Mortgage Design and Slow Recoveries. The Role of Recourse and Default.*

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This Draft: October 2022

Abstract

We show that mortgage recourse systems, by discouraging default, magnify the impact of nominal rigidities. They cause deeper and more persistent recessions. This mechanism can account for up to 31% of the recovery gap during the Great Recession between the U.S., mostly a non-recourse economy, and Spain, a recourse economy. General equilibrium effects explain most of the differences between mortgage systems. With recourse, highly indebted homeowners dramatically cut consumption in a crisis, and account for a larger share of the aggregate consumption decline. However, without recourse, mortgages would be more expensive for riskier households, and homeownership rates would be lower.

Keywords: Aggregate Demand, Consumption, Default, Europe, Foreclosures, Housing, Liquidity Traps, Mortgages, Nominal Rigidities, Recourse, Recovery

JEL Classification: E51, H81, G21, R2

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*We thank Dirk Krueger (editor), four anonymous referees, and many colleagues, seminar participants and discussants for helpful comments. Pedro Gete acknowledges and appreciates the support from MCIN /AEI /10.13039/501100011033 / FEDER, UE Grant No. PID2021-125359NB-I00. Franco Zecchetto thanks Asociación Mexicana de Cultura, A.C. for financial support.

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1 Introduction

Mortgage systems vary in striking ways through time and across countries. As discussed by Campbell (2017), Campbell, Clara and Cocco (2021), and Piskorski and Seru (2018), an important research question is what are the main lessons from the Great Recession for mortgage design. In a recourse mortgage, the defaulter remains liable for the deficiency, that is, the difference between the remaining principal balance and the sale price of the foreclosed house. In this paper we argue that whether mortgages allow for recourse or not is very important for macroeconomic dynamics once an economy is in a liquidity trap.

We build a quantitative incomplete-markets equilibrium model that features non-recourse and recourse mortgage default, endogenous borrowing spreads, house prices, labor supply, and aggregate unemployment. There is heterogeneity in housing tenure, leverage, and liquid savings, like in Corbae and Quintin (2015), Garriga and Hedlund (2020), Jeske, Krueger and Mitman (2013), or Kaplan, Mitman and Violante (2020), among others. The model yields empirically realistic distributions of current loan-to-value, housing tenure, liquid savings, and marginal propensities to consume. Using this quantitative framework, our paper shows that the recourse mechanism can account for up to 31% of the observed recovery gap in consumption between the U.S. and Spain, a canonical recourse economy. Moreover, recourse amplifies the asymmetry of household balance sheets effects in the transmission of house prices to consumption.

The key insight from this paper is that in a liquidity trap, default with non-recourse mortgages has positive aggregate effects, even in the presence of reasonable deadweight losses from foreclosure. By a liquidity trap we refer to a situation where nominal wage rigidities are binding, interest rates are at the lower bound, and the economy becomes "demand-driven". That is, output is below fundamentals, like in Guerrieri and Lorenzoni (2017), Korinek and Simsek (2016), or Schmitt-Grohé and Uribe (2017), among others. The intuition is as follows. Tighter credit restricts funding to new house buyers, putting downward pressure on house prices. The drop in house prices severely affects financially distressed homeowners. As a result, the demand for housing and consumption are depressed. Firms demand less labor after the drop in consumption. The downward nominal wage rigidity prevents the real wage from falling as much as needed to clear the labor market, leading to unemployment. The disruption in the labor market depresses consumption and the demand for housing, putting more downward pressure on house prices. The marginal product of capital, investment, and output decline. In this situation, the lower bound prevents the real interest rate from playing an equilibrating role. The economy enters into a liquidity trap, with collapsing house prices and rising unemployment.

With non-recourse mortgages, the borrower is not liable for any deficiency balance, so default frees up valuable resources to sustain consumption. This works as a mechanism that redistributes wealth towards highly indebted, high propensity to consume borrowers. In fact, it may be the only permanent mechanism since debt relief policies are usually "one-off policies" (Agarwal et al. 2017, Gabriel, Iacoviello and Lutz 2016), and equity mortgages are still rarely used (Greenwald, Landvoigt and Van Nieuwerburgh 2021, Piskorski and Tchistyi 2017). By contrast, recourse plays a major role in discouraging defaults, preventing the discharge of current mortgage payments. Thus, recourse magnifies the contraction in consumption. At the same time, recourse amplifies the drop in housing demand, since it makes taking out a mortgage less attractive at the onset of the crisis. This triggers an even greater disruption in the housing and labor markets, ultimately leading to a more severe recession. Also, recourse increases financial fragility by having more poorer households buying houses with high leverage before the crisis.

A comparison of aggregate data for the U.S. and Europe provides suggestive evidence of the previous mechanism. In practice, the U.S. is mostly non-recourse while most European countries have recourse systems (Willen 2014). Interestingly, Spain and the U.S. had similar patterns pre-crisis and at the start of the crisis. However, their economic recoveries have been very different. Figure 1 illustrates these dynamics. Pre-crisis, housing prices and mortgage debt increased during the 1996-2006 period together with current account deficits (Bernanke 2010, Gete 2009). At the start of the crisis, on both sides of the Atlantic housing prices fell by a similar amount, economic performance tanked, and by 2009 monetary policy hit the zero-lower bound (Gros 2014). However, over the 2011-2013 period the U.S. economy grew by about 4.5% more on a per capita basis. The main reason for the gap is the difference in private consumption, which grew in the U.S., but fell in the Eurozone.[1] Moreover, in the U.S. it took four years for housing prices to start to recover while in Spain it took more than six years. In Spain it took nearly five years for aggregate consumption to stop falling.

Figure 1 panels (e) and (f) motivate the mechanism that we explore. Through default, U.S. households have reduced their mortgage debt burden since 2007 much faster than households in Spain. Here, lenders have full recourse to the borrowers' personal assets and future income until the deficiency is fully paid off. The response of mortgage defaults in Spain was much smaller, despite the fact that this country experienced a much more severe recession. We argue that, by discouraging defaults, the European mortgage recourse system depressed the consumption of low-income debtors unable to discharge their debts and mortgage payments. This contributed to a deeper and more persistent recession.[2]

[1]Public consumption and investment actually subtracted more demand in the U.S. than in the European Union. The contraction of private investment in Europe accounted for one-third of the growth gap (Gros 2014).

[2]Other differences between the U.S. and Spain that could be driving the different aggregate dynamics shown in Figure 1 are the low productivity growth experienced by Spain over the decade that preceded the crisis, the

We quantify the general equilibrium effects along the dynamic transition path, after unexpected productivity and credit shocks that drive both economies into a liquidity trap. First, we parameterize the steady state to the U.S. economy (non-recourse), and generate the recourse economy by introducing recourse mortgages, while keeping most of the parameters fixed. The recourse economy experiences a significantly more severe recession, with falls in housing prices, aggregate consumption, and output around 27%, 68%, and 73% larger relative to non-recourse. With recourse, the unemployment rate is roughly twice as large (21% versus 10%), and the disruption in the labor market lasts for three years instead of two. Second, we parameterize the steady state to Spain, and compare its response with the U.S. model economy. The results are similar to the first experiment. In both experiments, recourse mortgages amplify the relevance of highly indebted borrowers in accounting for the consumption decline during the crisis.

Our results indicate that non-recourse systems would be better at providing debt relief by discharging mortgage payments, and thus supporting aggregate demand during liquidity traps in economies with more nominal rigidities like Europe. However, without recourse, mortgage credit would be more expensive for low income, high risk households. Homeownership rates would be lower. More generally, our results help to understand the consequences of different institutional arrangements in mortgage markets for the macroeconomy.

There are four features of our model that are key for the results, and that make the model consistent with the empirical evidence. First, both housing prices and labor earnings are endogenous in a general equilibrium framework. Second, there are housing transaction costs. Third, credit spreads are endogenous. Fourth, mortgages are long-term contracts.

Endogenous house prices and labor income are important because general equilibrium forces account for most of the differences in consumption responses between the mortgage systems. That is, recourse and non-recourse mortgages provide different incentives to default, but the main reason why these two systems differ, from a macroeconomic point of view, is because they trigger very different dynamics for house prices and employment.

The model generates households with high consumption responses to income changes. This results from *housing* and *mortgage illiquidity*, which increase the exposure of households to idiosyncratic and aggregate risk, making consumption more responsive to income shocks. Housing illiquidity arises from transaction costs. Homeowners move out from their house infrequently. Mortgage illiquidity arises from endogenous spreads, making access to credit and home equity more difficult for highly indebted, riskier households, and making default more likely.

deterioration in external competitiveness, the large exposure of tax revenue to the real estate market during the housing boom, and the European debt crisis, among others.

Long-term debt matters for two reasons. First, it prevents debt from disappearing after one period. Thus, non-recourse is important as it is the only way for over-indebted households to default and start afresh. Second, since mortgages are long-term, the loan-to-value (LTV) constraint only holds at origination. Thus, when the LTV limit tightens or house prices drop, existing borrowers are not mechanically forced to deleverage, as it would be the case with one-period debt. In our model, homeowners do not deleverage if they keep making the scheduled payment, but they can do so by prepaying or defaulting on the mortgage. Non-recourse and recourse mortgages provide different incentives for these endogenous choices.

The model generates substantial heterogeneity in the marginal propensity to consume (MPC). Highly leveraged households have large MPCs, in contrast to households with large housing equity which have low MPCs.[3] This result is key since our recession experiments involve the transmission of income and house prices changes into consumption, and the latter have been shown by Berger et al. (2017) to be closely linked to transitory income shocks.

The rest of the paper is organized as follows. Section 1.1 briefly discusses the related literature. Section 2 documents the key macroeconomic facts motivating the analysis. Section 3 presents the model. Section 4 discusses the parameterization to the U.S. and the fit of the model. Section 5 contains the core exercise. Section 6 redoes the exercise for the parameterization to Spain. Section 7 discusses some robustness exercises. Section 8 concludes. The Appendix contains all the details and extra results.

1.1 Related Literature

This paper connects four different literatures. First, we contribute to the literature that explores the consequences of cross-country variation in mortgage market structure. Campbell (2013) is an early survey. Recent research has focused on the role of adjustable versus fixed rates mortgages (Auclert 2019, Campbell and Cocco 2003, Campbell, Clara and Cocco 2021, Di Maggio et al. 2017, Garriga, Kydland and Šustek 2017, Guren, Krishnamurthy and McQuade 2021), high leveraged mortgages (Corbae and Quintin 2015), equity mortgages (Greenwald, Landvoigt and Van Nieuwerburgh 2021, Kung 2015, Piskorski and Tchistyi 2017), recourse mortgages affecting the choice of leverage before crises (Hatchondo, Martinez and Sánchez 2015), and on the role of automatically indexed mortgage contracts and debt relief polices (Piskorski and Seru 2018). It is interesting to highlight that Corbae and Quintin (2015) find that recourse economies are less sensitive to aggregate housing price shocks. We obtain the

[3]These patterns have been documented, for instance, in the summary in Kaplan, Moll and Violante (2018), or Misra and Surico (2014).

opposite result (recourse amplifies house price falls and downturns) because we analyze a model with both endogenous house prices and nominal rigidities that allow for demand-driven output.

Second, we contribute to the growing literature that studies liquidity traps. Like, for example, Auclert and Rognlie (2020), Eggerston and Krugman (2012), Farhi and Werning (2016), Guerrieri and Lorenzoni (2017), Korinek and Simsek (2016), or Schmitt-Grohé and Uribe (2017). This literature has focused on models with one-period debt and no default. We show that long-term debt and default generate a powerful mechanism that influences economic recoveries. The mechanism is new in the literature since long-term debt alters the link between debt and consumption.

Third, we connect with the literature on mortgage default (see Foote and Willen 2018 for a recent survey). A major insight from this literature is that the level of liquid assets is a key determinant of default. We confirm that result. Moreover, we show that in recourse economies liquid assets are more important drivers of default than in non-recourse economies. This is a relevant result when comparing default rates across countries.

Using loan-level data and exploiting cross-state variation within the U.S. on recourse laws, Ghent and Kudlyak (2011) find that recourse decreases borrower's sensitivity to negative equity. At the mean value of negative equity, borrowers are 30% more likely to default in non-recourse states. Our paper confirms this finding with a structural approach.[4]

In our model, like in dynamic models of mortgage default as Campbell and Cocco (2015), the link between home equity and default is non-linear. Default probabilities rise dramatically for high leverage mortgagors. This is a fact stressed by Ganong and Noel (2017). In this paper we bring insights from general equilibrium to this literature. Moreover, we highlight that lack of default amplifies the severity of recessions when nominal rigidities bind and there are no mechanisms for reducing debt and payments.

We also differentiate the reasons why borrowers default based on the prevailing theories of mortgage default. In our model, the majority of underwater defaults are driven exclusively by negative liquidity events ("cash-flow" default). Moreover, a significant share are due to the interaction between adverse liquidity events and negative equity ("double-trigger" default). In contrast, there is little prevalence of defaults driven solely by negative equity ("strategic" default). These results are consistent with the empirical findings of Ganong and Noel (2022).

Fourth, our paper contributes to the literature on the effects of social insurance policies on credit markets (see for example, Athreya, Mustre-del-Río and Sánchez 2019, Athreya, Tam

[4] Moreover, Li and Oswald (2017) find that making the deficiency judgment law more default friendly in Nevada led to reduced supply of mortgage credit. Our model is also consistent with this result.

and Young 2015, Chatterjee et al. 2007, Livshits, MacGee and Tertilt 2007, or Mitman 2016). This literature has focused on unsecured credit.[5] A consensus in the literature is that debt relief policies are ex-ante beneficial only for sudden large shocks, because these policies make credit expensive and so sensitive to borrower circumstances that the overall ability to smooth consumption is substantially worsened. Our paper is one of the first to analyze debt relief in mortgage markets in general equilibrium. This is important because the multiplier effect of debt relief happens in a liquidity trap. Kaplan, Mitman and Violante (2020) study the macroeconomic implications of one-time debt forgiveness programs in which all highly leveraged homeowners have a fraction of their mortgage debt forgiven so that their LTV is lowered to 95%, implying a reduction in payments.[6] Our analysis is very different since we compare permanent mortgage systems that differ markedly in the ability of lenders to collect upon default of the borrower, with non-recourse implying the complete discharge of payments and debt. Also, we examine the impact that recourse has on the economy before and after the crisis.

2 Motivating Facts

We now document the key macroeconomic facts that motivate our analysis. We compare the aggregate dynamics during the Great Recession in the U.S. and Spain. The latter has recourse mortgages, meaning that defaulters are responsible for the deficiency. This regulation increases the cost of default for borrowers. In contrast, in most U.S. states mortgages are non-recourse, and even in those states where recourse is allowed, the deficiency can be discharged in bankruptcy. This makes the U.S. mostly a non-recourse country in practice.

Figure 1 displays the paths of several macroeconomic variables for both countries during the period 2007-2016. To facilitate the comparisons, the series are normalized to 100 in the first quarter of 2007. Panel (a) shows that real house prices in the U.S. fell by about 34%. Despite starting to fall later than in the U.S., real house prices in Spain eventually collapsed by roughly 43%. Furthermore, in the U.S. it took four years for house prices to begin to recover since late 2007, while in Spain it took more than six years. In the first quarter of 2020, house prices in the U.S. were still 8% below their pre-crisis level, while in Spain they were 27% below. Thus, the disruption in the housing market was more severe and lasted longer in Spain.

At the same time, both economies displayed very different paths for real activity. Panels (b) and (c) show that in the U.S., real consumption and GDP fell by approximately 2% and 4%

[5] Eberly and Krishnamurthy (2014) study mortgage debt relief in a partial equilibrium analysis.

[6] These authors find that such program would have had little effect in cushioning the decline in house prices and expenditures during the crisis, but that would have had a significant effect in reducing foreclosures.

respectively from peak (second quarter of 2008). Both variables returned to their pre-crisis levels in the third quarter of 2010. In Spain, the evolution of real consumption and GDP was similar at the beginning of the crisis. However, performance eventually crashed, with both variables falling by roughly 13% and 9% respectively from peak. It took five years for consumption and GDP to stop falling, and both returned to their pre-crisis levels in late 2019 and early 2017, respectively. In addition, panel (d) shows that in the U.S., the unemployment rate doubled and recovered its pre-crisis level in early 2017. The disruption in the labor market was much more severe in Spain, where the unemployment rate more than tripled and by early 2020 had not yet recovered. In short, Spain experienced a deeper recession and a slower recovery.

Panels (e) and (f) reveal the dynamics of real mortgage debt outstanding and mortgage defaults. Since the peak in late 2007, U.S. households reduced their mortgage debt burden by 20%. Although it took seven years, the deleveraging process was much faster than that of Spain. For example, four years after the start of the crisis, outstanding mortgage debt in Spain was still close to its pre-crisis level, while in the U.S. it was 13% below. Furthermore, during the same period, in the U.S. mortgage defaults increased sharply and quadrupled in 2011 relative to 2007, while in Spain less than doubled.

3 Model

We analyze an infinite horizon economy composed by a continuum of households and lenders, a representative firm that produces the final good, the government, and the central bank. Households face uninsurable idiosyncratic labor productivity and house value risk. Time is discrete and denoted by t. The non-housing consumption good serves as numeraire. We consider economies with only non-recourse or recourse mortgage loans.

We define the model recursively. The formal recursive formulation of the household problem and the definition of equilibrium are contained in Appendixes B.1 and B.8 respectively. The computational details are found in Appendix D.

3.1 Household Sector

3.1.1 Preferences and Endowments

Households have preferences over non-housing consumption c, housing services s, and hours worked ℓ. Households are endowed with one unit of time every period, which they allocate between work and leisure. The period utility is $u(c, s, \ell)$. Preferences are time-separable and the future is discounted at rate β. The expected lifetime utility of a household is

$$\mathbb{E}\left[\sum_{t=0}^{\infty} \beta^t u(c_t, s_t, \ell_t)\right]. \tag{1}$$

Households can obtain housing services by renting or owning a house. Moreover, there is an ownership utility benefit. That is, renting a house of size h generates a service flow of $s = h$, while owning a house of size h generates a service flow of $s = (1+\chi)h$, where $\chi > 0$ captures the motives towards ownership beyond those explicitly modeled.

The labor supply of a household is $z\ell$. The idiosyncratic labor productivity shock z follows an exogenous finite state Markov chain with transition probabilities $f_z(z'|z)$.

3.1.2 Household Disposable Income

Denote by W_t and P_t the nominal wage and the price level. Household labor earnings are the product of the real wage, labor productivity, and hours worked. Thus, labor earnings after taxes τ_t and lump-sum transfers T_t are given by $y_t(z, \ell) = (1 - \tau_t)(W_t/P_t)z\ell + T_t$.[7]

Our setting involves downward nominal wage rigidities, which implies that the labor market might experience rationing. In this case, households become employed with probability $\kappa(z, n_t)$, which depends upon their current idiosyncratic labor productivity z and the aggregate employment rate n_t, which is determined in equilibrium. The function κ allows us to parsimoniously parameterize the incidence of aggregate unemployment across households.

Unemployment insurance is given by $\tilde{T}^U(z) = \bar{T}^U \min\{z, \bar{z}^U\}$. This specification captures the link between unemployment benefits and past earnings given the persistence of the labor productivity z, and mirrors the U.S. law since benefits are linear in z with slope $\bar{T}^U$ and have a maximum cap $\bar{z}^U$. Unemployment benefits are taxable like in the U.S. and Spain. Thus, unemployment benefits after taxes and transfers are given by $T_t^U(z) = (1 - \tau_t)\tilde{T}^U(z) + T_t$.

3.1.3 Liquid Savings and Housing

Households invest in one-period deposits a' paying a real risk-free interest rate r_t between time t and $t + 1$. It is convenient to define the associated deposit price $q_t^A = 1/(1 + r_t)$.

[7] We follow the common notation that aggregate variables have the time t subscript, while the state and decision variables like labor productivity z and hours worked ℓ in the household recursive problems do not.

The economy has a constant aggregate stock of owner-occupied housing H. Houses are available in discrete sizes $h \in \{\underline{h}, ..., \bar{h}\}$. The housing price per unit is p_t^H and is determined endogenously. Buying a house of size h costs $p_t^H h$ units of the final good. Homeowners can only have one house and cannot rent it. This assumption simplifies the solution of the model and does not affect the key mechanisms that we study. There are proportional transaction costs ζ_b and ζ_s of buying and selling houses. The transaction costs, along with other frictions that we will introduce later, give rise to housing illiquidity, which makes homeowners to adjust their house size (by moving out) infrequently, like in the data. Importantly, housing illiquidity also contributes to obtaining a realistic heterogeneity in marginal propensities to consume (see Kaplan and Violante 2014), which is one of the key ingredients for the quantitative results.

Houses are risky assets. They are subject to random depreciation shocks δ, such that if a household has a house of size h, then after the shock, the size of the house becomes $(1-\delta)h$. The depreciation shock is idiosyncratic across households and independent over time, and has associated probabilities $f_\delta(\delta)$. Staying in the house involves covering the depreciation cost $p_t^H \delta h$. Importantly, the depreciation shock helps the model achieve default rates like in the data.

Regarding the rental market, we assume that rental landlords have access to a linear technology that transforms one unit of the final good into A_S units of rental space, and vice versa. The rental market is competitive. Therefore, our model is one of perfectly elastic supply of rental housing that generates a constant unit price of rental $p^S = 1/A_S$, but endogenous house prices p_t^H and price-to-rent ratios. Renting a house of size s costs $p^S s$ units of the final good.

3.1.4 Mortgage Contracts

Mortgages are long-term, real, subject to being prepaid and refinanced, and defaultable.[8] A household that takes out a new mortgage with amount to be repaid m' receives from the lender $q_t^0(m', h', a', z)m'$ funds today (in units of the numeraire good). The mortgage pricing function at origination q_t^0 depends on the principal amount m', the borrower's individual portfolio for the next period (house h' and liquid savings a'), and its current labor productivity z. The mortgage pricing function q_t^0 is endogenously determined as we explain below. The downpayment made by the borrower at origination is $p_t^H h' - q_t^0(m', h', a', z)m'$.

[8] Assuming real mortgages simplifies the model and emphasizes alternative mechanisms to the inflation channels studied in Garriga, Kydland and Šustek (2017).

Mortgage originations are subject to an exogenous loan-to-value (LTV) cap θ

$$q_t^0(m', h', a', z)m' \leq \theta p_t^H h'. \tag{2}$$

Thus, the maximum amount that a household can borrow is a fraction θ of the house being purchased. Lenders incur a proportional origination cost ζ_0. This cost helps generate realistic mortgage interest rates.

The outstanding mortgage balance evolves according to $m' = (1 + r_t^M)m - x$, where x is the payment and r_t^M is the mortgage interest rate between time t and $t+1$.[9] The outstanding loan balance decays geometrically at rate λ, that is, $m' = \lambda m$.[10] This assumption coupled with the law of motion for the loan balance implies that the mortgage payment at time t becomes

$$x = (1 - \lambda)m + r_t^M m. \tag{3}$$

Therefore, the payment is completely determined by the mortgage rate r_t^M and the outstanding loan balance m, which is a state variable for the household.[11] Note that the payment in (3) is the sum of the amortization payment $(1 - \lambda)m$ and the interest payment $r_t^M m$. The parameter λ proxies the duration of the mortgage. For instance, if $\lambda = 0$ then the mortgage is a one-period contract. The mortgage rate is linked to the deposit rate through

$$1 + r_t^M = (1 + r_t)(1 + \zeta_m), \tag{4}$$

where ζ_m are the servicing costs incurred by the lender. This cost helps generate realistic mortgage interest rates. The current LTV for an outstanding mortgage is given by $m/(p_t^H h)$, which means that we compute the LTV at the beginning of period, before any household choices are made.

Since mortgages are long-term, the LTV constraint only holds at origination. Therefore, when the LTV cap tightens or house prices fall, existing borrowers are not mechanically forced to deleverage, as it would be the case with one-period debt where the LTV constraint (2) would hold in every period. This is true even if the decline in house prices is so large that many borrowers become underwater (that is, with current LTV $> 100\%$), as it happens in our quantitative experiments. In our setting, homeowners do not deleverage if they keep making

[9] We assume a common mortgage rate r_t^M across borrowers for tractability. Still, the heterogeneity in the amount to be repaid m' and mortgage price q_t^0 implies heterogeneous effective lending rates (yield).

[10] This assumption allows us to economize a state variable (the time to maturity of the mortgage).

[11] Note that $m' = \lambda m$ implies $x' = \lambda x$, provided that the interest rate r_t^M is constant, like in steady state. Geometrically declining real mortgage payments can result from a positive inflation rate.

the mortgage payment, but they can do so by prepaying or defaulting on the mortgage. Non-recourse and recourse mortgages provide different incentives for these endogenous choices.

Borrowers can prepay and refinance the mortgage at any time by paying off the principal balance m plus interest and taking out a new mortgage, if any. In this case, borrowers incur a prepayment penalty that is a proportion ζ_p of the outstanding balance plus interest. This penalty is necessary to prevent having an unrealistically high rate of cash-out refinancing.[12] Selling a house also involves prepaying the mortgage attached to the house.

3.1.5 Default and Recourse

Default entails deadweight costs such that the value of a foreclosed house is reduced by a proportion ζ_d. That is, if a household with a house of size $(1-\delta)h$ defaults on the mortgage, then the lender only receives $(1-\zeta_d)p_t^H(1-\delta)h$ when selling the house. The foreclosure cost captures the fact that usually foreclosed properties appreciate less than the area average, which is a source of loss for the lender. Moreover, a defaulter is excluded from the mortgage market for a random amount of time. That is, in each period, a household in default can apply again for mortgage credit with probability ξ. This parameter controls the average exclusion period and therefore is important for a realistic assessment of the consequences of defaulting.[13]

If the mortgage is non-recourse, the sale of the foreclosed house completely extinguishes the remaining debt and the defaulter makes no additional payments. However, if the mortgage has recourse then the defaulter has to pay the following amount

$$x_D = \max\left\{\min\left\{(1+r_t^M)m - (1-\zeta_d)p_t^H(1-\delta)h, \phi(\tilde{y}_t + a)\right\}, 0\right\}. \tag{5}$$

If the proceeds from the foreclosed house sale are not enough to cover the outstanding mortgage balance plus the interest payment, then the lender garnishes the minimum between the remaining balance and a fraction ϕ of the household's labor income $\tilde{y}_t(z,\ell) = (W_t/P_t)z\ell$ and savings a. Otherwise, the lender does not garnish anything. Any remaining debt after the recourse payment is carried over to the next period, $m' = (1+r_t^M)m - (1-\zeta_d)p_t^H(1-\delta)h - x_D$.

With recourse, the payments out of labor income and liquid assets are made each period until the outstanding debt net of the proceeds from the house sale is fully repaid, or the defaulter

[12] This is important so as not to exaggerate the first-order effect that the tightening of the LTV constraint has on prices and demand in our quantitative experiments. See Greenwald, Landvoigt and Van Nieuwerburgh (2021) for an example of a macroeconomic model of housing and mortgages with prepayment costs.

[13] Also, in terms of the solution method, ξ smooths out the expected continuation value of a defaulter and thus helps to achieve convergence when we solve for a fixed point by iterating over the value functions.

re-enters the mortgage market, whichever occurs first. Thus, the difference between recourse and non-recourse is that under recourse a defaulter has to keep making payments given by

$$x_D = \min\left\{(1+r_t^M)m, \phi(\tilde{y}_t + a)\right\}. \tag{6}$$

Therefore, the recourse payment in each period is at most a fraction ϕ of labor income and savings. Unemployment benefits are exempt from garnishment. The remaining debt evolves according to $m' = (1+r_t^M)m - x_D$. All possible mortgage regimes are parameterized by ϕ, which we refer to as the "recourse parameter". In the non-recourse case, $\phi = 0$.

3.1.6 Household Decision Problems

Here we present an overview of the households' decision problems in recursive form. The formal description of the recursive household problems is contained in Appendix B.1.

A household starts period t as a renter, homeowner, or past defaulter.[14] At this point in time, the state variables for a renter are (a, z), where a are liquid asset savings and z current labor productivity. Homeowners have state variables (h, m, a, z, δ), where h is the house size, m the outstanding mortgage balance, and δ the house depreciation. Past defaulters have state variables (m, a, z). If mortgages are non-recourse, then $m = 0$.

Before any household decisions are made, aggregate employment n_t and current labor productivity z determine the individual probability that a household will be employed, $\kappa(z, n_t)$. Then, the employment shock e realizes ($e = 0$ unemployed, $e = 1$ employed). At this point in time within the period, the state variables of renters, homeowners, and past defaulters are (a, z, e), (h, m, a, z, δ, e) and (m, a, z, e), respectively.

Then, households decide whether to buy a house, pay the mortgage, refinance, sell the house, or default. In the final event within the period, all households choose non-housing consumption c, liquid asset savings a', and hours worked ℓ, the latter provided that they are employed, otherwise they receive unemployment benefits.

Renters decide whether to buy a house or to keep renting:

I. If they buy, then they must choose the house size h' and the mortgage amount m'. Buying a house involves a proportional transaction cost ζ_b. The mortgage origination is subject to the LTV limit (2) and a proportional origination cost ζ_0. The mortgage interest rate de-

[14] By a past defaulter, we mean a household that defaulted on its mortgage and is excluded from the mortgage market. Once the exclusion period ends, the household becomes a renter (with access to the mortgage market).

pends on the individual household's portfolio and current labor productivity (m', h', a', z).

II. If they keep renting, then they must choose the size of rental housing s.

Homeowners decide whether to stay in the house and make the mortgage payment, prepay or refinance the mortgage, sell the house, or default on the current mortgage:

I. If they stay in the current house h, then they must make the mortgage payment x, if any. This payment is completely determined by the state variables, so it is not a choice.

II. If they prepay the outstanding balance m, then they must choose the new mortgage amount m', if they want to refinance. Prepaying involves the proportional penalty ζ_p.

III. If they sell the house, then they must prepay the mortgage. Selling involves a proportional transaction cost ζ_s and choosing rental housing s in the current period.

IV. If they default, then they must choose rental housing s and make the recourse payment x_D, which is at most a fraction ϕ of labor earnings and liquid savings. This payment is determined by the state variables. If mortgages are non-recourse, then $x_D = 0$.

Past defaulters do not make any discrete choice. They decide on rental housing s and make the recourse payment x_D, if any. Unemployment benefits are exempt from garnishment. With probability ξ they become renters that can apply again for mortgage credit in the next period.

3.2 Mortgage Pricing

Lenders offer the pricing schedule $q_t^M(m', h', a', z)$ to potential borrowers with principal mortgage amount m', next period house size h', liquid savings a', and current labor productivity z. These variables predict the borrowers' individual probability of future repayment, prepayment, and default. Competitive lenders price mortgages to break-even in expectation loan by loan. That is, the borrower's inflows are expected to cover the lender's cost of funds r_t^M, which is the risk-free savings rate r_t plus the servicing cost ζ_m.

When issuing mortgages, lenders incur the proportional origination cost ζ_0. Thus, the mortgage price at origination is $q_t^0 = q_t^M/(1+\zeta_0)$. The pricing schedule q_t^0 embeds an effective lending rate.[15] Therefore, the heterogeneity of borrowers implies heterogeneous lending rates.

Denote by I_K, I_F, I_S, and I_D the indicator functions for the mutually exclusive decisions of keeping the mortgage and making the scheduled payment, refinancing, selling the house, and

[15] In Appendix B.2 we give the formula for the yield at origination.

defaulting, respectively. Moreover, denote by a'_K and a'_D the liquid saving decisions of a borrower that keeps the mortgage and a defaulter, respectively. Each indicator and saving decision is a function of the state variables of a homeowner and the time index t, which embeds the current and forecasted aggregate variables. We express mortgage prices using this notation.[16]

3.2.1 Recourse Mortgages

In the case of recourse mortgages, the price q_t^M is determined by

$$q_t^M(m', h', a', z)m' = \frac{1}{1+r_t^M}\mathbb{E}\Big[\underbrace{I'_K\left(x' + q_{t+1}^M(\lambda m', h', a''_K, z')\lambda m'\right)}_{\text{pay + continuation value}} \tag{7}$$

$$+ \underbrace{(I'_F + I'_S)(1+\zeta_p)(1+r_{t+1}^M)m'}_{\text{prepay}} + \underbrace{I'_D((1-\zeta_d)p_{t+1}^H(1-\delta')h' + x'_D + q_{t+1}^D(m''_D, a''_D, z')m''_D)}_{\text{default (house sale + debt service + continuation value)}}\Big].$$

If the borrower keeps the mortgage ($I'_K = 1$), then the lender receives the scheduled payment x' and gets the continuation value of the remaining balance, summarized by the next period pricing function. If the borrower refinances ($I'_F = 1$) or sells the house ($I'_S = 1$), then the lender receives the full outstanding balance plus the interest payment $(1 + r_{t+1}^M)m'$. If the borrower defaults ($I'_D = 1$), then the lender receives the proceeds from the foreclosed house sale, the recourse payment x'_D, and gets the continuation value of the remaining debt balance, summarized by the pricing function in default. The price q_t^D is determined by

$$q_t^D(m', a', z)m' = \frac{1-\xi}{1+r_t^M}\mathbb{E}\Big[\underbrace{x'_D + q_{t+1}^D(m''_D, a''_D, z')m''_D}_{\text{debt service + continuation value}}\Big]. \tag{8}$$

Here, a'_D denotes the savings decision of a past defaulter. With probability $1-\xi$, the defaulter will remain excluded from the mortgage market and the lender receives the recourse payment x'_D and gets the continuation value of the remaining debt balance.

3.2.2 Non-Recourse Mortgages

With non-recourse, if the borrower defaults ($I'_D = 1$) then the lender receives the proceeds from the foreclosed house sale and any deficiency is extinguished. The pricing equation is (7) but with no recourse payment $x'_D = 0$ and no continuation value in default $q_{t+1}^D = 0$.

[16]For simplicity, we omit the dependence of the indicator functions, payments, saving decisions, and next-period remaining debt balance (in the case of default under recourse) on the state variables.

3.3 Lenders

Lenders originate long-term mortgages and pool them to diversify household individual risk. They also invest in government bonds B^g_{t+1}. Lenders finance themselves by issuing one-period real risk-free deposits B^b_{t+1}. Households with liquid savings a' are the investors and pay the price q^A_t for this instrument. There are government transfers such that any ex-post profits or losses experienced by lenders are completely absorbed into the government budget.[17] Hence, transfers capture a bailout during our recession experiments. This implies that mortgage originations and investment in government bonds are fully funded with the issuance of deposits

$$q^A_t B^b_{t+1} = (1+\zeta_0)(1+\zeta_m)\left(\int I_B q^0_t m' \, d\Psi^R_t + \int I_F q^0_t m' \, d\Psi^O_t\right) + q^A_t B^g_{t+1}, \tag{9}$$

where I_B and I_F are indicator functions for the decisions of buying a house and refinancing, and Ψ^R_t and Ψ^O_t are the distributions over renters' (a, z, e) and homeowners' states (h, m, a, z, δ, e). In Appendix B.4 we discuss the lenders' balance sheet and the derivation of (9).[18]

3.4 Final Goods Firm

Output Y_t has price P_t and is produced by a final goods firm according to $Y_t = F(K_t, N_t)$, where K_t is the aggregate level of capital at the start of period t and N_t is labor. The firm chooses investment $I_t = K_{t+1} - (1-\delta_K)K_t$ where δ_K is capital depreciation, subject to quadratic adjustment costs parameterized by ζ_I, and chooses labor N_t to maximize the present value of future dividends $\{d_t\}$ discounted at the sequence of future real interest rates $\{r_t\}$. The solution to this problem links investment in new capital to the marginal value of the firm $V'_{t+1}(K_{t+1})$,

$$\zeta_I\left(\frac{K_{t+1}-K_t}{K_t}\right) = \frac{1}{1+r_t}V'_{t+1}(K_{t+1}) - 1, \tag{10}$$

and employment is determined by having the marginal product of labor equal to the real wage

$$F_L(K_t, N_t) = \frac{W_t}{P_t}. \tag{11}$$

[17] In other words, lenders do not retain earnings since profits are fully taxed by the government. This assumption simplifies the problem of pricing deposits when there are ex-post profits and losses. Otherwise, we would have to add the net worth of lenders as an additional state variable to our already large state space.

[18] An alternative interpretation for (9) is that the government-sponsored enterprises (GSEs) purchase diversified pool of mortgages from lenders and finance themselves by issuing mortgage backed securities B^b_{t+1}. Any ex-post gains or losses from the GSEs are absorbed into the government budget.

In steady state, the marginal product of capital equals the user cost, $F_K(K,N) = r + \delta_K$. Out of steady state, the adjustment costs slow down the changes in capital in response to movements in the rate r_t and employed labor N_t. In Appendix B.5 we give the details of the firm's problem.

3.5 Wage Rigidities and Unemployment

We introduce nominal rigidities by assuming that nominal wages are downwardly rigid as in Auclert and Rognlie (2020), Eggertsson, Mehrotra and Robbins (2018), Guerrieri and Lorenzoni (2017), and Schmitt-Grohé and Uribe (2016, 2017). That is, nominal wages cannot fall from period to period below a wage norm

$$W_t \geq \gamma W_{t-1}. \tag{12}$$

The parameter γ controls the degree of rigidity. For instance, if $\gamma = 1$, then nominal wages are perfectly downwardly rigid. If $\gamma = 0$, then nominal wages are fully flexible.

Because of the downward nominal rigidities, the economy might experience a labor demand shortfall with $N_t < L_t$, where L_t is the aggregate labor supply at the prevailing real wage. This structure is captured with a complementary slackness condition in wages and labor

$$N_t \leq L_t, \tag{13}$$

$$(L_t - N_t)(W_t - \gamma W_{t-1}) = 0. \tag{14}$$

Therefore, if the wage norm is not binding, then there is full employment ($N_t = L_t$). Conversely, if there is involuntary unemployment ($N_t < L_t$), then the wage norm must be binding. This simple specification allows us to introduce unemployment in a parsimonious way.

If the labor market experiences rationing, then households become employed with probability $\kappa(z, n_t)$ that depends upon their current labor productivity z and the aggregate unemployment rate $n_t = N_t/L_t$. The function κ needs to satisfy some conditions related to aggregation, which we explain in Appendix B.6. We calibrate the function κ such that the burden of aggregate unemployment falls disproportionately on poorer households, like in the data.

3.6 Government

The government collects labor taxes, unemployment benefits taxes, and dividends from the representative firm.[19] Labor income is taxed at the rate τ_t. The government issues real bonds B^g_{t+1}, with positive values denoting government debt. The government finances spending G_t, lump-sum transfers T_t, unemployment benefits $\tilde{T}^U(z)$, and transfers to lenders T^b_t. The intertemporal budget constraint of the government is

$$q^A_t B^g_{t+1} + \tau_t \frac{W_t}{P_t} N_t + d_t = B^g_t + G_t + T_t + (1-\tau_t) \int (1-e)\tilde{T}^U(z)\, d\Psi_t + T^b_t, \tag{15}$$

where Ψ_t is the overall distribution over households' state variables.

In our benchmark recession experiments, the labor income tax and government spending are fixed at their steady state levels ($\tau_t = \tau$ and $G_t = G$), while lump-sum transfers T_t adjust according to a fiscal rule that stabilizes the debt level,

$$T_t = \gamma_1 - \gamma_2 (B^g_t - B^g), \tag{16}$$

where B^g is the steady state government debt level. When the recession shocks hit, the government revenue falls while expenditures increase, implying that the government deficit finances the bailouts and unemployment benefits. In this case, (16) implies that lump-sum transfers T_t adjust downwards. Transfers to lenders T^b_t increase such that the credit condition (9) holds.

In our experiments, we also consider an alternative fiscal rule where spending G_t adjusts (with a similar fiscal rule) rather than lump-sum transfers.

3.7 Monetary Policy

The central bank sets the nominal interest rate i_t, which is connected to the real interest rate r_t along the perfect-foresight path by the Fisher equation

$$1 + r_t = \frac{1 + i_t}{1 + \pi_{t+1}}, \tag{17}$$

where $\pi_{t+1} = P_{t+1}/P_t - 1$ is the inflation rate. In our benchmark specification, the central bank targets a real interest rate that is constant at the steady state rate, $r_t = r$. This policy shuts down all equilibrating real interest rate movements, including those due to changes in expected

[19] This assumption simplifies the treatment of the property of the representative firm.

inflation. Alternatively, we consider a lower bound on the nominal interest rate, $i_t \geq \underline{i}$. When binding, movements in the real interest rate are only due to changes in expected inflation.

4 Parameterizing the Model

We parameterize the steady state of the model to be consistent with several key moments of the U.S. economy prior to the Great Recession. Given that this calibration has recourse parameter $\phi = 0$, we will refer to this version of the model as the non-recourse or U.S. model economy. The distribution of assets and debt in the model prior to the crisis are crucial for the response of aggregate consumption when the shocks hit. Therefore, we set many calibration targets to make sure that the model is consistent with the empirical distributions. Whenever possible, we calibrate to 2004 as this was the last year the Survey of Consumer Finances (SCF), a data source for many of our targets, was conducted before the Great Recession.

We divide the parameters into two groups. First, those that we choose exogenously, without the need to solve the steady state equilibrium. Second, those parameters that we choose endogenously to match the target moments. We do this by minimizing the distance between the model moments and their data counterparts.[20] Table 1 summarizes the parameterization for the U.S. model economy, and Table 2 compares the steady state moments to the targeted and non-targeted moments in the data. A period in the model is a quarter. We assume that in steady-state the economy is at full employment, $N = L$.

4.1 Model Parameters

4.1.1 Preferences

We assume a CRRA utility function over a CES aggregator for non-housing consumption (net of disutility from work) and housing services

$$u_z(c, s, \ell) = \frac{\left[(1-\eta)(c - g_z(\ell))^{\frac{\epsilon-1}{\epsilon}} + \eta s^{\frac{\epsilon-1}{\epsilon}}\right]^{\frac{\epsilon(1-\sigma)}{\epsilon-1}}}{1-\sigma}, \text{ with } g_z(\ell) = \varphi z \frac{\ell^{1+\nu}}{1+\nu}. \tag{18}$$

The parameters σ, ϵ, and η are the inverse of the intertemporal elasticity of substitution, the intratemporal elasticity of substitution between non-housing consumption and housing services,

[20]In Appendix D.4 we outline the algorithm to calibrate the steady state.

and the share of housing services in total consumption. The utility over non-housing consumption and hours worked is given by GHH preferences (Greenwood, Hercowitz and Huffman 1988), so that there are no wealth effects on labor supply. The parameters ν and φ are the inverse of the Frisch elasticity of labor supply and the weight of disutility from work. As in Bayer et al. (2019), we assume that the disutility from work is proportional to the idiosyncratic labor productivity z. This implies that all households will supply the same number of hours given the aggregate real wage W/P and labor income tax τ.[21] This simplifies the numerical solution of the model and allows us to calibrate directly to earnings data, as we discuss below.

We set the CRRA parameter to $\sigma = 2$ so that the intertemporal elasticity of substitution equals 0.5, a standard value. The intratemporal elasticity between non-housing consumption and housing is set to $\epsilon = 1.25$ as found by Piazzesi, Schneider and Tuzel (2007). We set the Frisch elasticity of labor supply to $1/\nu = 0.5$, and the disutility from work to $\varphi = 20.25$ so that hours worked by all households but defaulters under recourse are 1/3 of the time endowment in steady state. The remaining preference parameters (discount factor β, share of housing services in total consumption η, and homeownership utility premium χ) are set endogenously.

4.1.2 Housing and Mortgage Markets

We set the cost of buying a house to $\zeta_b = 2.5\%$ and the cost of selling to $\zeta_s = 5\%$, which are consistent with the values estimated in the literature (for example, see Berger and Vavra 2015), and with evidence reported by Gruber and Martin (2003) that the costs of selling are larger than those of buying. We normalize the price of a unit of owner-occupied housing to $p^H = 1$. The maximum house size is set to $\bar{h} = 30$ (the model equivalent to around $400,000 in 2004 dollars).[22] The idiosyncratic depreciation shock is a two-point distribution, where we set as low outcome $\underline{\delta} = 0$. The minimum house size $\underline{h}$, the high depreciation outcome $\bar{\delta}$, and the probability of the high outcome $f_\delta(\bar{\delta})$ are set endogenously.

We set the maximum LTV at mortgage origination to $\theta = 100\%$, which captures the fact that during the pre-crisis period (2002-2006) in the U.S., the 90th percentile combined LTV at origination was roughly 100% (Urban Institute Chartbook December 2019). We set the mortgage origination cost to $\zeta_0 = 0.4\%$, which is consistent with the average origination costs for 2003-2005 (Table 20 FHFA Monthly Interest Rate Survey). The servicing cost ζ_m is set such that the mortgage rate r^M is 3.5% annual, and the prepayment penalty is set to $\zeta_p = 3.5\%$. We

[21]The exception are defaulters under recourse, which may work less hours because a fraction ϕ of their labor income is garnished. Dobbie and Song (2015) document that when a lender has a claim on a person's earnings, she will work less. We give the closed-form solutions for labor supply and all the details in Appendix D.1.

[22]For reference, the U.S. median price for a new home was around $220,000 in 2004 (U.S. Census Bureau).

set the deadweight foreclosure cost to $\zeta_d = 22\%$ following the estimates by Pennington-Cross (2006) for the lower appreciation of foreclosed properties compared to the area average. The per-period probability of reentering the mortgage market is set to $\xi = 0.0417$ so that the average exclusion period is six years, consistent with U.S. Chapter 7 bankruptcies, and with the typical period of time (between five and seven years) devoted to debt service after default in most of continental Europe (Gross 2014). The amortization parameter λ is set endogenously.

4.1.3 Endowments, Production, and Technology

In our model, labor income is the product of the aggregate real wage, labor productivity, and hours worked. The preferences in (18) imply that all households choose to supply the same number of hours ℓ, so we can treat labor earnings risk and productivity risk interchangeably. We use the 33-point idiosyncratic labor productivity process from Kaplan, Moll and Violante (2018), which captures the higher-order moments of the distribution of earning changes in Social Security Administration data documented by Guvenen et al. (2015). This skewed labor earnings distribution, together with illiquid housing, is key for obtaining a realistic distribution of liquid assets up to the very top percentiles. We give the details in Appendix C.1.

We assume a Cobb-Douglas production function, $F(K, N) = AK^{1-\alpha}N^{\alpha}$. We target an annual capital-output ratio of 2.5, a standard value for the U.S. prior to the Great Recession, and an annual real risk-free rate of 1%, which implies $r = 0.25\%$. These choices, along with the rest of the parameters of the production function, are such that the median quarterly labor earnings in steady state are normalized to one (equivalent to $52,000 annual in the 2004 SCF). The downward nominal wage rigidity is set to $\gamma = 1$, which implies zero steady state wage inflation. In Appendix C.2 we give the details of the remaining parameters.

We calibrate the function $\kappa(z, n)$ to match the empirical evidence by Guvenen et al. (2017) on "worker betas", i.e., the exposure of gross worker earnings to GDP growth conditional on their percentile in the earnings distribution. They find that aggregate risk exposure to GDP growth is U-shaped with respect to the earnings level. We adjust the worker betas at the top of the earnings distribution such that the model captures the fact that although the unemployment rate increases significantly in each earnings quintile during recessions, the lower quintiles experience the largest increases. We refer the details to Appendix C.3. We set the transformation of final goods into rental units A_S endogenously.

4.1.4 Government and Central Bank

We set the proportional tax on labor income to $\tau = 0.25$ and the lump-sum transfer to $T = 0.21$, such that in steady state about 30% of households receive a net transfer from the government. We set the slope parameter $\bar{T}^U$ such that the replacement rate of unemployment benefits is 0.52 of labor earnings in steady state. The cap on unemployment benefits is set at $\bar{z}^U = 1$, the median labor earnings in steady state.[23] Regarding the fiscal rule, we set γ_1 equal to the steady state lump-sum transfer, and $\gamma_2 = 0.1$ which delivers a limited downward adjustment of lump-sum transfers, so that the government deficit finances the bailouts and unemployment benefits in our recession experiments. The zero steady state price inflation together with our target for the real risk-free rate imply a nominal interest rate of $i = 0.25\%$ (1% annual).

4.2 Joint Parameterization and Model Fit

We need to map aggregate housing wealth, mortgage debt, and liquid savings in the model to the data. To do this, we measure the aggregate size of the balance sheet of U.S. households in 2004 using Table C.1 in Kaplan, Moll and Violante (2018). Based on the analysis of these authors, we choose the Flow of Funds (FoF) measures for gross housing wealth ($21,000B) and mortgage debt ($7,600B), and the Survey of Consumer Finances (SCF) measures for liquid savings ($3,500B), which are composed of deposits (which include an imputation for cash holdings done by these authors), government bonds, and corporate bonds. We target these quantities as multiples of 2004 annual GDP ($12,300B).

The eight endogenous parameters (discount factor β, share of housing in consumption η, homeownership premium χ, minimum house size $\underline{h}$, high outcome depreciation $\bar{\delta}$ and its probability $f_\delta(\bar{\delta})$, amortization parameter λ, rental technology A_S) are jointly determined to match the twelve target data moments in the top panel of Table 2. The model fits all targeted moments well. The model matches the homeownership rate (69%) and the annual price-to-rent ratio (20.8) for 2004 in the U.S. Census Bureau,[24] the annual foreclosure rate (1.15%) for 2004 in the National Delinquency Survey of the Mortgage Bankers' Association, and the average annual housing depreciation rate (1.48%) for the period 1960-2002 reported by Jeske, Krueger and Mitman (2013). Having a realistic distribution of assets and debt in the model prior to the crisis is crucial for obtaining a plausible response of aggregate consumption when the shocks hit. Our calibration targets ensure that the model is consistent with the empirical distributions. Table 2 shows that the calibrated model matches the aggregate (or mean) level of housing wealth

[23] In Appendix D.4 we explain how government debt and spending are determined in the calibration.
[24] We calculate the price-to rent by dividing the median house price ($p^H h$) by the median annual rent ($p^S s$).

(1.71) and mortgage debt (0.62) in the 2004 FoF, the aggregate level of liquid assets (0.29) in the 2004 SCF, and the right tail of the LTV distribution (share or mortgagors with LTV $\geq$ 70%, 80%, 90% and 95%) in the SCF, which is key given the focus of our paper on households' default behavior. Figure 2(a) shows the distribution of current LTV in steady state.

The bottom panel in Table 2 reports the liquid wealth shares in the model and data, and shows that the model is consistent with the distribution of liquid savings in the SCF up to the very top percentiles, except for the extreme right tail. The Gini index of liquid assets in the model (0.88) is close to the data (0.87), despite the fact that we only target the mean of the distribution. This success follows from the combination of a realistically skewed labor earnings distribution and the illiquid housing structure, similar to Kaplan, Moll and Violante (2018). A fraction of households receive consecutive streams of very high labor income shocks, which allows them to buy a house with a small or no mortgage, or prepay the mortgage attached to an existing house, and accumulate a large amount of savings. This is in contrast to other households that have to spend a significant fraction of their income on mortgage payments, which makes it difficult for them to accumulate savings. Figure 2(c) shows the distribution of liquid assets in steady state.

Kaplan and Violante (2014) highlight the importance of "wealthy-hand-to-mouth" households for understanding consumption dynamics. These households have a large fraction of their wealth in illiquid assets and therefore exhibit a large propensity to consume out of additional transitory income. We define a wealthy hand-to-mouth household as one that has liquid assets less than one-half of their monthly labor earnings and owns a house. Using this definition, 20% of households are wealthy-hand-to mouth in the 2004 SCF, versus 25% in the model. While our parameterization does not directly target this moment, it produces a plausible result.

4.3 Model Validation

Before using the parameterized model to study how recourse affects the dynamics of the economy during recessions, we discuss additional aggregate and cross-sectional predictions from the steady state of the model that we did not directly target during the calibration.[25]

[25] In Appendix C.5 we discuss other additional moments related to the frequency of cash-out refinance, share of high LTV originations, and the housing market.

4.3.1 Marginal Propensity to Consume

Like the distributions of assets and debt, the associated marginal propensity to consume (MPC) distribution before the recession is crucial for the aggregate consumption response when the shocks hit. Table 3 reports the MPC out of a purely transitory increase in income for different household segments,[26] grouped by current LTV and liquid savings. The aggregate (or mean) MPC out of income is 0.25, which closely replicates the empirical estimates summarized, for example, in Kaplan and Violante (2014). This result is key since our recession experiments involve the transmission of both income and house price changes into consumption, and the latter have been shown by Berger et al. (2017) to be closely linked to transitory income shocks. The model generates substantial heterogeneity in MPCs. High debt households (LTV $\geq 80\%$) exhibit on average a very strong consumption response, in contrast to low debt households (LTV $< 50\%$) who exhibit a low consumption response. Medium debt households (LTV $\in [50\%, 80\%)$) have an intermediate consumption response. Since leverage is negatively correlated with income in the model, indebted households with low resources exhibit a much higher MPC than richer households. Moreover, the MPCs change with the amount of liquid assets, as households with close to zero liquid savings have higher MPCs even if they own a house. These heterogeneities are consistent with the patterns of the distribution of MPCs reported in the empirical literature, see for example, the summary in Kaplan, Moll and Violante (2018), or Misra and Surico (2014). Figure 2(d) shows the distribution of MPCs in steady state.

What mechanisms of the model generate households with high consumption responses to income changes? This results from *housing* and *mortgage illiquidity*, which increase the exposure of households to idiosyncratic and aggregate risk, making consumption more responsive to income shocks. Consumption smoothing becomes more difficult. First, housing illiquidity arises from: (i) transaction costs; (ii) depreciation costs that have to be covered to stay in the house; and (iii) the requirement that the homeowner has to prepay the mortgage before moving out. As we will discuss below, homeowners adjust their house size infrequently. Second, mortgage illiquidity arises from endogenous spreads, making access to credit and home equity more difficult for highly leveraged, riskier households. In Section 5.1 we will see that in steady state both the probability of default and lending rates increase rapidly with leverage.

[26] More specifically, we compute the MPC to the model equivalent of a one-time \$500 quarterly transfer. This calculation is directly comparable to the empirical evidence. We give the formula in Appendix D.6.

4.3.2 Consumption Elasticity to House Price Changes

The consumption responses to house price changes are large. The aggregate (or mean) elasticity to a 5% permanent increase in house prices is 0.25.[27] This number closely matches the empirical estimates reported, for example, in Berger et al. (2017) and Mian, Rao and Sufi (2013). There is also significant heterogeneity in the consumption response to house price changes. High LTV households exhibit on average a very strong consumption elasticity to falls in house prices compared to medium and low LTV households. We will discuss the mechanism that explains this heterogeneity in the context of our main results in Section 5.6.

4.3.3 Frequency of Housing Adjustments

Using the 2005-2007 panel of the American Housing Survey (AHS), Emrath (2009) estimates that 96% of households that bought a house in 2005 continued to live in the same house after one year. The bottom panel of Table 2 reports that in steady state, 97% of households that buy a house do not move out in the following year (meaning that they choose to keep the mortgage or refinance during the year), which replicates the empirical estimate. Thus, homeowners adjust their house size infrequently like in the data, which is important for consumption dynamics.

5 Recourse Mortgages and Deeper Recessions

We now pursue a quantitative evaluation of the macroeconomic consequences of non-recourse versus recourse mortgages. In our model, recessions are triggered by productivity and credit shocks. We generate a Great Recession in both economies and document how much of the differential experience during the recovery can be accounted for by the difference in mortgage arrangements. We answer this question by introducing recourse mortgages to the U.S. model economy while keeping most of the parameters and shocks fixed. This constitutes our benchmark experiment.

5.1 The Steady State

We start the analysis by studying the impact that the different mortgage arrangements have on the steady state of the economy. We do this in an environment where essentially the

[27] We focus on the consumption elasticity to house prices, that is, the percentage change in non-housing consumption due to a given percent change in house prices. We give the formula in Appendix D.6

only thing that separates the two economies is the recourse rule. We generate the recourse economy by introducing recourse mortgages to the U.S. model economy, while keeping most of the parameters, idiosyncratic shocks, and prices fixed. This is done in three steps. First, defaulters now have to make the recourse payments (5) and (6), and the mortgage pricing equations become (7) and (8). Second, we set the recourse parameter to $\phi = 0.3$, which is an intermediate value in the range used by Hatchondo, Martinez and Sánchez (2015). Third, we normalize house prices to $p^H = 1$, like before. We also keep the real interest rate at $r = 0.25\%$ (1% annual). All remaining parameters are kept at the values reported in Table 1.

The LTV distribution and homeownership rate prior to the crisis are crucial for the aggregate consumption response when the shocks hit. The key difference between non-recourse and recourse mortgages is who bears the risk from falls in house prices. With non-recourse, that risk is suffered by the lenders. If house prices fall enough to trigger a default, the lender repossesses the house, and the borrower walks away from debt. Under recourse there are two offsetting effects: (i) the more severe penalty of default discourages households from taking on debt, and (ii) the greater protection that the lender receives allows her to offer more favorable credit terms for borrowers. Given that in the steady state no aggregate adverse shocks are anticipated, the second effect dominates, resulting in more demand for mortgages and a higher homeownership rate.

Table 4 shows that recourse mortgages lead to lower default rates. The effect is quantitatively significant, since the default rate is reduced by roughly half relative to non-recourse (0.6% versus 1.2% annual). In both economies, highly leveraged borrowers with no liquid savings ($a = 0$) display the highest default rates. Our model predicts that borrowers who default have little liquidity relative to their mortgage and housing-related commitments. In the non-recourse economy, defaulting borrowers have on average liquid savings a less than one-third of their current mortgage payment x and house maintenance costs $p^H \delta h$.[28] In addition, on average their combined disposable income y and liquid savings a are barely enough to cover their current commitments.[29] However, with recourse, defaulting borrowers have even less liquidity, which reflects that they tried even harder to avoid default. Borrowers have on average liquid savings of about one-eight of their commitments at default, and their combined income and liquid savings can cover only half of their commitments. Under recourse, the benefit of the default option is impaired as the defaulter remains liable for any deficiency.

Figure 3 panels (a) and (b) plot the mortgage spread (annualized yield over the risk-free rate) as a function of LTV for households with the median house and different levels of labor

[28]By defaulting, the household avoids not only the mortgage payment but also the house maintenance cost.

[29]In contrast, the *median* ratio of income plus savings to commitments is about 15 for non-defaulter borrowers.

income. Comparing both panels shows that as a result of the lower default risk, recourse leads to lower lending rates, especially for the riskier, high LTV mortgagors. Moreover, low income households face a much steeper mortgage rate schedule, particularly in the case of non-recourse in panel (a). This steeper slope prevents risky mortgagors from refinancing as documented by Agarwal et al. (2017). That is, mortgage illiquidity arises from endogenous spreads, making access to credit and home equity more difficult for highly leveraged, riskier households.

We previously argued that recourse implies a higher homeownership rate, as well as higher mortgage debt. This effect is quantitatively significant. Because of the lower lending rates, the recourse economy has a homeownership rate of 77% (close to the 80.5% reported by the Spanish National Statistics Institute for 2005) compared to 68% in the non-recourse economy, a higher aggregate housing wealth (1.69 versus 1.51) and mortgage debt to annual output (0.76 versus 0.65), and a larger share of debtors in the upper tail of the LTV distribution. The latter also holds for the LTV distribution *at origination*, where the share of debtors with LTV $\geq$ 70% is 61% with recourse, while it is 52% without recourse. Low-income borrowers are more leveraged with recourse mortgages. These differences between the two economies resemble those of the U.S. and Spain just before the Great Recession. Moreover, these differences are important for understanding the aggregate dynamics following the crisis shocks.[30]

5.2 The Liquidity Trap: Aggregate Effects

Many macroeconomic models feature productivity shocks as one of the drivers of business cycles. Moreover, there is evidence of a decline of total factor productivity during the Great Recession, as documented, for instance, by Huo and Ríos-Rull (2016), and Khan and Thomas (2013). The U.S. model implementation of the productivity shock consists of a 2% drop in total factor productivity A, which mirrors the evidence provided by the authors above.

There is also evidence that the housing boom was a period characterized by a widespread relaxation of underwriting standards in both the U.S. and international mortgage markets, which was followed by a tightening of housing financing constraints during the Great Recession and housing bust. For instance, Keys, Seru and Vig (2012) provide evidence that securitization affected lenders' screening decisions in the subprime market for low-documentation, leading to a relaxation of underwriting standards. To capture the tightening of credit during the Great Recession, the LTV limit at origination θ decreases from 100% to 70%. Studying the effect of exogenous shifts in the LTV limit is the main exercise of several papers, like Favilukis, Ludvigson and Van Nieuwerburgh (2017), Garriga and Hedlund (2020), Guerrieri and Lorenzoni (2017),

[30] Table A3 in the Appendix summarizes the steady state equilibrium for both mortgage systems.

Huo and Ríos-Rull (2016), and Kaplan, Mitman and Violante (2020).

Moreover, the mortgage origination costs ζ_0 rise from 0.4% to 1.2%. This is consistent with FHFA Mortgage Interest Rate Survey data. The effects of changes in mortgage origination costs are also studied in Garriga and Hedlund (2020), and Kaplan, Mitman and Violante (2020).

We generate a Great Recession in both the non-recourse and recourse economies and document how much of the differential experience during the recovery can be accounted for by the difference in mortgage systems. We do this by hitting the steady state of each economy with the three shocks discussed above. All shocks are unanticipated and revert linearly to the original level after five years. We study the perfect-foresight transition.

Before comparing the aggregate dynamics of the economies with and without recourse, we assess the quantitative credibility of the model in the recession experiment. The U.S. model economy mirrors not only the disruption of the housing market but also the response of real activity during the Great Recession. Table 5 shows that the model captures the actual collapse of house prices by 34.5% (recall that house prices are endogenous in our model), the rise of foreclosures to 4.6% annual, and the fall of the homeownership rate from 69.0% to 64.5%. In addition to housing, the model captures the decline of (detrended) real consumption and output by 8.6% and 8.7% respectively, and the rise of unemployment to 10%.[31] Please note that the aggregate responses of the model following the recession shocks are *not* targeted in the calibration.

We also decompose the motives for default according to the prevailing theories of mortgage default. We find that the majority of underwater defaults are driven exclusively by negative liquidity events ("cash-flow" default), but also a significant share are due to the interaction between adverse liquidity events and negative equity ("double-trigger" default). In contrast, there is little prevalence of defaults driven exclusively by negative equity ("strategic" default). That is, 67% of underwater defaults in the first year of the crisis are caused entirely by the "cash-flow" motive, 20% are "double-trigger", and only 13% are "strategic". Furthermore, if we focus on underwater borrowers with LTV $\leq$ 180%, we find that 75% of defaults are "cash-flow", 21% are "double-trigger", and only 4% are "strategic". All the details are contained in Appendix H. These results are consistent with the empirical findings of Ganong and Noel (2022). Moreover, the relevance of "double-trigger" behavior in our model is consistent with the empirical evidence in Gerardi et al. (2018).

The U.S. model also mirrors the differential labor market impacts across the earnings distri-

[31] The steep decline in consumption and output is also discussed in Huo and Ríos-Rull (2016). We calculate the percentage deviations from a linear trend as they do, and find results similar to them (see their Figure 1).

bution experienced in recent recessions. Although the unemployment rate increases markedly in each quintile, the lower quintiles experience the largest increases by far. The endogenous labor demand shortfall together with the calibrated κ function imply that the unemployment rate rises to 18%, 11%, and 5% for the bottom, middle, and top quintiles, respectively. In Appendix C.3 we show that these numbers are similar to the data.

Figure 4 displays the aggregate dynamics following the crisis shocks for the U.S. model (the non-recourse economy). Panels (a), (e) and (f) show that the model generates an immediate collapse in house prices by 39%, a surge in foreclosures (from 1.2% to 5.6% annual), and an increase in aggregate leverage, which are followed by a slow endogenous deleveraging. The rise in foreclosures dampens the credit channel into consumption, as the higher foreclosure risk tightens the supply of credit. Figure 2 panels (a) and (b) show the LTV distribution in steady state and one year into the crisis. The collapse of house prices implies that the LTV distribution shifts to the right and many borrowers become underwater at impact (LTV $>$ 100%), which contributes to the surge in foreclosures. Also, this effect is persistent. For instance, one year after the start of the crisis 32% of borrowers are underwater in the model. This result is consistent with the fact that during the peak of the financial crisis in 2009, about 25% of U.S. homes were underwater, according to CoreLogic.

Figure 4 panels (b) and (c) show that the model generates an immediate drop in aggregate (non-housing) consumption and output of 10% and 8% respectively. Then both variables slowly return to their pre-crisis values. Panel (d) shows that the unemployment rate reaches 10% on impact to return to the pre-crisis level after about two years. Consumption and output remain very depressed during the period of high unemployment. Panel (g) shows that mortgage originations fall sharply (about 65%), which reflects the lower demand for housing at the onset of the recession, triggered by the tighter credit conditions. The contraction of capital investment shown in panel (h) follows the drop in the marginal product of capital, driven, in turn, by the fall in productivity and labor employment. Panel (i) reveals a sharp increase in government debt of 48%. This is due to the fall in labor tax and dividend revenue, and the financing of bailouts for lenders and unemployment insurance benefits. The government pays off the additional debt over time, by reducing lump-sum transfers, to return to the pre-crisis level.

5.3 Recourse and Aggregate Dynamics

We now examine the impact that recourse has on the aggregate dynamics. Figure 4 also shows that the recourse economy experiences a significantly more severe recession, despite the fact that the shocks that trigger the recession are the same as in the non-recourse economy.

Panels (a), (b), and (c) show that house prices, consumption and output fall by 49%, 17%, and 14% respectively, compared to 39%, 10%, and 8% in the non-recourse economy. Panel (d) shows that the unemployment rate at impact is about twice the value without recourse (21% versus 10%). Recourse also makes the disruption in the labor market more persistent, since it takes about three years for employment to return to the pre-crisis level instead of two years. During this extended period, house prices, consumption and output remain depressed. Importantly, panel (e) reveals that the default rate at impact is about 20% smaller relative to non-recourse, although the recourse economy experiences a deeper recession. This reflects the fact that recourse severely compromises the consumption-smoothing and debt relief advantages of the default option. The substantial amplification in the decline of mortgage originations (panel (g)) and capital investment (panel (h)) stems from the larger fall in the demand for housing and in the marginal product of capital, respectively. Likewise, the amplification in the increase of aggregate leverage (panel (f)) and public debt (panel (i)) is mainly due to the larger collapse in house prices and rise in unemployment benefits, respectively.

Taken together, these findings constitute our main result: recourse mortgages lead to deeper recessions and slower recoveries, even in the presence of reasonable foreclosure costs. Table 7 summarizes the recession experiments discussed so far. Comparing the non-recourse and recourse economies (columns (1) and (2) from left to right) provides an alternative way of visualizing our finding that recourse mortgages amplify the severity of recessions. Furthermore, when comparing the actual consumption responses in Figure 1(b) with those of the model counterpart in Figure 4(b), we find that the recourse mechanism accounts for 31% of the observed recovery gap in consumption between the U.S. and Spain over the first seven years since 2007. We define the recovery gap as the time-series average of the difference in the consumption deviations between the non-recourse and recourse economies. We explain the details in Appendix E.

5.4 Understanding the Mechanism

Why productivity and credit shocks, and in particular the tightening of the LTV constraint which only binds at origination, have a large effect on prices and demand? What is the role that the rigidities play here? To answer these questions it is useful to track the effects of each shock in isolation.[32] The productivity shock lowers the marginal product of labor (hence also real wages) and the marginal product of capital. As a consequence, consumption, output, and capital investment drop. The shock triggers a very small effect on house prices, foreclosures, leverage,

[32] In Appendix G we decompose the aggregate responses into the effects of productivity and credit shocks.

aggregate labor employed (which as no effect on the unemployment rate), and government debt.

Tighter credit conditions restrict funding to new house buyers, putting downward pressure on house prices. At the same time, they limit equity extraction through refinancing by existing homeowners. This severely affects financially distressed homeowners trying to smooth consumption by tapping their home equity. Faced with the options of keeping mortgage payments and drastically reducing consumption, selling the house (which requires paying off the outstanding mortgage debt), or defaulting on their mortgage, many homeowners choose the latter. With non-recourse mortgages, the borrower is not liable for any deficiency balance, so default frees up valuable resources to sustain consumption. As a result, foreclosures increase.

The situation above triggers a drop in house prices. By affecting only the asset side of the households' balance sheet, falling house prices leave many borrowers underwater, pushing them to deleverage and cut spending. The higher foreclosure risk tightens the supply of credit even more, making equity extraction more costly. This situation distresses many homeowners, as plummeting home prices wipe out their home equity, pushing more of them into default. As a result, the demand for housing, homeownership, and consumption are depressed. Firms demand less labor after the drop in consumption. The downward nominal wage rigidity prevents the real wage from falling as much as needed to clear the labor market, leading to unemployment. The disruption in the labor market depresses consumption and the demand for housing, putting more downward pressure on house prices. The marginal product of capital, investment, and output decline. Public debt expands as the government deficit finances the bailouts to lenders and unemployment benefits. The government pays off the additional debt over time by reducing lump-sum transfers. In this situation, the lower bound prevents the real interest rate from playing an equilibrating role. This implies that the adjustment happens through house prices and unemployment. The economy enters into a liquidity trap. This interaction generates a negative self-reinforcing loop and substantial amplification of house prices, foreclosures, and unemployment.

Why the price level cannot adjust to clear the labor market in the wake of the recession? In our benchmark specification, the monetary rule is such that the real interest rate is constant at the steady state level, $r_t = r$. This policy shuts down all equilibrating real interest movements, including those driven by changes in expected inflation. Intuitively, when the recession shocks hit, the real interest rate r_t would fall to spur demand for consumption, houses and mortgage credit. Since this cannot happen under the monetary rules that we consider, the equilibrium adjustment happens through the employment rate n_t. This is the reason why the price level cannot adjust to clear the labor market, which would require $n_t = 1$. This mechanism is similar to that of Auclert and Rognlie (2020). This also explains why prices and demand react strongly to the credit tightening shocks.

In equilibrium, the recourse economy generates a smaller foreclosure activity than the non-recourse economy, despite the fact that the former experiences a more severe recession. Another way of looking at the role of recourse is by studying a counterfactual where the recourse economy is fed the house price, unemployment, real wage, and lump-sum transfer equilibrium paths of the non-recourse economy. In this experiment, recourse generates a consumption decline of 12% and a foreclosure rate of 4.1% at impact. Although this consumption decline is greater and the foreclosure rate is lower than in the non-recourse economy, the magnitude of the responses in this experiment is still well below the equilibrium responses in the recourse economy (this is, a consumption decline of 17% and a foreclosure rate of 4.4% at impact). This counterfactual indicates that much of the amplification in the severity of the recession due to recourse mortgages comes from general equilibrium effects. We will return to this issue in Section 5.6.

When examining the direct or partial equilibrium effect of the tightening of credit conditions alone, we find that recourse generates a greater disequilibrium between the demand for owner-occupied housing (from renters) and supply (from sellers and foreclosure sales), which will trigger the larger drop in house prices found in equilibrium. The bulk of the amplification in the disequilibrium comes from differences in the initial distribution of assets and debt when the credit shocks hit. We have reported that the recourse economy has a higher homeownership rate in steady state due to lower lending rates, which allow lower-income households to buy houses with more leverage upon origination. Thus, when credit conditions tighten, the contraction in housing demand is more severe with recourse. On the supply side, in the face of the adverse credit shocks alone, a fraction of homeowners go from refinancing to selling their house, increasing the supply of houses, while foreclosures remain essentially unchanged.

Summarizing, there are two key reasons why non-recourse mortgages cause smaller and shorter recessions: (i) there are fewer medium and high LTV poorer households upon impact, which are the ones that reduce their consumption the most in the crisis, and more importantly, the ones which drive the disruption in the housing and mortgage markets when credit tightens, this is what we could call "the macroprudential effect of non-recourse"; and (ii) because high LTV households, when facing unemployment and lower house prices, go into default and this cushions the fall in their consumption. This supports aggregate demand. At the same time, the downside protection of the default option allows for a faster recovery in housing demand during the recession. This is what we could call the "stimulative effect of non-recourse".

5.5 The Liquidity Trap: Balance Sheet Effects

So far, we have established that the foreclosure activity in the wake of the recession is lower with recourse than without, and that recourse significantly amplifies the fall in housing prices, consumption, output, and the increase in unemployment and government debt.

The aggregate results discussed above hide important heterogeneity across households. In our model, large declines in house prices affect the asset side of the household balance sheet, but do not affect the liability side. Therefore, balance sheet effects are at the core of the transmission of house price movements to consumption. The interaction of housing illiquidity and endogenous mortgage spreads, together with the asymmetric balance sheet effects, leads to heterogeneity across households in MPCs out of liquid income and in consumption responses to house price movements.

To better understand the aggregate results, we examine the heterogeneity in consumption dynamics across different household segments. Figure 5(a) plots, for the non-recourse economy, the household consumption responses grouped by their house tenure, LTV, and liquid assets at the beginning of the period, when the recession shocks hit. Medium and high LTV homeowners with no liquid assets experience the largest decline in consumption, roughly 18% at impact. Renters come next, with a consumption decline of 15%. Importantly, the consumption of high LTV households falls by 13% on average, an intermediate value relative to other households. The share of high LTV households that choose to refinance plummets at the start of the recession, with the majority switching to keeping the mortgage or defaulting. The declines in house prices and mortgage credit liquidity prevent highly indebted households from using their home equity to smooth consumption. However, default under non-recourse allows a significant fraction of highly indebted homeowners to cushion the fall in their consumption. Finally, low LTV households experience the smallest consumption decline, about 5%. These results are consistent with empirical evidence pointing out that highly leveraged households experienced the largest declines in consumption during the Great Recession (see, for example, Mian, Rao and Sufi 2013).

Figure 5(b) shows that recourse amplifies the fall in consumption for all groups. The most severe drop in consumption is experienced by high LTV households, roughly 30% at impact, followed by medium LTV households (26%), renters (18%), and low LTV households (4%). That is, with recourse mortgages, the highly leveraged households become those that suffer the largest fall in consumption, unlike the case of non-recourse, where they experience an intermediate fall relative to other households. Default with non-recourse is valuable, given that the option to smooth consumption through equity withdrawals is impaired as the higher foreclosure risk causes the credit supply to tighten. With recourse, the consumption-smoothing and debt relief benefits of the default option are severely compromised since defaulters, unlike the case of non-recourse, have to continue making debt payments. Figure 5 panels (c) and (d) show that less high LTV borrowers default in the recourse economy (6.0% annual versus 8.4%, that is about 30% lower),[33] despite this economy experiencing a much more severe recession. Many highly indebted households that would have defaulted under non-recourse prefer to keep their mortgages and reduce consumption, or sell the house at a capital loss under recourse.

Figure 5 panels (a) and (b) also show that despite the initial decline, renters' consumption eventually exceeds their pre-crisis level. As we will see in more detail in Section 5.6, this happens because the collapse in house prices leads to a positive wealth effect for renters which plan to become homeowners in the future. Since housing is cheaper, renters do not have to save as much for the downpayment and can afford to consume more. This effect contributes to the recovery, and is also found in Kaplan, Mitman and Violante (2020).

These results illustrate the significant heterogeneity in consumption responses across homeownership, leverage and liquid assets, pointing to the importance of balance sheet effects. But how do they help to understand the difference in the drop in aggregate consumption between the non-recourse and recourse economies? Columns (1) and (2) from left to right of Table 6 show that, in the non-recourse economy, high LTV borrowers account for almost 40% of the consumption decline, despite the fact that they represent 30% of consumption prior to the crisis.[34] By contrast, low LTV borrowers account for 21% of the consumption decline (roughly half the contribution of high LTV borrowers), although they account for 40% of pre-crisis consumption.

Columns (3) and (4) of Table 6 show that the consumption shares of each group before the crisis in the recourse economy are similar to those in the non-recourse economy, except for the fact that high LTV households represent a somewhat larger share (since with recourse there is more leverage), and that renters account for a somewhat smaller share (as the homeownership rate is higher). However, when examining the drop in consumption, important quantitative differences appear between the two economies. With recourse, high LTV homeowners account for 63% of the decline in consumption, which exceeds by far their 37% share of consumption before the crisis. Despite low LTV households accounting for a similar share of pre-crisis consumption as high LTV households, they account for only 8% of the consumption decline, far less than the share accounted for by highly leveraged homeowners. By drastically reducing the insurance value of default, recourse disproportionately amplifies the relevance of highly

[33] The group of households with LTV $\geq 80\%$ is larger in the first period of the crisis compared to the steady state (Table 4) since in the former the house price is depressed. Thus, both groups cannot be directly compared.

[34] In Table 6 the household groups before and after the crisis are exactly the same, since we use the house price upon impact to classify homeowners.

indebted borrowers in accounting for the consumption decline during the crisis.

5.6 The Liquidity Trap: Partial vs General Equilibrium Effects

We now investigate the response of each economy to the recession shocks by decomposing the total effect of these shocks into direct (partial equilibrium) and indirect (general equilibrium) effects. We focus on the transmission mechanism of the shocks on the dynamics of aggregate consumption. We adapt the decomposition proposed by Kaplan, Moll and Violante (2018) to our model of mortgage default. Thus, the direct effect is the partial equilibrium consumption response of households facing the exogenous time paths for LTV limit $\{\theta_t\}_{t=1}^{\infty}$ and mortgage origination costs $\{\zeta_{0,t}\}_{t=1}^{\infty}$, while keeping house prices p^H, aggregate employment n, real wages W/P, and lump-sum transfers T fixed at their steady-state values.[35] We calculate this term by feeding these time paths into the households' optimization problem, computing the consumption path for each household, and aggregating across households using the appropriate distribution over household's states. The other terms in the decomposition are computed in a similar way.[36]

The first quantitative insight from this exercise is that the combined indirect effects are considerably larger than the direct effects. In the non-recourse economy, the combined indirect effects account for 86% of the first year consumption response, while the direct effects account for only 6%. These findings are similar in the recourse economy: the indirect effects account for 79% of the response, while the indirect effects only account for 5% (note that the higher order, interaction effects are stronger in the recourse economy). The second insight is that the direct effects generate similar consumption responses in both economies: consumption falls 0.6% (non-recourse) and 0.9% (recourse) at impact. These results highlight that general equilibrium forces account for most of the differences in consumption among the mortgage systems. That is, recourse and non-recourse mortgages provide different incentives to default, but the main reason why these two systems differ from a macroeconomic point of view is because they trigger very different dynamics for house prices, employment, and lump-sum transfers.

[35] We omit the time path for productivity $\{A_t\}_{t=1}^{\infty}$ as this term does not enter directly the household optimization problem (see Appendix B.1). Nevertheless, it is implicitly included in the path of real wages $\{W_t/P_t\}_{t=1}^{\infty}$.

[36] Most equilibrium responses are highly non-linear and depend on a complex interaction between the shocks, falling house prices and transfers, and rising unemployment. In general, the sum of the decomposition components is not equal to the equilibrium responses that occur when all shocks hit the economy simultaneously.

5.6.1 Examining the Direct Effects

To understand why the direct effects are small, and the indirect effects are large, we examine the consumption response to the shocks across households. Figure 6 shows, for the non-recourse economy, the decomposition of the consumption responses by initial housing tenure, LTV, and availability of liquid savings. Panel (a) reveals that a tightening in credit conditions alone (direct effect) trigger a consumption fall for medium and high LTV borrowers of 1.3% and 1%, respectively, but the aggregate consumption decline is rather small (around 0.6%), as discussed above. This is because these groups account for about 40% of the pre-crisis aggregate consumption, and low LTV and renters' consumption react little. The tighter credit conditions directly affect those households that were planning to extract equity through refinancing. The consumption of medium LTV households reacts more than that of high LTV households because the former are more likely to refinance. Figure 7(a) shows that these results are quantitatively similar for the recourse economy. The medium and high LTV households' consumption fall by roughly 2%. Since both groups account for slightly less than half of pre-crisis consumption, aggregate consumption reacts by roughly 0.9%.

To further understand why the credit shocks trigger a large effect on prices and demand, we inspect the partial equilibrium response of the *discrete* household choices to the credit tightening shock alone (the direct effect). In the non-recourse economy, the share of renters that choose to buy a house falls by 43% at impact. This sharp drop in the demand for housing triggers the collapse in house prices in general equilibrium, which in turn will be transmitted to consumption through balance sheet effects. In addition, the share of homeowners that choose to refinance drops by 33%, with an increase in the share of sellers. These decision changes translate into reduced consumption and additional downward pressure on house prices in general equilibrium. Interestingly, the share of homeowners that choose to default remains essentially unchanged. One implication is that the mechanism through which an increase in foreclosure risk makes equity extraction more costly, therefore amplifying the decline in consumption, only emerges in general equilibrium.[37] The results are similar in the recourse economy but of greater magnitude, as we discussed in Section 5.4. These results reinforce the insight that, although there are small differences in the consumption responses in partial equilibrium between the mortgage systems, they trigger different changes in house prices because recourse mortgages generate a larger disequilibrium in the housing and mortgage market when credit shocks hit.

[37] When we compute the direct and indirect effects, we also update mortgage prices.

5.6.2 Examining the Indirect Effects

We now focus on the indirect effects. Figure 6(b) reveals that there are strong balance sheet effects in the transmission of house prices to consumption. High LTV debtors and renters experience the largest drop in consumption at impact (close to 12%), but for different reasons. In the case of high LTV borrowers, the large decline in house prices creates an imbalance between assets and liabilities that pushes them to deleverage and substantially reduce consumption. In effect, very few highly indebted borrowers refinance given their higher credit risk. Many of them default on the mortgage, while others sell the house to get resources even at a significant capital loss. In the case of renters, they take advantage of the collapse in house prices by cutting consumption to save for the downpayment and buy a house, which explains why their consumption eventually exceeds the pre-crisis level.[38] The consumption of low LTV households is essentially insensitive. Figure 7(b) shows the case of recourse. As before, there are strong balance sheet effects. Low LTV borrowers display a relatively small consumption response, while medium and high LTV borrowers experience a significant consumption drop of 8% and 20%, respectively. With recourse, the fall in consumption is more severe and persistent because of the greater disruption of the housing market and the lower insurance value of default.

Figure 6(c) shows the consumption responses to the rise in aggregate unemployment for the non-recourse economy.[39] The consumption of low and medium LTV households fall roughly by 3%, while high LTV households and renters experience declines of 4% and 4.5% respectively. This happens because of two reasons. First, highly indebted borrowers and renters have the largest MPCs. Second, the incidence of unemployment is higher for these households, as their labor productivity is lower on average. Figure 7(c) shows similar patterns for the consumption responses in the recourse economy, although these are more severe and persistent.

There is substantial heterogeneity in the consumption declines following the drop in lump-sum transfers, ranging from 0.5% to 3.5%, as shown in Figure 6(d). Renters experience the largest consumption fall, followed by high, medium, and low LTV homeowners, according to the ordering of their MPCs. Figure 7(d) shows similar patterns for the consumption responses in the recourse economy. Interestingly, in both economies, foreclosures respond little to the drop in lump-sum transfers. Households resort to delaying the purchase of a house, refinancing the mortgage, or selling to cushion the fall in consumption. One implication is that falling house prices and rising unemployment are the main reasons for the rise in foreclosures.

[38] In general equilibrium, the contraction of credit together with the rise in unemployment and fall in lump-sum transfers will dampen this effect.

[39] This effect also includes changes in real wages, which are small due to the nominal wage rigidity.

6 The Model Economy for Spain

So far, we have generated a Great Recession in the U.S. model economy and have documented how much of the differential responses during the recovery can be explained by the difference in mortgage systems. We answered this question by introducing recourse mortgages into the U.S. model, holding most parameters and shocks fixed. To better understand why recourse mortgages lead to more severe recessions, we have performed a series of decompositions and examined the heterogeneity in consumption responses across households.

We now study a version of the model parameterized directly to Spain, a canonical recourse economy. This calibration differs from the U.S. model not only in the recourse rule and the housing, mortgage debt, and liquid asset moments that are targeted, but also in the generosity of the welfare state. We then provide a second answer to the question posed above, by comparing the recessions in the models for the U.S. and Spain, where the parameters and shocks differ.

We refer the details of the parameterization to Appendix F. Table 8 summarizes the parameterization of the model economy for Spain, and Table 9 compares the steady state moments to the targeted and non-targeted moments in the data. Like before, a period in the model is a quarter. We assume that in steady state the economy is at full employment, $N = L$.[40]

6.1 The Steady State

We now examine the differences between the steady states of the models for the U.S. (non-recourse) and Spain (recourse). Table 9 summarizes the steady state moments in the model for Spain. Compared to the U.S. model economy (Table 2), Spain has a higher homeownership rate (78% versus 68%), aggregate mortgage debt to annual output (0.81 versus 0.65), housing wealth to annual output (2.02 versus 1.51), and median LTV at origination (82% versus 73%), like the data. It also has a lower default rate (0.4% versus 1.2% annual). The protection that recourse gives to lenders implies that the model for Spain has a lower mortgage risk-premium for highly indebted borrowers. Cheaper access to credit makes it easier for poorer households to buy a house, while other borrowers take larger loans than they would have without recourse. For instance, the share of mortgage originations with LTV $\geq 70\%$ ($\geq 80\%$) is 72% (64%), compared to 52% (19%) in the U.S. model economy. These differences are important to understand the aggregate response of the economies when the shocks hit. For example, tighter credit conditions have a larger direct or first-order effect on the demand for housing in the model for Spain, as

[40] Although the unemployment rate in Spain was 9.2% in 2005, the structural unemployment rate was higher (around 12%) according to estimates by the European Commission (Domènech 2017).

there are more households taking mortgages before the crisis. Also, falling house prices reduce the equity of a larger share of households, pushing many of them underwater.

The model for Spain has a much more generous welfare state. Income inequality before taxes and transfers is similar in both model economies, like in the data. However, the amount of redistribution is much higher in the model for Spain. Here, taxes and transfers reduce income inequality (measured by the Gini index) by 25%, compared to a reduction of just 14% in the U.S. model. These reductions in income inequality are consistent with those reported for both countries by the OECD Income Distribution Database.[41] Moreover, the replacement rate of unemployment benefits $\bar{T}^U$ is much higher in the model for Spain (0.76 versus 0.52).

These differences are important for understanding the macroeconomic dynamics and evaluating our claim that a significant part of the greater severity of the recession in Spain relative to the U.S. was due to recourse mortgages. For instance, Harris and Meir (2015) speculate that one of the reasons that accounts for the difference between the mortgage systems of the U.S. and continental Europe is the approach to social welfare, as it seems more natural for these countries to address borrowers' financial distress with the social security system. Thus, we need to assess whether the model for Spain continues to experience a more severe recession despite having a larger welfare state. In what follows, we show that this is indeed the case.

6.2 The Model for Spain: Aggregate Effects

There is evidence that Spanish total factor productivity growth remained subdued during the 2008-2013 recession and started recovering during 2013-2016, as documented, for instance, by Fu and Moral-Benito (2018). These authors present several estimates for the total factor productivity decline over the five-year recession period, ranging from 0.5% to 5%, depending on the source. The model implementation of the productivity shock consists in a 3% fall in total factor productivity A, an intermediate value in the range of empirical estimates.

As in the case of the U.S., there is evidence for Spain of loose credit conditions and standards (loan-to-values and loan spreads) in the pre-crisis period, and that the tightening of lending conditions came in the summer of 2007. For instance, Akin et al. (2014) show evidence that during the boom period in Spain, real estate appraisal firms were encouraged by banks to inflate appraisal prices in order to meet LTV regulatory thresholds.[42] This implied that many

[41]For instance, the database reports Gini coefficients for market income (before taxes and transfers) and disposable income (post taxes and transfers) for the working age population (18-65) in 2014 of 0.476 and 0.349 (a reduction of 26.7%) for Spain, and of 0.473 and 0.389 (a reduction of 17.8%) for the U.S.

[42]Bover, Torrado and Villanueva (2019) show that the median LTV based on transaction price was much

borrowers obtained high loans when they did not have enough resources for the downpayment, or borrowed larger amounts circumventing regulatory restrictions. To capture the tightening of credit, the LTV limit at origination θ decreases from 125% to 70%. Also, the mortgage origination costs ζ_0 rise from 0.5% to 1.3%, similar to the benchmark economy.

Like before, all shocks are unanticipated and revert linearly to the original level after five years. We study the perfect-foresight transition.

Figure 8 shows the macroeconomic dynamics following the crisis shocks for the model for Spain (recourse) and the U.S. model (non-recourse) studied in Section 5. Panels (a), (b), and (c) reveal that in the model for Spain, house prices, consumption, and output fall at impact by 51%, 16%, and 13%, respectively, compared to 39%, 10%, and 8% in the U.S. model. Due to the collapse in house prices in the model for Spain, aggregate leverage rises to about 90%, and 36% of homeowners become underwater. The homeownership rate falls from 78% to 75%. Panel (d) shows that the unemployment rate rises to 18% compared to 10% in the U.S. model. The disruption of the labor market is persistent, as it takes about two years to regain the pre-crisis employment level. Panel (f) shows that the default rate rises to 4.1% annual in the model for Spain, about 27% smaller relative to the U.S. model (5.6%). The default rate remains well below the one observed in the U.S. model throughout the crisis, despite the model for Spain experiencing a more disruptive crisis. There is also substantial amplification in the decline of mortgage originations (panel (g)) and capital investment (panel (h)), due to the fall in the demand for housing and marginal product of capital, respectively.

If we compare the aggregate dynamics of the model for Spain in Figure 8 with the recourse model studied in Figure 4, we conclude that the recovery is faster in the model for Spain, although the severity of the recession on impact is similar in both models. For example, aggregate unemployment recedes in approximately eight quarters instead of twelve, a period during which consumption and output remain very depressed. The more generous unemployment insurance benefits in the model for Spain (i) supports aggregate demand by directing resources to poorer, high MPC households, which contributes to the faster recovery, and (ii) are reflected in the more dramatic increase of public debt (almost 150%, see panel (i)).[43]

In this exercise, where both the parameters and the shocks differ between the two economies, the main result obtained in Section 5.3 still holds: recourse mortgages lead to more severe recessions, even in the presence of reasonable foreclosure costs and a larger welfare state. Columns (1) and (2) from left to right of Table 11 summarize the recession experiment. Moreover, if

higher than the median LTV based on appraisal value during the real estate boom (110% versus 70%).

[43]This increase is consistent with data from the Bank of Spain. We find that government debt deflated by CPI increased roughly by 130% between 2005 and 2014.

we generate a non-recourse economy by removing recourse mortgages ($\phi = 0$) from Spain and compare the consumption responses between both economies, we find that recourse accounts for 18% of the observed recovery gap in consumption between the U.S. and Spain.[44]

We now replicate the exercise we did at the end of Section 5.4, where we studied a counterfactual where the household sector of the recourse economy is fed with the house price, unemployment, real wage, and lump-sum transfer paths of the U.S. model. We find that recourse generates a consumption drop of 13.5% and a foreclosure rate of 3.6% at impact. Thus, like before, the magnitude of these responses is significantly below the equilibrium responses (consumption decline of 16% and foreclosure rate of 4.1% on impact). The conclusion that much of the amplification in the severity of the crisis comes from general equilibrium effects still holds.

6.3 The Model for Spain: Balance Sheet Effects

The aggregate results mask important heterogeneity in consumption responses across households, due to the interaction of balance sheet effects, housing illiquidity, and endogenous mortgage spreads. To better understand the aggregate results, we examine the heterogeneity in consumption dynamics across different household segments.

In the model for Spain, medium and high LTV borrowers suffer a significant consumption fall of about 25%. Low LTV homeowners experience a much smaller drop of roughly 5%. Renters also suffer a sharp drop in consumption of about 26%, however, their consumption recovers quickly and eventually exceeds their pre-crisis level, for similar reasons to those discussed in Section 5.5. We still conclude that recourse amplifies the balance sheet effects.

Columns (3) and (4) from left to right of Table 10 show that the consumption shares before the crisis in the model for Spain are similar to those in the U.S. model, except for a slightly higher share for high LTV borrowers (since there are more households buying houses with debt), and a lower share for renters and past defaulters (since there are fewer defaults). However, like before, quantitative differences appear between the two economies during the crisis. In the model for Spain, high LTV households account for 53% of the consumption decline, which exceeds by far their 35% consumption share before the crisis. Although low LTV households represent the largest consumption share before the crisis (44%), they account for only 15% of the consumption decline. We still observe that recourse mortgages disproportionately amplifies the importance of highly indebted households in accounting for the consumption decline.

[44] Figure A1 in the Appendix shows the macroeconomic dynamics of this exercise.

7 Alternative Specifications

7.1 Fiscal Rule for Government Spending

The main insight from our analysis is that recourse mortgages lead to deeper recessions. When establishing this result, we assumed that the government borrows to finance the unemployment benefits and bailouts to lenders, and then pays off the additional debt over time with lower lump-sum transfers to return to the original steady state. We now examine an alternative fiscal rule, where the government adjusts spending G_t instead of lump-sum transfers T_t.

We replace (16) with a fiscal rule for government spending that stabilizes the debt level,

$$G_t = \gamma_1 - \gamma_2(B_t^g - B^g), \tag{19}$$

where the labor income tax and lump-sum transfers remain fixed at their steady state levels ($\tau_t = \tau$ and $T_t = T$). We set γ_1 equal to the government spending level in steady state, and $\gamma_2 = 0.1$. This fiscal rule implies that if public debt rises when the crisis shocks hit (which happens in our experiments), then government spending adjusts downwards.

First, we compare the aggregate responses of the U.S. (non-recourse) and the recourse model economies, where the latter is generated by introducing recourse mortgages to the former while keeping most of the parameters and shocks fixed (see Section 5.1). Second, we compare the aggregate dynamics of the U.S. and Spain model economies, where the parameters and shocks differ (see Section 6.1). Figure A2 in the Appendix combines all responses. The aggregate dynamics and the associated mechanisms are similar to those discussed in Sections 5.2, 5.3, and 6.2.

Our main insight that recourse mortgages lead to more severe crisis still holds under the alternative fiscal rule. Table 7 summarizes the recession experiments for the benchmark case, and Table 11 does the same for the U.S. and Spain models. When comparing from left to right, column (1) with column (3) (non-recourse case), and column (2) with column (4) (recourse case), we find that when government spending adjusts, the fall of house prices, homeownership, consumption, and output, and the rise in unemployment, foreclosures, and public debt, while still very significant, are smaller than when lump-sum transfers adjust.

7.2 Lower Bound on Nominal Interest Rates

So far, the central bank has followed a constant real rate policy, $r_t = r$. As we explained in Section 3.7, this policy shuts down all equilibrating real interest rate movements, including those due to changes in expected inflation. In an alternative specification, we consider a lower bound on the nominal interest rate, $i_t \geq \underline{i}$. When binding, movements in the real interest rate are only due to changes in expected inflation. In our experiments, we assume that the lower bound on the nominal interest rate is always binding at the steady state rate, $i_t = 0.25\%$.

First, we examine the non-recourse and recourse model economies discussed in Section 5. Figure A3 in the Appendix exhibits the responses for house prices, consumption, and foreclosures, where the lower bound on the nominal interest rate is binding. These responses are quantitatively very similar not only at impact, but also throughout the transition path to those of the benchmark experiment discussed in Sections 5.2 and 5.3, where the real rate is constant (see Figure 4 panels (a), (b), and (e)). Thus, the differential responses between the mortgage systems are also quantitatively very similar, regardless of the type of rigidity in interest rates (real or nominal). Second, we look at the U.S. and Spain model economies studied in Section 6. Panels (d), (e), and (f) show that the responses of house prices, consumption, and foreclosures are quantitatively similar to those studied in Section 6.2 (see Figure 8 panels (a), (b), and (e)).

Thus, our main insight that recourse mortgages lead to more severe recessions is quantitatively robust to assuming that the central bank, instead of following a constant real rate policy, is subject to a lower bound on nominal interest rates. The lower bound prevents the real rate from falling as much as needed to have any significant stimulative effect.

8 Conclusions

Several authors, for example, Bernanke (2017) and Kiley and Roberts (2017), argue that the zero-lower bound will happen often in the near future. Thus, modern economies will see liquidity traps more frequently. This paper shows that the structure of the mortgage system is a key determinant of the reaction of an economy to a liquidity trap.

We show that recourse mortgages amplify liquidity traps by discouraging default, which is a form of social insurance. This redistribution has positive aggregate effects once an economy is in a liquidity trap as it cushions the fall in house prices and lowers unemployment. In addition, recourse mortgages increase financial fragility as leverage is higher. Thus, this paper suggests that non-recourse systems could be better during downturns for economies with more nominal rigidities, like Europe. However, without recourse, access to mortgage credit would be more expensive for low income, high debt mortgagors, and homeownership rates would be lower.

Debt relief mechanisms (such as reducing mortgage payments) or equity mortgages could be even better policies as they decouple foreclosures from the wealth redistribution mechanism that we show in this paper. An open area of research is how to design such mechanisms or contracts while mitigating moral hazard.

Understanding the macroeconomic implications of different mortgage systems is very important for the macro-housing literature and policy, as stressed, for instance, by Campbell (2017). By focusing on how recourse policy influences real outcomes during recessions, our results provide a novel contribution to this literature.[45]

Our model abstracts from some dimensions that could attenuate our findings:

First, the assumption that lenders are immediately bailed out by the government implies that our model is missing a potential channel of contagion through the financial sector due to concerns about default risk in the mortgage market. For instance, Bernanke (2018), and Gertler and Gilchrist (2018) find that the panic in funding and securitization markets, which disrupted banking and the supply of credit, was central to the aggregate employment contraction during the Great Recession. Thus, our analysis may be understating a potential benefit of the recourse system, namely, that the financial sector seems less likely to be damaged by unexpected default risk, therefore reducing the effect of the contagion channel.[46] To assess the relevance of this channel, we ask how much smaller the credit contraction has to be in the recourse economy to match the unemployment rate of 10% in the non-recourse economy. In our benchmark parameterization, we find that the LTV limit has to contract from 100% to 75% rather than to 70%, implying that mortgage originations drop 63% instead of 80%.

Second, our model abstracts from direct foreclosure externalities on the price of neighboring houses (see Anenberg and Kung 2014, and Gupta 2019 for empirical estimates).[47] Relatedly, Gupta (2019) finds that each foreclosure leads to additional foreclosures in the neighborhood of the distressed property. In addition to the house price channel, this spillover effect would also be explained by a refinancing channel, where foreclosures result in a contraction of credit

[45] An interesting extension of our analysis is to study a combination of recourse and non-recourse countries, as default risk in non-recourse countries may spillover and lead to larger recessions in recourse countries.

[46] Lenders' losses when the crisis shocks hit are 8% of the outstanding balance in the non-recourse economy and 10% in the recourse economy. Although there are fewer defaults with recourse, lenders liquidate foreclosed houses at lower prices. To see more clearly the protection offered by recourse, we look at the counterfactual in Section 5.4 where the recourse economy is fed with the equilibrium paths of the non-recourse economy. In this case, lenders' losses are only 4% of the outstanding balance. See also Appendix B.4.

[47] Our model captures part of this effect by having more houses on sale after foreclosures.

supply through loan denials. Therefore, our analysis may be understating a potential foreclosure spillover cost of the non-recourse system, since it facilitates defaults.

Third, our infinite horizon setup may be overstating the insurance value of home equity. That is, in our model, home equity is useful to insure against future income risk, whereas in a life-cycle setup households pay their mortgages also for life-cycle and bequest reasons, meaning that their consumption may be less sensitive to adjustments in the LTV constraint.

Integrating the mechanisms above with a detailed modeling of the household decisions and default as in our paper is left for future research.

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Tables

Table 1: Benchmark Parameterization (U.S.)

Parameter	Value	Interpretation	Endogenous
		Preferences	
β	0.972	Discount factor	Yes
η	0.204	Housing share in consumption	Yes
σ	2	CRRA parameter	No
ϵ	1.25	Intratemporal elasticity of substitution	No
χ	0.057	Homeownership utility premium	Yes
ν	2	Inverse Frisch elasticity labor supply	No
φ	20.25	Disutility labor supply	No
		Housing	
ζ_b, ζ_s	2.5%, 5%	Transaction cost buying (selling) a house	No
$\underline{h}$	6.10	Minimum house size	Yes
$\bar{h}$	30	Maximum house size	No
$\underline{\delta}$	0	Low realization of housing depreciation	No
$\bar{\delta}$	0.192	High realization of housing depreciation	Yes
$f_\delta(\bar{\delta})$	0.019	Probability high depreciation shock	Yes
		Mortgages	
ϕ	0	Recourse parameter	No
θ	100%	Maximum LTV at mortgage origination	No
ζ_0	0.4%	Mortgage origination cost	No
ζ_m	0.61%	Mortgage servicing cost	No
ζ_p	3.5%	Prepayment penalty	No
ζ_d	22%	Foreclosure cost	No
λ	0.9902	Mortgage amortization parameter	Yes
ξ	0.0417	Probability defaulter re-entries mortgage market	No
		Endowments, production and technology	
$f_z(z'\|z)$	See text	Idiosyncratic labor productivity process	No
A	1.672	Total productivity level	No
α	0.769	Labor share of output	No
δ_K	2.06%	Depreciation capital (quarterly)	No
ζ_I	12.12	Capital adjustment cost	No
A_S	54.56	Transformation final goods into rental units	Yes
γ	1	Downward nominal wage rigidity	No
$\kappa(z,n)$	See text	Individual probability employment	No
		Government and central bank	
τ	0.25	Proportional tax on labor income	No
T	0.21	Lump-sum transfer to households	No
$\bar{T}^U$	0.52	Replacement rate unemployment benefits	No
$\bar{z}^U$	1	Maximum cap unemployment benefits	No
γ_1, γ_2	See text, 0.1	Transfer or spending reaction function	No
i	0.25%	Nominal interest rate (quarterly)	No

Note: See Section 4 and Appendix C for details. The model period is one quarter. The endogenous parameters are jointly determined to match the data moments in Table 2.

Table 2: Steady State Moments (U.S. Parameterization)

Variable	Model	Target	Source
Targeted moments			
Homeownership rate (%)	68.2	69.0	U.S. Census Bureau
Ratio aggregate housing wealth to annual output	1.51	1.71	2004 Flow of Funds
Ratio aggregate mortgage debt to annual output	0.65	0.62	2004 Flow of Funds
Ratio aggregate liquid assets to annual output	0.24	0.29	2004 Survey of Cons. Finances
Median LTV mortgagors (%)	56.2	53.3	2004 Survey of Cons. Finances
% of mortgagors with LTV $\geq$ 70%	30.5	29.6	2004 Survey of Cons. Finances
% of mortgagors with LTV $\geq$ 80%	12.5	18.4	2004 Survey of Cons. Finances
% of mortgagors with LTV $\geq$ 90%	9.54	8.34	2004 Survey of Cons. Finances
% of mortgagors with LTV $\geq$ 95%	3.92	4.13	2004 Survey of Cons. Finances
Default rate (% annual)	1.18	1.15	Mortgage Bankers' Association
Average housing depreciation rate (% annual)	1.50	1.48	Jeske et al. (2013)
Price-to-rent ratio (annual)	17.6	20.8	U.S. Census Bureau
Non-Targeted moments			
Gini index liquid assets	0.88	0.87	2004 Survey of Cons. Finances
Bottom 50% share liquid assets (%)	0.82	1.39	2004 Survey of Cons. Finances
Top 20% share liquid assets (%)	90.8	89.7	2004 Survey of Cons. Finances
Top 10% share liquid assets (%)	83.2	79.2	2004 Survey of Cons. Finances
Top 1% share liquid assets (%)	24.6	42.9	2004 Survey of Cons. Finances
Top 0.1% share liquid assets (%)	2.79	16.1	2004 Survey of Cons. Finances
Ratio average income owners to renters	1.81	2.32	2004 Survey of Cons. Finances
Ratio median house size owners to renters	1.29	1.38	2005 American Housing Survey
Median LTV at origination (%)	0.73	0.80	Urban Institute
% of homeowners that do not move in a year	96.9	96.2	Nat'l. Assoc. of Home Builders
% of wealthy hand-to-mouth	25.4	20.1	2004 Survey of Cons. Finances

Note: Section 4 and Appendix C discuss the details. LTV is loan-to-value. The model parameterization only uses the targeted moments.

Table 3: Marginal Propensity to Consume (MPC)

Subgroup	All mortgagors	Illiquid mortgagors
LTV $\geq 80\%$	0.52	0.51
LTV $\in [50\%, 80\%)$	0.32	0.52
LTV $< 50\%$	0.09	0.09
All households	0.25	

Note: The MPC is the fraction consumed today out of an unexpected, purely transitory increase in income. We compute the MPC to the model equivalent of a one-time $500 quarterly transfer, in the steady-state of the non-recourse economy (U.S. parameterization). Illiquid mortgagors are those with no liquid savings ($a = 0$). Section 4.3.1 and Appendix D.6 discuss the details.

Table 4: Probability of Default (% Annual)

	Non-Recourse		Recourse	
Subgroup	All mortgagors	Illiquid mortgagors	All mortgagors	Illiquid mortgagors
LTV $\geq 80\%$	8.79	10.3	4.02	8.02
LTV $\in [50\%, 80\%)$	0.09	0.17	0.00	0.00
LTV $< 50\%$	0.00	0.00	0.00	0.00
All mortgagors	1.18		0.62	

Note: Default rates are expressed in annual terms. LTV is loan-to-value. Illiquid mortgagors are those with no liquid savings ($a = 0$). We compute the default probabilities in the steady state of the non-recourse economy (U.S. parameterization). Section 5.1 discusses the details.

Table 5: The Disruption of the Housing Market and Real Activity in the Great Recession

Variable	Model	Data
Change in house prices (%)	-38.6	-34.5
Change in consumption (%)	-10.3	-8.6
Change in output (%)	-7.8	-8.7
Unemployment rate (%)	10.3	9.9
Foreclosure rate (% annual)	5.60	4.60
Homeownership rate (pre crisis) (%)	68.2	69.0
Homeownership rate (in crisis) (%)	64.6	64.5

Note: In the U.S. model, the changes in house prices, consumption, and output are measured in percentage deviations from the steady state values. All variables are first quarter responses, except for the homeownership rate which is the trough of the recession experiment. The data sources are: Case-Shiller U.S. home price index net of CPI (house prices), linearly detrended natural logs of real personal consumption expenditures and gross domestic product per capita (consumption and output), U.S. Bureau of Labor Statistics (unemployment rate), Mortgage Bankers Association data for 2004-2014 (foreclosure rate), U.S. Census Bureau data for 2004-2014 (homeownership rate). Section 5.2 discusses the details.

Table 6: Decomposing the Consumption Decline (U.S. Parameterization) (%)

	Non-Recourse		Recourse	
Subgroup	Pre-Crisis share	Decline share	Pre-Crisis share	Decline share
LTV $\geq$ 80%	30.4	38.8	37.2	63.8
LTV $\in [50\%, 80\%)$	8.7	15.1	9.6	14.3
LTV $<$ 50%	42.7	20.8	40.0	8.8
Renters	15.3	22.8	11.8	12.3
Past defaulters	2.9	2.5	1.4	0.8

Note: The table reports consumption shares (in %) by LTV, initial housing tenure, and default status. The household groups before and after the crisis are exactly the same, since we use the house price upon impact to classify homeowners. Section 5.5 discusses the details.

Table 7: Summary of the Recession Experiments (U.S. Parameterization)

Variable	Transfer adjusts T_t		Gov. spending adjusts G_t	
	Non-Recourse	Recourse	Non-Recourse	Recourse
Change in house prices (%)	-38.6	-49.1	-35.2	-47.0
Change in consumption (%)	-10.3	-17.3	-5.72	-9.52
Change in output (%)	-7.77	-13.4	-4.44	-7.92
Unemployment rate (%)	10.3	21.0	5.33	12.8
Recovery time (quarters)	7	12	13	16
Default rate (% annual)	5.60	4.40	4.91	4.12
Aggregate LTV (%)	70.3	89.0	66.6	85.4
Homeownership rate (pre crisis) (%)	68.2	77.0	68.2	77.0
Homeownership rate (in crisis) (%)	64.6	69.4	64.8	70.5
Change in transfers/gov. spending (%)	-19.8	-35.1	-14.9	-21.9
Change in government debt (%)	47.7	67.1	44.3	59.4

Note: The changes in house prices, consumption, output, government debt, transfers, and government spending are measured in percentage deviations from the steady state values. The recovery time is the number of quarters since the shocks hit until the labor market is not rationed. The unemployment, default, aggregate LTV, and homeownership rates are expressed in percentage levels. Sections 5.2, 5.3, and 7.1 discuss the details.

Table 8: Parameterization (Spain)

Parameter	Value	Interpretation	Endogenous
Preferences			
β	0.977	Discount factor	Yes
η	0.226	Housing share in consumption	Yes
σ	2	CRRA parameter	No
ϵ	1.25	Intratemporal elasticity of substitution	No
χ	0.054	Homeownership utility premium	Yes
ν	2	Inverse Frisch elasticity labor supply	No
φ	17.82	Disutility labor supply	No
Housing			
ζ_b, ζ_s	2.5%, 5%	Transaction cost buying (selling) a house	No
$\underline{h}$	5.20	Minimum house size	Yes
$\bar{h}$	30	Maximum house size	No
$\underline{\delta}$	0	Low realization of housing depreciation	No
$\bar{\delta}$	0.206	High realization of housing depreciation	Yes
$f_\delta(\bar{\delta})$	0.017	Probability high depreciation shock	Yes
Mortgages			
ϕ	0.25	Recourse parameter	No
θ	125%	Maximum LTV at mortgage origination	No
ζ_0	0.5%	Mortgage origination cost	No
ζ_m	0.61%	Mortgage servicing cost	No
ζ_p	3.5%	Prepayment penalty	No
ζ_d	22%	Foreclosure cost	No
λ	0.9815	Mortgage amortization parameter	Yes
ξ	0.0417	Probability defaulter re-entries mortgage market	No
Endowments, production and technology			
$f_z(z'\|z)$	See text	Idiosyncratic labor productivity process	No
A	1.564	Total productivity level	No
α	0.760	Labor share of output	No
δ_K	1.75%	Depreciation capital (quarterly)	No
ζ_I	10	Capital adjustment cost	No
A_S	56.81	Transformation final goods into rental units	Yes
γ	1	Downward nominal wage rigidity	No
$\kappa(z,n)$	See text	Individual probability employment	No
Government and central bank			
τ	0.34	Proportional tax on labor income	No
T	0.37	Lump-sum transfer to households	No
$\bar{T}^U$	0.76	Replacement rate unemployment benefits	No
$\bar{z}^U$	1	Maximum cap unemployment benefits	No
γ_1, γ_2	See text, 0.1	Transfer or spending reaction function	No
i	0.25%	Nominal interest rate (quarterly)	No

Note: Appendix F discusses the details. The model period is one quarter. The endogenous parameters are jointly determined to match the data moments in Table 9.

Table 9: Steady State Moments (Spain Parameterization)

Variable	Model	Target	Source
Targeted moments			
Homeownership rate (%)	78.0	80.5	INE Spain
Ratio aggregate housing wealth to annual output	2.02	4.46	Blanco et al. (2020)
Ratio aggregate mortgage debt to annual output	0.81	0.71	Blanco et al. (2020)
Ratio aggregate liquid assets to annual output	0.26	0.30	2005 Survey of Hous. Finances
Median LTV at origination (%)	81.9	91.2	2005 Survey of Hous. Finances
Default rate (% annual)	0.39	0.42	Bank of Spain
Average housing depreciation rate (% annual)	1.37	1.39	Bank of Spain
Price-to-rent ratio (annual)	23.9	23.1	OECD Data and Numbeo
Non-Targeted moments			
% of originations with LTV $\geq$ 70%	71.9	76.1	2005 Survey of Hous. Finances
% of originations with LTV $\geq$ 80%	63.8	69.5	2005 Survey of Hous. Finances
Gini index liquid assets	0.85	0.78	2005 Survey of Hous. Finances
Bottom 50% share liquid assets (%)	1.82	3.32	2005 Survey of Hous. Finances
Top 20% share liquid assets (%)	88.8	81.7	2005 Survey of Hous. Finances
Top 10% share liquid assets (%)	80.7	66.3	2005 Survey of Hous. Finances
Top 1% share liquid assets (%)	21.9	23.7	2005 Survey of Hous. Finances
Top 0.1% share liquid assets (%)	2.35	6.93	2005 Survey of Hous. Finances
Ratio average income owners to renters	1.81	1.84	2005 Survey of Hous. Finances
% of wealthy hand-to-mouth	24.7	17.7	2005 Survey of Hous. Finances

Note: Appendix F discusses the details. LTV is loan-to-value. The model parameterization only uses the targeted moments.

Table 10: Decomposing the Consumption Decline (U.S. versus Spain Parameterization) (%)

	Non-Recourse		Recourse	
Subgroup	Pre-Crisis share	Decline share	Pre-Crisis share	Decline share
LTV $\geq$ 80%	30.4	38.8	35.3	53.4
LTV $\in [50\%, 80\%)$	8.7	15.1	8.8	13.2
LTV $<$ 50%	42.7	20.8	43.6	14.5
Renters	15.3	22.8	11.4	18.5
Past defaulters	2.9	2.5	0.9	0.4

Note: The table reports consumption shares (in %) by LTV, initial housing tenure, and default status. The household groups before and after the crisis are exactly the same, since we use the house price upon impact to classify homeowners. Section 6.3 discusses the details.

Table 11: Summary of the Recession Experiments (U.S. versus Spain Parameterization)

Variable	Transfer adjusts T_t		Gov. spending adjusts G_t	
	Non-Recourse	Recourse	Non-Recourse	Recourse
Change in house prices (%)	-38.6	-51.1	-35.2	-54.9
Change in consumption (%)	-10.3	-16.3	-5.72	-9.86
Change in output (%)	-7.77	-13.0	-4.44	-9.09
Unemployment rate (%)	10.3	18.3	5.33	13.4
Recovery time (quarters)	7	7	13	18
Default rate (% annual)	5.60	4.14	4.91	3.92
Aggregate LTV (%)	70.3	82.4	66.6	89.4
Homeownership rate (pre crisis) (%)	68.2	78.0	68.2	78.0
Homeownership rate (in crisis) (%)	64.6	74.7	64.8	76.2
Change in transfers/gov. spending (%)	-19.8	-33.3	-14.9	-40.3
Change in government debt (%)	47.7	147.2	44.3	132.3

Note: The changes in house prices, consumption, output, government debt, transfers, and government spending are measured in percentage deviations from the steady state values. The recovery time is the number of quarters since the shocks hit until the labor market is not rationed. The unemployment, default, aggregate LTV, and homeownership rates are expressed in percentage levels. Sections 5.2, 6.2, and 7.1 discuss the details.

Figures

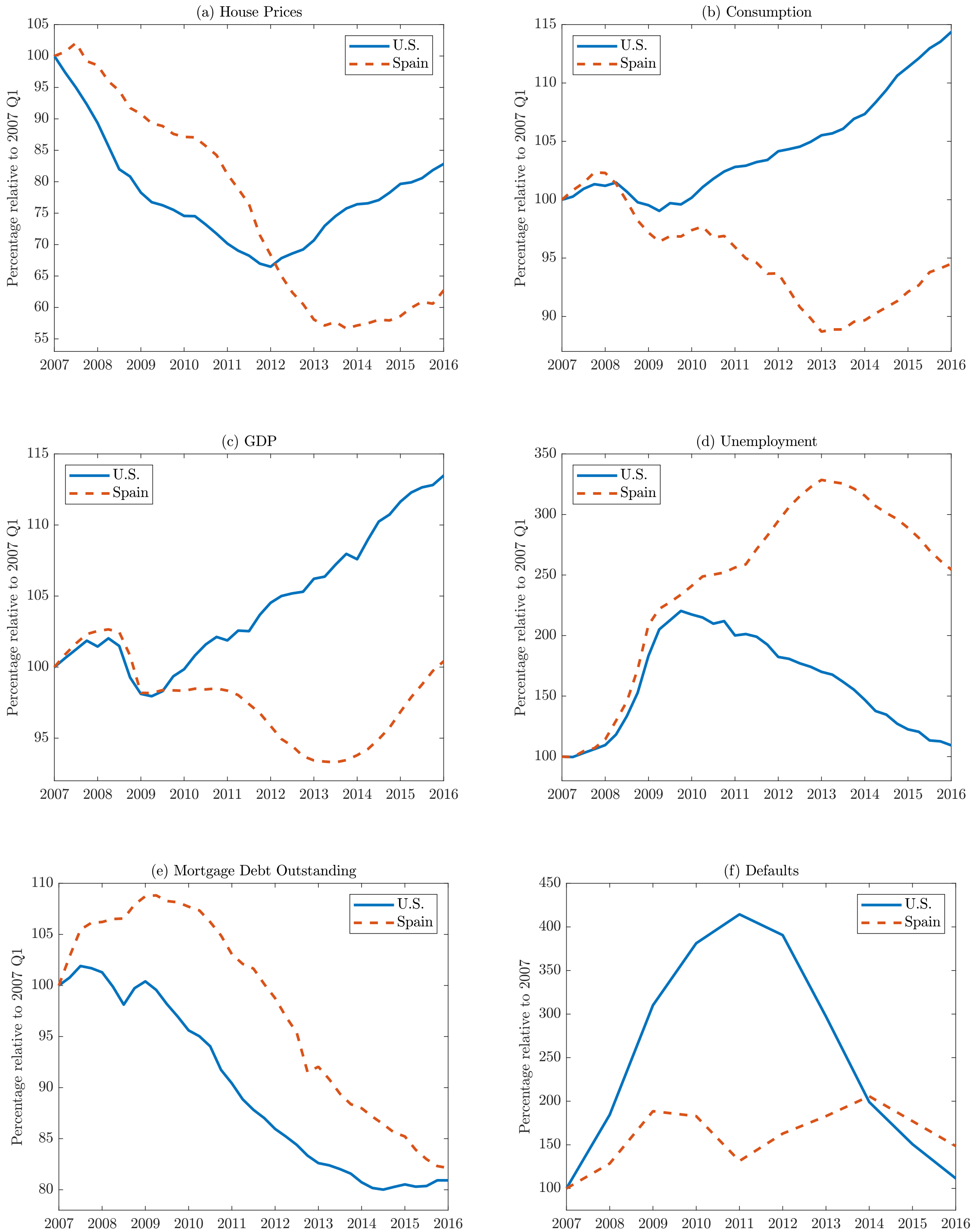

Figure 1: **Comparing Recoveries in Non-Recourse Versus Recourse Economies.** The U.S. is in practice a non-recourse economy, while Spain is a recourse economy. All series are at quarterly frequency (2007 Q1 = 100), except defaults which are at annual frequency. See Appendix A for the data sources and details.

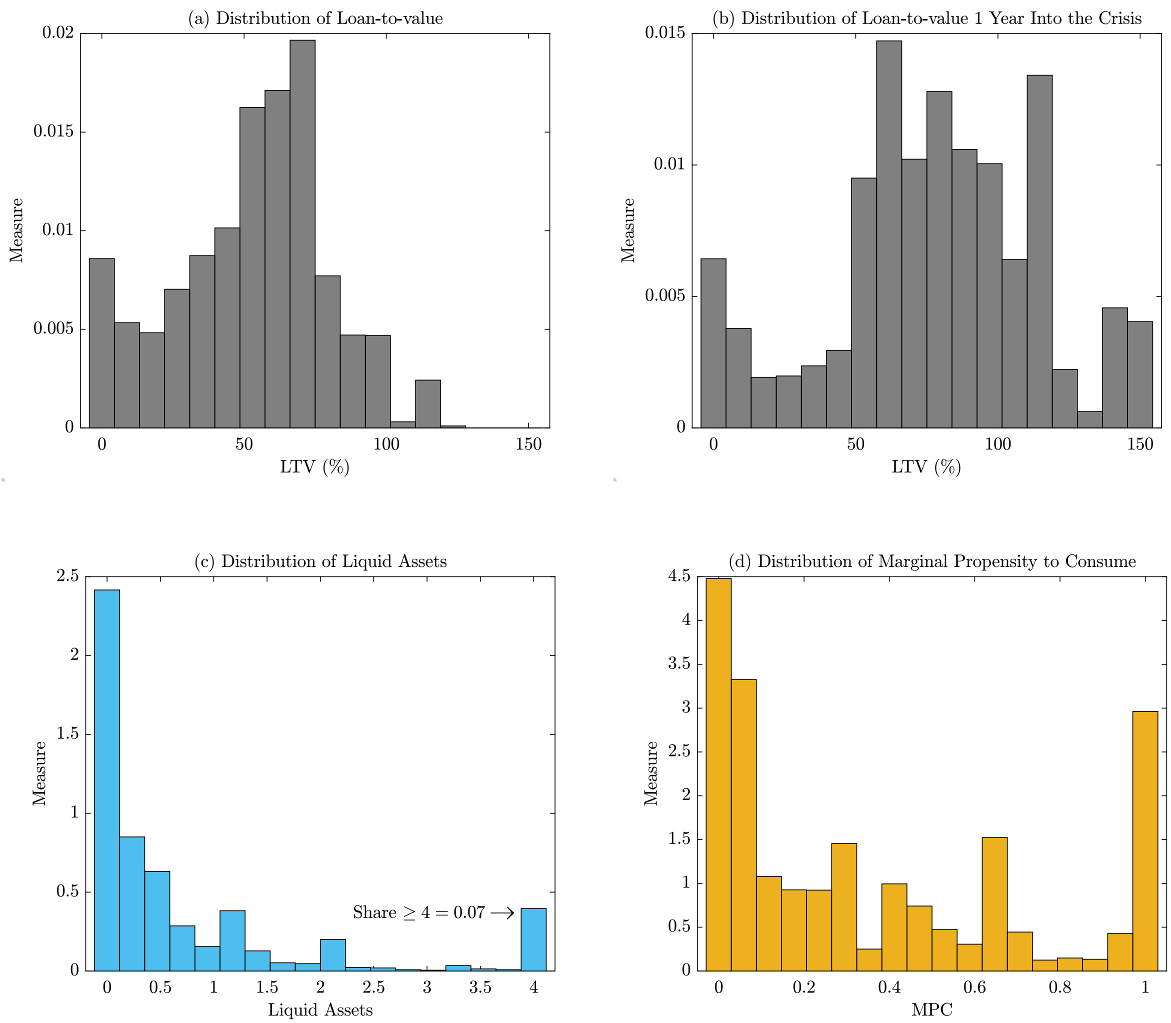

Figure 2: **Cross-sectional Distributions of Loan-to-value (LTV), Liquid Assets, and Marginal Propensity to Consume (MPC) out of Liquid Wealth in the Non-Recourse Economy.** The panels plot the distributions in the steady state of the non-recourse (U.S.) model economy. The LTV distribution is also plotted one year into the crisis.

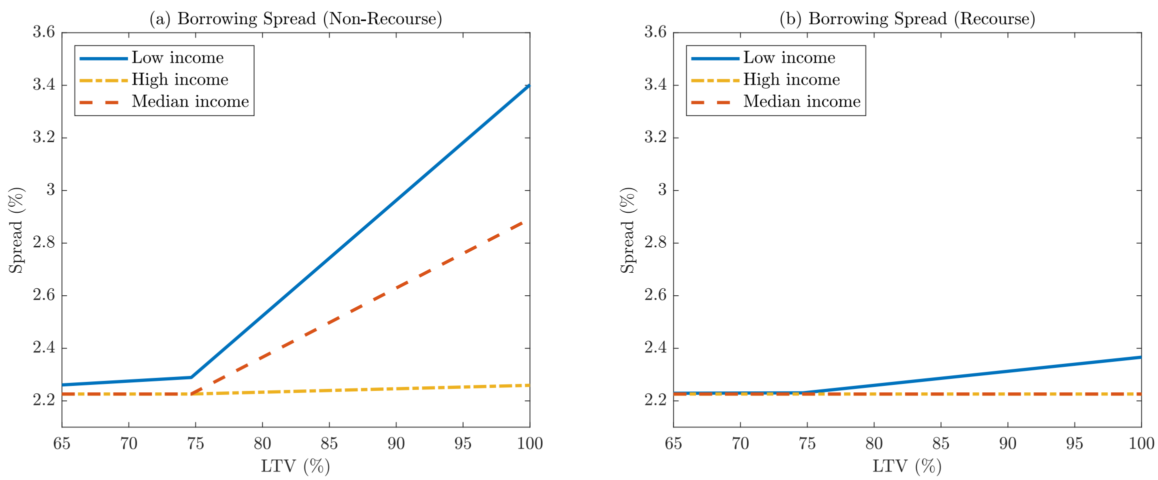

Figure 3: **Borrowing Spreads in Non-Recourse versus Recourse Economies.** The panels plot the spread between the mortgage rate that a borrower would face and the risk-free rate, expressed in annual terms, as a function of LTV and for three labor income levels. Panels (a) and (b) correspond to the non-recourse (U.S.) and recourse economies.

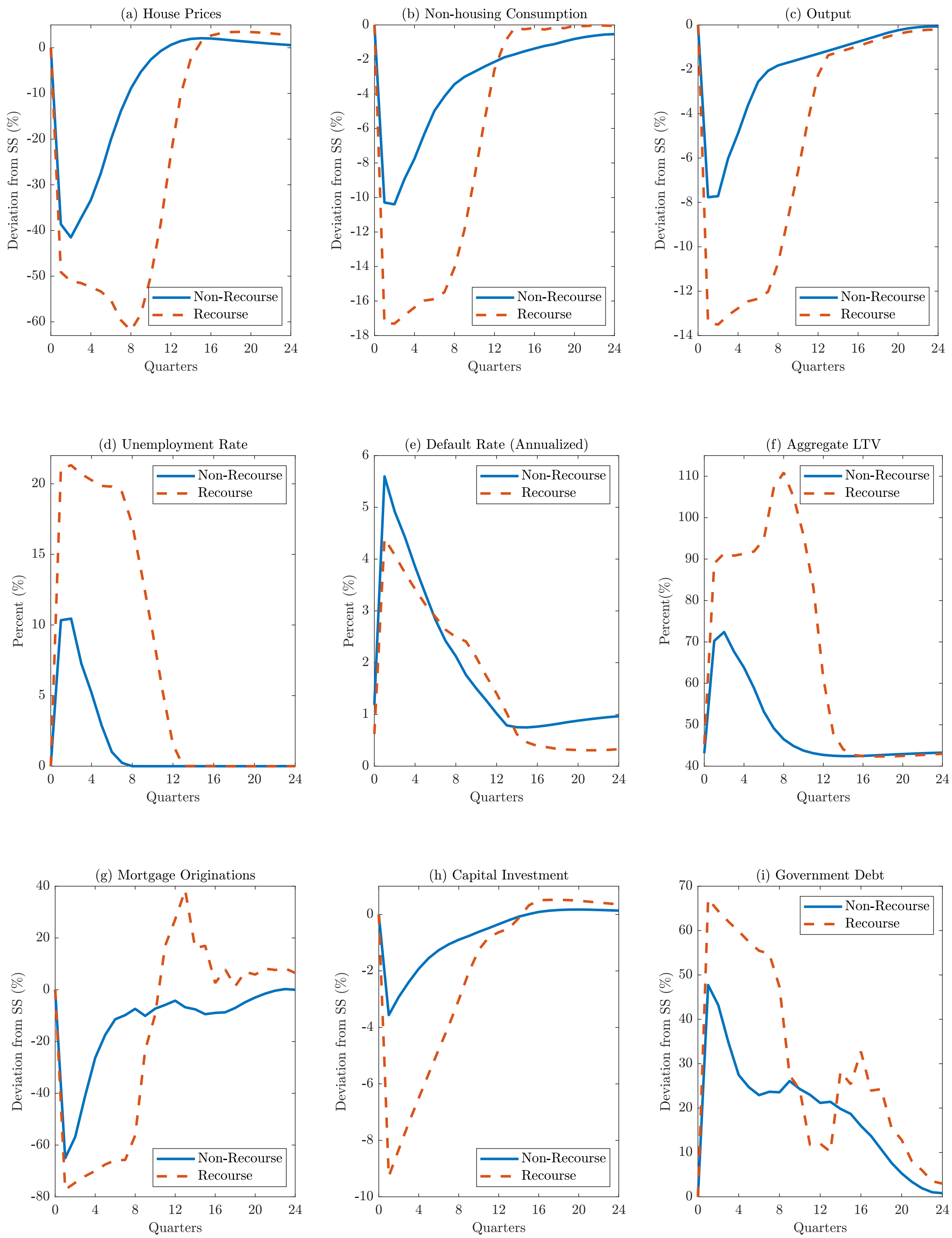

Figure 4: **Dynamics of Non-Recourse and Recourse Economies Following Unexpected Productivity and Credit Shocks.** The panels compare the equilibrium responses of the non-recourse (U.S.) and recourse model economies to the exogenous crisis shocks. Sections 5.2 and 5.3 discuss the details.

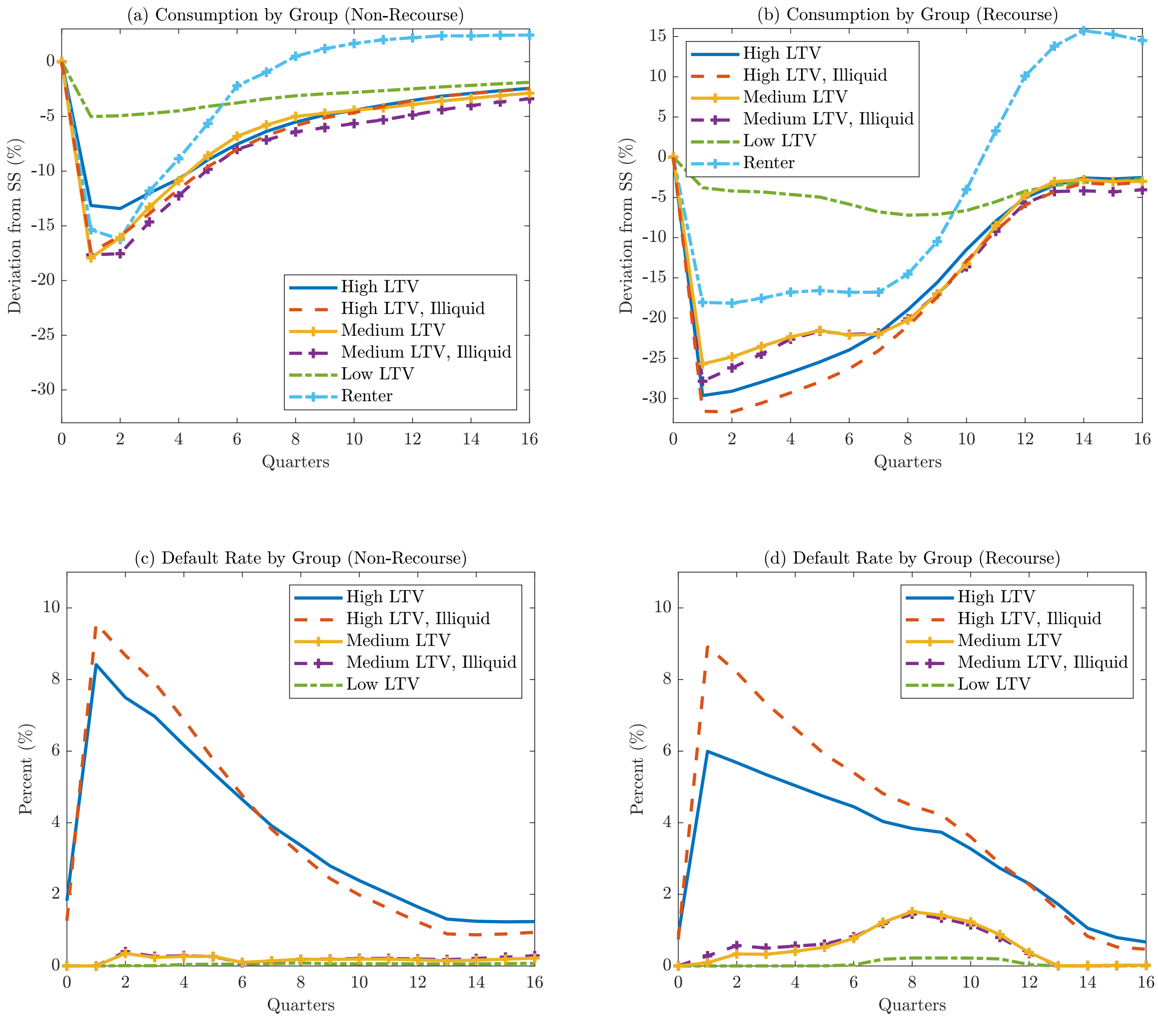

Figure 5: **Consumption and Default Responses by Initial Housing Tenure, LTV, and Liquid Assets.** The panels plot the equilibrium consumption and default responses to the exogenous crisis shocks. Panels (a) and (c) are the non-recourse (U.S.) model economy, and panels (b) and (d) are the recourse economy. High LTV means $\geq 80\%$, medium LTV means $\in [50\%, 80\%)$, and low LTV means $< 50\%$. Illiquid households are those with no liquid savings ($a = 0$). Section 5.5 discusses the details.

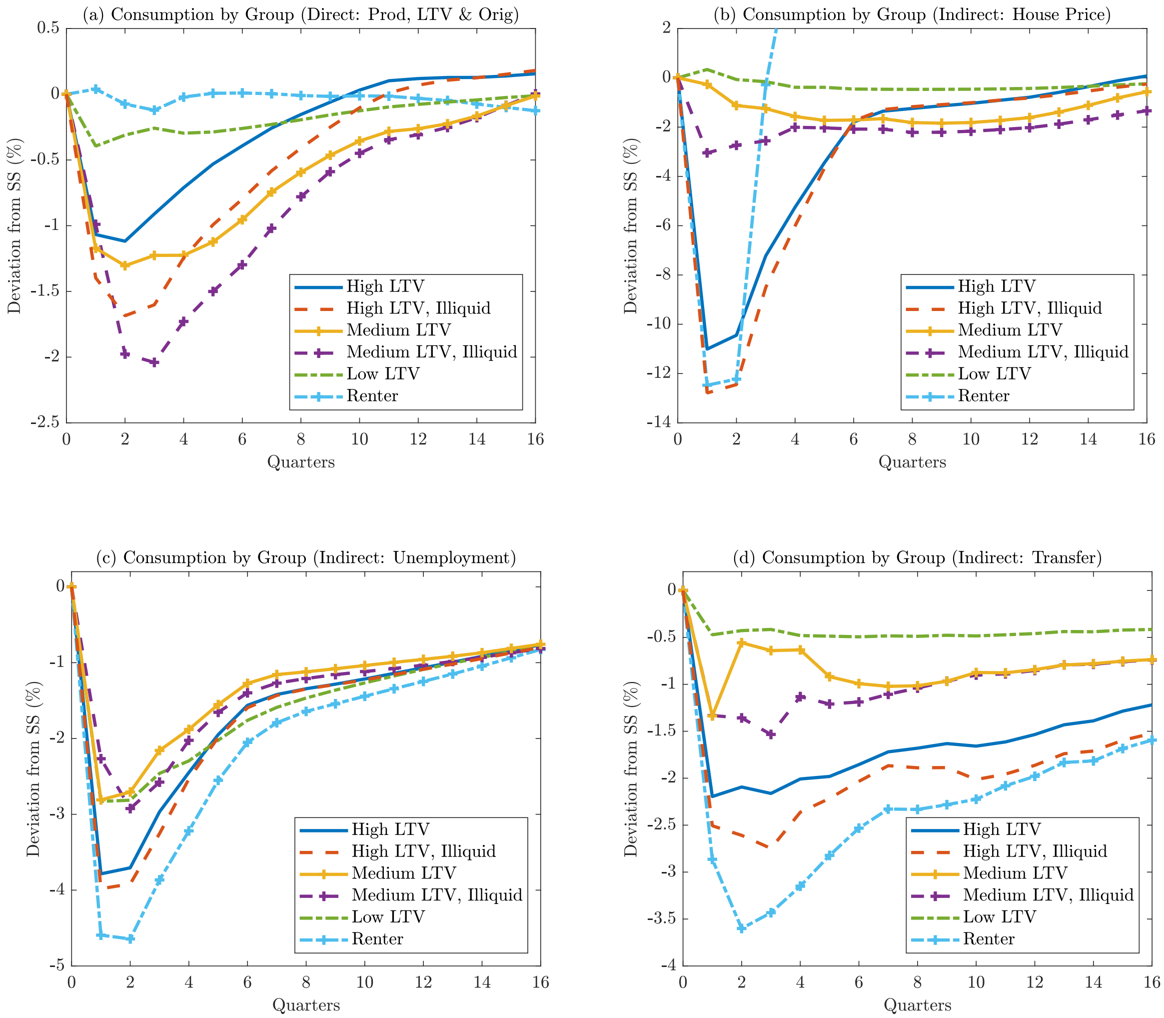

Figure 6: **Decomposing the Consumption Responses into Direct and Indirect Effects by Initial Housing Tenure, LTV, and Liquid Assets in the Non-Recourse Economy.** The panels plot the consumption responses in the non-recourse (U.S.) model economy to: (i) the exogenous crisis shocks (direct effect), and the endogenous (ii) fall in house prices, (iii) rise in unemployment, and (iv) drop in lump-sum transfers (indirect effects). LTV and illiquid classifications are as in Figure 5. Section 5.6 discusses the details.

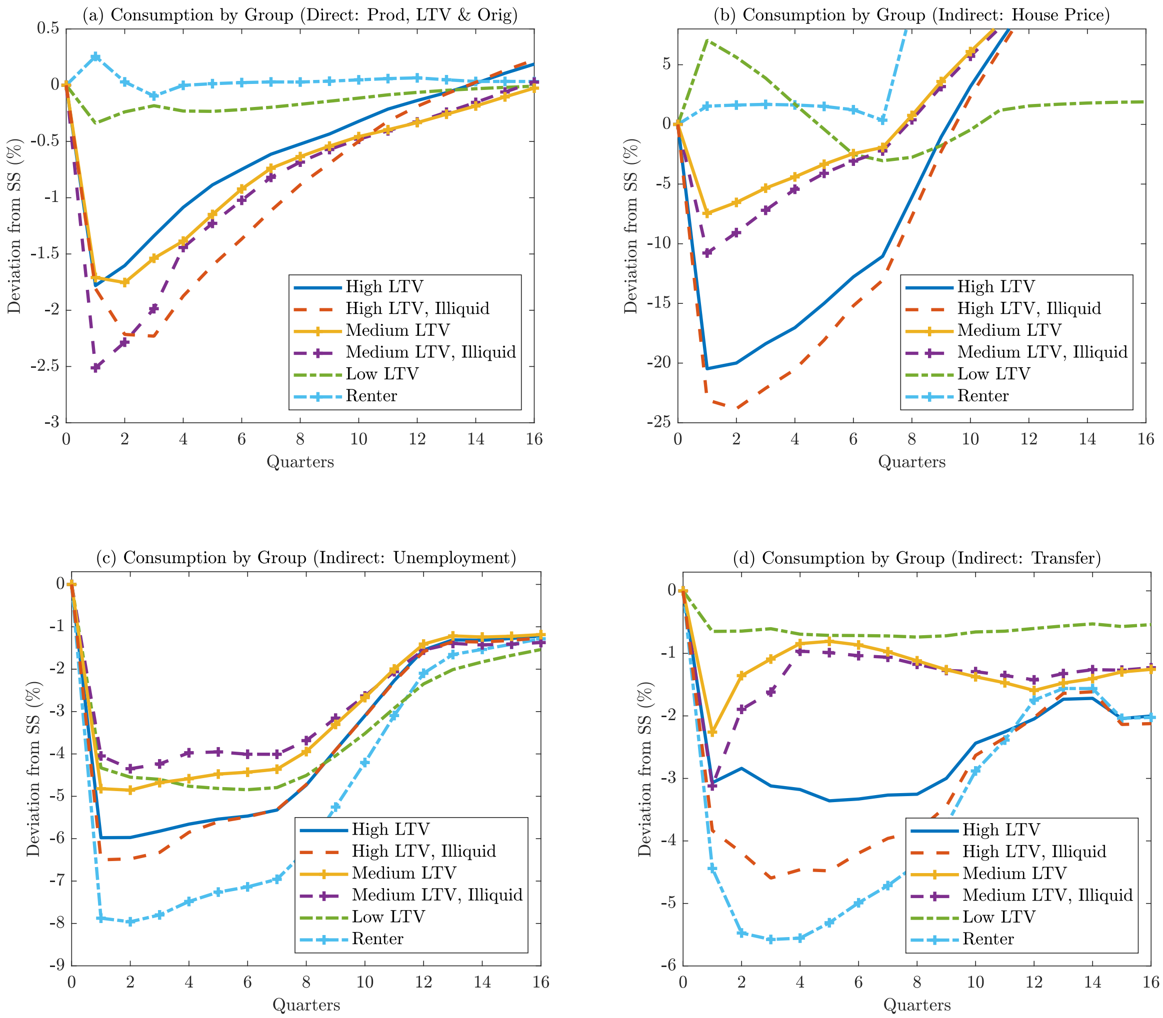

Figure 7: **Decomposing the Consumption Responses into Direct and Indirect Effects by Initial Housing Tenure, LTV, and Liquid Assets in the Recourse Economy.** The panels plot the consumption responses in the recourse model economy to: (i) the exogenous crisis shocks (direct effect), and the endogenous (ii) fall in house prices, (iii) rise in unemployment, and (iv) drop in lump-sum transfers (indirect effects). LTV and illiquid classifications are as in Figure 5. Section 5.6 discusses the details.

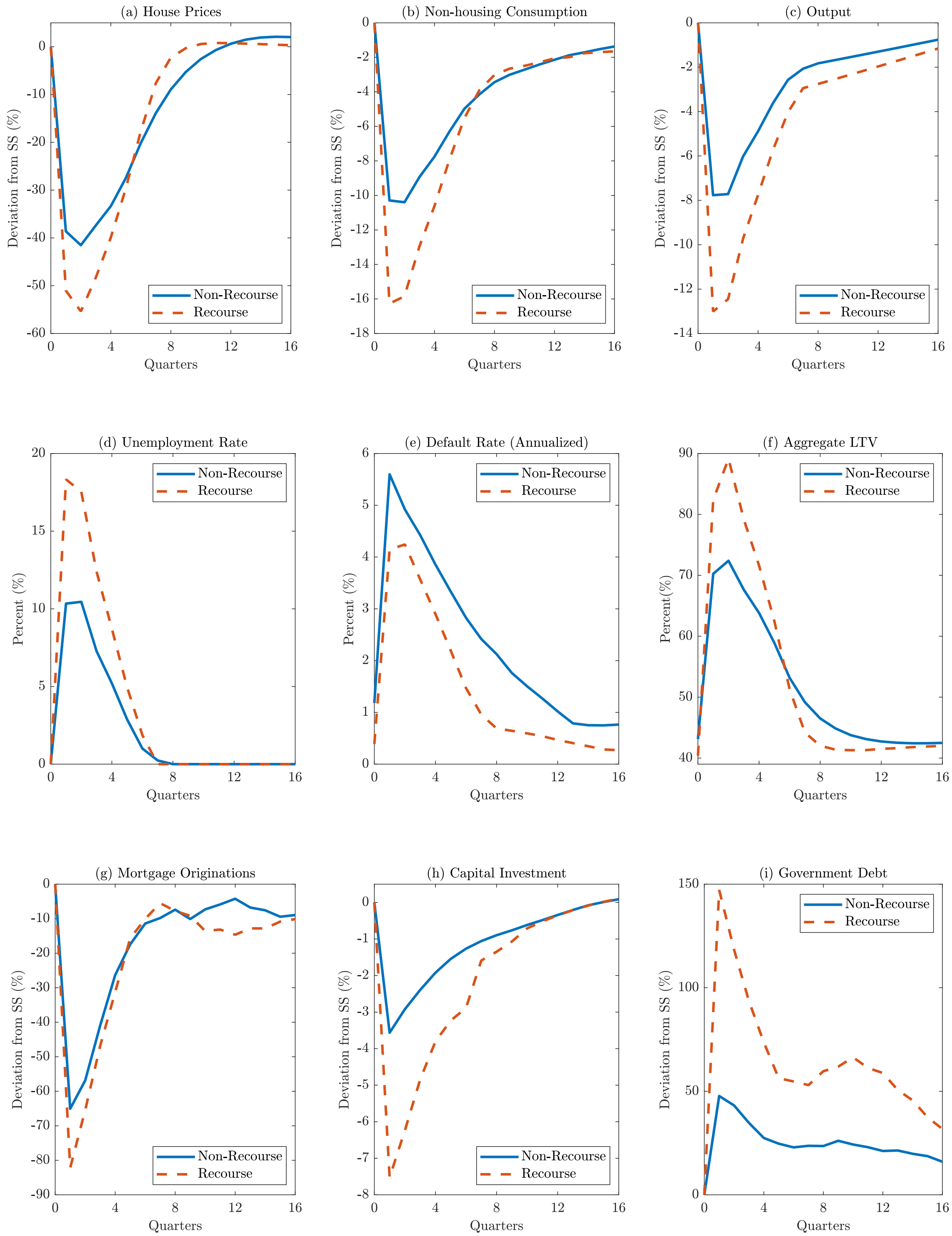

Figure 8: **Dynamics of Non-Recourse and Recourse Economies Following Unexpected Productivity and Credit Shocks (U.S. versus Spain).** The panels compare the equilibrium responses of the non-recourse (U.S.) and recourse (Spain) economies to the exogenous crisis shocks. Sections 5.2 and 6.2 discuss the details.

Online Appendix for Mortgage Design and Slow Recoveries. The Role of Recourse and Default.

A Data Sources of Figure 1

Unless otherwise stated, all data is at quarterly frequency and retrieved from the Federal Reserve Economic Data (FRED) database. House prices, consumption, GDP, and outstanding mortgage debt are expressed in real terms.

House Prices: For the U.S., we use the S&P/Case-Shiller National Home Price Index (CSUSHPISA). We deflate using the Consumer Price Index for All Urban Consumers (CPIAUCSL). For Spain, we use the House Price Index, Deflated (TIPSHO30) from Eurostat.

Consumption: We use the Gross Domestic Product by Expenditure in Constant Prices: Private Final Consumption Expenditure for the U.S. (NAEXKP02USQ189S) and Spain (NAEXKP02ESQ189S).

GDP: We use the Gross Domestic Product by Expenditure in Constant Prices: Total Gross Domestic Product for the U.S. (NAEXKP01USQ652S) and Spain (NAEXKP01ESQ652S).

Unemployment Rate: We use the Unemployment Rate: Aged 15-64: All Persons for the U.S. (LRUN64TTUSQ156S) and Spain (LRUN64TTESQ156S).

Mortgage Debt Outstanding: For the U.S., we use the Financial Accounts (Z.1) of the Federal Reserve, Table L.217 Total Mortgages (1), Line 7 (FL153165005 Household Sector). We deflate using the price index described above. For Spain, we use the Housing Market Indicators (Table 1.5) by the Bank of Spain. We derive the outstanding mortgage debt for households from three series: (i) Crédito Hipotecario, Total (SI_1_5.52), (ii) Crédito Hipotecario, Total, Saldo en % del PIB (SI_1_5.53), and (iii) Crédito Hipotecario, Crédito a los Hogares para Adquisición de Viviendas, Saldo en % del PIB (SI_1_5.55).[48] We deflate using the Consumer Price Index (National Overall Index) by the Instituto Nacional de Estadística. We seasonally adjust the price index and modify the series from monthly to quarterly frequency.[49]

Mortgage Defaults: For the U.S., we use foreclosure rate data from CoreLogic, Inc. We proxy defaults for Spain with Arrears on Mortgage or Rent Payments - EU-SILC survey from

[48] As a cross-check, the resulting series for outstanding mortgage debt for households are very close to those from Datastream, ES Mortgage Loans: Outstanding - Residential (ESMLTORMB).

[49] We use the X-13ARIMA-SEATS program developed by the U.S. Census Bureau in collaboration with the Bank of Spain. This is the seasonal adjustment software currently used by the Census Bureau.

Eurostat. A closer concept in the U.S. is the serious delinquency rate, which we also obtained from CoreLogic. Using this data in Figure 1(f) instead of foreclosures gives similar results. All default data is at annual frequency.

B Model Details

B.1 Household Problems

Here we formalize the household problems described in Section 3.1.6. We denote the value functions of households entering the period (after the realization of the employment shock e) as renters, homeowners, and past defaulters by $V_t^R(a,z,e)$, $V_t^O(h,m,a,z,\delta,e)$, and $V_t^D(m,a,z,e)$ respectively (in the last case, $V_t^D(a,z,e)$ if non-recourse). Aggregate variables have time t subscript. We omit this subscript for the state and decision variables of the household problem.

B.1.1 Renter

Renters with access to the mortgage market have two options. First, buy a house with a mortgage loan, if any. The value function in this case is

$$J_t^B(a,z,e) = \max_{c,h',\ell,m',a'} \left\{ u_z(c,h',\ell) + \beta \mathbb{E}\left[V_{t+1}^O(h',m',a',z',\delta',e')\right] \right\} \quad \text{s.t.} \tag{20}$$

$$c + (1+\zeta_b)p_t^H h' + q_t^A a' = y_t(z,\ell) + (1-e)T_t^U(z) + a + q_t^0(m',h',a',z)m',$$
$$q_t^0(m',h',a',z)m' \leq \theta p_t^H h',$$
$$(1-e)\ell = 0.$$

Second, keep renting. The value function in this case is

$$J_t^R(a,z,e) = \max_{c,s,\ell,a'} \left\{ u_z(c,s,\ell) + \beta \mathbb{E}\left[V_{t+1}^R(a',z',e')\right] \right\} \quad \text{s.t.} \tag{21}$$

$$c + p^S s + q_t^A a' = y_t(z,\ell) + (1-e)T_t^U(z) + a,$$
$$(1-e)\ell = 0.$$

The value of a renter is given by the option that provides the maximum utility

$$V_t^R(a,z,e) = \max \left\{ J_t^B(a,z,e), J_t^R(a,z,e) \right\}. \tag{22}$$

B.1.2 Homeowner

A homeowner chooses among four options. First, stay in the current house and make the mortgage payment, if any. The value function in this case is

$$J_t^K(h,m,a,z,\delta,e) = \max_{c,\ell,a'} \left\{ u_z(c,h,\ell) + \beta \mathbb{E}\left[V_{t+1}^O(h,\lambda m,a',z',\delta',e')\right] \right\} \quad \text{s.t.} \tag{23}$$

$$c + p_t^H \delta h + x + q_t^A a' = y_t(z,\ell) + (1-e)T_t^U(z) + a,$$

$$x = (1-\lambda)m + r_t^M m,$$

$$(1-e)\ell = 0.$$

Second, stay in the current house, prepay the outstanding loan balance, and choose a new mortgage loan, if any. The value function in this case is

$$J_t^F(h,m,a,z,\delta,e) = \max_{c,\ell,m',a'} \left\{ u_z(c,h,\ell) + \beta \mathbb{E}\left[V_{t+1}^O(h,m',a',z',\delta',e')\right] \right\} \quad \text{s.t.} \tag{24}$$

$$c + p_t^H \delta h + (1+\zeta_p)(1+r_t^M)m + q_t^A a' = y_t(z,\ell) + (1-e)T_t^U(z) + a + q_t^0(m',h',a',z)m',$$

$$q_t^0(m',h',a',z)m' \le \theta p_t^H h,$$

$$(1-e)\ell = 0.$$

Third, sell the house and prepay the outstanding mortgage balance, if any. Sellers rent in the current period. The value function in this case is

$$J_t^S(h,m,a,z,\delta,e) = \max_{c,s,\ell,a'} \left\{ u_z(c,s,\ell) + \beta \mathbb{E}\left[V_{t+1}^R(a',z',e')\right] \right\} \quad \text{s.t.} \tag{25}$$

$$c + p^S s + p_t^H \delta h + (1+\zeta_p)(1+r_t^M)m + q_t^A a' = y_t(z,\ell) + (1-e)T_t^U(z) + a + (1-\zeta_s)p_t^H h,$$

$$(1-e)\ell = 0.$$

Fourth, default on the mortgage if there is one. Defaulters rent in current period, do not cover the housing depreciation cost, and are excluded from the mortgage market for a random amount of time. The value function depends on whether mortgages are recourse or not.

Recourse mortgages. In this case, the defaulter pays the minimum between the deficiency (if any) and a fraction ϕ of its labor earnings and savings. Any remaining balance after the recourse payment is carried over to the next period. The value function is

$$J_t^D(h,m,a,z,\delta,e) = \max_{c,s,\ell,a'} \left\{ u_z(c,s,\ell) + \beta\mathbb{E}\left[\xi V_{t+1}^R(a',z',e') + (1-\xi)V_{t+1}^D(m',a',z',e')\right] \right\} \quad \text{s.t.} \tag{26}$$

$$c + p^S s + x_D + q_t^A a' = y_t(z,\ell) + (1-e)T_t^U(z) + a,$$

$$x_D = \max\left\{ \min\left\{ (1+r_t^M)m - (1-\zeta_d)p_t^H(1-\delta)h, \phi(\tilde{y}_t(z,\ell)+a) \right\}, 0 \right\},$$

$$m' = (1+r_t^M)m - (1-\zeta_d)p_t^H(1-\delta)h - x_D,$$

$$(1-e)\ell = 0.$$

Non-recourse mortgages. In this case, the defaulter is not liable for any deficiency and does not make additional payments. The value function is

$$J_t^D(h,m,a,z,\delta,e) = \max_{c,s,\ell,a'} \left\{ u_z(c,s,\ell) + \beta\mathbb{E}\left[\xi V_{t+1}^R(a',z',e') + (1-\xi)V_{t+1}^D(a',z',e')\right] \right\} \quad \text{s.t.} \tag{27}$$

$$c + p^S s + q_t^A a' = y_t(z,\ell) + (1-e)T_t^U(z) + a,$$

$$(1-e)\ell = 0.$$

The value of a homeowner is given by the option that provides the maximum utility

$$V_t^O(h,m,a,z,\delta,e) = \max\left\{ J_t^K(\cdot), J_t^F(\cdot), J_t^S(\cdot), J_t^D(\cdot) \right\}. \tag{28}$$

B.1.3 Past Defaulter

Past defaulters do not make any discrete choice and have to rent in the current period. Again, the value function depends on whether mortgages are recourse or not.

Recourse mortgages. In this case, the defaulter has to make the recourse payment, if any

$$V_t^D(m,a,z,e) = \max_{c,s,\ell,a'} \left\{ u_z(c,s,\ell) + \beta\mathbb{E}\left[\xi V_{t+1}^R(a',z',e') + (1-\xi)V_{t+1}^D(m',a',z',e')\right] \right\} \quad \text{s.t.} \tag{29}$$

$$c + p^S s + x_D + q_t^A a' = y_t(z,\ell) + (1-e)T_t^U(z) + a,$$

$$x_D = \min\left\{ (1+r_t^M)m, \phi(\tilde{y}_t(z,\ell)+a) \right\},$$

$$m' = (1+r_t^M)m - x_D,$$

$$(1-e)\ell = 0.$$

Non-recourse mortgages. In this case, the defaulter does not make any debt payment

$$V_t^D(a,z,e) = \max_{c,s,\ell,a'} \left\{ u_z(c,s,\ell) + \beta \mathbb{E}\left[\xi V_{t+1}^R(a',z',e') + (1-\xi)V_{t+1}^D(a',z',e')\right] \right\} \quad \text{s.t.} \tag{30}$$

$$c + p^S s + q_t^A a' = y_t(z,\ell) + (1-e)T_t^U(z) + a,$$

$$(1-e)\ell = 0.$$

B.2 Derivation of Mortgage Lending Rates

Denote the sequence of scheduled mortgage payments by $x^{(0)} = x$, $x^{(1)} = x'$, $x^{(2)} = x''$, etc. We focus on the steady state, where the interest rate r^M is constant. The assumption of geometrically declining outstanding balances $m' = \lambda m$ implies the same property for the payments $x' = \lambda x$. To ease notation, we suppress the dependence of the mortgage price at origination q_t^0 on the loan amount m', house size h', liquid savings a', and productivity z. Since we model mortgages as perpetuities, the yield at origination y_t^0 is given by

$$q_t^0 m' = \sum_{i=1}^{\infty} \frac{x^{(i)}}{(1+y_t^0)^i} = \sum_{i=1}^{\infty} \frac{\lambda^{(i-1)} x'}{(1+y_t^0)^i} = \frac{x'}{1+y_t^0} \sum_{i=0}^{\infty} \left(\frac{\lambda}{1+y_t^0}\right)^i = \frac{x'}{1+y_t^0-\lambda} \tag{31}$$

Solving for the yield and using (3), we get

$$y_t^0(m',h',a',z) = \frac{(1-\lambda)(1-q_t^0) + r^M}{q_t^0}. \tag{32}$$

The panels of Figure 3 plot the yield over the risk-free rate, expressed in annual terms.

In Section 3.1.4 we assume a common mortgage rate r^M across borrowers for tractability. Otherwise, we would have to add the borrower's specific interest rate as an additional state variable in the homeowner problem. This is a common assumption in recent macroeconomic models with housing and mortgages (for example, see Garriga and Hedlund 2020, and Kaplan, Mitman and Violante 2020). However, although all borrowers pay the same interest rate on the outstanding balance, the heterogeneity in the amount to be repaid m' and the mortgage price at origination q_t^0 implies that effective lending rates are heterogeneous.

B.3 Non-Recourse Mortgage Pricing

In the case of non-recourse mortgages, the price q_t^M is determined by

$$q_t^M(m', h', a', z)m' = \frac{1}{1+r_t^M}\mathbb{E}\Big[\underbrace{I'_K\left(x' + q_{t+1}^M(\lambda m', h', a''_K, z')\lambda m'\right)}_{\text{pay + continuation value}} + \underbrace{(I'_F + I'_S)(1+\zeta_p)(1+r_{t+1}^M)m'}_{\text{prepay}} + \underbrace{I'_D(1-\zeta_d)p_{t+1}^H(1-\delta')h'}_{\text{default (house sale)}}\Big]. \quad (33)$$

If the borrower keeps the mortgage ($I'_K = 1$), then the lender receives the scheduled payment x' and gets the continuation value of the remaining balance, summarized by the next period pricing function. If the borrower refinances ($I'_F = 1$) or sells the house ($I'_S = 1$), then the lender receives the full outstanding balance plus the interest payment $(1 + r_{t+1}^M)m'$. If the borrower defaults ($I'_D = 1$), then the lender receives the proceeds from the foreclosed house sale.

B.4 Lenders' Balance Sheet

The balance sheet of the lenders is

$$q_t^A B_{t+1}^b + T_t^b + \int \Big[I_K\bar{x} + (I_F + I_S)(1+\zeta_p)(1+r_t)m + I_D((1-\zeta_d)p_t^H(1-\delta)h + \bar{x}_D)\Big]d\Psi_t^O$$
$$+ \int \bar{x}_D\, d\Psi_t^D + B_t^g = B_t^b + (1+\zeta_0)(1+\zeta_m)\left(\int I_B q_t^0 m'\, d\Psi_t^R + \int I_F q_t^0 m'\, d\Psi_t^O\right) + q_t^A B_{t+1}^g, \quad (34)$$

where B_t^b are the deposits issued by lenders (with positive values denoting liabilities), T_t^b are transfers from the government, and $\bar{x} = x - \zeta_m(1+r_t)m$ and $\bar{x}_D = x_D - \zeta_m(1+r_t)m_D$ are the scheduled and recourse payments net of servicing costs, respectively. $x_D = m_D = 0$ if mortgages are non-recourse. Any ex-post profits or losses experienced by lenders (induced by aggregate uninsurable shocks like those we study in Section 5.2) are fully absorbed into the government budget through the transfer T_t^b. This assumption, together with (34) implies (9), and allows us to overcome the problem of pricing deposits when there are ex-post profits and losses.

B.5 Firm's Problem

Denote by $V_t(K_t)$ the value of the representative firm with aggregate capital K_t at the start of period t. The recursive problem of the firm is

$$V_t(K_t) = \max_{K_{t+1},N_t} \left\{ d_t + \frac{1}{1+r_t} V_{t+1}(K_{t+1}) \right\} \quad \text{s.t.} \tag{35}$$

$$d_t = F(K_t, N_t) - \frac{W_t}{P_t} N_t - (K_{t+1} - (1-\delta_K)K_t) - \frac{\zeta_I}{2} \left(\frac{K_{t+1} - K_t}{K_t} \right)^2 K_t. \tag{36}$$

Taking the first-order condition with respect to K_{t+1} we get

$$\zeta_I \left(\frac{K_{t+1} - K_t}{K_t} \right) = \frac{1}{1+r_t} V'_{t+1}(K_{t+1}) - 1, \tag{37}$$

where we define $q_t = V'_{t+1}(K_{t+1})/(1+r_t)$ as the marginal value of capital. Taking the envelope condition and rearranging we get

$$V'_t(K_t) = F_K(K_t, N_t) + (1-\delta_K) + \zeta_I \left(\frac{K_{t+1} - K_t}{K_t} \right) \frac{K_{t+1}}{K_t} - \frac{\zeta_I}{2} \left(\frac{K_{t+1} - K_t}{K_t} \right)^2. \tag{38}$$

Moreover, taking the first-order condition with respect to N_t we get

$$F_N(K_t, N_t) = \frac{W_t}{P_t}. \tag{39}$$

We assume that the production function F is homogeneous of degree one (for example, Cobb-Douglas). Using this property and (39), we can rewrite (36) as

$$d_t = F_K(K_t, N_t)K_t - (K_{t+1} - (1-\delta_K)K_t) - \frac{\zeta_I}{2} \left(\frac{K_{t+1} - K_t}{K_t} \right)^2 K_t. \tag{40}$$

Together, equations (37), (39), and (40) characterize the solution to the firm's problem.

B.6 Incidence of Aggregate Unemployment

The function $\kappa(z, n_t)$ satisfies the following conditions for aggregation:

$$\text{(a)} \quad \kappa(z,1) = 1 \text{ for all } z, \text{ which implies } \mathbb{E}[z\ell] = L_t, \tag{41}$$

$$\text{(b)} \quad \mathbb{E}[\kappa(z,n_t)z\ell] = n_t\mathbb{E}[z\ell], \text{ which along (a) implies } \mathbb{E}[\kappa(z,n_t)z\ell] = N_t, \tag{42}$$

where the expectation $\mathbb{E}$ is taken over the cross-section of households and assumes full employment. Condition (a) states that given full employment, the mean (or aggregate) effective labor supply across households equals the aggregate labor supply L_t. Condition (b) says that given aggregate unemployment n_t, the mean rationed labor supply across households equals labor demand $N_t < L_t$. Thus, labor rationing operates through the probability of employment k, which is also the share of employed households at a given point in time.

B.7 Distribution over Households States after Employment

Let $\tilde{\Psi}_t^R(a,z)$, $\tilde{\Psi}_t^O(h,m,a,z,\delta)$, $\tilde{\Psi}_t^D(m,a,z)$ be the distributions over renters', homeowners', and past defaulters' states, at the start of the period, before the employment status has occurred. Then, aggregate unemployment n_t and the current labor productivity z determine the individual probability that a household will be employed $\kappa(z,n_t)$. After the employment shock e realizes ($e = 0$ unemployed, $e = 1$ employed), the distribution over renters' states becomes

$$\Psi_t^R(a,z,0) = (1-\kappa(z,n_t))\tilde{\Psi}_t^R(a,z) \tag{43}$$

$$\Psi_t^R(a,z,1) = \kappa(z,n_t)\tilde{\Psi}_t^R(a,z). \tag{44}$$

Note that the only difference between the distributions is the addition of the employment status e. The distributions for homeowners and defaulters are computed in a similar way. Thus, we use $\Psi_t^R(a,z,e)$, $\Psi_t^O(h,m,a,z,\delta,e)$, and $\Psi_t^D(m,a,z,e)$ to aggregate households' decisions.

B.8 Definition of Equilibrium

Given a mortgage recourse system ϕ, an *equilibrium* is a sequence of house prices, price levels, nominal wages, asset prices, and real interest rates $\{p_t^H, P_t, W_t, q_t^A, r_t\}_{t=0}^{\infty}$, household decision rules $\{I_B, I_R, I_K, I_F, I_S, I_D, c, s, h', \ell, m', a'\}_{t=0}^{\infty}$, mortgage price functions $\{q_t^M,\ q_t^D\}_{t=0}^{\infty}$, issuances of deposits $\{B_{t+1}^b\}_{t=0}^{\infty}$, employed labor and capital investment $\{N_t, I_t\}_{t=0}^{\infty}$, government and central bank policy $\{B_{t+1}^g, G_t, \tau_t, T_t, T_t^b, i_t\}_{t=0}^{\infty}$, and distributions over households' states before employment status $\{\tilde{\Psi}_t^R, \tilde{\Psi}_t^O, \tilde{\Psi}_t^D\}_{t=0}^{\infty}$, such that, given an initial nominal wage W_{-1}, aggregate capital K_0, government debt B_0^g, and distributions $\tilde{\Psi}_0^R$, $\tilde{\Psi}_0^O$ and $\tilde{\Psi}_0^D$, at every time t:

1. The household decision rules solve (20)-(30).

2. The mortgage pricing functions satisfy (7), (8) if recourse; or (33) if non-recourse.

3. The lenders' credit condition (9) holds.

4. Employed labor and capital investment solve (35).

5. The government satisfies the budget constraint (15) and follows its fiscal rule (16).

6. The central bank follows its monetary policy rule and the Fisher equation (17) holds.

7. The distribution of households is consistent with the decision rules, the exogenous law of motion for the idiosyncratic labor productivity and housing depreciation shocks, and the incidence of aggregate unemployment across households.

8. All markets clear, except perhaps the labor market:

   (a) Housing market clears: $\int h' \, d\Psi_t = H$.

   (b) Labor market either clears or there is involuntary unemployment according to (13) and (14).

   (c) Deposit market clears: $\int a' \, d\Psi_t = B^b_{t+1}$.

   (d) Goods market clears:

$$\int c \, d\Psi_t + \int p^S s \, d\Psi_t + I^H_t + Z^\zeta_t + I_t + \frac{\zeta_I}{2} \left(\frac{K_{t+1} - K_t}{K_t} \right)^2 K_t + G_t = Y_t,$$

   where I^H_t is the investment to cover the housing net depreciation and foreclosure costs:

$$I^H_t = \int (I_K + I_F + I_S) p^H_t \delta h \, d\Psi^O_t + \int I_D p^H_t (1 - (1 - \zeta_d)(1 - \delta)) h \, d\Psi^O_t,$$

   and Z^ζ_t is aggregate spending on housing transaction and mortgage costs:

$$Z^\zeta_t = \zeta_b \int I_B p^H_t h' \, d\Psi^R_t + \zeta_s \int I_S p^H_t h \, d\Psi^O_t + \zeta_m \left(\int (I_K + I_D)(1 + r_t) m \, d\Psi^O_t + \int (1 + r_t) m \, d\Psi^D_t \right) + ((1 + \zeta_0)(1 + \zeta_m) - 1) \left(\int I_B q^0_t m' \, d\Psi^R_t + \int I_F q^0_t m' \, d\Psi^O_t \right).$$

If the deposit market clears (c), then the goods market will clear (d).

C Parameterization Details

C.1 Productivity Process

We use the idiosyncratic labor productivity process from Kaplan, Moll and Violante (2018).[50] We import their 33-point grid for log earnings (`ygrid_combined.txt`) and their 33×33 quarterly Markov transition matrix (`ytrans_qu_combined.txt`). Using this process, we replicate the annual earnings moments from Guvenen et al. (2015) targeted by these authors in their earnings process estimation. Table A1 shows that we obtain similar results.

C.2 Production Function and Firm Parameters

Regarding the remaining parameters of the Cobb-Douglas production function, we set the capital depreciation rate δ_K to generate an annual rate of 8%. In steady state, (37) and (38) imply that the marginal product of capital equals the user cost $F_K(K, N) = r + \delta_K$, which in turn implies that the capital share satisfies $1 - \alpha = (K/Y)(r + \delta_K)$. Our choices for K/Y, r, and δ_K imply a labor share of $\alpha = 0.769$. This value is higher than typical long-run average estimates (around 0.64), which is natural for a model without an equity premium. Then, we set the total productivity level to $A = 1.672$ so that the median quarterly labor earnings in steady state are normalized to one (the model equivalent to $52,000 annual in the 2004 SCF).

Let $q_t = V'_{t+1}(K_{t+1})/(1 + r_t)$ be the price of capital. Replacing this in (37) gives

$$q_t = \zeta_I \left(\frac{I_t}{K_t} - \delta_K \right) + 1. \tag{45}$$

The log-linearization of this equation gives $\bar{q}_t = \zeta_I \delta_K (\bar{I}_t - \bar{K}_t)$ where the "bar" variables denote percentage deviations from the steady state. This is the equivalent of equation (4.19) in Bernanke, Gertler and Gilchrist (1999). We set the capital adjustment cost to $\zeta_I = 12.12$ to match the elasticity of the price of capital with respect to the investment-capital ratio of 0.25 taken by these authors in their calibration at quarterly frequency.

[50] Available at http://benjaminmoll.com/wp-content/uploads/2019/07/HANK_replication.zip

C.3 Incidence of Aggregate Unemployment

We calibrate the function $\kappa(z, n)$ to match the empirical evidence by Guvenen et al. (2017) on the exposure of gross worker earnings to GDP growth conditional on their percentile in the earnings distribution.[51] They find that aggregate risk exposure to GDP growth is U-shaped with respect to the earnings level. Therefore, when we map their worker betas into unemployment probabilities, the incidence of aggregate unemployment inherits the U-shape across the earnings distribution, which is clearly counterfactual. To fix this, we adjust the worker betas at the top of the earnings distribution such that the model captures the fact that although the unemployment rate increases significantly in each earnings quintile during recessions, the lower quintiles experience the largest increases. Note that the persistence in the employment probability $\kappa(z, n)$ is captured by the persistence of the labor productivity z.

The top panel of Table A2 shows the difference in the unemployment rate (in percentage points) by earnings quintile between January and April 2020 documented by Amburgey and Birinci (2020) according to the 2019-2020 Current Population Survey. For example, workers in occupations in the third quintile experienced an unemployment rate of 2.80% in January and 13.52% in April, a change of 10.73 percentage points. The bottom panel of Table A2 shows the unemployment rate change (in percentage points) between the steady state and upon impact in our benchmark recession experiment described in Section 5.2. The changes in the unemployment rate for each income quintile in the model and data are similar.

C.4 Survey of Consumer Finances Data

We use the 2004 Survey of Consumer Finances (SCF) data from Kaplan, Moll and Violante (2018), whose replication material is available on the website provided in Section C.1. A homeowner is defined as a household with positive gross housing wealth (`housepos`). The homeownership rate in the SCF (71.7%) is consistent with the U.S. Census Bureau for 2004 (69.0%). We compute current LTV as the ratio of mortgage debt (`houseneg`) to gross housing wealth (`housepos`). We define liquid assets as the sum of liquid savings plus cash imputation (`liqpos`), corporate bonds (`cb`), and government bonds (`gb`). The annual labor income is obtained from (`wagesalinc`). Monthly labor income is obtained by dividing this value by 12.

[51] Our formulation is similar to Auclert and Rognlie (2020) with the important difference that we map the worker betas into unemployment probabilities instead of rationing of hours supplied.

C.5 Model Validation: Additional Moments

C.5.1 Cash-out Refinancing

As we explain in Section 5.2, our recession experiments involve the tightening of the LTV constraint, among other shocks. Therefore, it is important to check that the model does not have a very high rate of cash-out refinance and high LTV originations compared to the data, since this could overstate the effect that the tightening of the LTV limit has on prices and demand.

The refinancing activity was very volatile in the U.S. prior to the Great Recession. Yu (2020) documents that the constant prepayment rate (CPR) rose during 2002-2003,[52] reaching values between 40-60%, at a time where refinancing incentives were large (the difference between prevailing and outstanding mortgage rates), around 100 basis points. The CPR then fell to around 20% during 2004-2005, a period of refinancing incentives below 50 basis points. Moreover, according to Freddie Mac's annual refinance statistics, the percentage of refinances resulting in a 5% higher loan amount (their definition of cash-out refinance) increased sharply during the build up of the crisis, from 36% in 2003 to 87% in 2006.

In steady state of the U.S. model economy, the annual prepayment rate (which considers refinances and prepayments due to selling the house) is 44% if measured by principal balance, or 60% if measured by loan count. The percentage of refinances resulting in a 5% higher loan amount is 62%. The annual rate of cash-out refinance is 27% if measured by principal balance, or 39% if measured by loan count. Therefore, the cash-out refinancing activity in the model appears to be somewhat higher relative to the data, but not so far off.

C.5.2 High LTV Originations

During the period 2002-2006 in the U.S., the median combined LTV at origination was 80% and the 90th percentile was roughly 100% (Urban Institute Chartbook December 2019). Table 2 shows that the corresponding moments in the U.S. model are 73% and 81% respectively. Thus, the share of high LTV originations in the model is like in the data.

[52]The CPR is the annualized percentage of a mortgage pool's principal balance that is paid ahead of schedule.

C.5.3 Housing and Mortgage Markets

We endogenously get a share of housing services in total consumption $\eta = 0.204$, which is consistent with typical calibrations around 0.2 to match the housing expenditure share. We also get a minimum owner-occupied house size $\underline{h} = 6.10$, which means that the cheapest house is around \$80,000 in 2004 dollars. The bottom panel of Table 2 shows that the ratio of average labor income of owners to renters in the model (1.81) is in line with the 2004 SCF (2.32), and that the ratio of median house size of owners to renters in the model (0.73) is consistent with the 2005 AHS (0.80). Thus, the U.S. model generates a degree of segmentation between owner-occupied and rental housing that is in line with some basic moments in the data.

The typical mortgage in the U.S. is a 30-year fixed-rate mortgage in which the borrower makes constant payments. Given our choice for the mortgage rate of 3.5% annual, the half-life (the halfway point of principal balance repayment) is 18.76 years. In contrast, in our model the principal loan balance declines geometrically at rate λ. We endogenously get $\lambda = 0.9902$, which implies a half-life of $(\ln(0.5)/\ln(\lambda) + 1)/4 = 17.94$ years, consistent with the data.

D Computation

D.1 Labor Supply Decision

When fixing all housing and portfolio household choices, the only remaining choices are non-housing consumption c and hours worked ℓ. Let ℓ_1 and ℓ_2 be hours worked given by

$$\ell_1 = \left[\frac{(1-\tau)(W/P)}{\varphi}\right]^{\frac{1}{\nu}}, \quad \ell_2 = \left[\frac{(1-\tau-\phi)(W/P)}{\varphi}\right]^{\frac{1}{\nu}}, \tag{46}$$

where W/P is the real wage. Assuming the preferences (18), the household's first-order conditions imply that the optimal hours worked are ℓ_1 for all households, with the possible exception of defaulters with recourse. For this last group of households, the kink introduced by the min operator in the recourse payment x_D in (26) and (29) means that there are two candidates for the optimal labor supply: ℓ_1 and ℓ_2. In our numerical solution, we simply choose the one that gives the highest current utility (18). Thus, defaulters under recourse may work less hours.[53] Intuitively, when the remaining debt is high enough that it cannot be liquidated with the current

[53] Note that we omit the intertemporal effect of hours worked ℓ due to its impact on the remaining balance for the next period m', see (26) and (29). This allows us to have a closed form solution for the hours worked. Given that defaulters in the recourse economy are very few, this simplification has no impact on our results.

payment, the household will work fewer hours since part of its income will be garnished.

D.2 Consumption-Shelter Decision

After obtaining the labor supply decision (46), we further simplify the renter maximization problems (21), (25), (26), (27), (29), and (30) by first solving analytically the static problem of how to allocate resources between non-housing consumption c and shelter s. Denote by g the resources available for total consumption, that is

$$g = \begin{cases} y_t(z,\ell) + (1-e)T_t^U(z) + a - q_t^A a' & \text{if renter keeps renting,} \\ y_t(z,\ell) + (1-e)T_t^U(z) + a + (1-\zeta_s)p_t^H h - p_t^H \delta h - (1+\zeta_p)m - q_t^A a' & \text{if owner sells,} \\ y_t(z,\ell) + (1-e)T_t^U(z) + a - x_D - q_t^A a' & \text{if defaulter,} \end{cases}$$

where $x_D = 0$ if mortgages are non-recourse. The resource constraint becomes $c + p^S s = g$.

Let $\bar{c} = c - g_z(\ell)$ be non-housing consumption net of disutility from work, and $\bar{g} = g - g_z(\ell)$. The problem of allocating $\bar{g}$ resources between consumption $\bar{c}$ and shelter s is

$$U(\bar{g}) = \max_{\bar{c}, s \geq 0} \frac{\left[(1-\eta)\bar{c}^{\frac{\epsilon-1}{\epsilon}} + \eta s^{\frac{\epsilon-1}{\epsilon}}\right]^{\frac{\epsilon(1-\sigma)}{\epsilon-1}}}{1-\sigma} \quad \text{s.t.}$$
$$\bar{c} + p^S s = \bar{g}.$$

The closed-form solution to the maximization problem is $\bar{c}(\bar{g}) = \bar{g} - p^S s$, and

$$s(\bar{g}) = \frac{\eta^\epsilon (p^S)^{1-\epsilon}}{(1-\eta)^\epsilon + \eta^\epsilon (p^S)^{1-\epsilon}} \frac{\bar{g}}{p^S}.$$

The associated indirect utility is

$$U(\bar{g}) = \frac{\left[(1-\eta)^\epsilon + \eta^\epsilon (p^S)^{1-\epsilon}\right]^{\frac{1-\sigma}{\epsilon-1}} \bar{g}^{1-\sigma}}{1-\sigma}.$$

Then, non-housing consumption can be recovered from $c = \bar{c} + g_z(\ell)$.

D.3 Outline of the Solution Method

We now outline our solution method. This can be helpful to understand the equilibrium movements in house prices and unemployment in our recession experiments. Appendix B.8

contains the definition of equilibrium, and Appendix D.5 describes the solution method.

After combining the different optimality and equilibrium equations, we end up with a system of two unknowns and two equations in each period t: (i) the housing market clearing equation

$$\int h' \, d\Psi_t = H, \tag{47}$$

which states that aggregate housing holdings equals the constant stock of owner-occupied housing, and (ii) the asset market clearing equation

$$\int a' \, d\Psi_t = \frac{1}{q_t^A}(1+\zeta_0)(1+\zeta_m)\left(\int I_B q_t^0 m' \, d\Psi_t^R + \int I_F q_t^0 m' \, d\Psi_t^O\right) + B_{t+1}^g, \tag{48}$$

which states that aggregate savings finance the mortgage originations and government bonds.

In each period t, the house price p_t^H and aggregate employment rate n_t are the unknowns to be solved such that the house and asset market clearing equations (47) and (48) hold, given the distribution over states at the beginning of the period and the expected continuation values. The conditions controlling monetary policy and the government budget constraint always hold exactly in our solution method. Since the monetary rules that we consider shut down or prevent the equilibrating real interest movements, the equilibrium adjustment happens through the employment rate n_t. This mechanism is similar to that of Auclert and Rognlie (2020).

D.4 Calibrating the Steady State

Define the expected value functions on the right-hand-side of the household Bellman equations (20), (21), (23)-(27), (29), and (30) at time t by

$$\begin{aligned} EV_t^R(a',z) &= \mathbb{E}\left[V_{t+1}^R(a',z',e')\right], \\ EV_t^O(h',m',a',z) &= \mathbb{E}\left[V_{t+1}^O(h',m',a',z',\delta',e')\right], \\ EV_t^D(m',a',z) &= \mathbb{E}\left[\xi V_{t+1}^R(a',z',e') + (1-\xi)V_{t+1}^D(m',a',z',e')\right]. \end{aligned}$$

Likewise, define the expected repayment values on the right-hand-side of the pricing equations (7), (8), and (33) by $EP_t^M(m',h',a',z)$ and $EP_t^D(m',a',z)$ for current and defaulted mortgages. For instance, the mortgage price in (7) is $q_t^M(m',h',a',z) = EP_t^M(m',h',a',z)/(1+r_t^M)$.

The recursive household problems are solved on a grid. The number of grid points for house size h, mortgage debt m, liquid savings a, labor productivity z, housing depreciation δ, and employment status e is 6, 18, 18, 33, 2, and 2, respectively. When solving the decision rules for

m' and a' we allow for choices that are off the grid. Specifically, we search over 54 points for m' and 54 points for a'. For h we use an equally spaced grid from $\underline{h}$ (an endogenous parameter) to $\bar{h}$. For m, a, m', a', we construct polynomial spaced grids with points concentrated at the lower bound by taking an equally spaced grid, v from $[0, 1]$, then constructing the grid for m as $\underline{m} + (\bar{m} - \underline{m})v^{1/k}$ and similarly for the other variables. We use $k = 0.4$.

Following Hatchondo, Martinez and Sapriza (2010), we update the value and mortgage pricing functions jointly rather than using nested loops. We assume that in steady state the economy is at full employment, $N = L$.

We set the exogenous parameters as explained in Section 4.1. Then, the eight remaining endogenous parameters summarized in Table 1 are solved jointly to match the twelve target moments summarized in Table 2. This is done according to the following metric:

$$\Theta = \sum_{i=1}^{12} \left(\frac{M_i^{\text{Model}} - M_i^{\text{Target}}}{M_i^{\text{Target}}} \right)^2 ,$$

that is, our objective is the sum of squared percentage deviations of the model generated moments from the target moments using equal weights. We search over the endogenous parameters to minimize Θ using a combination of global and local optimization routines.

We compute the mapping from the endogenous parameters to Θ as follows:

1. Guess the expected value functions EV^R, EV^O, EV^D, and repayments EP^M and EP^D.

2. Solve the household recursive problems (20)-(30) using the guessed expected value functions EV^R, EV^O, and EV^D, and the guessed expected payments EP^M and EP^D. For m' and a' values off grids, approximate the value and repayment functions using linear interpolation. The solution gives new value functions and associated decision rules. Compute the new expected continuation values EV^R_{new}, EV^O_{new}, and EV^D_{new}.

3. Compute the implied expected repayments $\tilde{EP}^M$ and $\tilde{EP}^D$ using the new decision rules and the pricing equations (7), (8), and (33). Update the expected repayments using a relaxation parameter μ: $EP^M_{new} = \mu\tilde{EP}^M + (1-\mu)EP^M$ and $EP^D_{new} = \mu\tilde{EP}^D + (1-\mu)EP^D$.

4. Check whether the new values EV^R_{new}, EV^O_{new}, EV^D_{new}, and repayments EP^M_{new}, EP^D_{new} are sufficiently close to their respective guesses under the sup-norm metric and a predetermined tolerance. If not, update the guesses to the new values and repeat steps 2-3.

5. Guess the distributions before employment $\tilde{\Psi}^R$, $\tilde{\Psi}^O$, and $\tilde{\Psi}^D$. We approximate the distributions with discrete density functions (histograms) over the state spaces, that is (a, z)

for renters (R), (h, m, a, z, δ) for homeowners (O), and (m, a, z) for defaulters (D).

6. Iterate forward the distributions $\tilde{\Psi}^R$, $\tilde{\Psi}^O$, and $\tilde{\Psi}^D$ one time to obtain $\tilde{\Psi}^R_{new}$, $\tilde{\Psi}^O_{new}$, and $\tilde{\Psi}^D_{new}$ using the converged decision rules (this step involves computing the distributions *after* the employment status Ψ^R, Ψ^O, and Ψ^D). We use a non-stochastic simulation method. The transition for the household status, that is renter (R), homeowner (O), and defaulter (D) is governed by the discrete choices. The transitions for h', m' and a' are given by the decision rules. Whenever the choices for m' and a' are off grids, the transition is approximated by assigning mass to the adjacent grid points proportionally in a way that preserves total mortgage holdings and liquid savings. See Young (2010) for a description of non-stochastic simulation in this manner. Transitions for labor productivity and depreciation shocks follow the corresponding probability transition matrices.

7. Check whether the iterated distributions $\tilde{\Psi}^R_{new}$, $\tilde{\Psi}^O_{new}$, and $\tilde{\Psi}^D_{new}$ are sufficiently close to their respective guesses under the sup-norm metric and a predetermined tolerance. If not, set the guesses equal to the iterated distributions and repeat step 6.

8. Compute the model moments. Then compute Θ.

Once the procedure to minimize Θ is finished, the housing stock H is set such that (47) holds. Then, public debt B^g is determined from (48). The transfer to lenders T^b is computed from (9) and (34). Finally, spending G is determined from (15).

D.5 Solving for Transition Paths

We solve for the perfect foresight transition path (meaning that agents became aware and perfectly anticipate this path after entering period $t = 1$) induced by the exogenous shocks described in Section 5.2. All shocks revert linearly to their original levels after twenty quarters. We assume that the transition path from the initial steady state to its return takes T quarters. The assumption that the exogenous shocks in $t = 1$ are unanticipated implies that we know the distributions before the employment status $\tilde{\Psi}^R_1$, $\tilde{\Psi}^O_1$, and $\tilde{\Psi}^D_1$, since they are equal to those in steady state ($t = 0$). We also know the final expected values EV^R_T, EV^O_T, EV^D_T, and expected repayments EP^M_T, EP^D_T.

The firm's first-order condition (39) determines real wages. If the downward nominal wage rigidity is binding (as it is in all our experiments, and like in Auclert and Rognlie 2020) then

$W_t = W_{t-1}$ (we set $\gamma = 1$) and price inflation π_{t+1} is determined from the path of real wages

$$\frac{W_{t+1}}{P_{t+1}} / \frac{W_t}{P_t} = \frac{1}{1+\pi_{t+1}}. \tag{49}$$

If the initial nominal wage W_{-1} is given, then the price level P_t is determined. However, the latter is not necessary in our solution method for the equilibrium transition paths. Moreover, in benchmark experiments the real interest rate is fixed $r_t = r$.

To simplify the notation, denote the real wage by $w_t = W_t/P_t$.

We compute the equilibrium transition path as follows:

1. Guess a sequence of house prices, unemployment, real wages, and lump-sum transfers $\{p_t^H, n_t, w_t, T_t\}_{t=1}^T$. In practice, we initialize the sequence at the steady state values.

2. *Backward iteration.* Solve the household problems (20)-(30) using the expected continuation values EV_T^R, EV_T^O, and EV_T^D, and the expected repayments EP_T^M and EP_T^D. With the optimal values and associated decision rules at time T, compute the expected continuation values and repayments EV_{T-1}^R, EV_{T-1}^O, EV_{T-1}^D, EP_{T-1}^M, and EP_{T-1}^D. Use the continuation marginal value of the firm $V'_{T+1}(K_{T+1})$ to compute the marginal value $V'_T(K_T)$ by solving (37), (39) and (40). Proceed backwards in this way, computing the remaining sequence of expected household continuation values and decision rules, expected repayments, and marginal values of the firm, going from $t = T-1$ to $t = 1$.

3. *Forward iteration.* Find the pair $(\bar{p}_1^H, \bar{n}_1)$ that clears the housing (47) and credit (48) markets in $t = 1$, given the expected values and repayments EV_1^R, EV_1^O, EV_1^D, EP_1^M, and EP_1^D found in step 2 and the distributions before the employment status $\tilde{\Psi}_1^R$, $\tilde{\Psi}_1^O$, and $\tilde{\Psi}_1^D$. This process also gives the real wage $\bar{w}_1$ and lump-sum transfers $\bar{T}_1$, as described below. Then, compute the implied distributions for the next period, $\tilde{\Psi}_2^R$, $\tilde{\Psi}_2^O$, and $\tilde{\Psi}_2^D$. Iterate forward in this way to compute a sequence of updated aggregates $\{\bar{p}_t^H, \bar{n}_t, \bar{w}_t, \bar{T}_t\}_{t=1}^T$.

   We find the pair $(\bar{p}_1^H, \bar{n}_1)$ such that the housing and asset markets clear as follows:

   (a) Compute the probability of employment $\kappa(z, \bar{n}_1)$. Then, solve for the real wage $\bar{w}_1$ such that $N_1 = \bar{n}_1 L_1$ using (39) and (46). Then, recover ℓ, L_1, and N_1.

   (b) Solve for the next period capital K_2 and dividends d_1 from (37) and (40), using the continuation marginal value $V'_2(K_2)$ obtained in step 2.

   (c) Compute lump-sum transfers $\bar{T}_t$ using the fiscal rule (16). Then compute labor earnings and unemployment benefits: $\tilde{y}_1(z, \ell)$, $y_1(z, \ell)$, and $T_1^U(z)$.

(d) Solve the household problems (20)-(30), using the expected continuation values and repayments EV_1^R, EV_1^O, EV_1^D, EP_1^M, and EP_1^D found in step 2 (backward iteration).

(e) Compute the distributions after employment, Ψ_1^R, Ψ_1^O, and Ψ_1^D, using $\kappa(z, \bar{n}_1)$.

(f) Compute the transfer to lenders T_1^b from (9) and (34).

(g) Solve for next period public debt B_2^g from the government budget constraint (15).

(h) Check if the market clearing conditions (47) and (48) hold up to a predetermined tolerance. If not, update $(\bar{p}_1^H, \bar{n}_1)$ and return to step (a).

4. Check whether the updated aggregates $\{\bar{p}_t^H, \bar{n}_t, \bar{w}_t, \bar{T}_t\}_{t=1}^T$ are close to the corresponding guesses $\{p_t^H, n_t, w_t, T_t\}_{t=1}^T$ under the sup-norm and a predetermined tolerance. If not, update the initial guess using a relaxation parameter μ: $\mu\bar{p}_t^H + (1-\mu)p_t^H$, $\mu\bar{n}_t + (1-\mu)n_t$, $\mu\bar{w}_t + (1-\mu)w_t$, and $\mu\bar{T}_t + (1-\mu)T_t$ for all t and go back to step 2.

D.6 Computation of MPCs and Elasticities in the Model

Suppose a steady state environment. Consider a household that starts the period as a renter (R). The MPC out of an unexpected, transitory increase of k units in liquid wealth is

$$\text{MPC}_k(a, z, e) = \frac{c(a+k, z, e) - c(a, z, e)}{k}.$$

Since we focus on a steady state, both current and future house prices equal p^H. The (current) consumption elasticity to a $100 \times k$ percent permanent change in house prices is

$$\varepsilon_k(a, z, e; p^H) = \frac{c(a, z, e; p^H(1+k)) - c(a, z, e; p^H)}{c(a, z, e; p^H)k}.$$

The calculation of MPC and elasticities is similar for homeowners (O) and past defaulters (D).

E Calculation of the Recovery Gap

Referring to Figure 1(b), let $c_{t,q}^{\text{U.S.}}$, $c_{t,q}^{\text{Spain}}$ be the percentage deviation of quarterly consumption in year t and quarter q relative to the first quarter of 2007. We define the recovery gap as the difference of the consumption deviations between the U.S. and Spain: $c_{t,q}^{\text{Spain}} - c_{t,q}^{\text{U.S.}}$. Then, we compute the time-series average of the recovery gap for the first seven years since 2007: $g^{\text{Data}} = \frac{1}{28}\sum_{t=2008}^{2014}\sum_{q=1}^{4}(c_{t,q}^{\text{Spain}} - c_{t,q}^{\text{U.S.}})$. The calculation is similar for the model counterpart, taking the steady state as the reference level and the average over 28 quarters into the recession. The percentage of the data gap accounted for by the model gap is $100 \times \frac{g^{\text{Model}}}{g^{\text{Data}}}$.

F Spain Parameterization Details

We calibrate to 2005, as this was the last year the Spanish Survey of Household Finances (EFF), a data source for many of our targets, was conducted before the Great Recession. Table 8 summarizes the parameterization, and Table 9 compares the steady state moments to the targeted and non-targeted moments in the data.

F.1 Model Parameters

F.1.1 Preferences

We assume the utility function (18). The CRRA parameter σ, intratemporal elasticity between non-housing consumption and housing ϵ, and Frisch elasticity of labor supply $1/\nu$ are kept at the values in the benchmark calibration.[54] We set the disutility from work to $\varphi = 17.82$ so that hours worked by all households (except defaulters) are 1/3 of the time endowment. The remaining preference parameters (discount factor β, share of housing services in total consumption η, and homeownership utility premium χ) are set endogenously.

F.1.2 Housing and Mortgage Markets

We set the cost of buying a house ζ_b, the cost of selling ζ_s, and the maximum house size $\bar{h}$ as in the benchmark calibration. The idiosyncratic depreciation shock is a two-point distribution, where we set as low outcome $\underline{\delta} = 0$. Like before, we normalize the price of a unit of owner-occupied housing to $p^H = 1$. The minimum house size $\underline{h}$, the high depreciation outcome $\bar{\delta}$, and the probability of the high outcome $f_\delta(\bar{\delta})$ are set endogenously.

We set the recourse parameter to $\phi = 0.25$, an intermediate value in the range used by Hatchondo, Martinez and Sánchez (2015). The maximum LTV at mortgage origination is set to $\theta = 125\%$. This value is higher than the one we choose for the U.S. model economy (100%), and tries to capture the fact that mortgage originations in Spain tended to be larger than in the

[54] Our choice is consistent with the estimated Frisch elasticity for a macroeconomic model of the Spanish economy by Burriel, Fernández-Villaverde and Rubio-Ramírez (2010).

U.S. during the housing boom that preceded the crisis.[55] The mortgage origination cost is set to $\zeta_0 = 0.5\%$, in the range of typical values (Spanish Property Insight). We set the mortgage servicing cost ζ_m such that the mortgage rate r^M is 3.5% annual, consistent with the average mortgage rates between 2004-2005 according to the Bank of Spain. We set the prepayment penalty ζ_p, foreclosure cost ζ_d, and per-period probability of reentering the mortgage market ξ to the same values as before. The latter implies an average exclusion period from credit markets of six years, consistent with the typical period of time devoted to debt service after default in most of continental Europe (Gross 2014). The amortization parameter λ is set endogenously.

F.1.3 Endowments, Production and Technology

To our knowledge, there are no publicly available estimates of the earnings process for Spain that have been estimated by targeting moments from administrative earnings data as in Kaplan, Moll and Violante (2018). Thus, we keep the same idiosyncratic labor productivity process as in the U.S. parameterization. This earnings process features a large amount of right-tail inequality, which is important for obtaining a realistically skewed distribution of liquid assets.

Like before, we calibrate to a Cobb-Douglas production function, $F(K,N) = AK^{1-\alpha}N^{\alpha}$. We target an annual capital-output ratio of 3, in line with the values for Spain before the Great Recession (Conesa and Kehoe 2017, IMF Country Report June 2006), and an annual real risk-free rate of 1%, which implies $r = 0.25\%$. The capital depreciation rate is set to $\delta_K = 1.75\%$ as in Burriel, Fernández-Villaverde and Rubio-Ramírez (2010). Following the same argument of Appendix C.2, our choices for K/Y, r, and δ_K imply a labor share of $\alpha = 0.760$.[56] We set the total productivity level to $A = 1.564$ such that median quarterly labor earnings in steady state are normalized to one (the equivalent to €23,000 annual in the 2005 EFF). We set the capital adjustment cost to $\zeta_I = 10$ as in Andrés, Burriel and Estrada (2006). The nominal wage rigidity is set to $\gamma = 1$. The incidence function κ is calibrated as in the U.S. model economy. We set the transformation of final goods into rental units A_S endogenously.

[55] Bover, Torrado and Villanueva (2019) find that the median LTV at origination for Spain in 2005 was 70% if the appraisal value is used, 106% if the transaction price at the Property Registry is used, and 91% according to the households' responses in the 2005 EFF. Using this survey we get the same estimate. In the U.S., the median combined LTV at origination was 80% in 2004 (Urban Institute Chartbook December 2019).

[56] Like in the U.S. calibration, this value is higher than usual estimates around 0.63 (see Burriel, Fernández-Villaverde and Rubio-Ramírez 2010 or Conesa and Kehoe 2017), since our model has no equity premium.

F.1.4 Government and Central Bank

Importantly, the welfare state in the Spain model is more generous than in the U.S. model. Following Burriel, Fernández-Villaverde and Rubio-Ramírez (2010), we set the lump-sum transfer to $T = 0.37$ and the proportional tax on labor income to $\tau = 0.34$, compared to 0.21 and 0.24 respectively in the U.S. model. We set the slope parameter $\bar{T}^U$ such that the replacement rate of unemployment benefits is 0.76 (OECD Data for Spain 2005), instead of 0.52 as in the U.S. model. The cap on unemployment benefits is set at $\bar{z}^U = 1$. We set the fiscal rule parameter γ_1 to the steady state lump-sum transfer, and $\gamma_2 = 0.1$. The zero steady state inflation coupled with our choice for the real risk-free rate imply a nominal interest rate of $i = 0.25\%$.

F.2 Joint Parameterization and Model Fit

Like we did in Section 4.2, we need to map aggregate housing wealth, mortgage debt, and liquid savings in the model to the data. We do this by measuring the aggregate size of the balance sheet of Spanish households in 2005. We choose the Spain Wealth Database (Blanco, Bauluz and Martínez-Toledano 2020) measures for gross housing wealth (€4,133B) and mortgage debt (€659B),[57] and the Spanish Survey of Household Finances (EFF) measure for liquid savings (€275B). We target these quantities as multiples of 2005 annual GDP (€927B).

The eight endogenous parameters (discount factor β, share of housing in consumption η, homeownership premium χ, minimum house size $\underline{h}$, high outcome depreciation $\bar{\delta}$ and its probability $f_\delta(\bar{\delta})$, amortization parameter λ, rental technology A_S) are jointly determined to match the eight target data moments in the top panel of Table 9. The model matches several dimensions of the data well, like the homeownership rate (80.5%) for 2005 in the National Statistics Institute (INE), the annual default rate (0.42%) for 2005 reported by the Housing Market Indicators of the Bank of Spain, the average annual housing depreciation rate (1.39%), and the annual-price-to-rent ratio (23.1) for 2005 estimated from OECD data. Regarding the asset and debt moments, Table 9 shows that the parameterized model matches the aggregate (or mean) level of mortgage debt (0.71) in the Spain Wealth Database, the aggregate level of liquid assets (0.30) in the 2005 EFF, and the median LTV at origination (91%) in the EFF.

The bottom panel in Table 9 shows that the model is also reasonably consistent with non-targeted moments such as the share of mortgage originations with LTV $\geq 70\%$ and 80%, and the distribution of liquid assets in the EFF up to the very top percentiles. The Gini index of

[57]Mortgage debt is proxied by total household liabilities. This is reasonable since real estate debt accounts for more than 80% of total household debt in 2005 according to the EFF.

liquid assets in the model (0.85) is close to the data (0.78). Also, using the definition in Section 4.2, 25% of households are wealthy-hand-to mouth in the model, compared to 18% in the EFF.

G Sources of Difference in Recessions

Here we investigate which source contributes the most to the difference in recessions between the mortgage systems documented in Sections 5.3 and 6.2. We decompose the aggregate responses into the effects of the productivity and credit shocks. To do this, we calculate the equilibrium dynamics that occur when each shock hits the economy in isolation. Although the shocks are orthogonal, most equilibrium responses are highly non-linear and depend on a complex interaction between the shocks and the endogenous variables (house prices, unemployment, transfers). Therefore, in general, the sum of the decomposition components is not equal to the equilibrium responses that occur when all shocks hit the economy simultaneously.

G.1 The U.S. Model Economy

The first finding is that the productivity shock alone is not enough to generate a crisis of the magnitude of the Great Recession. In the non-recourse economy (U.S. model), the productivity shock generates a very small drop in house prices of 50 basis points, a drop in consumption and output of around 2% and 3% respectively, no disruption in the labor market (real wages fall by 2% with no significant effect on unemployment), and a very small effect (about 30 annual basis points) on the foreclosure rate. The result that productivity shocks alone cannot generate significant falls in house prices and consumption, or sharp increases in foreclosures, is also found in Garriga and Hedlund (2020), and Kaplan, Mitman and Violante (2020).

In the recourse economy of Section 5, the productivity shock triggers a very small fall in house prices of 40 basis points, a fall in consumption and output of roughly 2% and 3%, and essentially no effect on unemployment (real wages fall around 2%) and foreclosures. Therefore, the aggregate responses of both economies are similar if only productivity shocks are considered.

As opposed to the productivity shock, changes in credit conditions alone generate a sizable recession, with disruptions in both the housing market and real activity. In the non-recourse economy, house prices collapse by 36% at impact, consumption and output drop by 6% and 4% respectively, unemployment rises to 8%, and the default rate reaches 4.9% annual. The same credit shocks trigger a larger recession in the recourse economy: house prices fall by 46%, consumption and output fall by 15% and 12%, unemployment rises to 23%, and the foreclosure rate jumps to 4.3% annual. Summarizing, this exercise reveals that the deterioration in credit conditions is: (i) the main driver of the housing bust and severe recession, and (ii) the source of the difference in the equilibrium responses between the non-recourse and recourse economies.

G.2 The Model Economy for Spain

In the model for Spain, the productivity shock alone generates a very small fall in house prices of about 33 basis points, and virtually no effect on foreclosures. In terms of real activity, consumption and output fall by around 2% and 4% respectively, with no effect on unemployment. Contrary to the productivity shock, the credit shocks alone trigger a sizable recession in the model for Spain, characterized by disruptions in the housing market and the real economy. House prices collapse by 51%, consumption and output fall by 15% and 12% respectively, unemployment rises to 23%, and the foreclosure rate jumps from 0.4% to 4.0% annual. Therefore, this exercise confirms the findings in Section G.1.

H Decomposing Default Motives

Here we analyze the reasons why borrowers default in our model through the lens of prevailing theories of mortgage default.[58] The literature focuses on three theories: (i) default is triggered exclusively by negative equity, known as "strategic" default; (ii) default is driven exclusively by a negative life event (such as unemployment) that reduces cash flows or income available to make the mortgage payment, known as "cash-flow" default; and (iii) both negative equity and negative life events are necessary for default, known as "double-trigger" default.[59]

To distinguish between these theories in our model, we adopt the potential outcomes model of mortgage default proposed by Ganong and Noel (2022). Let T denote the occurrence of a negative cash flow or liquidity event (a "life event" in our model), and let G denote the status of having negative equity, that is, LTV $>$ 100%. The potential outcome function $D(T, G)$ represents the transition to default. Therefore, each household has four potential outcomes: $D(0,0)$, $D(1,0)$, $D(0,1)$, and $D(1,1)$. Within this framework: (i) "strategic" defaulters are those for whom negative equity is a necessary and sufficient condition ($D(0,1) = D(1,1) = 1$), but who would not default solely because of a liquidity event ($D(1,0) = 0$); (ii) "cash-flow" defaulters are those for whom negative liquidity events are a necessary and sufficient condition

[58]We focus on the non-recourse economy (U.S. parameterization).
[59]See Foote and Willen (2018) for a review of these mortgage default theories.

$(D(1,0) = D(1,1) = 1)$, but who would not default solely due to negative equity $(D(0,1) = 0)$; (iii) "double-trigger" defaulters are those for whom both negative equity and liquidity events are necessary $(D(1,1) = 1)$, but who would not default to a single trigger $(D(1,0) = D(0,1) = 0)$. Denote the shares of each type by ST, CF, and DT respectively. Under a couple of regularity assumptions, all underwater defaulters fall into one of these three types, $ST + CF + DT = 1$.[60]

We want to determine the share of underwater defaults driven by liquidity-based reasons. To do this, we perform a counterfactual exercise where we calculate the share of underwater defaults that would be eliminated in the absence of negative liquidity events $(T = 0)$,

$$\alpha_{\text{LE}} = \frac{\mathbb{E}\left[D(T,1)|G=1\right] - \mathbb{E}\left[D(0,1)|G=1\right]}{\mathbb{E}\left[D(T,1)|G=1\right]} = 1 - ST = CF + DT, \tag{50}$$

where the second equality follows because in the absence of negative liquidity events, there would be only strategic defaulters. Therefore, α_{LE} captures the share of defaults for which negative liquidity shocks are necessary (that is, cash-flow and double-trigger combined).

We can compute (50) directly because we can perform counterfactuals on the model. We simulate a cross-section of 1,000,000 households, initialized by sampling from the steady state distribution of the model. We track their state variables and decisions over time, and sample their idiosyncratic shocks from the corresponding probability distributions. We start the simulation four quarters before the recession shocks hit. We also verify that the cross-sectional moments of households over time are consistent with those discussed in the main text.

Consider a household entering period t with house h, mortgage debt m, liquid savings a, labor productivity z, depreciation δ, and employment status e. We focus on disposable income after taxes and transfers (and also after the labor supply decision), which equals $y_t(z,\ell)$ if the household is employed $(e = 1)$ or $T_t^U(z)$ if the household is unemployed $(e = 0)$, relative to the scheduled mortgage payment $x = (1-\lambda)m + r_t^M m$ plus the housing maintenance cost $p_t^H \delta h$,

$$\frac{Income_t}{Payment_t + Maintenance_t} = \frac{e y_t + (1-e)T_t^U}{x + p_t^H \delta h}. \tag{51}$$

Note that relative income is determined at the start of period t (given that labor supply decisions do not interact with other decisions conditional on not defaulting). We identify a negative liquidity event by looking at the within-borrower *change* in relative income, which directly affects the borrower's ability to pay mortgage and house-related commitments. Thus, an adverse

[60] See Ganong and Noel (2022) for the details. One assumption is that default requires at least one trigger, that is $D(0,0) = 0$ with probability one. In our model, defaults are virtually zero if we remove both negative liquidity events and negative equity. Later in this section we explain how we implement this counterfactual.

liquidity event may arise due to a transition to unemployment, a drop in labor productivity, or an increase in maintenance costs.[61] A fall in relative income could lead to default.

We calculate α_{LE} for each quarter of the first year of the crisis separately. To eliminate negative liquidity shocks, we proceed as follows. For each quarter t, we look at underwater borrowers (that is, with current LTV $>$ 100%) and we check whether: (i) the borrower is currently unemployed relative to one year ago, that is $e_t = 0$ and $e_{t-4} = 1$; (ii) its productivity is lower than a year ago, that is $z_t < z_{t-4}$; and (iii) if the current depreciation shock is higher than a year ago, that is $\delta_t > \delta_{t-4}$. If at least one condition is met, then we say that the borrower is facing a negative liquidity event, which we eliminate by adjusting its current individual state back to its value one year ago (for instance, $z_t = z_{t-4}$). We then use the household decision rules to determine the number of defaults in the counterfactual experiment, and thus α_{LE}.

Equipped with the calculation of α_{LE} for each quarter, we obtain the share of defaults that would be eliminated in the absence of adverse liquidity events in the first year of the crisis. We find that 87% of underwater defaults are due to negative liquidity shocks, so they can be categorized as "cash-flow" or "double-trigger", while 13% are "strategic". Moreover, if we focus on underwater borrowers with LTV $\leq$ 180% (thus still including substantial negative equity positions), we obtain that 96% of defaults are driven by negative liquidity shocks, and only 4% are strategic. In any case, we find that the vast majority of underwater defaults are triggered by a liquidity event, and that there is limited strategic default behavior.[62]

We also look at α_{LE} for different LTV groups. We find that adverse liquidity shocks are a necessary condition for 97% of defaults for borrowers with 100% $<$ LTV $\leq$ 140%, 91% for borrowers with 140% $<$ LTV $\leq$ 180%, and 33% for borrowers with LTV $\geq$ 180%. Therefore, strategic default has little prevalence until underwater borrowers are very deep to the right of the LTV distribution, consistent with previous results.

We also want to decompose the defaults for which the liquidity motive is a necessary condition, that is, differentiate between cash-flow and double-trigger defaults. To do this, we perform a counterfactual exercise similar to the previous one, where we calculate the share of underwater

[61] In our model, depreciation shocks affect borrowers only by tightening their current budget constraints, are completely transitory, and involve a maintenance cost that can be avoided entirely by defaulting.

[62] These results are very similar under different formulations, namely: (i) identifying a negative liquidity event by a drop in income relative to payment and maintenance (this requires conditioning on underwater borrowers who had a mortgage four quarters ago); (ii) the previous case but using labor earnings $Income_t = ey_t$ rather than disposable income; (iii) adjusting the current state back to its value one year before the start of the crisis; and (iv) using income plus available liquid savings a relative to payment and maintenance.

defaults that would be eliminated in the absence of negative equity ($G = 0$),

$$\alpha_{\text{NE}} = \frac{\mathbb{E}\left[D(T,1)|G=1\right] - \mathbb{E}\left[D(T,0)|G=1\right]}{\mathbb{E}\left[D(T,1)|G=1\right]} = 1 - CF = ST + DT, \tag{52}$$

where the second equality follows because without negative equity, there would be no strategic or double-trigger defaults, so there would be only cash-flow defaults.

We eliminate negative equity as follows. For each quarter t, we reassign underwater borrowers to an LTV of 100%. We do this by reducing the current mortgage balance m by the minimum amount such that the borrower becomes above water, that is, we look for the maximum $\tilde{m}$ in the grid for mortgage debt such that $\tilde{m} \leq p_t^H h$. We then use the household decision rules to determine the number of defaults in the counterfactual, and thus α_{NE}.

As before, armed with α_{NE} for each quarter, we get the share of defaults that would be eliminated in the absence of negative equity in the first year of the crisis. We find that 67% of the underwater defaults are caused entirely by the "cash-flow" motive. Combined with our previous calculation that 13% of defaults are strategic, we find that 20% of defaults are "double-trigger". Furthermore, if we focus on underwater borrowers with LTV $\leq$ 180%, we obtain that 75% of defaults are "cash-flow", which along our previous calculation that 4% of defaults are "strategic" for this group of borrowers, gives that 21% of defaults are "double-trigger". These results are largely consistent with the empirical findings in Ganong and Noel (2022).[63]

Summarizing, we find that the majority of underwater defaults are driven *exclusively* by negative liquidity events, but also a significant share are due to the *interaction* between adverse liquidity events and negative equity. In contrast, there is little prevalence of strategic default.

In Section 5.1 we documented the strong cross-sectional correlation between LTV and mortgage default in the steady state of the model. Underwater borrowers are more likely to default than above water borrowers. For example, in the quarter when the crisis shocks hit, their annualized default rates are 9.7% and 2.4%, respectively. This fact can be consistent with the low prevalence of strategic defaults. Ganong and Noel (2022) explain that this can happen either: (i) because underwater borrowers are more likely to face negative liquidity events; or (ii) because underwater borrowers are more likely to default conditional on a life event. Given our liquidity measure, our results indicate that both channels are at play.

We provide additional results to understand the finding of little strategic default. Our model predicts substantial income (relative to mortgage and house-related commitments) drops *at default* for above water and underwater borrowers with LTV $\leq$ 180%. During the first

[63] These authors estimate 70% for "cash flow", 24% for "double trigger", and 6% for "strategic".

year of the crisis (and conditional on households who had a mortgage four quarters before defaulting), relative income falls on average by 93% for above water defaulters, and by 81% for underwater defaulters with LTV $\leq$ 180%. Thus, these underwater borrowers experience similar negative liquidity events at default to above water defaulters, who do not have a strategic default motive. In addition, the model predicts little liquid savings a relative to commitments for these borrowers at default. Above water defaulters have savings of about one-sixth of their current commitments, while underwater defaulters with LTV $\leq$ 180% have about one-fourth.

In contrast, for defaulters with substantial negative equity (LTV $>$ 180%) the strategic motive dominates. They default without experiencing significant drops in relative income on average. Therefore, their default decisions are driven by negative equity rather than cash flow.

Tables Online Appendix

Table A1: Moments of the Earnings Process

Variable	Model	Target
Variance of annual log earnings	0.76	0.70
Variance of one year change	0.22	0.23
Variance of five year change	0.54	0.46
Kurtosis of one year change	13.1	17.8
Kurtosis of five year change	10.5	11.6
Fraction of one year change $< 10\%$	0.68	0.54
Fraction of one year change $< 20\%$	0.70	0.71
Fraction of one year change $< 50\%$	0.81	0.86

Note: Section 4.1.3 and the Appendix C.1 discuss the details. Changes are in log annual earnings. We use the quarterly earnings process from Kaplan, Moll and Violante (2018). The column "target" shows the data moments that these authors target in their earnings process estimation (see their Tables 3 and D.1). The data moments are from Guvenen et al. (2015). The column "model" shows our calculation of these moments.

Table A2: Unemployment Rate Change by Earnings Quintile: Data versus Model

	Earnings Quintile				
Variable	(1)	(2)	(3)	(4)	(5)
		Data			
Unemployment rate January (%)	5.62	4.40	2.80	2.23	2.18
Unemployment rate April (%)	26.0	17.8	13.5	7.42	5.34
Change (percentage points)	20.4	13.4	10.7	5.19	3.16
		Model			
Change (percentage points)	18.3	13.3	10.6	8.85	5.68

Note: The data source is the 2019-2020 Current Population Survey documented by Amburgey and Birinci (2020). The "change" row represents the difference in the unemployment rate between January and April 2020. The unemployment rate change in the model is between the steady state and upon impact. Between January and April 2020, the aggregate unemployment rate experienced an increase of 11.3 percentage points (from 3.5% to 14.8%). This is comparable to the increase of 10.3 percentage points in the recession experiment in Section 5.2.

Table A3: Steady State: Non-Recourse (U.S. Parameterization) versus Recourse

Variable	Non-Recourse	Recourse
Garnishment fraction on labor income and savings (ϕ)	0	0.3
Homeownership rate (%)	68.2	77.0
Ratio aggregate housing wealth to annual output	1.51	1.69
Ratio aggregate mortgage debt to annual output	0.65	0.76
Ratio aggregate liquid assets to annual output	0.24	0.25
Median LTV mortgagors (%)	56.2	56.2
% of mortgagors with LTV $\geq$ 70%	30.5	31.4
% of mortgagors with LTV $\geq$ 80%	12.5	15.2
% of mortgagors with LTV $\geq$ 90%	9.54	7.83
% of mortgagors with LTV $\geq$ 95%	3.93	5.05
Default rate (% annual)	1.18	0.62

Note: In both economies, the risk-free rate is 1% annual and house prices are normalized to one. LTV is loan-to-value. Section 5.1 discusses the details.

Figures Online Appendix

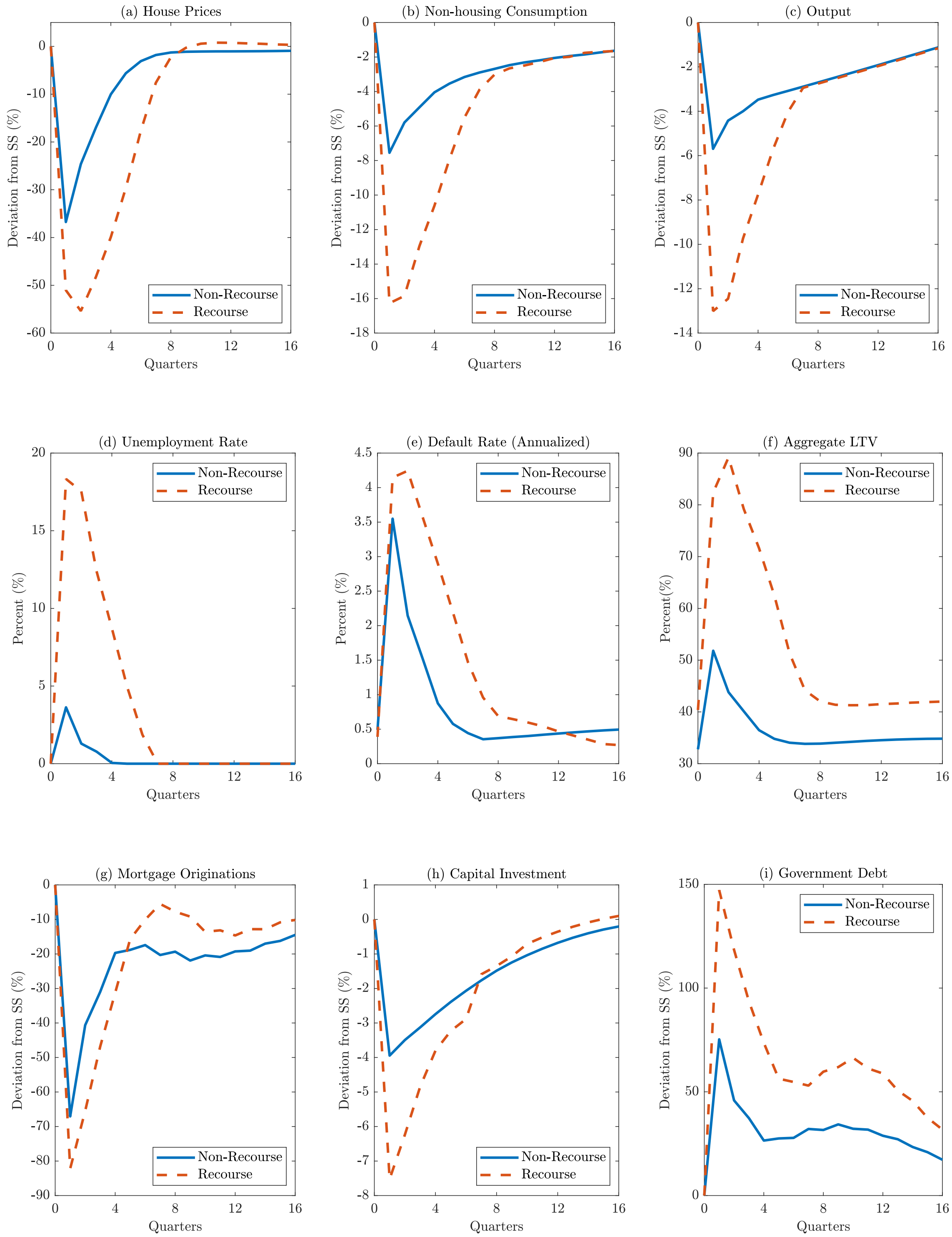

Figure A1: **Dynamics of Non-Recourse and Recourse Economies Following Unexpected Productivity and Credit Shocks.** The panels compare the equilibrium responses of the non-recourse and recourse (Spain) models. The non-recourse economy is generated by removing recourse mortgages from the model for Spain. Section 6.2 discusses the details.

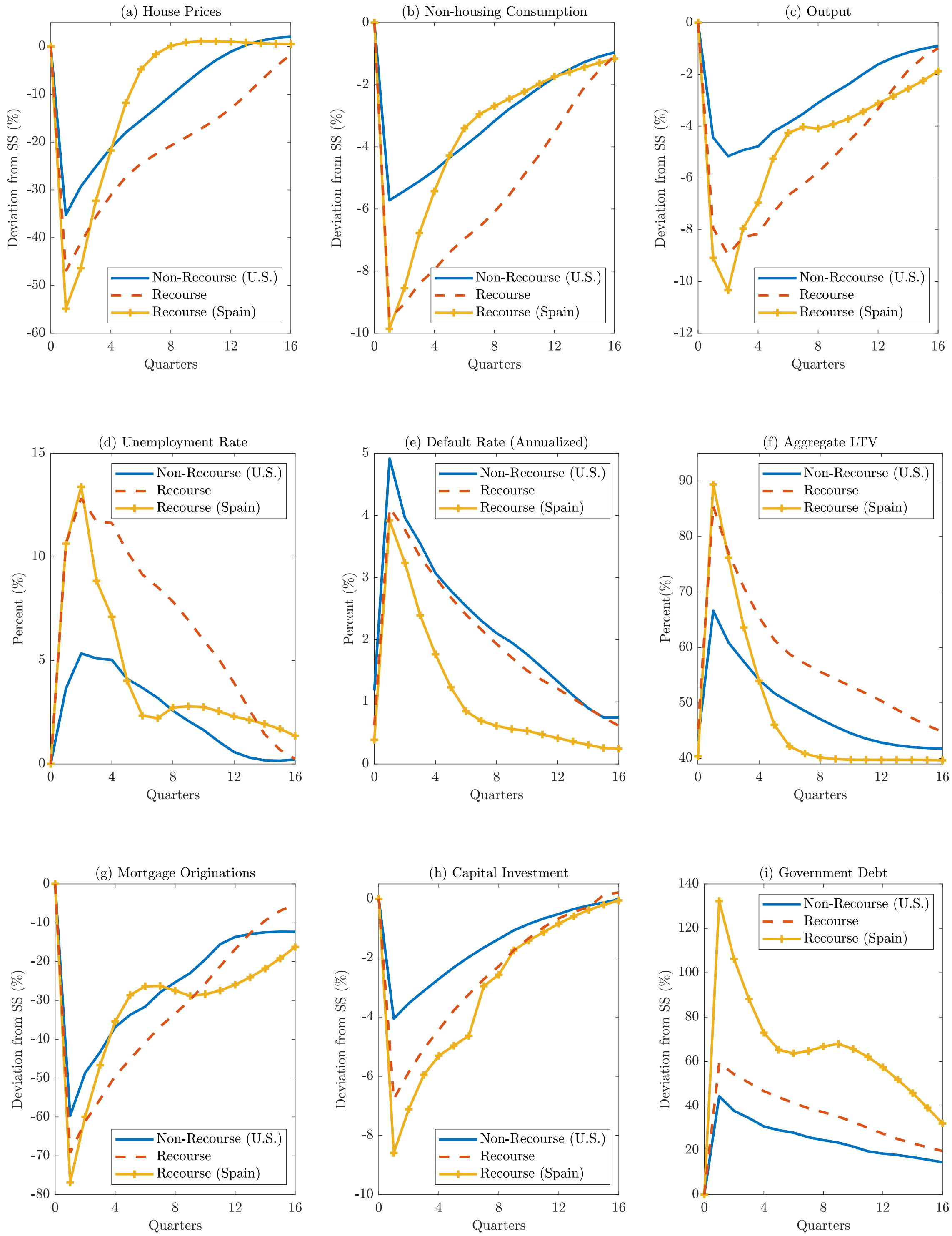

Figure A2: **Dynamics of Non-Recourse and Recourse Economies Following Unexpected Productivity and Credit Shocks.** The panels compare the equilibrium responses of the model economies for the U.S., recourse, and Spain to the exogenous crisis shocks. In all cases the government adjusts spending. Section 7.1 discusses the details.

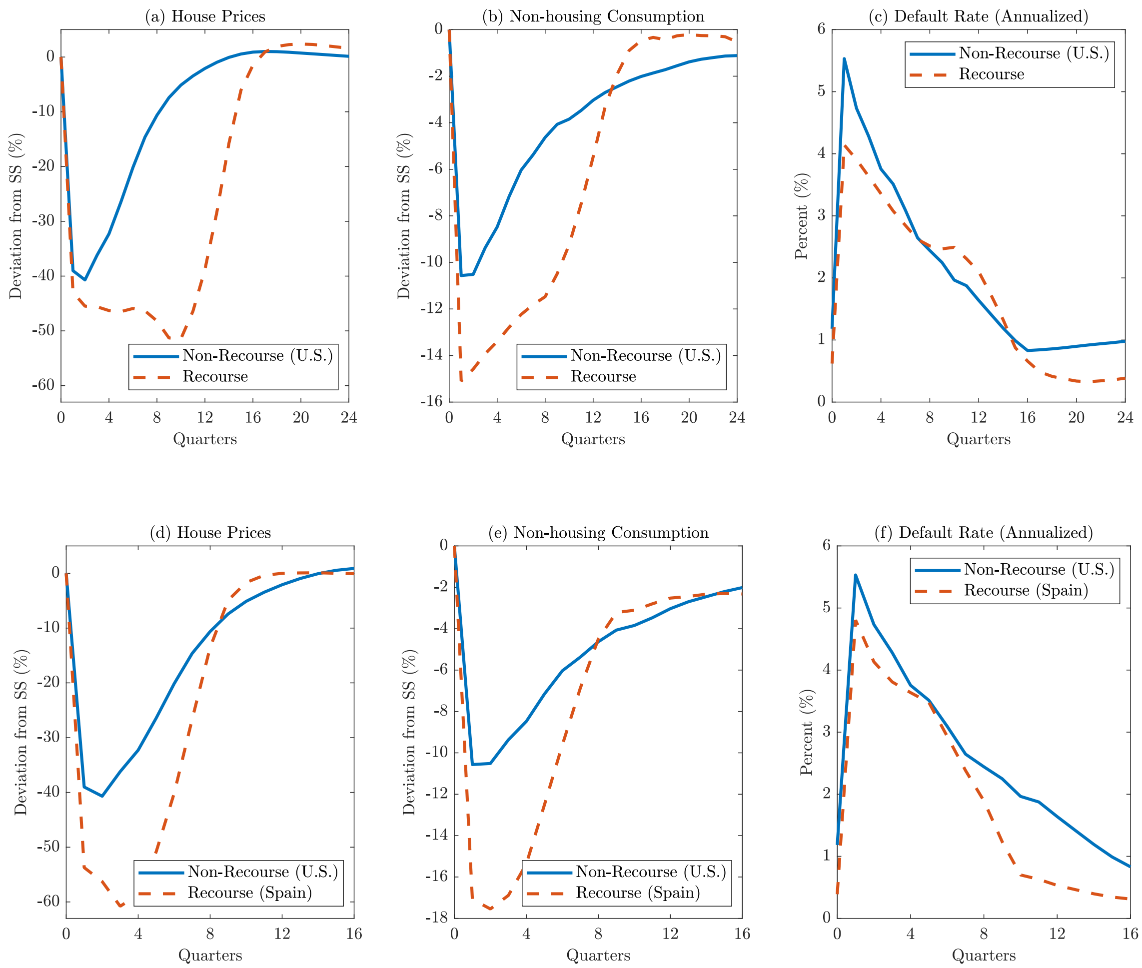

Figure A3: **Dynamics of Non-Recourse and Recourse Economies Following Unexpected Productivity and Credit Shocks.** The panels compare the equilibrium responses of the model economies for the U.S., recourse, and Spain to the exogenous crisis shocks. In all cases the lower bound on the nominal interest rate is binding. Section 7.2 discusses the details.