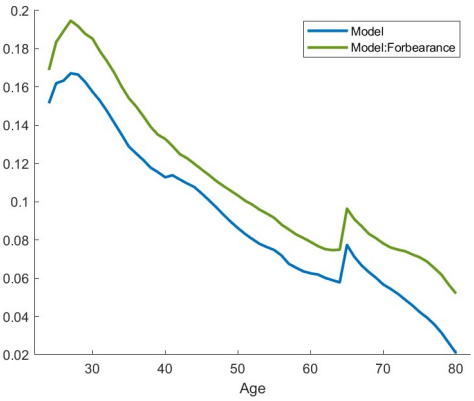
(d) Ownership Rate



(e) LTV



(f) DTI



(g) PTI

C Households' Recursive Problem in Our More Detailed Model of Mortgage Default

The state variables (Λ) of a household are its 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 it has a default flag on file $\Omega \in \{0, 1\}$. 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 a decision on the size of house to rent and whether to become an owner starting from the current period; (2) a homeowner with positive owned housing size $h > 0$ who makes the decision to change house size, sell and rent, pay their mortgage, or default the next period; (3) a defaulted owner who is behind on their mortgage payment and who makes a decision to pay late fees and become current, get foreclosed on and rent, or pay their mortgage, sell, and rent; and (4) a flagged renter with a foreclosure record on file $\Omega = 1$ makes a decision on the size of the house to rent. Figure 3 details the options of different types of households.

C.1 Baseline

C.1.1 Renters' maximization problem

Households that enter the period with no owned housing ($h = 0$) choose between getting the service through the rental market by making a decision on the size of the 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 choosing 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 in the superscripts. Because 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:

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

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 the risk-free asset.

Become owners The value of becoming an owner is:

$$
\begin{aligned}
V^{RO}(0,0,0,k,\epsilon,z,\zeta,s,j,0) = \max_{h',m',k'} \{ & \frac{((1-\eta)c^{1-\phi}+\eta(h')^{1-\phi})^{\frac{1-\sigma}{1-\phi}}}{1-\sigma} \\
& + \beta E_{(\epsilon',\zeta',s')|(\epsilon,\zeta,s)} V(1,h',m',k',\epsilon',z',\zeta,s,j,0)\} \\
& s.t. \\
& \frac{m'(1-(1+r_m)^{-N})}{r_m P h'} < 1-\xi \qquad , \quad (12) \\
c + k' + (1+\tau_b)\bar{P}\zeta h' + (\delta+\tau_h)\bar{P}h' = & (1-\tau(y(\epsilon,j))y(\epsilon,j) + (1+r)k \\
& + (1-\omega_1)\frac{m'(1-(1+r_m)^{-N})}{r_m} - \omega_0 \mathbb{1}_{m>0} \\
& \frac{m'}{y(\epsilon,j)} < PTI^{limit}
\end{aligned}
$$

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 a 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 the cost of maintenance and property tax. Down-payment 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.

C.1.2 Homeowners' maximization problem

A homeowner, $h > 0$, with a mortgage contract m that was signed n years ago has 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); 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 Equation (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 contract is:

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

where $\mathbb{1}_{n=N}$ is an indicator function that takes a value of 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 $\tau_h\bar{P}h$ is the 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 savings, 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 then get a new mortgage contract (m') and a new house (h'). The value of getting a new loan is:

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

where $\mathbb{1}_{h\neq h'}$ is an indicator function that takes a value of 1 if the household adjusts its house size (that is, $h \neq h'$). 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 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 the 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, the loan-to-value ratio has to be lower than $1-\xi$, which is equivalent to a minimum down-payment of ξ. Second, the scheduled 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:

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

where Rh^r is rental cost. Specifically, $(1-\tau_s)\bar{P}\zeta h - D(m,n)$ is the profit from selling the house net of transaction costs 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 a current mortgage contract is:

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

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

Note that while we assume that 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]

C.1.3 Defaulted owners' maximization problem

Defaulted owners have three options: (1) become current on their debt by paying all outstanding dues (missed payments and current payments), late fees, and applicable interest on late payments (option labeled as U); (2) pay the outstanding dues, sell the house, and rent (option labeled as S); (3) get foreclosed on and start the next period as renters with a 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 amounts, and rent. Note that underwater households may prefer this option to being foreclosed on, as it allows them to get another house in the near future. The value of this option is:

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

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 the preceding period, and $(1-\tau_s)\bar{P}\zeta h - D(m,n+1)$ is the profit from selling the house net of the transaction costs and mortgage debt. Note that after households pay the outstanding amount due, the remaining debt becomes $D(m,n+1)$.

Foreclosure If delinquent households decide to walk away from their debt, their household is foreclosed on, and they will start the next period with a foreclosure flag, which prevents them from becoming owners. 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 $\bar{R}h^r$.

C.1.4 Flagged renters

Renters with a foreclosure flag cannot become owners in the 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:

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

C.2 Mortgage Forbearance

We consider a forbearance option that is available to non-delinquent borrowers experiencing financial distress, defined as having a payment-to-after-tax income ratio above 31 percent and having made at least one prior mortgage payment ($n > 1$).Under this program, homeowners whose problem is described in Section C.1.2 receive an additional choice: (5) mortgage forbearance (option labeled as FB). Accordingly, the household value function becomes

$$V(n,h,m,k,\epsilon,\zeta,s,j,0) = \max_{C,N,OR,D,FB}\{V^C(.),V^N(.),V^{OR}(.),V^D(.),V^{FB}(.)\}. \tag{23}$$

Eligible borrowers who choose mortgage forbearance skip the scheduled mortgage payment, and the unpaid principal accrues interest and is capitalized into the outstanding balance.

The value of choosing mortgage forbearance is

$$V^{FB}(n,h,m,k,\epsilon,\zeta,s,j,0) = \max_{k'} \frac{((1-\eta)c^{1-\phi}+\eta(h)^{1-\phi})^{\frac{1-\sigma}{1-\phi}}}{1-\sigma} + \beta E_{(\epsilon',\zeta',s')|(\epsilon,\zeta,s)} VFB(n,h,m,k',\epsilon',\zeta',s',j+1,0) \quad , \quad s.t. \;\; c + k' + (\delta+\tau_h)\bar{P}h = (1-\tau(y(\epsilon,j)))y(\epsilon,j) + (1+r)k \tag{24}$$

One advantage of choosing forbearance rather than default (see 28) is that forbearance avoids the direct utility cost associated with default.

C.2.1 Existing Forbearance

Borrowers with forbearance have four options: (1) Resume mortgage payment (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); or (4) default on the mortgage (option labeled as D)

Resume mortgage payments

Owners who decide to resume mortgage payments choose current consumption c and saving k'. The value of resuming mortgage payment:

$$
\begin{aligned}
&VFB^C(n,h,m,k,\epsilon,\zeta,s,j,0) = \max_{k'} \frac{((1-\eta)c^{1-\phi}+\eta(h)^{1-\phi})^{\frac{1-\sigma}{1-\phi}}}{1-\sigma} + \\
&\beta E_{(\epsilon',\zeta',s')|(\epsilon,\zeta,s)}\{\omega \mathbb{1}_{n<N} V(n,h,m,k',\epsilon',\zeta',s',j+1,0) + \\
&(1-\omega)[\mathbb{1}_{n<N} V(n+1,h,m,k',\epsilon',\zeta',s',j+1,0) + \mathbb{1}_{n=N} V(0,h,0,k',\epsilon',\zeta',s',j+1,0)]\} \\
&s.t. \;\; c + k' + (\delta+\tau_h)\bar{P}h = (1-\tau(y(\epsilon,j)))y(\epsilon,j) + (1+r)k - \\
&\max\{\frac{m}{(1+\pi)^n}, \frac{((1+r_m)^2-(1+\pi)^2)D(m,n)}{(1+\pi)(1+r_m)}\} \\
&\omega = \frac{\frac{(1+r_m)D(m,n)}{1+\pi} - \max\{\frac{m}{(1+\pi)^n}, \frac{((1+r_m)^2-(1+\pi)^2)D(m,n)}{(1+\pi)(1+r_m)}\} - \frac{(1+\pi)D(m,n+1)}{1+r_m}}{\frac{(1+\pi)[D(m,n)-D(m,n+1)]}{1+r_m}}
\end{aligned}
\quad , \quad (25)
$$

Due to the accrued interest, the household's real mortgage balance increases to $\frac{(1+r_m)D(m,n)}{1+\pi}$. If the additional interest accumulated over two periods (the forbearance period and the current period) exceeds the scheduled mortgage payment, that is, if $\frac{((1+r_m)^2-(1+\pi)^2)D(m,n)}{(1+\pi)(1+r_m)} \geq \frac{m}{(1+\pi)^n}$, then the household pays only the interest and does not advance along the amortization schedule. In this case, the outstanding balance after paying interest is $\frac{D(m,n)(1+\pi)}{1+r_m}$ which returns $D(m,n)$ in the following period. Otherwise, the household makes the regular mortgage payment and moves one step along the amortization schedule in the next period with probability $1-\omega$ and does not move along the amortization schedule in the next period with probability ω, where ω interpolates the post-forbearance debt balance net of (or after) payment which lies between $D(m,n)$ and $D(m,n+1)$.

Refinance or change house size

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

$$
\begin{aligned}
VFB^N(n,h,m,k,z,\zeta,s,j,0) = \max_{k',h',m'} & \frac{((1-\eta)c^{1-\phi}+\eta(h')^{1-\phi})^{\frac{1-\sigma}{1-\phi}}}{1-\sigma} \\
& + \beta E_{(\epsilon',\zeta',s')|(\epsilon,\zeta,s)} V(1,h',m',k',z',\zeta',s',j+1,0) \\
& s.t. \\
& \frac{m'(1-(1+r_m)^{-N})}{r_m \bar{P}\zeta h'} < 1-\xi \\
& \frac{m'}{y(z,\epsilon,j)} < PTI^{limit} \\
c + k' + (\delta+\tau_h)Ph + (\tau_s \bar{P}\zeta h + \tau_b \bar{P}\zeta h')\mathbb{1}_{h\neq h'} = & (1-\tau(y(\epsilon,j))y(\epsilon,j) \\
& + (1+r)k + \bar{P}\zeta h - \frac{(1+r_m)D(m,n)}{1+\pi} - \bar{P}\zeta h' \\
& + (1-\omega_1)\frac{m'(1-(1+r_m)^{-N})}{r_m} - \omega_0 \mathbb{1}_{m'>0}
\end{aligned}
\tag{26}
$$

where $\frac{(1+r_m)D(m,n)}{1+\pi}$ is the (real value) outstanding loan balance for a previously forborne loan.

Sell and rent

Owners who decide to sell and become renters will first pay the outstanding due before renting a house. The value of selling and renting is:

$$
\begin{aligned}
VFB^{OR}(n,h,m,k,z,\zeta,s,j,0) = \max_{k',h^r} & \frac{((1-\eta)c^{1-\phi}+\eta(h^r)^{1-\phi})^{\frac{1-\sigma}{1-\phi}}}{1-\sigma} \\
& + \beta E_{(\epsilon',\zeta',s')|(\epsilon,\zeta,s)} V(0,0,0,k',z',\zeta',s',j+1,0) \\
s.t. \;\; c + k' + \bar{R}h^r = & (1-\tau(y(\epsilon,j))y(\epsilon,j) + (1+r)k \\
& + (1-\tau_s)\bar{P}\zeta h - \frac{(1+r_m)D(m,n)}{1+\pi}
\end{aligned}
\tag{27}
$$

Default

Following the expiration of the forbearance period, households retain the option to default.

The value of default is:

$$VFB^D(n,h,m,k,\epsilon,\zeta,s,j,0) = \max_{k'} \frac{((1-\eta)c^{1-\phi}+\eta(h)^{1-\phi})^{\frac{1-\sigma}{1-\phi}}}{1-\sigma} - \psi$$
$$+ \beta E_{(\epsilon',\zeta',s')|(\epsilon,\zeta,s)} VQ(n,h,\frac{(1+r_m)m}{1+\pi},k',\epsilon',\zeta',s',j+1,0)$$
$$s.t.\ \ c+k'+(\delta+\tau_h)\bar{P}h = (1-\tau(y(\epsilon,j)))y(\epsilon,j)+(1+r)k \tag{28}$$

To sum up,

$$V^{FB}(n,h,m,k,\epsilon,\zeta,s,j,0) = \max_{C,N,OR,D}\{VFB^C(.), VFB^N(.), VFB^{OR}(.), VFB^D(.)\}. \tag{29}$$