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Appendix For Online Publication

This Appendix is organized as follows. Section A describes all the household problems in their recursive formulation. Section B defines a recursive competitive equilibrium for our economy. Section Section C outlines the algorithms for the computation of the equilibrium. Section D provides more details on the models we solved in our robustness analysis. Section E describes the various data sources used in the paper. Section F contains some additional plots. Section G tests some cross-sectional implications of the model. Section H contains some additional results on alternative ways of modelling a credit relaxation.

A Household Problems

To lighten notation, let $\Upsilon_j(y)$ denote the distribution of y' conditional on y, thus embedding both the Markov transition for the idiosyncratic components (χ_j, ϵ_j) and the Markov transition for aggregate labor productivity Θ (recall that idiosyncratic and aggregate productivity uncertainty are independent). Let $\mathcal{Z}$ be the vector of exogenous states and μ denote the measure of households. Let $\Gamma_{\mathcal{Z}}$ denote the conditional distribution of the exogenous aggregate states and $\Gamma_\mu(\mu; \mathcal{Z}, \mathcal{Z}')$ be the equilibrium law of motion of the measure. Recall that we denote the full vector of aggregate states as $\Omega = (\mathcal{Z}, \mu)$. We begin by stating the problem of non-homeowners (renters and buyers). Next we state the problem of home-owners (sellers, keepers who repay, keepers who refinance, and households who default). Finally, we describe the problem of the retiree in its last period of life when the warm-glow bequest motive is active.

Renters and Buyers: Let $\mathbf{V}_j^n$ denote the value function of households who start the period without owning any housing. These households choose between being a renter and buying a house to become an owner by solving:

$$\mathbf{V}_j^n(b, y; \Omega) = \max\left\{V_j^r(b, y; \Omega), V_j^o(b, y; \Omega)\right\}, \tag{A1}$$

where we let $g_j^o(b, y; \Omega) \in \{0, 1\}$ denote the decision to own a house.

Those who choose to rent solve:

$$
\begin{aligned}
V_j^r(b, y; \Omega) = \max_{c,\tilde{h}',b'} & \ u_j(c, s) + \beta \mathbb{E}_{y,\mathcal{Z}} \left[\mathbf{V}_{j+1}^n(b', y'; \Omega') \right] \\
& s.t. \\
& c + \rho(\Omega)\, \tilde{h}' + q_b b' \leq b + y - \mathcal{T}(y, 0) \\
& b' \geq 0 \\
& s = \tilde{h}' \in \tilde{\mathcal{H}} \\
& y' \sim \Upsilon_j(y), \quad \mathcal{Z}' \sim \Gamma_{\mathcal{Z}}(\mathcal{Z}) \\
& \mu' = \Gamma_\mu(\mu; \mathcal{Z}, \mathcal{Z}')
\end{aligned}
\tag{A2}
$$

Let $\mathbf{x} \equiv (b, h, m)$ denote the household portfolio of assets and liabilities. Those who choose to buy and become owners solve:

$$
\begin{aligned}
V_j^o(b, y; \Omega) = \max_{c,b',h',m'} & \ u_j(c, s) + \beta \mathbb{E}_{y,\mathcal{Z}} \left[\mathbf{V}_{j+1}^h(\mathbf{x}', y'; \Omega') \right] \\
& s.t. \\
& c + q_b b' + p_h(\Omega)\, h' + \kappa^m \leq b + y - \mathcal{T}(y, 0) + q_j(\mathbf{x}', y; \Omega)\, m' \\
& m' \leq \lambda^m p_h(\Omega)\, h' \\
& \pi_j^{\min}(m') \leq \lambda^\pi \\
& b' \geq 0 \\
& h' \in \mathcal{H}, \quad s = \omega h' \\
& y' \sim \Upsilon_j(y), \quad \mathcal{Z}' \sim \Gamma_{\mathcal{Z}}(\mathcal{Z}) \\
& \mu' = \Gamma_\mu(\mu; \mathcal{Z}, \mathcal{Z}')
\end{aligned}
\tag{A3}
$$

where $\mathbf{V}^h(\cdot)$ is the value function of a household that starts off the next period as a homeowner which we describe below. The expression for the minimum required mortgage payment is in equation (7) in the main text.

Homeowners: A homeowner has the option to keep the house and make its mortgage payment, refinance the house, sell the house, or default. Obviously, this latter option can be optimal only if the household has some residual mortgage debt.

$$\mathbf{V}_j^h(\mathbf{x}, y; \Omega) = \max \left\{ \begin{array}{ll} \text{Pay:} & V_j^p(\mathbf{x}, y; \Omega) \\ \text{Refinance:} & V_j^f(\mathbf{x}, y; \Omega) \\ \text{Sell:} & \mathbf{V}_j^n(b^n, y; \Omega) \\ \text{Default:} & V_j^d(b, y; \Omega) \end{array} \right\}$$

It is convenient to denote the refinance decision by $g_j^f(\mathbf{x}, y; \Omega)$, the selling decision by $g_j^n(\mathbf{x}, y; \Omega)$, and the mortgage default decision by $g_j^d(\mathbf{x}, y; \Omega)$. All these decisions are dummy variables in $\{0, 1\}$ and it is implicit that, when they are all zeros, the homeowner chooses to make a payment on its mortgage during that period. We now describe all these four options one by one.

A household that chooses to make a mortgage payment solves:

$$\begin{aligned} V_j^p(\mathbf{x}, y; \Omega) = \max_{c, b', \pi} \; & u_j(c, s) + \beta \mathbb{E}_{y, \mathcal{Z}} \left[\mathbf{V}_{j+1}^h(\mathbf{x}', y'; \Omega') \right] \\ & s.t. \\ & c + q_b b' + (\delta_h + \tau_h) \, p_h(\Omega) \, h + \pi \leq b + y - \mathcal{T}(y, m) \\ & \pi \geq \pi_j^{\min}(m) \\ & m' = (1 + r_m) \, m - \pi \\ & b' \geq -\lambda^b p_h(\Omega) \, h \\ & s = \omega h, \quad h' = h \\ & y' \sim \Upsilon_j(y), \quad \mathcal{Z}' \sim \Gamma_{\mathcal{Z}}(\mathcal{Z}) \\ & \mu' = \Gamma_\mu(\mu; \mathcal{Z}, \mathcal{Z}') \end{aligned} \tag{A4}$$

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An homeowner who chooses to refinance its mortgage solves the following problem:

$$
\begin{aligned}
V_j^f(\mathbf{x}, y; \Omega) = \max_{c,b',m'} & \ u_j(c,s) + \beta \mathbb{E}_{y,\mathcal{Z}}\left[\mathbf{V}_{j+1}^h(\mathbf{x}', y'; \Omega')\right] \\
& s.t. \\
& c_j + q_b b' + (\delta_h + \tau_h)\, p_h(\Omega)\, h + (1 + r_m)\, m + \kappa^m \\
& \quad \leq b + y - \mathcal{T}(y, m) + q_j(\mathbf{x}', y; \Omega)\, m' \\
& m' \leq \lambda^m p_h(\Omega)\, h \\
& \pi_j^{\min}(m') \leq \lambda^\pi y \\
& b' \geq -\lambda^b p_h(\Omega)\, h \\
& s = \omega h, \quad h' = h \\
& y' \sim \Upsilon_j(y), \quad \mathcal{Z}' \sim \Gamma_{\mathcal{Z}}(\mathcal{Z}) \\
& \mu' = \Gamma_\mu(\mu; \mathcal{Z}, \mathcal{Z}')
\end{aligned}
\tag{A5}
$$

A homeowner that chooses to sell its home solves the problem as if it started the period without any housing, i.e., with value function $\mathbf{V}_j^n$ given by ($A1$) with financial assets equal to its previous holdings b plus the net-of-costs proceeds from the sale of the home, i.e.

$$
b^n = b + (1 - \delta_h - \tau_h - \kappa_h)\, p_h(\Omega)\, h - (1 + r_m)\, m \tag{A6}
$$

The timing ensures that a household can sell and buy a new home within the period.

Finally, a household that defaults on its mortgage incurs a utility penalty ξ and must rent for a period, thus solving (A2). Only in the following period the household can become a home-owner again.

Bequest: In the last period of life, $j = J$, the warm-glow inheritance motive, apparent from the preference specification in (1), induces households to leave a bequest. For example,

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a retired homeowner of age J (who does not sell its house in this last period) would solve:

$$
\begin{aligned}
V_J^p(\mathbf{x}, y; \Omega) = \max_{c,b'} \, & u_J(c, s) + \beta v\left(\flat\right) \\
& s.t. \\
& c + q_b b' + (1 + r_m)\, m \leq b + y - \mathcal{T}\left(y, 0\right) \\
& \flat = b' + (1 - \delta_h - \tau_h - \kappa_h)\, \mathbb{E}_{\mathcal{Z}}\left[p_h\left(\Omega'\right)\right] h \\
& b' \geq 0 \\
& s = \omega h \\
& \mathcal{Z}' \sim \Gamma_{\mathcal{Z}}\left(\mathcal{Z}\right) \\
& \mu' = \Gamma_\mu\left(\mu; \mathcal{Z}, \mathcal{Z}'\right)
\end{aligned}
\tag{A7}
$$

In other words, in the last period of life households pay off their residual mortgage and HELOC and orders the house to be liquidated at the beginning of next period. Therefore, bequeathers take into account that their residual housing wealth contributes to bequests only as the expected net-of-costs proceedings from the sale.

B Equilibrium

To ease notation, in the definition of equilibrium we denote the vector of individual states for homeowners and non-homeowners as $\mathbf{x}^h := (b, h, m, y) \in \mathbb{X}^h$ and $\mathbf{x}^n := (b, y) \in \mathbb{X}^n$. Also, let μ_j^h and μ_j^n be the measure of these two types of households at age j, with $\sum_{j=1}^{J} \left(\mu_j^h + \mu_j^n\right) = 1$. As before, we denote compactly $\Omega = (\mathcal{Z}, \mu)$.

A *recursive competitive equilibrium* consists of value functions $\left\{\mathbf{V}_j^n\left(\mathbf{x}^n;\Omega\right), V_j^r\left(\mathbf{x}^n;\Omega\right), V_j^o\left(\mathbf{x}^n;\Omega\right), \mathbf{V}_j^h\left(\mathbf{x}^h;\Omega\right), V_j^p\left(\mathbf{x}^h;\Omega\right), V_j^f\left(\mathbf{x}^h;\Omega\right), V_j^d\left(\mathbf{x}^n;\Omega\right)\right\}$, decision rules $\Big\{g_j^o\left(\mathbf{x}^n;\Omega\right), g_j^n\left(\mathbf{x}^h;\Omega\right), g_j^f\left(\mathbf{x}^h;\Omega\right), g_j^d\left(\mathbf{x}^h;\Omega\right), c_j^h\left(\mathbf{x}^h;\Omega\right), c_j^n\left(\mathbf{x}^n;\Omega\right),$ $b_{j+1}^h\left(\mathbf{x}^h;\Omega\right), b_{j+1}^n\left(\mathbf{x}^n;\Omega\right), \tilde{h}_j\left(\mathbf{x}^n;\Omega\right), h_{j+1}\left(\mathbf{x}^n;\Omega\right), m_{j+1}\left(\mathbf{x}^n;\Omega\right), m_{j+1}^f\left(\mathbf{x}^h;\Omega\right)\Big\}$, a rental function $\rho\left(\Omega\right)$, house price function $p_h\left(\Omega\right)$, mortgage price function $q_j(\mathbf{x}_{j+1}^h;\Omega)$, aggregate functions for construction labor, rental units stock, property housing stock, housing investment, and government expenditures $\left\{N_h\left(\Omega\right), \tilde{H}\left(\Omega\right), H\left(\Omega\right), I_h\left(\Omega\right), G\left(\Omega\right)\right\}$, and a law of motion for the aggregate states Γ such that:

1. Household optimize, by solving problems (A1)-(A7), with associated value functions $\left\{\mathbf{V}_j^n, V_j^r, V_j^o, \mathbf{V}_j^h, V_j^p, V_j^f, V_j^d\right\}$ and decision rules $\left\{g_j^o, g_j^n, g_j^f, g_j^d, c_j^h, c_j^n, b_{j+1}^h, b_{j+1}^n, \tilde{h}_j, h_{j+1}, m_{j+1}, m_{j+1}^f\right\}$.

2. Firms in the construction sector maximize profits, by solving (13), with associated labor demand and housing investment functions $\left\{N_h\left(\Omega\right), I_h\left(\Omega\right)\right\}$.

3. The labor market clears at the wage rate $w = \Theta$, and labor demand in the final good sector is determined residually as $N_c\left(\Omega\right) = 1 - N_h\left(\Omega\right)$.

4. The financial intermediation market clears loan-by-loan with pricing function $q_j(\mathbf{x}_{j+1}^h;\Omega)$ determined by condition (10).

5. The rental market clears at price $\rho\left(\Omega\right)$ given by (11), and the equilibrium quantity of rental units satisfies:

$$\begin{aligned}\tilde{H}'\left(\Omega\right) &= \sum_{j=1}^{J}\Bigg[\int_{\mathbb{X}^h}\tilde{h}_j\left(b_j^n\left(\mathbf{x}^h;\Omega\right), y;\Omega\right)\left[1 - g_j^o\left(b_j^n\left(\mathbf{x}^h;\Omega\right), y;\Omega\right)\right]g_j^n\left(\mathbf{x}^h;\Omega\right)d\mu_j^h \\ &\quad + \int_{\mathbb{X}^h}\tilde{h}_j\left(\mathbf{x}^n;\Omega\right)g_j^d\left(\mathbf{x}^h;\Omega\right)d\mu_j^h + \int_{\mathbb{X}^n}\tilde{h}_j\left(\mathbf{x}^n;\Omega\right)\left[1 - g_j^o\left(\mathbf{x}^n;\Omega\right)\right]d\mu_j^n\Bigg]\end{aligned}$$

where the LHS is the total supply of rental units and the RHS is the demand of rental units by households who sell and become renters, households who default on their mortgage and must rent in that period, plus renters who stay renters. The function $b_j^n\left(\mathbf{x}^h;\Omega\right)$ represents the financial wealth of the seller, after the transaction, see equation (A6).

6. The housing market clears at price $p_h(\Omega)$ and the equilibrium quantity of housing, measured at the end of the period after all decisions are made, satisfies:

$$\begin{aligned}
& I_h(\Omega)-\delta_h H(\Omega)+\sum_{j=1}^{J}\left[\int_{\mathbb{X}^h} h_j\left[g_j^n\left(\mathbf{x}^h;\Omega\right)+\left(1-\left(\delta_h^d-\delta_h\right)\right)g_j^d\left(\mathbf{x}^h;\Omega\right)\right]d\mu_j^h\right] \\
& \qquad +\int_{\mathbb{X}^h} h_{J+1}\left(\mathbf{x}^h;\Omega\right)d\mu_J^h \\
& \quad = \left[\tilde{H}'(\Omega)-(1-\delta_h)\tilde{H}(\Omega)\right]+\sum_{j=1}^{J}\int_{\mathbb{X}^n} h_{j+1}\left(\mathbf{x}^n;\Omega\right)g_j^o\left(\mathbf{x}^n;\Omega\right)d\mu_j^n
\end{aligned}$$

The left-hand side represents the inflow of houses on the owner occupied market market, equal to the addition to the housing stock from the construction sector net of depreciation, plus sales of houses by owners and sales of foreclosed properties by financial intermediaries and houses sold on the market when the wills of the deceased are executed. The right-hand side combines outflows, equal to the owner-occupied houses purchased by the rental company and by new buyers.

7. The final good market clears:

$$\begin{aligned}
Y(\Omega) \;=\; & \sum_{j=1}^{J}\Bigg\{\int_{\mathbb{X}^h} c_j^h\left(\mathbf{x}^h;\Omega\right)d\mu_j^h+\int_{\mathbb{X}^n} c_j^n\left(\mathbf{x}^n;\Omega\right)d\mu_j^n \qquad \text{(B1)}\\
& +\kappa_h p_h(\Omega)\int_{\mathbb{X}^h} h_j\left[g_j^n\left(\mathbf{x}^h;\Omega\right)+g_j^d\left(\mathbf{x}^h;\Omega\right)d\right]d\mu_j^h \\
& +\left(\zeta^m+\kappa^m\right)\left[\int_{\mathbb{X}^n} m_{j+1}\left(\mathbf{x}^n;\Omega\right)g_j^o\left(\mathbf{x}^n;\Omega\right)d\mu_j^n+\int_{\mathbb{X}^h} m_{j+1}^f\left(\mathbf{x}^h;\Omega\right)g_j^f\left(\mathbf{x}_j^h;\Omega\right)d\mu_j^h\right] \\
& +\iota r^b\int_{\mathbb{X}^h}\left(m_j+b_j\cdot\mathbb{I}_{\{b<0\}}\right)d\mu_j^h\Bigg\} \\
& +\kappa_h h_{J+1}\left(\mathbf{x}^h;\Omega\right)d\mu_J^h+\psi\tilde{H}'(\Omega)+G(\Omega)+NX
\end{aligned}$$

where the first two terms on the RHS are expenditures in nondurable consumption of owners and renters, the terms in the second line are transaction fees on sales (including foreclosures), the terms on the third line are mortgage origination and refinancing costs, the fourth line represents flow intermediation costs on all mortgage and HELOC credit, and the last line includes transaction fees on sales from executed wills, operating costs of

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the rental company, government expenditures on the numeraire good, and net exports NX that are the counterpart of outflows of profits/losses of the financial and rental sector to their foreign owners.

Given the normalization that the aggregate efficiency units of labor equal 1, aggregate output is given by $Y(\Omega) = \Theta$.

8. The government budget constraint holds, with expenditures $G(\Omega)$ adjusting residually to absorb shocks:

$$\begin{aligned} G(\Omega) + \left(\frac{J - J^{ret} + 1}{J}\right) \int_{\mathbb{Y}^{ret}} y^{ret}\left(\epsilon_{J^{ret}}\right) d\Upsilon_{J^{ret}} = & \left[p_h(\Omega) I_h(\Omega) - \Theta N_h(\Omega)\right] \\ & + \sum_{j=1}^{J} \left[\int_{\mathbb{X}^h} \mathcal{T}(y, m)\, d\mu_j^h + \int_{\mathbb{X}^n} \mathcal{T}(y, 0)\, d\mu_j^n\right] \\ & + \tau_h p_h H(\Omega) \end{aligned} \tag{B2}$$

where expenditures on goods and pension payments (the LHS) are financed by revenues from selling new licences to developers, income taxes net of mortgage interest deductions (second line), and property taxes (third line).

9. The aggregate law of motion of the measure Γ_μ is induced by the exogenous stochastic processes for idiosyncratic and aggregate risk as well as all the decision rules and, as a result, it is consistent with individual behavior.

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C Numerical Computation

This section is organized as follows. We start by outlining the computation strategy to approximate the stochastic equilibrium. Next, we provide some measures of accuracy. Finally, we describe how we run the specific simulation corresponding to the boom-bust.

C.1 Strategy to Approximate the Stochastic Equilibrium

Reducing the state space To understand how we simplify the problem, consider for example the dynamic problem of renters which we rewrite here as

$$\begin{aligned} V_j^r(b, y; \mu, \mathcal{Z}) = &\max_{c,\tilde{h}',b'} u_j(c, s) + \beta \mathbb{E}_{y,\mathcal{Z}} \left[\mathbf{V}_{j+1}^n(b', y'; \mu', \mathcal{Z}') \right] \\ &s.t. \\ &c + \rho(\Omega) \tilde{h}' + q_b b' \leq b + y - \mathcal{T}(y, 0) \\ &b' \geq 0 \\ &s = \tilde{h}' \in \tilde{\mathcal{H}} \\ &y' \sim \Upsilon_j(y), \quad \mathcal{Z}' \sim \Gamma_{\mathcal{Z}}(\mathcal{Z}) \\ &\mu' = \Gamma_\mu(\mu; \mathcal{Z}, \mathcal{Z}') \end{aligned} \tag{C1}$$

to make the dependence of the value function on μ explicit. This is an infinite dimensional problem because of the presence of μ as an argument of values and is not solvable. The approximate problem we solve is

$$\begin{aligned} V_j^r(b, y; p_h, \mathcal{Z}) = &\max_{c,\tilde{h}',b'} u_j(c, s) + \beta \mathbb{E}_{y,\mathcal{Z}} \left[\mathbf{V}_{j+1}^n(b', y'; p_h', \mathcal{Z}') \right] \\ &s.t. \\ &c + \rho(p_h, \mathcal{Z}) \tilde{h}' + q_b b' \leq b + y - \mathcal{T}(y, 0) \\ &b' \geq 0 \\ &s = \tilde{h}' \in \tilde{\mathcal{H}} \\ &y' \sim \Upsilon_j(y), \quad \mathcal{Z}' \sim \Gamma_{\mathcal{Z}}(\mathcal{Z}) \\ &p_h' = \Gamma_{p_h}(p_h; \mathcal{Z}, \mathcal{Z}') \end{aligned} \tag{C2}$$

which differs from ($C1$) because, instead of keeping tack of the distribution μ, we keep track of the variable p_h, with conditional law of motion Γ_{p_h} specified as in (14). Given Γ_{p_h}, one can compute the rental ρ from the optimality condition of the rental company, which we can restate as:

$$\rho\left(p_h, \mathcal{Z}\right) = \psi + p_h - \left(\frac{1-\delta_h-\tau_h}{1+r_b}\right)\mathbb{E}_{\mathcal{Z}}\left[\Gamma_{p_h}(p_h;\mathcal{Z},\mathcal{Z}')\right]$$

The other household problems are simplified in a similar way.

Solving the household problems The household value and policy functions are solved via backward induction starting with the final period of life. In order to solve the model, we discretize $\mathbb{X}^h$ and $\mathbb{X}^n$ by fixing grids on income Y (7 points), house sizes $\mathcal{H}$ (6 points), mortgages $\mathcal{M}$ (21 points) and liquid assets $\mathcal{B}$ (26 points). We also set a grid for the house price p_h (13 points). Household mortgage choice when purchasing or refinancing a mortgage is restricted to be on $\mathcal{M}$. However, when following the amortization schedule, the next period mortgage balance is computed via linear interpolation between grid points. Conditional on the mortgage and housing choice, we eliminate consumption via the budget constraint and then solve for the optimal level of liquid assets where we linearly interpolate to allow for choices off the grid.[42]

Updating the law of motion With the policy functions in hand, in order to simulate the model we fix distributions of owners $\mu_0^h \in \hat{\mathcal{B}}\times\mathcal{H}\times\hat{\mathcal{M}}\times Y\times J$ and $\mu_0^n \in \hat{\mathcal{B}}\times Y\times J$ space. We allow the 'hat' distribution over mortgages and liquid assets to be finer (by a factor of 3) than the grids over which we solved for the policy functions. We fix a long time series for the realization of the aggregate shocks, $\mathcal{Z}$. Using the realization $\mathcal{Z}_t$ and μ_t^h, μ_t^n, we can compute the excess demand for housing for each value in the grid over p_h. We linearly interpolate the excess demand function to solve for $p_{h,t}$ that clears the housing market within the period. To compute the update to the distributions, μ_{t+1}^h, μ_{t+1}^n we interpolate the intermediate value functions A2-A5 to determine the optimal discrete choice, and then interpolate the associated policy function.[43] We then apply the policy functions and the Markov transition matrix for y to the measures at date t.

We assume that the law of motion for the house price, $\Gamma_{p_h}(p_h;\mathcal{Z},\mathcal{Z}')$, takes the following form:

$$\log(\bar{p}_{h,t+1}) \quad = \quad a_0(\mathcal{Z}_t,\mathcal{Z}_{t+1}) + a_1(\mathcal{Z}_t,\mathcal{Z}_{t+1})\log(\bar{p}_{h,t}).$$

Since $\#\mathcal{Z}$=12 (2 values for aggregate productivity, 2 for credit conditions, and 3 for beliefs), we effectively have $(\#\mathcal{Z})^2 = 144$ forecasting equations that need to be estimated. We start

[42] For the case where a household is making a mortgage payment we use bilinear interpolation over the mortgage balance and liquid asset position.

[43] In the case the household buys a home we explicitly solve for the optimal house size constrained to be in $\mathcal{H}$.

off with initial guesses for the coefficients a_0 and a_1, solve the household problem, then simulate the economy. This generates a time series $\{p_{h,t}, \mathcal{Z}_t\}_{t=0}^{T}$. We update our forecasting equation by computing the associated regression on the model generated time series and check whether the regression coefficients are consistent with our guesses, a_0, a_1. If they are, we have found the law of motion; if not, we update our guesses and repeat until convergence.

C.2 Numerical Accuracy

Despite only using the house price and exogenous aggregate states to forecast the aggregate law of motion the R^2 for the forecasting regressions are in excess of 0.9997. While reassuring, as Den Haan (2010) has pointed out, the accuracy of the numerical solution could still be poor, despite having large R^2 values for the forecasting regressions. He suggests simulation of the aggregate endogenous state under the forecast rule and comparing it with the aggregate endogenous state that is calculated by aggregating across the distribution. We run many simulations for 1,000 time periods. The average one-period ahead forecast error between the implied law of motion from the forecast equations and the computed law of motion 0.08% with a maximal error of 0.71%. Even very long forecasts are very accurate: the average error 1,000 periods (2,000 years) ahead is 0.2%, with a maximum error of 1.9%.

C.3 Simulation of Boom-Bust

For the simulation of the Boom-Bust we start off by running the economy for 100 periods where we keep the credit conditions in the low state and the belief shock at ϕ_L, but allow for productivity to fluctuate. We save the pre-boom distribution (when all shocks are in the low state). Then, we simulate the boom-bust by first changing from the low productivity to the high productivity state. In the subsequent model period, we switch from the low credit condition to the high credit condition state. Then, in the subsequent model period we switch from ϕ_L to ϕ_L^*. After three periods all shocks then revert to the low state and remain there for five periods (10 years). For each of the decompositions we initialize the economy with the pre-boom distribution and then turn on the relevant shock with the same timing as in the benchmark experiment.

		Smallest → Largest						
		1	2	3	4	5	6	7
Baseline	O		•	•	•	•	•	•
	R	•	•	•				
No Segmentation	O	•	•	•	•	•	•	•
	R	•	•	•	•	•	•	•
Partial Segmentation 1	O		•	•	•	•	•	•
	R	•	•					
Partial Segmentation 2	O			•	•	•	•	•
	R	•	•	•				
Full Segmentation	O				•	•	•	•
	R	•	•	•				

Table D1: Overlap of owner-occupied and rental house sizes in various versions of the model. O means that house size can be owned, R means that house size can be rented. These seven classes correspond, respectively, to $1.17, 1.50, 1.92, 2.46, 3.15, 4.03, 5.15$ units of housing.

D Alternative Models

In this Appendix we provide more details on some of the experiments with the alternative models described in Sections 5.3 and 5.4.

D.1 Segmentation of Rental and Property Housing Markets

In section 5.3.1 we discussed our results under various assumptions about the degree of overlap between types (sizes) of rental and owner-occupied units. Table illustrates the nature of the segmentation under these alternative assumptions. We note here that the home ownership rate changes slightly in these experiments, it changes to 69% under No Segmentation, 68% under Partial Segmentation 1 and 63% under Partial Segmentation 2. Under Full Segmentation, absent recalibration, the home ownership rate would fall to 55%. As such, we introduce an additive utility benefit of home ownership to the model to match the benchmark ownership rate of 67%.

D.2 Generalizing the Problem of the Rental Sector

In this appendix we derive the user-cost formulas for the rent-price ratio in equations (11) and (15). We lay out a general problem for the rental company of which the baseline model of Section 2.4 is a special case. We write the problem in recursive form, as for the rest of the model. Recall that Ω summarizes the vector of exogenous and endogenous aggregate states.

The rental company is owned by individual households and its decisions are based on an

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aggregate stochastic discount factor $m(\Omega, \Omega')$ determined by some assignment of property rights across households. We maintain generality and do not specify such assignment or how it evolves over time. Let H be the total stock of housing units owned by the rental company and let h is the number of new units purchased. Let X be the number of housing units owned by the rental company that are rented out and let x be the number of new rental housing units that are added/subtracted to the stock. We assume that the rental company faces a linear operation cost on rental units as well as quadratic adjustment costs $\kappa(x) = \frac{\kappa_x}{2}x^2$ in converting housing units to rent-ready units and vice-versa. We allow κ to vary over time, and thus to be part of Ω. The rental company can borrow to finance purchases of housing subject to a net worth constraint. Let B be the amount of one-period non-defaultable debt owed by the company that must be repaid at gross interest rate $R = 1 + r$ in the following period.[44] Finally, the rental company faces a non-negative dividend constraint, i.e. it cannot receive equity injection from its shareholders. Combining these assumptions, the problem of the rental company becomes:

$$
\begin{aligned}
J(H, X, B; \Omega) = \max_{d,h,x,B'} \; & d + \mathbb{E}_{\Omega}\left[m(\Omega, \Omega') J(H', X', B'; \Omega')\right] \\
& \text{subject to} \\
& d = [\rho(\Omega) - \psi] X' + B' - p_h(\Omega) h - \tau_h p_h(\Omega) H - \kappa_x(x) - RB \geq 0 \\
& H' = (1 - \delta_h) H + h \\
& X' = (1 - \delta_h) X + x \\
& B' \leq \lambda^{\rho} p_h(\Omega) H' \\
& X' \leq H'
\end{aligned}
$$

The individual state variables are the total number of housing units owned by the company H, the number of rent-ready housing units X and the amount of debt outstanding B. As usual, Ω summarizes the vector of aggregate states.

The first equation is the definition of dividends, i.e. revenues which include net rental income $(\rho(\Omega) - \psi) X'$ and new debt issuance B' minus costs which include purchases of new houses $p_h(\Omega) h$ (sales if $h < 0$), property taxes $\tau_h p_h(\Omega) H$, costs of conversion to/from rental properties $\kappa(x)$, and repayment of outstanding debt RB. This equation states dividends cannot be negative. The second constraint is the accumulation equation for housing units, which says that next period housing units owned by rental company, H', are the units from last period net of depreciation plus new purchases. The third constraint is the accumulation

[44] We allow for B to be negative in which case the rental company would be saving possibly to overcome future collateral constraints. Thus $r = r_b$ when $B < 0$ and $r = r_b(1 + \iota) > r_b$ when $B > 0$. In what follows, we ignore the case where $B = 0$ is optimal, but none of our conclusions depend on it.

equation for rental units, which says that next period rent-ready units, X', equals rental units from last period net of depreciation plus new conversions. The fourth constraint is the borrowing constraint, which says that new debt issuances must be less than a fraction λ^{ρ} —possibly varying stochastically together with the other credit condition parameters— of the value of the rental company's assets $p(\Omega)H$. The fifth constraint is the rental conversion constraint, which says that the number of units rented out to households cannot be larger than the number of housing units owned by the rental company.

Substituting the laws of motion for H and X in the value function and attaching Lagrange multipliers (μ_d, μ_b, μ_x) to the three constraints, the problem of the rental company becomes:

$$
\begin{aligned}
&J(H,X,B;\Omega) = \max_{H',X',B'} [\rho(\Omega)-\psi]X' + B' - p(\Omega)[H'-(1-\delta_h)H] - \tau_h p_h(\Omega)H \\
&- \frac{\kappa_x}{2}[X'-(1-\delta_h)X]^2 - RB + \mathbb{E}_{\Omega}[m(\Omega,\Omega')J(H',X',B';\Omega')] \\
&+ \mu_d\left\{[\rho(\Omega)-\psi]X' + B' - p_h(\Omega)[H'-(1-\delta_h)H] - \tau_h p_h(\Omega)H - \frac{\kappa_x}{2}[X'-(1-\delta)X]^2 - RB\right\} \\
&+ \mu_b[\lambda^{\rho} p_h(\Omega)H' - B'] \\
&+ \mu_x[H'-X']
\end{aligned}
$$

Rearranging the first-order and envelope conditions of this Lagrangian, we arrive at the following two optimality conditions for the rental company:

$$
R\mathbb{E}_{\Omega}\left[m(\Omega,\Omega')\left(\tfrac{1+\mu_d'}{1+\mu_d}\right)\right] = 1 - \tfrac{\mu_b}{1+\mu_d} \tag{D1}
$$

$$
\begin{aligned}
\rho(\Omega) = \psi + p_h(\Omega) - p_h(\Omega)\left(\tfrac{\lambda^{\rho}\mu_b}{1+\mu_d}\right) - (1-\delta_h-\tau_h)\mathbb{E}_{\Omega}\left[m(\Omega,\Omega')\left(\tfrac{1+\mu_d'}{1+\mu_d}\right)p_h(\Omega')\right] \\
- (1-\delta_h)\mathbb{E}_{\Omega}\left[m(\Omega,\Omega')\left(\tfrac{1+\mu_d'}{1+\mu_d}\right)\kappa_x' x'\right] + \kappa_x x
\end{aligned} \tag{D2}
$$

The first condition links the rental company stochastic discount factor to the multipliers on the dividend and collateral constraints. If neither one binds ($\mu_d = \mu_b = 0$), we obtain the standard asset price equation linking the risky asset (shares of the rental company) to the risk free rate.

The second condition can be rearranged as:

$$
\rho(\Omega) = \psi + p_h(\Omega) - (1-\delta_h-\tau_h)\mathbb{E}_{\Omega}[\mathfrak{m}(\Omega,\Omega')\cdot p_h(\Omega')] - p_h(\Omega)\eta(\Omega) + \zeta(\Omega), \tag{D3}
$$

where we have defined

$$\mathfrak{m}(\Omega,\Omega') = m(\Omega,\Omega')\left(\frac{1+\mu_d'}{1+\mu_d}\right) \tag{D4}$$

$$\eta(\Omega) = \frac{\lambda^\rho \mu_b}{1+\mu_d} \tag{D5}$$

$$\zeta(\Omega) = \kappa_x x - (1-\delta_h)\,\mathbb{E}_\Omega\left[\mathfrak{m}(\Omega,\Omega')\cdot \kappa_x' x'\right] \tag{D6}$$

Equation (D3) —or equation (15) in the main text— establishes a standard 'Jorgensonian' relationship between equilibrium rent and current and future equilibrium house prices. Consider first the case where there is no financial friction ($\mu_d = \mu_b = 0$) and no convertibility cost ($\kappa_x = 0$). If we also assume that the owners of the rental company are deep-pocketed and hence effectively risk neutral individuals, then combining (D3) with (D4) and (D1), we obtain $\mathfrak{m}(\Omega,\Omega') = \frac{1}{1+r_b}$. In this case, the rent-price user cost condition becomes the one in the baseline, equation (11).

More in general, equation (D3) illustrates that a number of factors, besides shifts in expectations, can cause fluctuations in the rent-price ratio. The first is movements in the households' stochastic discount factor aggregator m due to changes in aggregate economic conditions, including tighter or looser household credit. For example, tighter household credit would strengthen the negative covariance between m and p_h' and increase the rent-price ratio. The second is shocks to the collateral parameter λ^ρ that directly affect the problem of the rental company. Tighter credit conditions for the rental company impede its ability to convert owner-occupied into rental units when households desire to switch from owning to renting and thus, increase the rent-price ratio. Third, and similarly, a negative shocks to convertibility which raises the value of κ_x can affect the rent-price ratio. Finally, endogenous fluctuations in the multipliers μ_d and μ_b on the dividend and collateral constraints induced by each of the aggregate shocks in the economy have the ability of moving the rent-price ratio. In Section 5.3, we examine these possibilities one at the time.

D.3 Model with Fixed Rents

In the model described in Section 5.3.3, a linear technology to produce rental services pins down the rent to a constant. Now the aggregate housing stock consists only of owner occupied housing, so when a renter becomes a homeowner, this necessarily increases the housing stock and the house price. We set the fixed rental rate in this version of the model to match the same average rent-price ratio from the benchmark in the stochastic steady state of 5% annually.

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D.4 Model with Household-Landlords

In the model described in Section 5.3.4, all of the housing stock is owned by households who can freely trade the housing services generated by the housing that they own.

In this version of the model we treat housing as a pure asset that pays a tradable dividend in housing services as in Jeske, Krueger, and Mitman (2013). We assume that households can continuously choose the rental services they want to consume, but for owning the housing asset we assume that it comes in the same six house sizes as in the benchmark economy. We keep this formulation as opposed to a continuous housing choice to try to maintain a meaningful home ownership characterization[45]. In this version of the model, both the house price and rental price become aggregate state variables which clear the market for housing investment and housing services, such that all housing services are generated by houses owned by households and all housing services are consumed by households (no vacancies).

Unlike in the benchmark economy, the rental price is now explicitly a state variable. We approximate the law of motion for the rental price similarly to how we approximate the law of motion for the house price:

$$\log \rho' = b_0(\mathcal{Z}, \mathcal{Z}') + b_1(\mathcal{Z}, \mathcal{Z}') \log \rho. \tag{D7}$$

When we simulate the model, we clear the housing market by using bilinear interpolation of the excess demand functions for the housing stock and housing services. We then iterate on the laws of motion for the house prices and the rental price until we achieve convergence on the vector of coefficients $\{a_0(\mathcal{Z}, \mathcal{Z}'), a_1(\mathcal{Z}, \mathcal{Z}'), b_0(\mathcal{Z}, \mathcal{Z}'), b_1(\mathcal{Z}, \mathcal{Z}')\}$. To keep the model tractable, and as we are mainly interested in studying the effects of credit relaxation under alternative formulations of the housing market, we solve this version of the model without the belief shock and only consider the income and credit relaxation shocks.

We calibrate the utility benefit of owning housing to match the same home ownership rate as in the benchmark. We replace the multiplicative utility benefit of home ownership with an additive utility benefit, as we now have a distinction between the size of the owned house and the services consumed.

D.5 Economy Where Credit Conditions Affect House Prices

For the model of Section 5.4, we move our economy closer to the one studied in Favilukis et al. (2017). We eliminate the rental sector so that all households must now own homes (we allow the smallest house size, which previously could only be rented to now be owned). On

[45] If we allowed a truly continuous choice of owned housing stock we would generate a counterfactual home ownership rate as essentially all unconstrained households would own some small fraction of a house.

the mortgage side, we increase the cost of default to eliminate foreclosure except in case of an empty budget set. We eliminate the fixed cost κ^m and the intermediation wedge ι, set the HELOC limit, λ^b, to 0 and eliminate the PTI limit, λ^π. We set the mortgage amortization horizon to one period. In the low credit state the max LTV, λ_L^m is set to 0.75 and in the relaxed credit state λ_H^m equals 1.1, as in our benchmark. We adjust the proportional origination cost in the low credit state, ζ_L^m, to be 5% of the value of the loan and in the high credit state (λ_H^b) relax it to 3% (so a 40% reduction as in our benchmark). This configuration of cost and constraint parameters are chosen to mimic the credit relaxation experiment in Favilukis et al. (2017).

In order to calibrate the high-risk-aversion version of our benchmark economy, we first set $\gamma = 8$. Next, we calibrate the discount factor to match the same aggregate net worth as in the benchmark, which yields a value $\beta = 0.941$. In addition, we want to ensure that along the home ownership dimension the high-risk-aversion model is comparable to the benchmark, so we lower the additional utility value of home ownership until we have a comparable home-ownership rate in the steady state.

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E Data Sources

E.1 Aggregate Data

- **Consumption**: Nominal nondurable consumption expenditures (line 8 of NIPA Table 2.3.5. Personal Consumption Expenditures by Major Type of Product) divided by the price index for nondurable consumption (line 8 of NIPA Table 2.3.4. Price Indexes for Personal Consumption Expenditures by Major Type of Product).

- **Home Ownership**: Census Bureau Homeownership rate for the U.S. (Table 14) and by age of the householder (Table 19). Housing Vacancies and Homeownership (CPS/HVS) - Historical Tables.

- **House Prices**: House Price Index for the entire U.S. (Source: Federal Housing Finance Agency) divided by the price index for nondurable consumption (line 6 of NIPA Table 2.3.4. Price Indexes for Personal Consumption Expenditures by Major Type of Product).

- **House Rent-Price Ratio**: Rents (Bureau of Labor Statistics Consumer Price Index for All Urban Consumers: Rent of primary residence) divided by nominal house prices.

- **Foreclosures**: Number of Consumers with New Foreclosures and Bankruptcies from the Federal Reserve Bank of New York Quarterly Report on Household Debt and Credit divided by Population (FRED-St. Louis Fed series CNP16OV, Civilian Noninstitutional Population).

- **Leverage**: Home Mortgage Liabilities divided by Owner Occupied Housing Real Estate at Market Value. Source: Flow of Funds B.101 Balance Sheet of Households and Nonprofit Organizations.

- **Labor Productivity**: FRED-St. Louis Fed series ULQELP01USQ661S (Total Labor Productivity for the United States).

- **Mortgage and Treasury Interest Rates**: FRED-St. Louis Fed series MORTGAGE30US (30-Year Fixed Rate Mortgage Average in the United States) and GS10 (10-Year Treasury Constant Maturity Rate).

The data for real consumption expenditures and real house prices used in all plots in the paper are detrended through a linear trend estimated over the pre-boom period 1975-1996.

E.2 Measurement of House-Size Changes from PSID

The objective of this exercise is to estimate the change in house sizes for households that transition across different houses and, possibly, at the same time switch their tenure status from renters to owners or viceversa. These moments are helpful to assess the plausibility of the degree of substitutability between the rental and owner-occupied stock implied by our segmentation described in Section 3.

The PSID is the only survey that allows to track over a long period of time a representative sample of the U.S. population and that has information on house sizes and tenure status. The PSID questions we use for this purpose are the following:

- *How many rooms do you have here for your family (not counting bathrooms)?* (e.g., variables V102 for 1968 and V592 for 1969). This is the measure of house size we use, as it is the only one available.

- *Do you (FU [family unit]) own this home or pay rent or what?* (e.g., variables V103 for 1968 and V593 for 1969). The potential answers here are own, rent, or neither. This variable is used to identify house ownership status and how it changes from a survey to the next, i.e. the four type of transitions: owner-to-renter (O-R), renter-to-owner (R-O), owner-to-owner (O-O) and renter-to-renter (R-R).

- *Have you (HEAD) moved since last spring?* (e.g., V603 for 1969). This variable is useful to identify people who move between different houses.

We collect responses for all heads of households over the survey years 1968-1996, i.e. the pre-boom period corresponding to the stochastic steady state of our model. The total sample size includes 13,782 individuals and 105,774 observations. However, for a number of heads of households it is impossible to identify whether they underwent a transition for a number of reasons: (i) it is their first or last year in the PSID sample as heads; (ii) in some cases the heads temporarily disappear from the sample only to reappear later; (iii) the head is present in adjacent years but her/his answers to these specific questions are missing (for example, in 1994, there is a significantly higher fraction of missing variables, nearly 7%, compared to the other years). Overall, we are left with 9,283 individuals for which we can identify tenure status and house size. 5,301 of these individuals move at least once, totaling 15,235 transitions.

We aim at comparing house-size changes upon moving in the data and in the model. In the data, we have information on number of rooms (excluding bathrooms). In the model changes are measured in housing units. The two would exactly coincide under the following scenario. Imagine every house is composed of bedrooms, one living room and one kitchen (plus bathrooms). Normalize the size of a bedroom to 1 and assume that the area including living room plus kitchen is always double the size of a bedroom, i.e. 2. Also assume that the bathroom space is always proportional to the rest of the space in the house, e.g. 10%. Then, the percentage change in rooms (excluding bathrooms) exactly corresponds to the percentage change in housing units. For example, moving from a 1 to a 2 bedroom house implies an increase of rooms (excluding bathrooms, so only bedrooms, the living room and the kitchen) from 3 to 4 and it implies exactly an increase in housing units from 3.3 to 4.4, corresponding to a percentage change of 33%. Moving from a 2 to a 3 bedroom house implies an increase in the number of rooms from 4 to 5 and an increase in housing units from 4.4 to 5.5 (or a change of 25%), etc. Under these assumptions, data and model calculations are comparable.

Our findings are shown in Table 6 in the main text.

Size	< 35		35 – 49		50 – 64		>= 64	
Class	Data	Model	Data	Model	Data	Model	Data	Model
1-2	42	63	30	52	32	41	34	37
3	28	24	24	19	24	19	25	18
4	15	12	18	10	18	16	18	18
5	8	1	10	17	11	15	9	16
6	5	0	11	2	9	9	8	9
7	3	0	6	0	6	1	5	2

Table F1: Distribution of owner-occupied housing sizes over the life-cycle (percentages). Data: AHS. Our segmentation assumption implies that the smallest house size cannot be owned, so in the table we grouped house sizes 1 and 2 together. In the data, on average only 9% of owners live in the smallest house size.

F Additional Figures and Tables

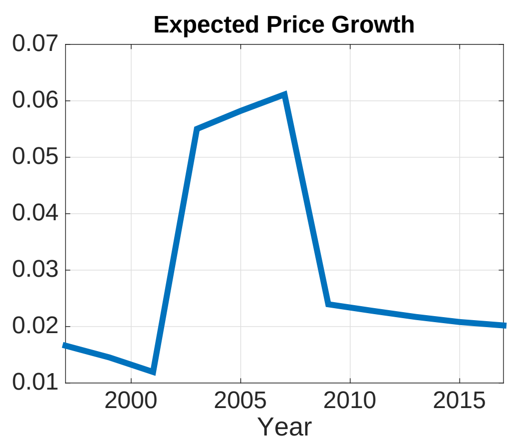

Figure F1: Expected annual house appreciation in the model along the realized history of the boom-bust episode.

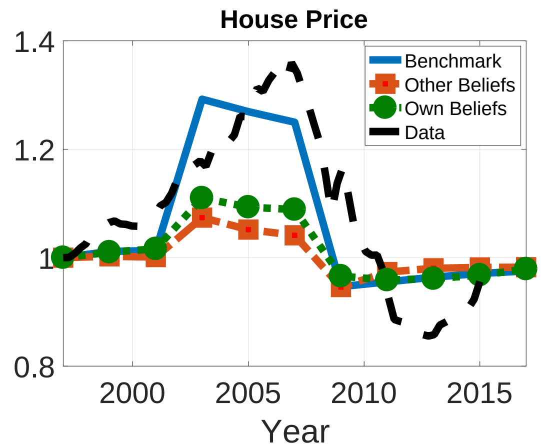

Figure F2: Implied house price dynamics under own vs. other households' shifts in beliefs. Other beliefs: the economy where households think that only other households (but not themselves) experience the belief shock. Own beliefs: the economy where you believe that only your own preferences for housing (but not those of other households) may possibly change. Benchmark: both own and others' shift in beliefs active. All series are normalized to 1 in 1997.

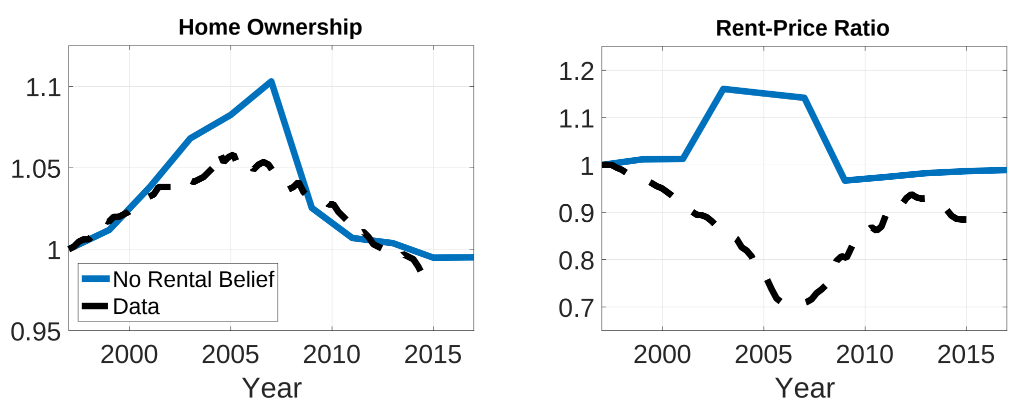

Figure F3: House price and rent-price ratio dynamics in an economy where the rental company does not have optimistic beliefs. Both series are normalized to 1 in 1997.

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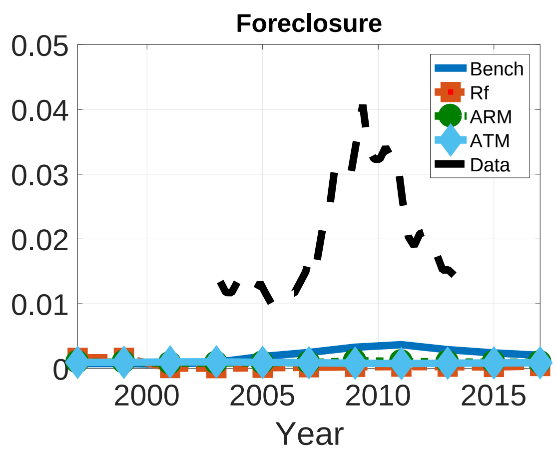

Figure F4: Foreclosure dynamics under alternative models of credit relaxation. ATM: shifts in the maximum HELOC limit. ARM: shifts in the amortization rate. Risk free: decline in the risk free rate. Bench: benchmark shock to credit conditions. All series are normalized to 1 in 1997.

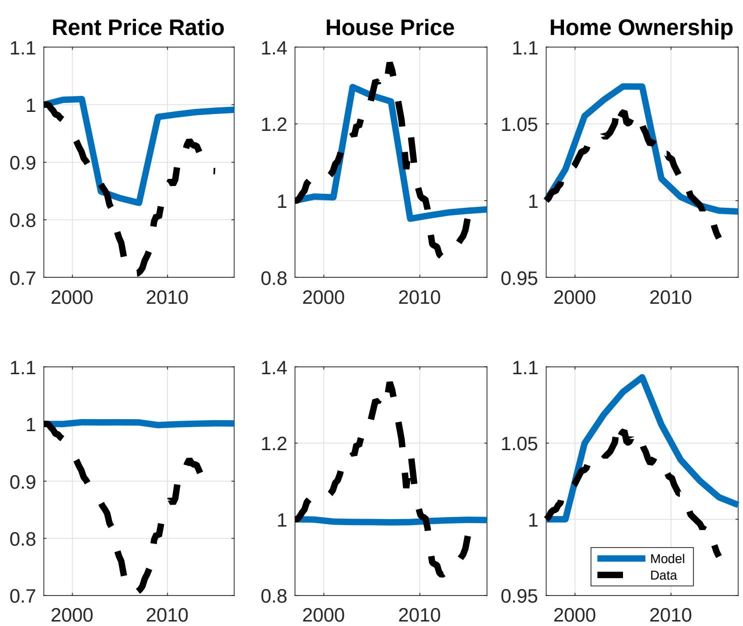

Figure F5: Implied dynamics of rent-price ratio, house prices and home ownership in the ‘No Segmentation’ model with complete overlap of rental and housing house sizes in response to the three benchmark shocks (top row) and only credit relaxation (bottom row). Dashed line: data. Solid line: model.

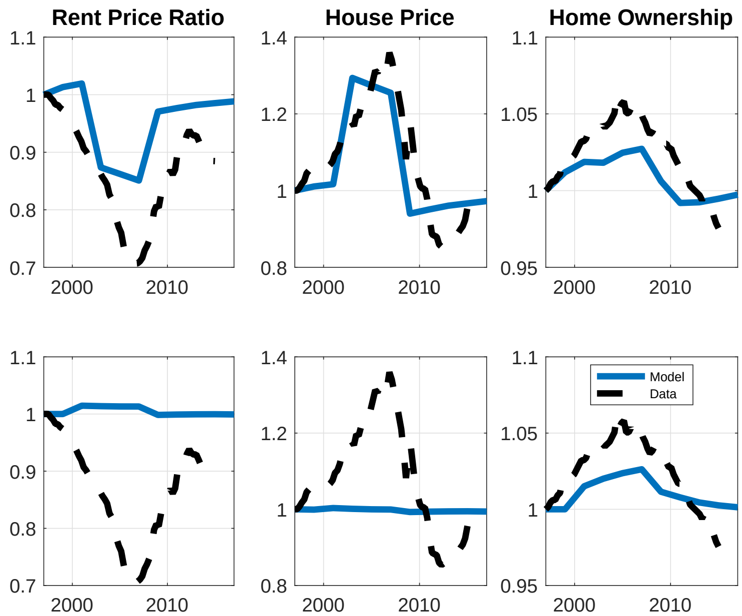

Figure F6: Implied dynamics of rent-price ratio, house prices and home ownership in the 'Partial Segmentation 1' model with two rental house sizes (and an overlap of 1) in response to the three benchmark shocks (top row) and only credit relaxation (bottom row). Dashed line: data. Solid line: model.

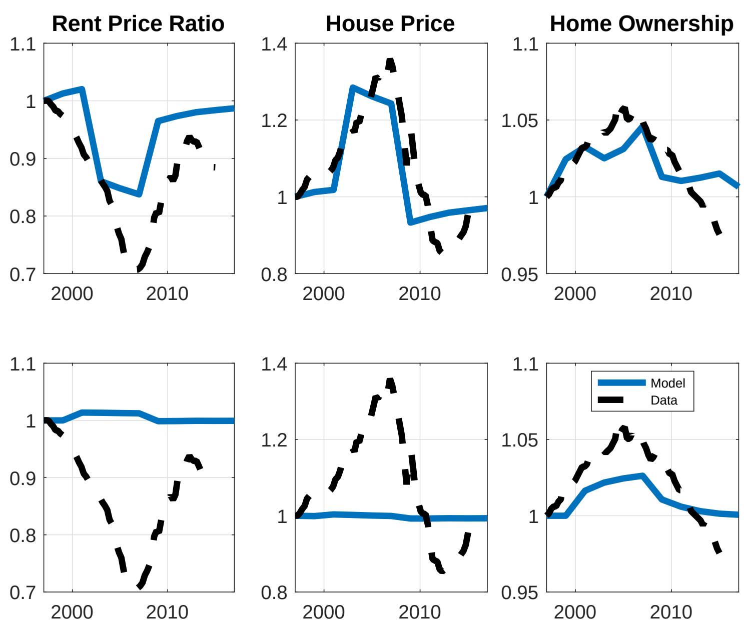

Figure F7: Implied dynamics of rent-price ratio, house prices and home ownership in the 'Partial Segmentation 2' model with three rental house sizes (and an overlap of 1) in response to the three benchmark shocks (top row) and only credit relaxation (bottom row). Dashed line: data. Solid line: model.

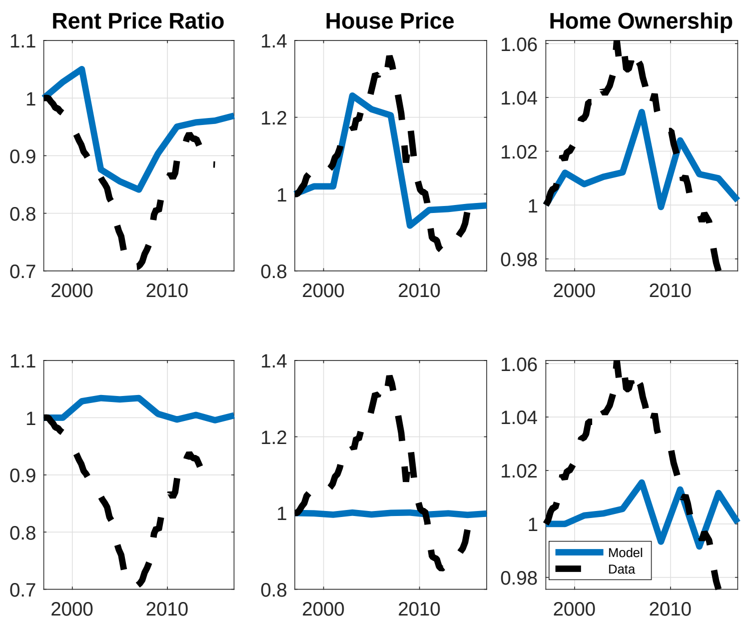

Figure F8: Implied dynamics of rent-price ratio, house prices and home ownership in the 'Full Segmentation ' model with no overlap of rental and housing house sizes in response to the three benchmark shocks (top row) and only credit relaxation (bottom row). Dashed line: data. Solid line: model.

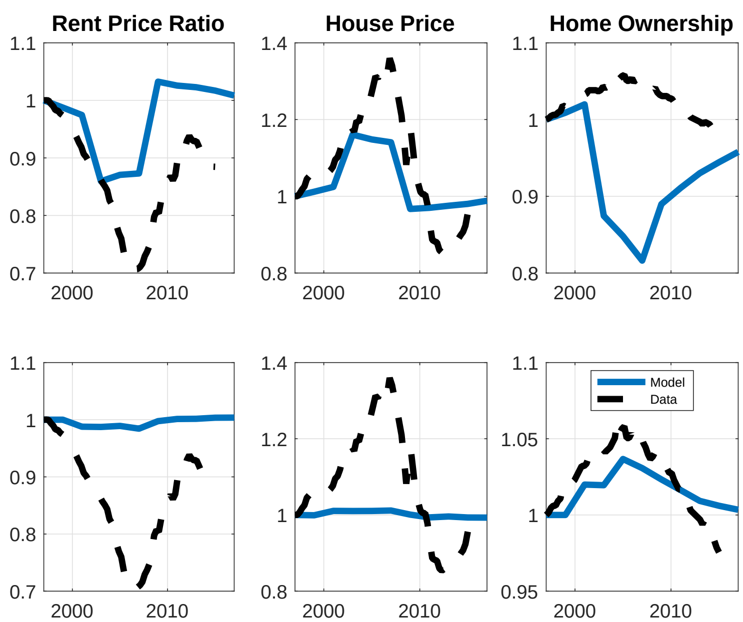

Figure F9: Implied dynamics of rent-price ratio, house prices and home ownership in the fixed-rent model in response to the three benchmark shocks (top row) and only credit relaxation (bottom row).

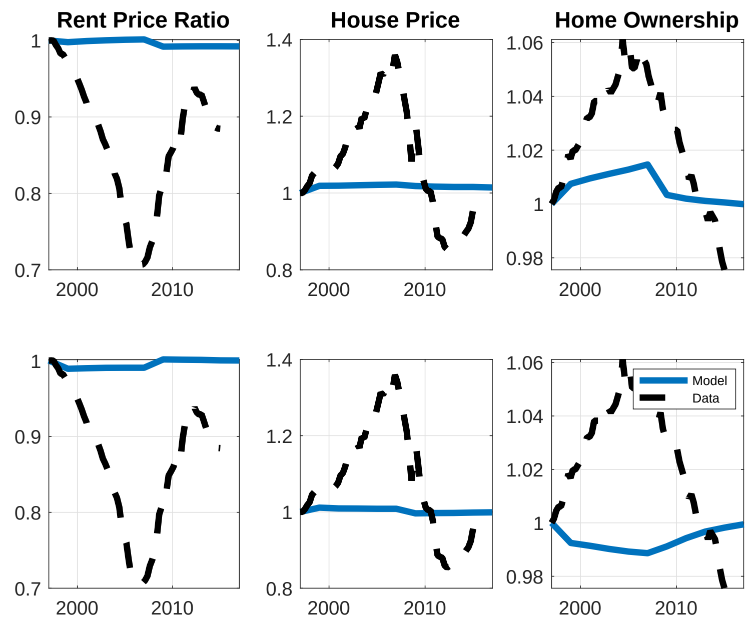

Figure F10: Implied dynamics of rent-price ratio, house prices and home ownership in the household-landlord model in response to the income and credit relaxation shocks (top row) and only credit relaxation (bottom row).

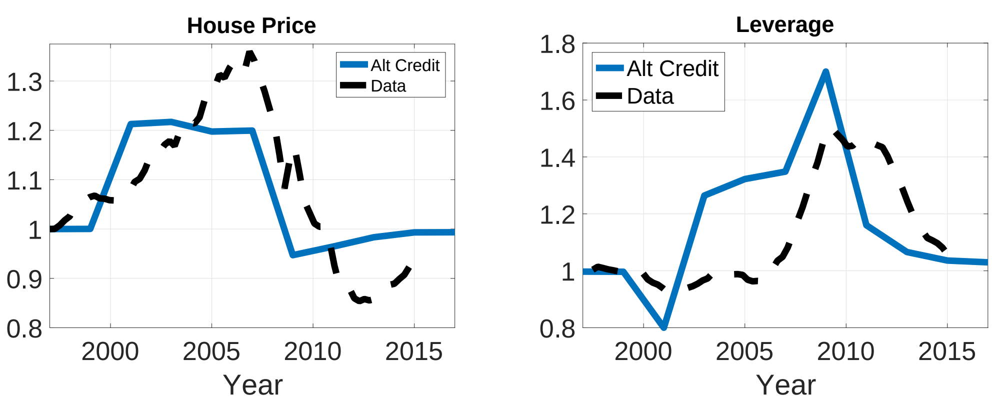

Figure F11: House price and leverage dynamics in the economy of Section 5.4 where credit conditions have a large effect on prices. Both series are normalized to 1 in 1997.

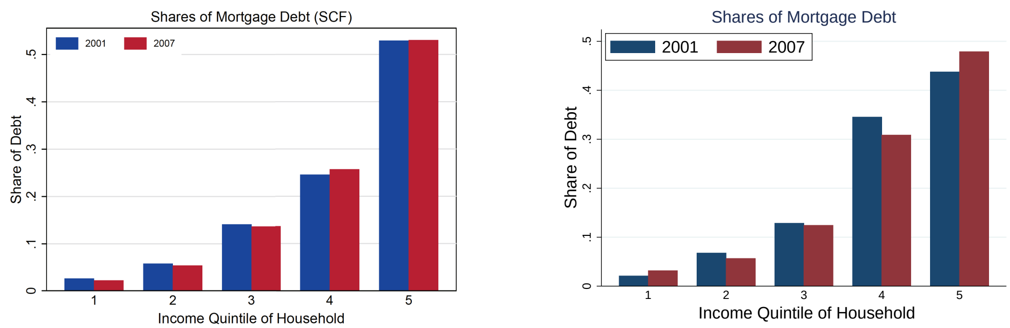

Figure G1: Left panel: Share of mortgage debt by income level in 2001 and 2006 from Foote et al. (2016). Right panel: Share of mortgage debt by income level in the model in 2001 and 2007.

G Cross-Sectional Distribution of Debt and Foreclosures

In the last decade, a large empirical literature has developed that seeks to advance our understanding of the causes and consequences of the housing boom and bust by exploiting cross-sectional variation (across either households or regions) in house prices, balance sheets, housing market outcomes, financial conditions, consumer expenditures and labor market outcomes. A centerpiece of the early literature (Mian and Sufi, 2009; Mian et al., 2013; Mian and Sufi, 2014) was the emphasis on subprime borrowers – households who were excluded from mortgage markets before the credit relaxation of the early 2000's opened the door for them to become home owners. This group of low-income, high-risk households was identified as the group most responsible for the expansion in mortgage debt during the boom, and for the consequent delinquencies and foreclosures during the bust.

As more and better data have become available (e.g. credit bureau data and loan-level data), the consensus on what these cross-sectional patterns reveal has evolved (Adelino, Schoar, and Severino, 2016; Albanesi et al., 2016; Foote et al., 2016). At least two challenges to the subprime view have been raised.

First, the left-panel of Figure G1, reproduced from Foote et al. (2016), demonstrates that credit growth during the boom years was not concentrated among low-income households, but rather was uniformly distributed across the income distribution. The right-panel of Figure G1 shows that our model is consistent with this observation. The shift in expectations about future house price growth is the key reason why the model generates an expansion of credit even for high-income households. All households expect large capital gains from holding housing, but high-income, low-risk households are those in the best position to take advantage of the optimistic beliefs, since they can access low-cost mortgages even in the absence of looser credit conditions.

Second, the left panel of Figure G2, reproduced from Albanesi et al. (2016), shows that

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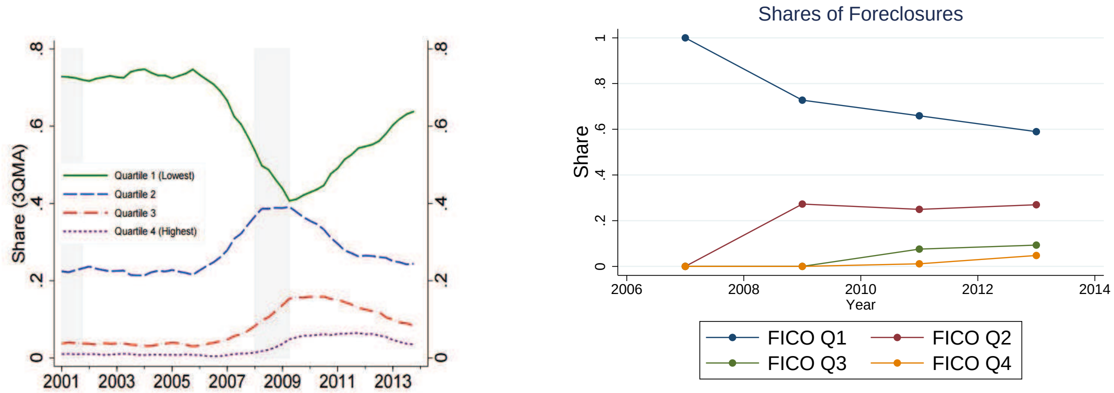

Figure G2: Left panel: Share of foreclosures by quartile of FICO score from Albanesi et al. (2016). Right panel: Share of foreclosures in the model by quartile of default probability, a proxy for FICO score.

the shares of foreclosures for households in the lowest quartile of the FICO score distribution at origination decreased during the bust. This observation suggests that prime borrowers contributed to the dynamics of the housing crisis at least as much as sub-prime ones. There is no explicit notion of credit score in our model, but we can proxy a household's credit score by computing its default probability from the viewpoint of the financial institution, i.e. the value of the individual equilibrium mortgage rate spread at origination. The right panel uses this approach to construct the model counterpart of the left panel.

The model is consistent with a decline in the share of foreclosures among subprime borrowers (who, as in the data, always account for by far the largest share). Once again, the reversal of expectations is key. A sizable fraction of prime borrowers, who levered up to buy more housing expecting to soon realize capital gains, find themselves with negative equity and choose to default.[46]

[46] In the data, credit growth is also uniform across FICO scores at origination (Adelino et al., 2017). When we use our same model-proxy for credit scores, we find that the model is also consistent with this observation.

H Alternative Models of Credit Relaxation

In this Appendix, we show that our findings are robust to three alternative ways in which we could have modeled the relaxation and subsequent tightening of credit conditions.

H.1 Houses as ATMs

One aspect of the rise in securitization of private label mortgages that we have not so far considered, is the rise in approval rates for second liens and looser limits on HELOCs, which allowed both new and existing homeowners to extract a larger fraction of their home equity. In our model, we capture these effects, which are commonly referred to as "houses as ATMs" (Chen et al., 2013), through an increase in the maximum HELOC limit λ_b.

Figure H1 shows the equilibrium house price (top left panel) and consumption dynamics (top right panel) in response to a loosening and subsequent tightening of HELOC limits, from 0.2 to 0.3 and back again (line labelled "ATM").[47] As with the baseline model of credit conditions, changes in HELOC limits have almost no effect on house prices and consumption. This finding is a consequence of matching the distribution of HELOC take-up and usage rates in the data, which suggest that only a minority of households were close to their limit at the time of the relaxation, so the looser constraint barely affects their consumption or housing demand. Figure H1 shows also that the equilibrium dynamics for home ownership (bottom left panel) and leverage (bottom right panel) are also barely affected by the change in HELOC limits.[48]

H.2 Adjustable Rate Mortgages

Another aspect of the mortgage market environment of the early 2000's that we have not so far considered was the proliferation of adjustable rate and low teaser-rate mortgages. These had the effect of lowering monthly mortgage payments and thus simultaneously making home ownership more attractive while freeing up funds for nondurable consumption. From the perspective of households in our model, a simple way to capture these effects is through changes in the amortization rate r^m, which determines the minimum required mortgage payment in equation (7). The lines labelled 'ARM' in Figure H1 show the results of an experiment where the relaxation in credit conditions is modeled as a fall in r^m (engineered through a lower wedge ι) from 4% p.a. to 3.75%. This reduction is chosen to match the

[47] The value of 0.3 corresponds to the 90th percentile of the HELOC limit distribution for households in the SCF who originated mortgages within the previous two years during the boom.

[48] Figure F4 in the Appendix shows foreclosures for all alternative representations of the credit shock. In all of them, as in the benchmark, the shift in credit conditions alone has virtually no impact on foreclosures.

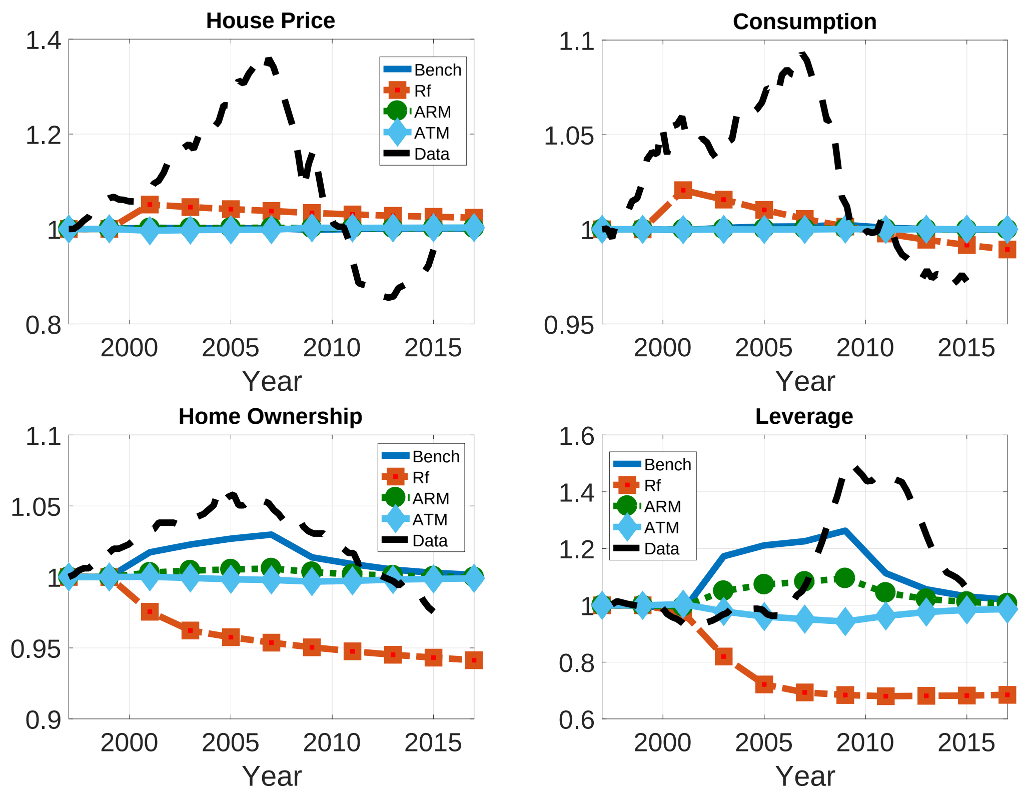

Figure H1: House price, consumption, home ownership and leverage dynamics under alternative models of credit relaxation. Bench: benchmark credit shock. ATM: shifts in the maximum HELOC limit. ARM: shifts in the amortization rate. Risk free: decline in the risk free rate. All series are normalized to 1 in 1997.

decline in the average spread between private-label mortgage-backed securities and maturity-matched Treasuries (see Levitin and Wachter, 2011, Figure 5). The fall in r^m translates into a 7% average reduction in minimum mortgage payments.

Figure H1 shows that the change in required mortgage payments has almost no effect on either house prices of consumption, and that the equilibrium dynamics for home ownership and leverage are qualitatively similar, but more muted, than in the benchmark model.

H.3 Movements in the Risk-free Rate

One further candidate explanation for the boom in house prices was the dramatic decline in the risk-free rate experienced in the U.S. in the 2000s. We did not include movements in the risk-free rate as part of our benchmark experiments because, while lower risk-free rates have the potential to explain the housing and consumption boom, the absence of a corresponding rise to pre-2000 levels in the data makes it impossible to explain the subsequent bust.

To evaluate the potential strength of changes in the risk-free rate, we consider a version of the economy with a stochastic risk-free rate r_b, and model the relaxation in credit conditions as a fall in r_b from 3% p.a. to 2% p.a. in 2001, which persists until 2020.[49] Figure H1 shows that the drop in r^b does generate an increase in house prices and consumption, followed by a gradual decline, but the movements are much smaller than in the data.[50] House prices rise because the return on housing increases relative to the return from saving in bonds, pushing up housing demand. The fall in rents, due to the fact that the expected capital gain component is exacerbated by the decline in the risk-free rate (see equation 11), pulls down home ownership. Finally, since the marginal buyers with high LTV now opt to rent, the rise in aggregate mortgage debt is much weaker and so leverage declines.

[49] Ideally, we would model the dynamics of the risk-free rate as a long-term trend, rather than a sudden changes. However, this would require computational complexity that our model can not handle.

[50] The semi-elasticity of house prices to interest rates implied by this simulation is around 5.5, not far from the value estimated by Glaeser, Gottlieb, and Gyourko (2012), which is between 7 and 8.

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