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Joint Dynamics of House Prices and Foreclosures

This paper studies the joint transitional dynamics of the foreclosures and house prices in a standard life-cycle incomplete markets model with housing and a realistic long-term mortgage structure. We calibrate our model to match several long-term features of the U.S. housing market, and analyze the effects of several unexpected and permanent shocks on the house price and the foreclosure rate both across the steady states and along the transition between the steady states. We examine permanent, unexpected shocks to the risk-free interest rate, the minimum down-payment ratio, and unemployment. During the transition, these shocks create large movements in house prices. More importantly, the foreclosure dynamics are quite significant along the transition compared to the steady-state changes, and there are strong feedbacks between foreclosures and house prices. We assess the effects of a temporary reduction in the risk-free interest rate, which has moderate effects on house prices but little effect on foreclosure dynamics. We also study the effects of an *ex ante* macroprudential policy, which establishes a minimum down-payment requirement at a higher threshold. Such a macroprudential policy helps substantially stabilize both house prices and foreclosures.

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In this paper, we study the joint transitional dynamics of the foreclosures and house prices in a standard life-cycle incomplete markets model

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with housing and realistic long-term mortgage structure. In particular, we analyze how the house price and the foreclosure rate in our model respond to a number of unexpected and permanent shocks. We particularly focus on the effect of an increase in the risk-free interest rate, an increase in the minimum down-payment requirement, and an increase in the unemployment rate. One of the distinguishing features of our framework is that foreclosure choice and the house price are both endogenous in our model so that we can analyze the feedback mechanism between them as well.

In a nutshell, we find that the responses of the house price and foreclosures to the shocks can be quantitatively large. In our calibrated model, a 1% increase in the risk-free rate together with a 20% increase in the minimum down-payment requirement and a 1% increase in the unemployment rate result in a 27% decrease in the house price and almost 3 percentage points increase in the foreclosure rate. Our quantitative experiments also show that an *ex post* accommodative monetary policy has limited effects on house prices and foreclosure rates. On the other hand, an *ex ante* macroprudential policy implemented through an increase in the minimum down-payment requirement can help stabilize both house prices and foreclosures substantially.

We study a standard life-cycle model with incomplete markets and idiosyncratic labor income and moving shocks. The distinguishing feature of our model is the incorporation of the housing and a realistic mortgage structure into the model. We explicitly model the housing tenure choice. Households are born as renters. Every period, renters decide whether or not to purchase a house. There is a continuum of risk-free lenders who offer mortgage contracts to prospective home buyers. A mortgage contract consists of a mortgage interest rate, loan amount, mortgage repayment schedule, and maturity. Mortgages are fully amortizing; that is, homeowners have to pay the mortgage back in full until the end of the mortgage contract, as specified by the maturity. However, homeowners also have the option to sell their houses, or default on the mortgage, and return to the rental market.[1] Selling a house is different from defaulting, because a seller has to pay back the outstanding mortgage balance to the lender whereas a defaulter has no obligation. Therefore, default occurs in equilibrium as long as the selling price is lower than the outstanding mortgage debt. Upon default, the household becomes a renter again and is excluded from the mortgage market stochastically as a punishment. There is free entry into the credit market, so in equilibrium, lenders make zero-profit on each contract. Since mortgages are long-term contracts, it is essential for the lenders to infer the default probability of each household at every date and state, which depends on the characteristics of the household. We calibrate our model to match several long-term features of the U.S. housing market such as average default rate, wealth-to-income ratio, average moving rate of homeowners, and average homeownership rate.

As our first exercise, we feed the economy with an unexpected and permanent interest rate shock where the risk-free interest rate increases from 2% to 3%. We show

1. We use the terms “default” and “foreclosure” interchangeably for the same activity.

that, if we compare the first and the second steady states, the house price is around 8% lower in the second steady state. On the other hand, the foreclosure rate declines from 1.7% to 1.5%. Higher risk-free interest rate increases the mortgage interest rate, and makes mortgages less affordable. So, the demand for houses decreases, and results a drop in the house price. Lower house price and higher average wealth, due to high risk-free interest rate, increases the average down payment in the economy. Hence, the foreclosure rate drops. We get similar results when the economy is hit by unemployment and financial shocks.

The comparison of the steady states reveal that unexpected and permanent fundamental shocks can create sizable movements in the house price. However, their effect on the foreclosure rate is counterfactual. Although we consider adverse shocks, they decrease the foreclosure rate. However, the transitional dynamics differ considerably from the steady-state comparisons. The analysis of the same shocks along the transition show that the drop in the house price can be quite larger (around 27% on impact of the shock), and the foreclosure rate can increase to significant levels (around 4.5%). Hence, studying the transitional dynamics reveals that a very important determinant of the foreclosure activity is the movement in the house price, not the level of house price.

Another contribution of our study is that we quantify the feedback mechanism between house prices and foreclosures. Declining house prices induces more foreclosure due to negative home equity, and more foreclosures put downside pressure on the housing price. In our model, this feedback mechanism can generate up to 150% further decline in the house price. The analysis of transitional dynamics under unemployment and financial shocks return similar results. Therefore, we conclude that it is crucial to study the transition in order to understand the amplified quantitative effect of the shocks.

We also study the effect of the monetary policy in this framework, and question how the transition would look in the presence of a monetary policy. In particular, we study a case where the monetary authority decreases the risk-free interest rate to 0.5% for several periods after the initial decline in the house price. We consider two cases: first, interest rate is decreased immediately upon receiving the adverse shocks; second, the policy is implemented two periods after the adverse shocks are realized. Monetary policy is found to be effective in stabilizing both house price and foreclosure if it is implemented immediately after realizing adverse shocks, but these effects are very limited.

Finally, we analyze the implications of a macroprudential policy tool, which is implemented through higher minimum down-payment requirement. In particular, we study how the model would react to the same interest rate shock and unemployment shock if the minimum down-payment requirement of 20% has been always in place. We find that with a higher minimum down-payment requirement, the decline of the house price is around 6% instead of 14% in the benchmark economy. More importantly, the increase in the foreclosure rate is significantly lower in the presence of the macroprudential policy (0.02% instead of 3.1%). These results show us the importance of the macroprudential policies in mitigating the effect of the shocks on the house price and foreclosures.

We contribute to the quantitative strand of the housing literature focusing on the house price and foreclosure dynamics. A number of papers studied foreclosure dynamics while taking house prices as exogenous (e.g., Guler Forthcoming, Corbae and Quintin 2014, Campbell and Cocco 2014, Hatchondo, Martinez, and Sanchez 2014). Another group of papers studied the dynamics of house prices without foreclosures (e.g., Heathcote and Davis 2005, Arslan 2014, Kiyotaki, Michaelides, and Nikolov 2011, Garriga, Manuelli, and Peralta-Alva 2012, Sommer, Sullivan, and Verbrugge 2013, Favilukis, Ludvigson, and Van Nieuwerburgh 2011). We differ from these papers since we model both house price and foreclosure endogenously, and analyze their joint dynamics and feedback mechanisms.

Our paper is most closely related to Chatterjee and Eyigungor (2014), who analyze foreclosures and house prices jointly as well. Heterogeneity in home equity is an important ingredient in their model similar to ours.[2] However, our model differs from theirs in the life-cycle component and mortgage structure. The nature of the shocks and the types of the policies studied in the two papers also differ from each other.

Our paper also adjoins to the empirical literature on housing. The earlier studies were generally motivated to understand the increase in U.S. house price during the boom of the mid-2000s. After the collapse of the housing market, both understanding the decline in the house price and the increase in the foreclosure rate have become the main interest of research. For instance, Foote, Gerardi, and Willen (2012) outline the facts about the housing and mortgage market, and compare the success of different theories in explaining these facts. Their main finding, consistent with ours, is that the unexpected decline in the house prices is an important driving force behind the increase in the foreclosure rates. Our quantitative model produces results consistent with their finding.[3]

The rest of the paper is organized as follows. We present the model and calibration in Section 1, we analyze the initial steady-state equilibrium in Section 2, we present transitional dynamics in Section 3, we discuss some policy experiments in Section 4, and we conclude in Section 5.

1. MODEL

We begin by describing the environment agents face in the economy. We then specify the decision problems of households and lenders. We finally define the equilibrium.

2. See Foote, Gerardi, and Willen (2008) and Mian and Sufi (2011) for empirical relevance of home equity in foreclosures.

3. Similar findings can be found in Foote, Gerardi, and Willen (2008), Gerardi et al. (2009), Mayer, Pence, and Sherlund (2009), and Bajari, Chu, and Park (2010).

1.1 Environment

The economy is populated by overlapping generations of J period lived households and a continuum of lenders. Each generation has a continuum of households. Time is discrete and households live for a finite horizon. There is no aggregate uncertainty but households face idiosyncratic labor income and moving shocks. Markets are incomplete so that these shocks are not fully insurable. There is mandatory retirement at the age J_r. Retirement income is constant and depends on the income of the household at age J_r and the average income in the economy. Households can save at an exogenously given interest rate r, but they are not allowed to make unsecured borrowing.

Households. Households live in houses, which they can either rent or own. At the beginning of each period, a household is in one of the three housing statuses: *inactive renter*, *active renter*, or *homeowner*. Inactive renters are the renters with default flag in their credit history whereas active renters are the renters without any default flag in their credit history.[4] Active renters are always allowed to purchase a house, whereas inactive renters are not allowed to buy and are forced to stay as renters for that period. Homeowners are the households who start the period by owning a house. Households derive utility from consumption and housing services. Preferences are represented by

$$E_0\left[\sum_{j=1}^{J_r}\beta^{j-1}u_k(c_j)+\beta^{J_r+1}W(w_{J_r},y_{J_r})\right],$$

where $\beta < 1$ is the discount factor, c is the consumption, and k is the housing status: renter or homeowner. W represents the value function of the household at retirement given wealth w_{J_r} and income y_{J_r}.[5] The house size is fixed and the utility from housing services is summarized as three different utility functions: one for the inactive renter, u_d; one for the active renter, u_r; and one for the homeowner, u_h. A homeowner receives a higher utility than an active renter, who receives a higher utility than an inactive renter from the same consumption: $u_h(c) > u_r(c) > u_d(c)$.[6]

4. This is to mimic the fact that default stays in the credit history of the individuals for a certain time and makes it hard for them to find credit.

5. Since there is no housing tenure choice and uncertainty after retirement, household's problem after retirement is trivial and can be calculated analytically.

6. Note that the size of the houses is fixed, so having separate utility functions for renters and homeowners implies that they get different housing services from the same house. This specification is also identical to a Cobb–Douglas specification between housing consumption and nondurable consumption.

The log of the income before retirement is a combination of a deterministic and a stochastic component, whereas after retirement it is λ fraction of the income at age J_r plus η fraction of the average income in the economy, $\bar{y}$:

$$
\begin{aligned}
y(j, z_j) &= \left\{ \begin{array}{cl} \exp(f(j) + z_j) & \text{if } j \leq J_r \text{ and employed} \\ \bar{y}_u(j) & \text{if } j \leq J_r \text{ and unemployed} \\ \lambda y_{J_r}(J_r, z_{J_r}) + \eta \bar{y} & \text{if } j > J_r \end{array} \right\} \\
z_j &= \rho z_{j-1} + e_j,
\end{aligned}
$$

where y_j is the income at age j, $f(j)$ is the age-dependent deterministic component of the log income, and z_j is the stochastic component of the log income. The stochastic component is modeled as an $AR(1)$ process with ρ as the persistency level. The innovation to the stochastic component, e_t, is assumed to be i.i.d. and normally distributed with mean 0 and variance σ_e^2. We also assume that in any period, the household is subject to an exogenous unemployment shock, u. The unemployment income is assumed to be age dependent and equal to $\bar{y}_u(j)$.[7] Households can save to smooth their consumption at the constant risk-free interest rate r, but there is no unsecured borrowing.

Households start the economy as active renters and can purchase a house and become an owner at any period. However, an inactive renter is only allowed to purchase a house with probability δ. With $(1-\delta)$ probability, she is forced to live as a renter. Home purchaser needs to pay φ_b fraction of the house value as a fixed transaction cost. The purchase of the house can be financed through a mortgage, which is also the only source of borrowing in the economy. A purchaser can choose among a menu of feasible mortgage contracts, each specified with a loan amount and interest rate, or she can purchase the house without any mortgage.[8] Maturity of the mortgages is assumed to be the remaining lifetime of the household until retirement.[9] Lenders offer only fixed-payment mortgages, so the payment is constant throughout the life of the mortgage.[10] As long as the household stays in the house, she has to make at least these constant payments. However, mortgage holders can prepay the mortgage in any period, and they can also reduce the mortgage principal more than

7. We assume away the endogenous choice of unemployment. So, given a low realization of income shock, households cannot choose to become unemployed. This assumption can be justified by a perfect monitoring technology for the unemployed.

8. Not every combination of mortgage interest rate and loan amount is feasible for the household. Lenders' inference about the type of the household and competition among lenders restrict the contracts offered to the household in the equilibrium.

9. Although the maturity of the contract is set exogenously in the origination of the contract, it becomes endogenous due to prepayment and principal reduction options mortgage holders have.

10. Since we assume constant interest rate, traditional fixed rate mortgages and adjustable rate mortgages would have fixed payments throughout the life of the mortgage, and they both fall into this category. These mortgages are not necessarily optimal contracts. A more convenient formulation should also include the mortgage payment as part of the contract and be determined in equilibrium. However, for simplicity we abstract from that and focus on the fixed-payment mortgage contracts that are the dominant type of mortgages in the U.S. history.

the amount implied by the contract. We also do not allow mortgage holders to save in the risk-free asset.[11]

Homeowners can leave their houses by two means. They can either sell their houses, or they can default on the mortgage. Selling the house is costly. First, upon deciding to sell, the individual receives mean-zero i.i.d. house price shock, ϵ_h, drawn from a distribution $F_h(\epsilon_h)$. This idiosyncratic shock changes the value of the house up or down.[12] In addition, there are some other costs (transaction costs including real-estate costs and maintenance costs) associated with selling the house. These costs are assumed to be proportional, φ_s fraction of the house price. Moreover, a seller has to pay the outstanding mortgage debt back to the lender.

There is another option for the household to quit ownership. She can default on the mortgage. A defaulter has no obligation to the lender. Upon default, the lender seizes the house, sells it, and pays back, if any, to the defaulter the amount net of outstanding mortgage debt and costs associated to selling the house. The lender's cost of selling the house is $\varphi_l > \varphi_s$ fraction of the house price. What makes default appealing for the household is the fact that a defaulter has no obligation to the lender whereas a seller has to pay back the debt in full. The same fact puts a risk of loss on the lender. The lender incurs a loss if the net value of the house is smaller than the outstanding debt upon default.

Default is not without any cost to the household. A defaulter becomes an inactive renter and can only enter to the housing market with probability δ.[13] Moreover, a defaulter receives a lower utility than an active renter from the same consumption. Since default is costly, and the selling price of the house to the homeowner is lower than the selling price to the lender, the homeowner who decides to leave the house defaults only if the outstanding mortgage balance is strictly higher than the selling price. Otherwise, it is always optimal to sell the house rather than defaulting.

In addition, we assume that in each period homeowners receive exogenous moving shock with probability ψ, and they are forced to quit to the rental market. These shocks represent the reasons households move other than the ones modeled here, like job mobility, family reasons, and so on. Movers again have two choices: either sell the house or default on the current mortgage, if there is one.

The supply of rental and owner-occupied units is constant, and targeted to match the average ownership rate in the United States. Rental price is normalized to 0, and purchase price is solved endogenously given the fixed supply of owner-occupied units. There is no mortgage refinancing or home-equity lines of credit.

11. This might seem to be a limitation of the model since, if they were allowed, households might choose to hold the risk-free asset for insurance purposes. However, prepayment and endogenous reduction of principal help us overcome this shortcoming of the model.

12. We can think of this shock as a local shock. We need this feature of the model to create realistic mortgage default rates in steady state. Since house prices are fixed in the steady state, without these local shocks, the incentive to default becomes very small.

13. This is to mimic the fact that default stays in the credit history of the individuals for a certain time, and makes it hard for her to find credit.

Lenders. There is a continuum of lenders. Financial markets are perfectly competitive, and there is no cost to entry. Lenders are risk neutral.[14] The economy is assumed to be an open economy, and the risk-free interest rate, r, is set exogenously. Mortgage contracts are long-term contracts, and the maturity of the contract is directly determined by the time to retirement, which is assumed to be certain and observable. Lenders have full commitment to the contract, and renegotiation is not allowed.

1.2 Decision Problems

Household's problem. At the beginning of each period, the household is in one of the three housing positions: inactive renter, active renter, or homeowner. After the realization of the income shock, the active renter and the homeowner make their housing tenure choices for the current period, and start the next period with their new housing statuses. We denote $V_j(\theta, s)$ as the value function of an age$-j$ household with current state variable θ and housing status $s \in \{d, r, h\}$, where d denotes inactive renter, r denotes active renter, and h denotes homeowner.

Inactive Renter. An inactive renter does not have any housing tenure choice; she is forced to be a renter in the current period. The only decisions she has to make are the consumption and saving allocations. She starts the next period as an active renter with probability δ and an inactive renter with probability $(1-\delta)$. Denoting the value function of an inactive renter with age j, period beginning saving a, and income z as $V_j(a, z, s = d)$, the inactive renter's problem is given by:[15]

$$V_j(a, z, s = d) = \max_{c, a' \geq 0} \{u_d(c) + \beta E[\delta V_{j+1}(a', z', s' = r) + (1-\delta) V_{j+1}(a', z', s' = d)]\} \tag{1}$$

subject to

$$c + a'/(1+r) + p_r = y(j, z) + a,$$

where c is the consumption, a' is the next period saving, and p_r is the exogenous rental price.

Active Renter. Different from an inactive renter, an active renter has to make housing tenure choice. After the realization of the income shock, an active renter has to decide whether to continue as a renter or purchase a house in the current period. We name an active renter who decides to stay as a renter as *renter*. Her problem is very similar to the inactive renter's problem apart from the fact that she starts the next

14. Securitization of mortgages helped lenders to diversify the risk they face and liquidate their asset holding. Risk-neutrality assumption corresponds to perfect securitization.

15. One can argue that unemployment should be another state in the recursive formulation. We basically stack unemployment state as another state to the income variable z to avoid another state variable.

period as an active renter for sure. Given all these facts, we can write down the problem of the renter as

$$V_j\,(a, z, s = rr) = \max_{c, a' \geq 0} \{u_r(c) + \beta E V_{j+1}(a', z', s' = r)\} \tag{2}$$

subject to

$$c + a'/\,(1 + r) + p_r = y\,(j, z) + a.$$

The second possible choice of an active renter is to purchase a house. We name an active renter who decides to purchase a house as *purchaser*. Housing purchase can be done through a mortgage contract. The purchaser, additional to the usual consumption choice, can choose a mortgage contract. Lenders design the mortgage contracts depending on the state variables of the household. Due to the perfect competition in the financial market, lenders need to make zero profit on these mortgage contracts. So, only the contracts that make zero profit are feasible, and offered to the household. We denote the set of feasible contracts for a household with state variables θ as $\Upsilon\,(\theta)$ where $\theta \equiv (a, z, j)$. A mortgage contract is specified with a loan amount a' and interest rate r_m. So, a typical element of the feasible contract set is $(a', r_m) \equiv \ell \in \Upsilon\,(\theta)$. We leave the construction of $\Upsilon\,(\theta)$ to the section where we define the lender's problem. Since mortgages are due by retirement, which is deterministic, household's age captures the maturity of the mortgage contract. Moreover, since we only focus on fixed-payment mortgages, the choice of the loan amount and interest rate, together with the age of the household, determine the amount of mortgage payments, m. The calculation of these payments is shown in the lender's problem. Out of the total financial wealth, net of the mortgage payment and the down-payment fraction, the household consumes the rest, and starts the next period as a homeowner. So, we can formulate the problem of the purchaser in the following way:

$$V_j\,(a, z, s = rh) = \max_{\substack{c \geq 0 \\ (a', r_m) \in \Upsilon(\theta)}} \{u_h(c) + \beta E V_{j+1}(a', z', r_m, s' = h)\} \tag{3}$$

subject to

$$c + a'/(1 + r_m) + p_h\,(1 + \varphi_b) = y\,(j, z) + a$$

$$\frac{-a'}{1 + r_m} + m(a', r_m, j) \leq p_h\,(1 - \phi)\,, \tag{4}$$

where p_h is the house price, φ_b is the transaction cost to purchase a house, and ϕ is the minimum down-payment requirement. The loan amount is the sum of the present value of debt $-a'/\,(1 + r_m)$ and mortgage payment $m(a', r_m, j)$. So, equation (4) means the original loan amount cannot exceed $(1 - \phi)$ fraction of the house purchase price. Notice that this formulation also encompasses the purchase of a house without any mortgage. In that case, we have $a' \geq 0$, $r_m = r$, and $m = 0$.

The value function for the renter together with the value function for the purchaser characterize the value function for the active renter:

$$V_j\,(a, z, s = r) = \max_{s'_r \in \{rr, rh\}} V_j\left(a, z, s'_r\right), \tag{5}$$

where s'_r is the policy function for the housing tenure of an active renter.

Homeowner. A homeowner has three housing tenure choices: stay in the current house, sell the house, or default on the mortgage. We name a homeowner who decides to stay in the current house as *stayer*. The stayer has to make at least the periodic mortgage payment, but also can prefer to make additional payments to reduce the outstanding mortgage debt. However, this will not effect the interest rate on the mortgage. Apart from the usual state variables (a, z, j), a stayer is also defined by the interest rate on the mortgage, r_m. In recursive formulation, the problem of the stayer becomes the following:

$$V_j\,(a, z, r_m, s = hh) = \max_{c \geq 0, a' \geq \underline{a}} \{u_h(c) + \beta E V_{j+1}(a', z', \tilde{r}_m, s' = h)\} \tag{6}$$

subject to

$$\begin{aligned} c + a'/\,(1 + \tilde{r}_m) &= y\,(j, z) + a \\ \underline{a} &= \left\{ \begin{array}{ll} (a + m\,(a, r_m, j))\,(1 + r_m) & \text{if } a < 0 \\ 0 & \text{if } a \geq 0 \end{array} \right\} \\ \tilde{r}_m &= \left\{ \begin{array}{l} r_m \ \text{ if } a' < 0 \\ r \ \text{ if } a' \geq 0 \end{array} \right\}. \end{aligned}$$

Notice that this problem also contains the problem of an outright owner ($a \geq 0$) who chooses to continue as a homeowner for the next period. The borrowing limit $\underline{a}$ implies that the stayer has to pay at least the implied mortgage payment , $m\,(a, r_m, j)$, to the lender. We do not allow mortgage holders to also hold a risk-free asset. Although this seems to be a limitation of the model, since we allow for prepayment and additional principal reduction, the effect of this limitation is mitigated.

The second possible choice for a homeowner is to sell the house and become a renter. We name such a household as *seller*. The selling price of the house is exogenously set to $(1 - \varphi_s)$ fraction of the purchase price p_h. Additional to this transaction cost, sellers also incur mean-zero i.i.d. capital loss/gain, ϵ_h. Moreover, a seller has to pay the outstanding mortgage debt, a, in full to the lender, if she has any. The recursive formulation of a seller's problem is the following:

$$V_j\,(a, z, r_m, s = hr) = \max_{a' \geq 0} \{E_{\epsilon_h}[u_r(c) + \beta E V_{j+1}(a', z', s = r)]\} \tag{7}$$

subject to

$$c + a'/\,(1 + r) + p_r = y\,(j, z) + a + p_h\,(1 - \varphi_s)\,(1 + \epsilon_h)\,,$$

where the expectation operator before the utility function is for the i.i.d. house price shocks.

The third and the last possible choice for a homeowner is to default on the mortgage. We name such a household as *defaulter*. A defaulter has no obligation to the lender. The lender seizes the house, sells it in the market, and pays any positive amount net of the outstanding mortgage debt and selling costs back to the defaulter.[16] Defaulter starts the next period as an active renter with probability δ. With $(1-\delta)$ probability she becomes an inactive renter. Defaulter's problem becomes the following:

$$V_j(a, z, s = hd) = \max_{c, a' \geq 0} \{u_d(c) + \beta E[\delta V_{j+1}(a', z', s = r) + (1-\delta) V_{j+1}(a', z', s = d)]\} \tag{8}$$

subject to

$$c + a'/(1+r) + p_r = y(j, z) + \max\{E_{\epsilon_h}[p_h(1-\varphi_l)(1+\epsilon_h)] + a, 0\},$$

where $E_{\epsilon_h}[p_h(1-\varphi_l)(1+\epsilon_h)]$ is the expected house sale price for a lender.

So, we can characterize homeowner's value function as:

$$V_j(a, z, r_m, s = h) = (1-\psi) \max_{s'_h \in \{hh, hr, hd\}} V_j(a, z, r_m, s'_h) + \psi \max_{s'_m \in \{hr, hd\}} V_j(a, z, r_m, s'_m), \tag{9}$$

where s'_h is the policy function for the housing tenure conditional on not receiving the moving shock, and s'_m is the policy function for the housing tenure conditional on receiving the moving shock.

Lender's problem. Since the mortgages are long-term contracts, the lender's problem is also a dynamic problem. The lender has to design a menu of contracts, $\Upsilon(\theta)$, depending on the state variables θ of the purchaser. As we mentioned above, a mortgage contract is a combination of a loan amount and an interest rate: $(a, r_m) \in \Upsilon(\theta)$. Note that we do not include mortgage payment m and maturity as parts of the mortgage contract, because maturity is directly determined through the age of the household, which is observable, and mortgage payment is assumed to be fixed and becomes a function of the loan amount, interest rate, and household's age.

Mortgage Payments. We first show how the mortgage payments are computed. Since the mortgages are fixed-payment mortgages, the payments are constant through the life of the mortgage. They are directly computed from the present value condition for the contract. This condition says that given the loan amount and the mortgage interest

16. In equilibrium, when there is positive home equity, selling is always better than defaulting. Thus, in case of defaulting, it means that the homeowner has negative home equity. Hence, the defaulter gets nothing from the lender.

rate, the present discounted value of the mortgage payments should be equal to the loan amount. Since the lender has full commitment on the contract, she calculates the payments as if the contract ends by the maturity. Assuming the interest rate on the mortgage is r_m and current age of the household is j, this gives us the following formulation for the per-period payments of a mortgage loan with outstanding debt $a < 0$:

$$-a = m + \frac{m}{1+r_m} + \frac{m}{(1+r_m)^2} + \cdots + \frac{m}{(1+r_m)^{J_r-j}}$$

$$m(a, r_m, j) = -\frac{1-\alpha}{1-\alpha^{J_r-j+1}}a, \text{ where } \alpha = \frac{1}{1+r_m}. \tag{10}$$

Mortgage Interest Rate. Given the mortgage payments and loan amount, the lender has to determine the mortgage interest rate. This rate is pinned down by the no-arbitrage condition. It says that given the expected mortgage payments, the lender should be indifferent between investing in the risk-free market, which is the only outside investment option for the lender, and extending the mortgage loan.

Let us denote the value of a mortgage contract with outstanding debt, a, and interest rate, r_m, offered to an age j household with income z as $V_j^{\ell}(a, z, r^m)$. Note that this function does not only represent the value of the contract at the origination, but also represents the continuation value of the contract at any time period through the mortgage life. Depending on the homeowner's tenure choices, the realized payments may change. If the household stays in the current house, the lender receives the calculated mortgage payment and the continuation value from the contract with the updated characteristics of the household and the loan amount. If the household defaults, then the lender receives $\min\{E_{\epsilon_h}[p_h(1-\varphi_l)(1+\epsilon_h)], -a\}$. If the household sells the house, the lender receives the outstanding loan amount, $-a$.

Given that the opportunity cost of the contract is the risk-free interest rate, r, and the lender is risk-neutral, the value function for the lender becomes the following:

$$V_j^{\ell}(a, z, r_m) = \left\{ \begin{array}{ll} \frac{a'}{1+r_m} - a + \frac{1}{1+r} E V_j^{\ell}(a', z', r_m) & \text{if hh stays} \\ \min\left\{E_{\epsilon_h}[p_h(1-\varphi_l)(1+\epsilon_h)], -a\right\} & \text{if hh defaults} \\ -a & \text{if hh sells} \end{array} \right\}, \tag{11}$$

where a' is the policy function to problems (3) and (6).

Then, at the time of the origination, the following no-arbitrage condition will determine the mortgage interest rate:

$$V_j^{\ell}(a, z, r_m) = -a. \tag{12}$$

TABLE 1
CALIBRATION

Parameter	Explanation	Value
σ	Risk aversion	2
ρ	Persistence of income	0.97
σ_e	Std of innovation to AR(1)	0.13
φ_s	Selling cost for a household	6%
φ_b	Buying cost for a household	2%
φ_l	Selling cost for a lender	27%
r	Risk-free interest rate–initial	2%
δ	Prob. of being an active renter	0.14
u	Unemployment shock	0.05
ϕ	Minimum down-payment	0%
β	Discount factor	0.93
γ_h	Utility advantage of ownership	0.58
ψ	Moving probability	5.23%
γ_d	Utility cost of default	−0.002

1.3 Equilibrium

Define the set of state variables for the household as Ω with a typical element (a, z, j, r_m, s), and let $\theta \in \Theta \subseteq \Omega$ be the state variables of the household by the lender.

DEFINITION 1. *Equilibrium: An equilibrium to the economy is a set of policy functions $\{c^*, a'^*, s'^*\}$, and a contract set Υ such that*

- (i) *given the feasible contract set Υ, $c^* : \Omega \times \Upsilon \to \Re$, and $a'^* : \Omega \times \Upsilon \to \Re$ solve equations (1)–(3) and (6)–(8), $s'^* : \Omega \times \Upsilon \to \{rr, rh, hh, hr, hd\}$ is a policy indicator function that solves equations (5) and (9);*
- (ii) *given the policy functions each contract $\ell \in \Omega \times \Upsilon$ solves equation (12); and*
- (iii) *no lender finds it profitable to offer another contract, which is not in the contract set, $\Omega \times \Upsilon$, that is, $\nexists (a, r_m)$ such that $V^\ell(\theta; a, r_m) > -a$ for $\forall$ $\theta \in \Theta$,with V^ℓ defined as in equation (11).*

1.4 Calibration

A set of the parameters is directly taken from the literature. For the rest of the parameters, we calibrate the economy to match some relevant data moments for the 2002–06 period. In particular, we calibrate the utility advantage of homeownership γ_h, utility cost of default γ_d, discount factor β, and exogenous moving probability ψ, to match the homeownership rate, mortgage default rate, wealth–income ratio, and moving rate of homeowners in the pre-2004 period. Table 1 presents the results of the calibration.

External Calibration. A model period is 1 year, and households live for 70 periods. So, we assume households start the economy at the age 20 and live until the age of 90. The mandatory retirement period is 25, resulting in a retirement age of 65. Utility function for the households is the standard CRRA utility function with a slight modification to account for the benefit of homeownership: $u_k(c) = \frac{((1+\gamma_k)c)^{1-\sigma}}{1-\sigma}$, $k \in \{d, r, h\}$, and γ_k is the utility advantage of being an inactive renter ($k = d$), and active renter ($k = r$) , or homeowner ($k = h$). We normalize $\gamma_r = 0$, and calibrate γ_h and γ_d internally. We set the risk-aversion parameter, σ, to 2.

For the income process before retirement, we set $\rho = 0.97$ and $\sigma_\varepsilon = 0.13$ to be consistent with Storesletten, Telmer, and Yaron (2004). We approximate this income process with a 21-state first-order Markov process using the discretization method outlined in Adda and Cooper (2003). For the retirement income, we assume $\lambda = 0.35$ and $\eta = 0.2$, meaning the retiree receives 35% of the income at the time of retirement plus 20% of the mean income in the economy. For the unemployment income, we set it to the lowest income shock for each age. This corresponds to around 40% of the average income of the household.[17] The probability of unemployment is set to 0.05 to match 5% average unemployment rate of the United States.

The probability of becoming an active renter, while the household is an inactive renter, is set to 0.14, to capture the fact that the bad credit flag stays, on average, 7 years in the credit history of the household. Consistent with the estimates of Gruber and Martin (2003), we set selling cost to $\varphi_s = 6\%$ and buying cost to 2%.[18] The initial distribution of the income is assumed to be the stationary distribution. Consistent with the estimates of Campbell, Giglio, and Pathak (2011), we set the selling cost for a lender to 27% of the house price. Following Gourinchas and Parker (2002), the initial distribution of the wealth-to-income ratio is assumed to be log-normal with mean $\mu_{w/y} = -2.794$ and standard deviation $\sigma_{w/y} = 1.784$.

The annual risk-free interest rate in the first steady state is set to $r = 2\%$. The minimum down-payment is assumed to be 0%. Rental price is normalized to 0, and we solve for the house price that equalizes the fixed supply of owner-occupied units in both steady states. We set the initial house price equal to three times annual average household income, consistent with the estimates of National Association of Realtors and Zillow. Finally, following Garriga and Schlagenhauf (2009), we set the i.i.d. house price shock to take seven values: $\epsilon_h \in \{-0.20, -0.1, -0.01, 0.06, 0.12, 0.18, 0.23\}$ with corresponding probabilities $\pi_{e_h} = \{0.0388, 0.2046, 0.4917, 0.1437, 0.0670, 0.0347, 0.0195\}$.

Internal calibration. The remaining parameters of the model are calibrated internally to jointly match some of the key moments of the data. We use the initial steady state in which the risk-free interest rate is set to 2% to calibrate the parameters. These parameters are the utility advantage of owning a house γ_h, utility cost of defaulting γ_d, discount factor β, and moving probability ψ. We internally calibrate these parameters to jointly match the following data moments: homeownership rate of 66% as reported in Census data, foreclosure rate of 1.7% as reported by Mortgage

17. This assumption also makes sure that employment is always preferred to unemployment.

18. Similar numbers are used in Li and Yao (2007), Chatterjee and Eyigungor (2014), and Corbae and Quintin (2014).

TABLE 2

INITIAL STEADY-STATE RESULTS

Statistic	Data	Model
Homeownership rate	66%	66%
Wealth–income ratio	3.5	3.5
Moving rate owners	8.0%	8.0%
Foreclosure rate	1.7%	1.7%
Price-to-income ratio	3.0	3.0
Average down-payment ratio	21.1%	20.6%
Combined loan-to-value ratio	58.4%	60%
Share of mortgage holders	66.0%	53.3%

NOTES: Homeownership rate, foreclosure rate, moving rate, and wealth–income ratio are matched to the data. Homeownership and moving data are from Census, foreclosure rate is from Mortgage Bankers Association, average down-payment is from the Monthly Interest Rate Survey of FHFA, price-to-income ratio is from the National Association of Realtors and Zillow, combined loan-to-value ratio is from Flow of Funds Account, and the share of mortgage holders is from 2004 Survey of Consumer Finance. Foreclosure rate is computed as the share defaulters among mortgage holders. Down-payment ratio is computed as the average down-payment among the buyers. Combined loan-to-value ratio is the ratio of average outstanding mortgage debt of the mortgage holders to the house price. Share of mortgage holders is the share of mortgage holders among homeowners.

Bankers Association, average wealth-to-income ratio of 3.5 consistent with the estimates of Heathcote, Perri, and Violante (2010), and homeowners' moving rate of 8% as reported in Census data.

2. STEADY-STATE ANALYSIS

Table 2 shows the success of the model in matching some aspects of the data. The model matches the homeownership rate, wealth–income ratio, foreclosure rate, and moving rate of the homeowners quite well since the parameters are chosen to deliver these results. However, the model also matches the data quite well along several other untargeted dimensions. The average down-payment in the model is 20.6%, which is similar to the average down-payment of 21.1% in the data during the 2001–05 period. Combined loan-to-value (LTV) ratio in the model is 60%, again very close to its data counterpart, 58.4%. The share of mortgage holders among homeowners in the model is 53.3% whereas it is 66% in the data.

The individuals in the model make three important choices regarding the housing market. When to buy the house, how much loan to obtain to buy the house, and when and how to exit homeownership. For all these decisions, wealth, income, and the level of home equity of the individuals should be important determinants. Figure 1(a) displays renting versus owning choice in the model as a function of wealth and income. Keeping household income constant, as wealth increases the household becomes more likely to choose owning over renting. Similarly, keeping the wealth constant as the income increases the household becomes more likely to own a house instead of renting.

Whenever a homeowner with a mortgage chooses to rent in the next period, she has two options: sell or default on the mortgage. In case of selling, the household receives

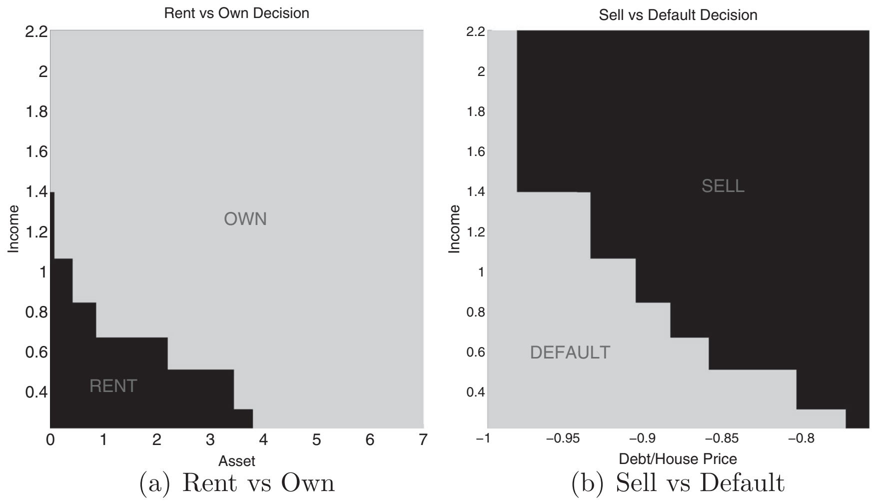


FIG. 1. Tenure Decisions as a Function of Income and Wealth.

NOTE: The figure shows the choice of tenure for a renter and a mover as a function of income and asset. The choices are depicted for an individual at the age of 35.

the selling price net of capital gain/loss and transaction costs. However, she has to pay the outstanding mortgage debt back to the lender. Given that the transaction cost is positive, and there is a risk of capital loss, it is possible that the household has negative equity in the house.[19] As a result she might choose defaulting over selling. Figure 1(b) displays selling versus defaulting choice as a function of income and mortgage debt. First of all, for sufficiently small amount of debt, the household never defaults. This is because in this region the household has always positive equity in her house. As debt increases it is more likely that the household has negative equity, which triggers default. Notice that even when the household has negative equity, she might not choose to default as default is costly due to the utility costs of defaulting and exclusion from the housing market. As a result, there are some states of the world in which the household sells the house although she is underwater and pays the difference through her wealth. In fact, with the current calibration, the model generates 9% of mortgage holders in negative equity at the steady state. However, out of these mortgage holders with negative equity, only 5% choose to default, and the rest choose to stay in the house. Among the movers with negative equity, 15% choose to sell the house rather than default.

At this point, it is important to emphasize that in the steady state the only triggering factors for foreclosures are the income and the moving shocks since there is no aggregate house price movement. Remember that the minimum down-payment in the initial steady state is 0. Moreover, selling a house requires paying some transaction

19. We define home equity as the house price less of the mortgage debt and transaction costs.

costs (6% in the current calibration). So, it is possible that households with mortgage loans higher than 94% of the house price are effectively underwater if we consider the house price as the net amount households receive after the transaction costs. However, without income or moving shocks, these households may not choose to default. As they receive an adverse income shock, they might not afford the periodic mortgages and should decide to default on their mortgages. Similarly, if they receive a moving shock, they are forced to quit the homeownership, they might find it optimal to default rather than to sell the house at a loss. To further quantify the effect of these shocks, using the steady-state policy functions and household distribution, we decompose the fraction of foreclosures due to income and moving shocks. Shutting down the moving shocks decreases the foreclosure rate from 1.7% to 1.2%, whereas shutting down the income shocks (including the unemployment shock) decreases the foreclosure rate 1.7–0.7%. So, around two-thirds of the foreclosures are due to income shocks. While income and moving shocks are the only triggering events for foreclosures in the steady state, as we will see later, if the economy is hit by an unexpected shock and the house price drops, then the change in the house price becomes the main force behind the foreclosures.

An important feature of the model is the endogenous mortgage contract terms. This feature of the model plays a crucial role in matching some features of the data as explained in Guler (Forthcoming).[20] Figure 2 shows how the mortgage premium responds to the down-payment fraction for different income levels. As a reflection of Figure 1(b), as the down-payment decreases, the mortgage debt increases, which increases the default probability. This, in turn, is reflected as a higher mortgage premium charged by the lenders as observed in Figure 2. Another observation we can derive from Figure 2 is the effect of income on the premium. As we know from Figure 1(b), lower income implies higher likelihood of default for the same amount of mortgage debt. Thus, we expect the premium to increase as the income decreases.

2.1 Steady-State Comparisons

Our baseline economy is in steady state with the risk-free interest rate set to 2%, the unemployment rate set to 5%, and the minimum down-payment set to 0%. Then, we hit the economy with three different shocks. In each case, the shock is assumed to be permanent and unexpected. We analyze four cases. In the first case, the economy is hit by an interest rate shock (the risk-free interest rate increases from 2% to 3%).[21] In the second case, we shock the economy with a financial shock; the minimum down-payment requirement increases from 0% to 20%. In the third case, the unemployment rate increases from 5% to 6%. Finally, we study a case

20. Guler (Forthcoming) also shows the life-cycle implications of this model, and we refer the reader to that paper for a discussion of these features of the model.

21. Haubrich, Pennacchi, and Ritchken (2011) estimate that 5-year real interest rates increased around 1.5 percentage points and 10-year real interest rates increased around 0.5 percentage points between 2005 and 2008. We use average of these increases.

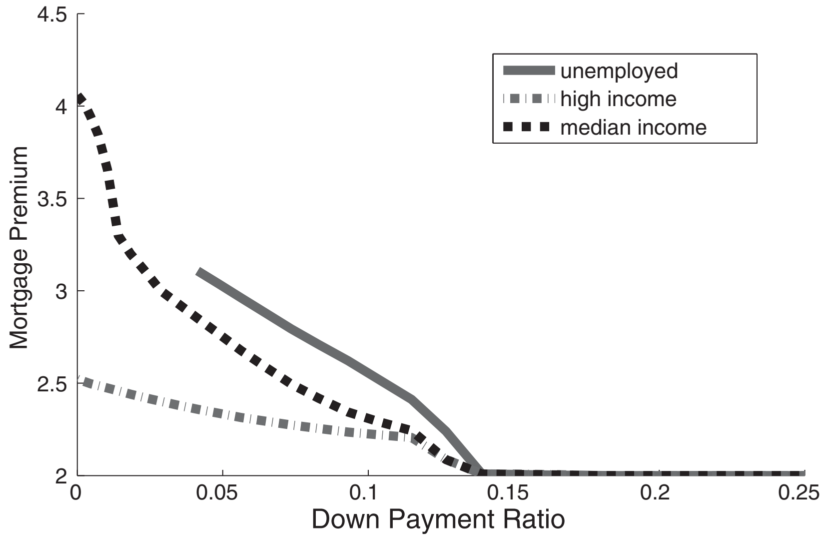


FIG. 2. Mortgage Interest Rate.

NOTES: The figure shows equilibrium mortgage interest rate charged by the lenders to an individual with different income levels at the age 35 as a function of the down-payment. In the model, we impose a cap on the mortgage interest rate, which is 7%. No household gets a mortgage with such an interest rate in the model. So, this practically imposes an endogenous borrowing limit for the household as can be seen for the unemployed.

TABLE 3

STEADY-STATE COMPARISONS

	SS1	SS2	SS3	SS4	SS5
	r=2%	r=3%	r=2%	r=2%	r=3%
	λ=0%	λ=0%	λ=20%	λ=0%	λ=20%
Statistic	u=5%	u=5%	u=5%	u=6%	u=6%
Homeownership rate	66%	66%	66%	66%	66%
Price-to-income ratio	3.0	2.77	2.77	2.92	2.49
Foreclosure rate	1.70%	1.49%	0%	0.74%	0%
Down-payment ratio	20.6%	22.5%	32.6%	23.4%	33.0%
Mortgage premium	0.43%	0.37%	0%	0.19%	0%
Mortgage holders	53.3%	47.2%	48.1%	53.0%	42.2%
Debt-to-income ratio	2.5	2.2	1.9	2.5	1.8

NOTES: This table compares the steady states for different risk-free interest rate, minimum down-payment requirement, and unemployment shock. SS1 shows the results for the benchmark economy. SS2 shows the results when the risk-free interest rate increases to 3%. SS3 shows the results when the minimum down-payment requirement increases to 20%. SS4 shows the results when unemployment increases to 6%. Finally, SS5 shows the results when all these changes happen simultaneously.

where all the three shocks are realized together. We assume that in all steady states homeownership rate is fixed at 66%, and we solve for the house prices endogenously.

Table 3 presents the comparison of the steady states along several important dimensions. In the table, the second column (SS1) shows the results for the initial steady state. In the third column (SS2), we present the results when the economy is hit by only the risk-free interest rate shock. As a response, the house price declines by around 8%. The basic mechanism is that the increase in the risk-free interest rate increases the cost of financing a house through mortgages since it also increases the mortgage interest rate. The fraction of mortgage holders decreases from 53.3% to 47.2%. The increase in the cost of mortgages decreases the demand for houses. Since we fix the homeownership rate to 66%, the house price declines.

However, in the new steady state while the house price is lower, the mortgage default rate is also lower. It declines to 1.49%. As the economy moves from the low-interest-rate state to the high-interest-rate state, mortgage payments become larger for a given loan amount (due to higher risk-free interest rate). This pushes the foreclosure rate up. However, there is also an opposing effect. In the high-interest-rate regime, households accumulate wealth at a faster rate, and they are able to put larger down-payments (average down-payment increases from 20.6% to 22.5%) to avoid the higher cost of borrowing (due to higher interest rates). This, in turn, means households have lower leverage levels (average outstanding debt-to-income ratio decreases from 2.5 to 2.2), which decreases the likelihood of default. The current calibration of the model suggests that the second effect dominates, and we observe a lower foreclosure rate in the second steady state.

In the third steady state (SS3), the risk-free interest rate stays at 2%, the unemployment rate stays at 5%, but the minimum down-payment rate increases from 0% to 20%. The decline in the house price in this steady state is the same as in the interest rate shock (around 8%). Again, the higher cost of mortgages decreases the fraction of mortgage holders to 48.1%, which decreases the demand for owner-occupied units and their prices. The foreclosure rate is almost zero, since with 20% down-payment it is unlikely to have negative home equity even in the presence of transaction costs and idiosyncratic house price shocks. Notice that with higher minimum down-payment requirement, the average down-payment in the economy increases to 32.6%, and debt-to-income ratio decreases to 1.9. So, households never choose to default on their mortgages, and mortgages essentially become risk free. The mortgage premium drops to 0%. The shock to the minimum down-payment requirement reveals the negative relationship between house price and down-payment ratio, which implies a positive relationship between house price and LTV ratio. This is consistent with the empirical findings of Duca, Muellbauer, and Murphy (2011), who document the positive relationship between house price/rent ratio and LTV ratio in both short run and long run.

In the fourth steady state (SS4), the economy moves from 5% unemployment rate to 6% unemployment rate.[22] All the other parameters are assumed to stay the same as in SS1. As the income becomes riskier and permanently lower, the demand for a rigid asset (housing) declines, and as a consequence, the price of a house declines by 3% (from 3 to 2.92). Again, due to the increased risk, lenders

22. This exercise not only captures a riskier income profile but also includes a decrease in the expected income. We calibrate the unemployment rate so that it results in a drop of 5% of the average income as we observe in the data. This gives us 6% unemployment rate.

require higher mortgage premium, and this makes larger loans less affordable. So, again, the average down-payment ratio increases to 23.4%. On the other hand, the increase in the unemployment rate makes households more riskier and more likely to default. However, with the current calibration, the effect of a decrease in the house price together with an increase in the average down-payment dominates, and the foreclosure rate decreases to 0.74% in the new steady state.

Finally, when we apply all the shocks together, the house price declines around 17% from 3.0 to 2.49. As the minimum down-payment is 20% in this new economy, the foreclosure rate is 0% and the average down-payment is 33% (as the ones with smaller than 20% are not allowed any more). The higher response is through the combination of all channels discussed above. Higher interest rate and higher minimum down-payment make mortgages less affordable. Higher income risk makes households riskier and forces the lenders to increase the mortgage premium, which again decreases the demand for mortgages. The fraction of mortgage holders drops to 42.2%. These forces a decrease in the demand for houses, which in turn results in a decrease in the house price. However, the foreclosure rate is 0% due to the 20% minimum down-payment requirement, which makes mortgages risk free for the lenders.

Three assumptions of the model are worth mentioning as a limitation of our analysis. These assumptions are fixed supply of owner-occupied units, fixed supply of total housing stock, and fixed rental price. In this study, we focus only on the effect of the shocks on the housing demand and their effect on the house price only through the changes in the housing demand. However, it is natural to expect the supply of owner-occupied units, the supply of total housing stock, and rental prices to react to the shocks. With flexible supply of owner-occupied units, one can expect that the change in the house price will be dampened, since the shocks will decrease the supply of owner-occupied units, which will absorb some of the decrease in the house price. The same is also true with flexible supply of housing stock. However, the effect of flexible rental prices is not that clear. It might depend on how one models the supply of rental units. If it is fixed, then the shocks increase the demand for rental units, and their prices, in turn. The increase in the rental prices will dampen the decrease in the demand for owner-occupied units and house prices. However, with flexible supply of rental units, it might be possible to have a decrease in the price of rental units, which in turn amplifies the decrease in the demand for owner-occupied units and house prices.

3. TRANSITIONAL DYNAMICS

Comparing just the steady states masks important dynamics during the transition. To better understand the dynamic implications of different kinds of shocks, we also analyze the transition between the two steady states. The main difference between the steady-state dynamics and the transitional dynamics comes from the fact that in the steady state each household and lender make their housing and mortgage plans according to their steady-state environment. However, in the transitional exercise, households who made their housing and mortgage choices with the assumption of the initial steady-state expectations revise their expectations after the shock is realized.

The nature of the exercise is the following. We first assume that the economy is in the initial steady state as in the benchmark economy at time 0. However, at time 1, the economy is hit by an unexpected and permanent shock. Then, we solve the transition of the economy from the initial steady state to the final steady state with perfect foresight. As in the steady-state analysis, we assume that during the transition, the homeownership rate is fixed at 66% and rental price is set to 0.[23]

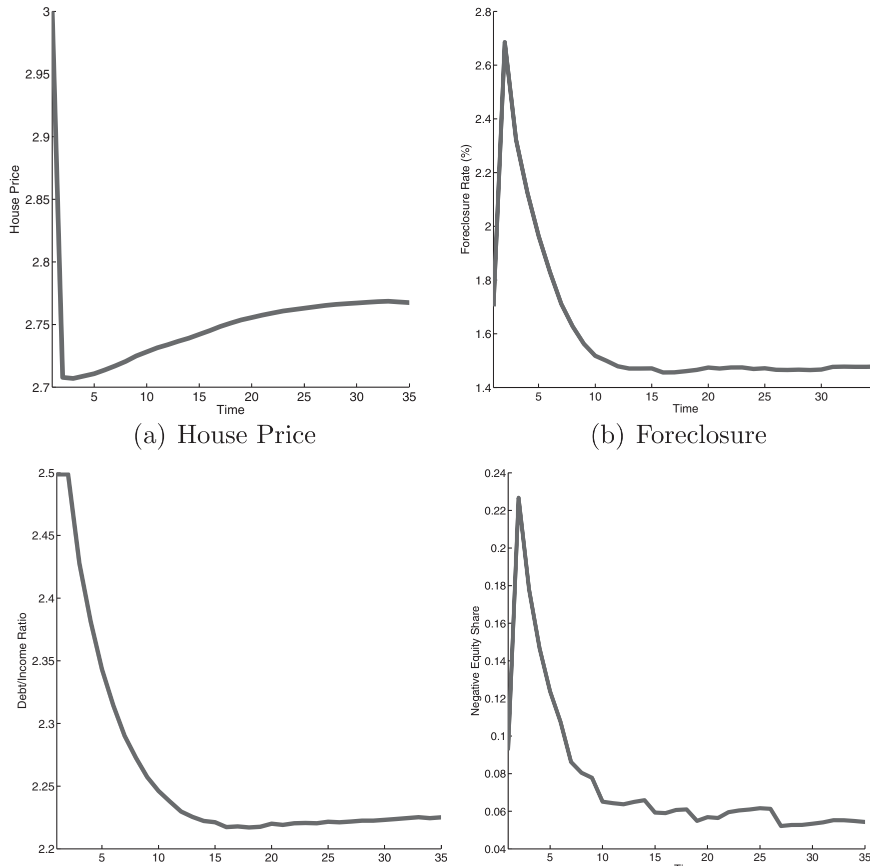
In the following transition exercises, we separately study the transition in response to an increase in the risk-free interest rate, an increase in the minimum down-payment requirement, and an increase in the unemployment rate. All three shocks are permanent and unexpected. Since it is more likely that all these shocks happened together during the latest financial crisis, we also study a scenario where all three shocks affect the economy together. In the first transition exercise, we provide extra information about various variables. For the other transition exercises, we only depict prices and foreclosures (our key variables of interest for this study) since the dynamics of other variables look similar for different exercises.[24]

Transition with only the interest rate shock

In response to a permanent and unexpected rise in the risk-free interest rate (from 2% to 3%), the demand for homeownership decreases as the cost of mortgages increases. Higher cost of mortgages decreases the demand for houses and decreases the house price. Different than the steady-state dynamics, now, some households are caught up with larger mortgage debts that were acquired with the assumption of initial steady-state house price level. As can be seen in Figure 3(d), the share of mortgage holders with negative equity increases from 9% to 23% on the impact of the shock. Some of these households default on their mortgages, which increases the effective supply of houses. Moreover, since defaulters are excluded from the mortgage market, for a while, the effective demand also decreases. Thus, the house price needs to decline sharply to the levels below the second steady state to achieve the homeownership rate of 66%. After the first fall, the house price increases gradually to the second steady state level as the effective supply decreases, and effective demand increases as fewer households default.

23. The same critics mentioned in Section 2.1 regarding the implications of these assumptions also apply here. So, the results should be considered with these caveats.

24. One other drawback of the transition exercises is the omission of the response of the lenders to the shocks on impact. In the initial steady state, lenders originate the mortgage loans to make zero profit. However, with the realization of the unexpected shock, lenders make losses on these loans, and since we do not model the lender balance sheet we do not carefully treat how the lenders respond to these shocks. With the current calibration, on the impact of the shocks, these losses range in between 0.2% and 2.4% of average income in the model. We assume that these lenders are the international investors, and they cover their losses with their additional wealth. If we further assume these investors face no financing constraint and they are risk neutral, then the reduction in their wealth should have no effect on the newly generated mortgage loans.



(a) House Price (b) Foreclosure

(c) Outstanding Debt (d) Negative Equity Share

Fig. 3. Transition in Response to Interest Rate Shock.

Notes: The figures show the evolution of the house price, foreclosure rate, outstanding debt-to-income ratio of mortgage holders, and share of mortgage holders with negative equity in response to an unexpected and permanent increase in the risk-free interest rate from 2% to 3%.

Figure 3(a) shows the evolution of the house price during the transition. Remember that the house price drops by 8% (from 3 to 2.77) from the initial steady state to the final steady state when hit by the assumed risk-free interest rate shock. However, with the transition exercise, we see that, on impact, the house price drops even further (from 3 to 2.70, a 10% drop).

An important difference between the steady states and the dynamics during the transition arises when we analyze the foreclosure rates. As we mentioned earlier, the foreclosure rate drops from 1.7% to 1.49% from the initial steady state to the final steady state. However, as shown in Figure 3(b), during the transition, at its peak, the foreclosure rate increases sharply compared to the initial steady-state level (from 1.7% to 2.7%). The results from the steady state and the transition analysis reveal that what matters for the foreclosure rate is the change in the house price, not the levels. The house price is around 8% lower in the final state compared to the initial steady state. Despite the significant difference in the house price levels between the two steady states, the average foreclosure rate is lower in the second steady state. The reason is that at the final steady state, since lenders and households respond to the changes in the environment, equilibrium mortgage contracts change, and the percentage of homeowners who have negative equity becomes lower than the initial steady state (9% versus 5%). Whereas during the transition, households with low levels of home equity end up with negative equity due to the significant and unexpected drop in the house price. As the share of mortgage holders with negative equity increases, the foreclosure rate increases on impact. However, households adjust their portfolios during the transition, and after a while, the foreclosure rate reaches its new steady-state level.

The initial spike in the foreclosure rate is due to the households who find themselves in negative home equity and strategically choose to default. However, the higher foreclosure rate after the first period compared to the final steady state is due to two reasons. First, it is due to the longer term mortgages. Not every household adjusts her mortgage portfolio on impact due to the transaction costs involved in house sale and purchase. As shown in Figure 3(c), average outstanding debt-to-income ratio of mortgage holders gradually declines from 2.5 to its final steady-state level of 2.2. Second, households tend to adjust their portfolio when they receive income and moving shocks. Although the share of mortgage holders with negative equity increases from 9% to 23% on the impact of the shock, not all of them default immediately, reflecting the utility advantage of owning and high transaction costs. As explained in Section 2, homeowners consider defaulting especially when they receive income and moving shocks. However, since the house price is still lower than the final steady-state level, and they have higher amount of mortgage debt, these households have higher incentives to default along the transition compared to their incentives in the final steady state. Hence, it takes some time for the foreclosure rate to achieve its final steady-state level of 1.49%.

Transition with only financial shock

In our model, the lender is a risk-neutral agent and has unlimited financing opportunities at the given risk-free interest rate. However, with the crisis, lenders had difficult times in financing themselves. There are several mechanisms, such as decline in collateral values and increase in haircuts, that made the borrowing difficult for financial companies to raise funds to give loans. Besides, there was an urgency to deleverage, which required selling assets on their book without issuing sizable loans. In addition, the uncertainty about the financial health of the lenders made things even worse. These mechanisms do not exist in our model. To simulate the effects of financial turmoil we exogenously force lenders in our model to require a 20% minimum down-payment unexpectedly and permanently.

Figures 4(a) and 4(b) show how house prices and foreclosures are affected from this shock. First of all, a comparison of the steady states reveals that the house price drops by 8% (from 3 to 2.77), and foreclosures decrease from 1.7% to 0% due to a high minimum down-payment requirement. However, during the transition the dynamics are quite different. A 20% permanent and unexpected increase in the down-payment requirement causes around a 22% decline (from 3 to 2.35) in the house price on impact. The main reason is that a higher minimum down-payment requirement imposes a limit on the affordability of the houses through mortgages for potential home buyers. Consequently, once the shock is realized, the number of potential buyers declines, and the demand for houses declines. The fraction of buyers in the first steady state is 5.1% of all households. On the impact of the shock, it decreases to 4%, and eventually reaches to its final steady-state level of 4.7%. Over time, people accumulate extra assets and overcome the constraint. But as the young agents cannot easily accumulate that much asset, the house price does not recover to the initial level even in the long run. Foreclosures sharply rise to around 3.6% on impact, and then decline to very low levels around zero. Very low levels of foreclosures in the second steady state is due to the larger down-payment requirement, which makes the probability of experiencing negative home equity almost zero and makes mortgages essentially risk free.

Transition with only unemployment shock

During the financial crisis, the U.S. economy experienced a deep recession and shrank around 5%. Despite the size of the recession, it can be thought that it should potentially have a small affect on the house price and the foreclosure rate since estimated income elasticity of housing is small (see Carliner 1973). One critical point, we believe, is that not every household is affected in the same way. While some incurred only small losses in their income, some got unemployed, which is a small probability but a very costly event. Hence, it is likely that a rise in unemployment can have quantitatively large and significant effects on house prices and foreclosures.

To understand the effects of unemployment and income risk, we run the following experiment. We assume that when the economy is in its initial steady state, it is hit by an unexpected unemployment shock, and the unemployment rate increases from 5% to 6% immediately and permanently. From the steady-state comparisons, we know that this shock decreases the house price by 3% (from 3 to 2.92). However, on impact, due to the unexpected nature of the shock and the feedback mechanism between foreclosures and the house price, the effect is larger: the house price drops by 4% (from 3 to 2.87; see Figure 5(a)). Although the foreclosure drops from 1.7% to 0.74% between the steady states, during the transition it spikes to the levels around 2.1% (see Figure 5(b)). Remember that households either default strategically due to the house price movements or they default due to some trigger events, like income or moving shocks. An increase in the unemployment probability increases the probability of receiving the worst income shock and forces households to default more frequently. But as the economy converges to a high unemployment steady state, lenders respond to the increase in the unemployment shock by increasing the mortgage premium and by making mortgages less affordable and less available to the households. This

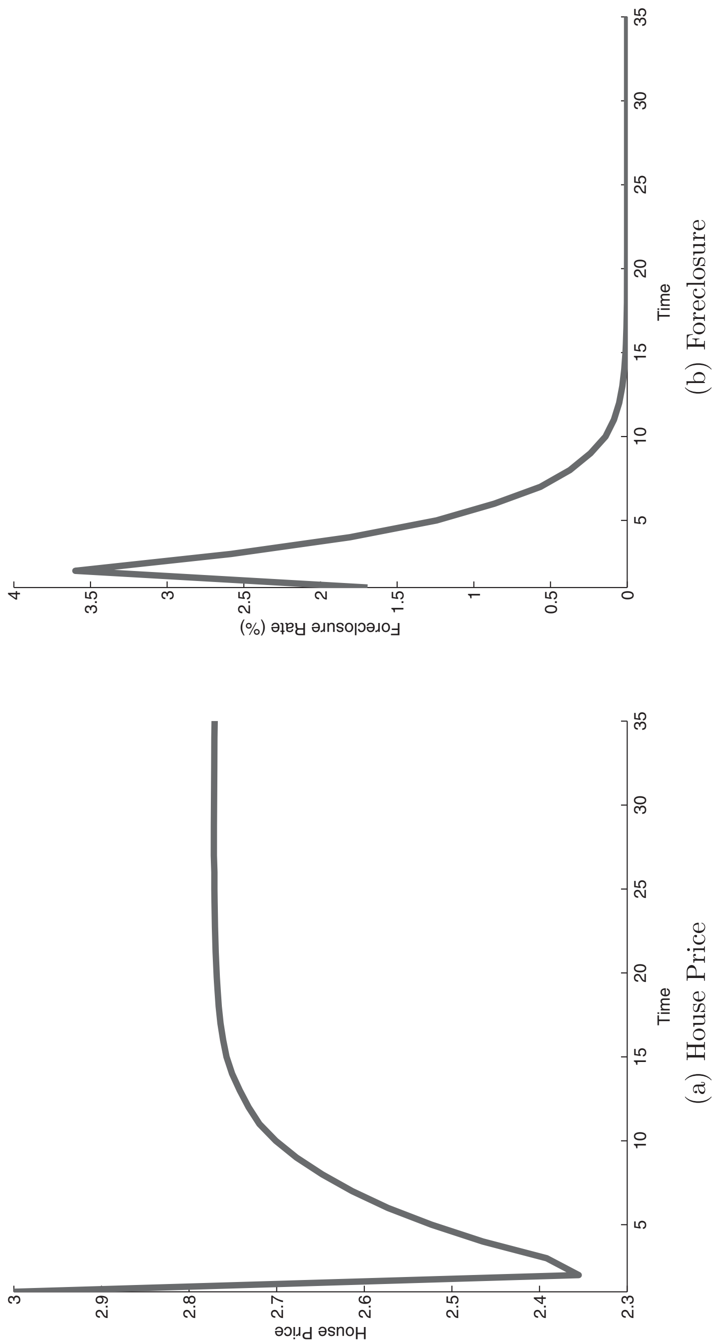


Fig. 4. Transition in Response to Financial Shock.

Notes: The figures show the evolution of the house price and the foreclosure rate in response to an unexpected and permanent increase in the minimum down-payment requirement to purchase a house from 0% to 20%.

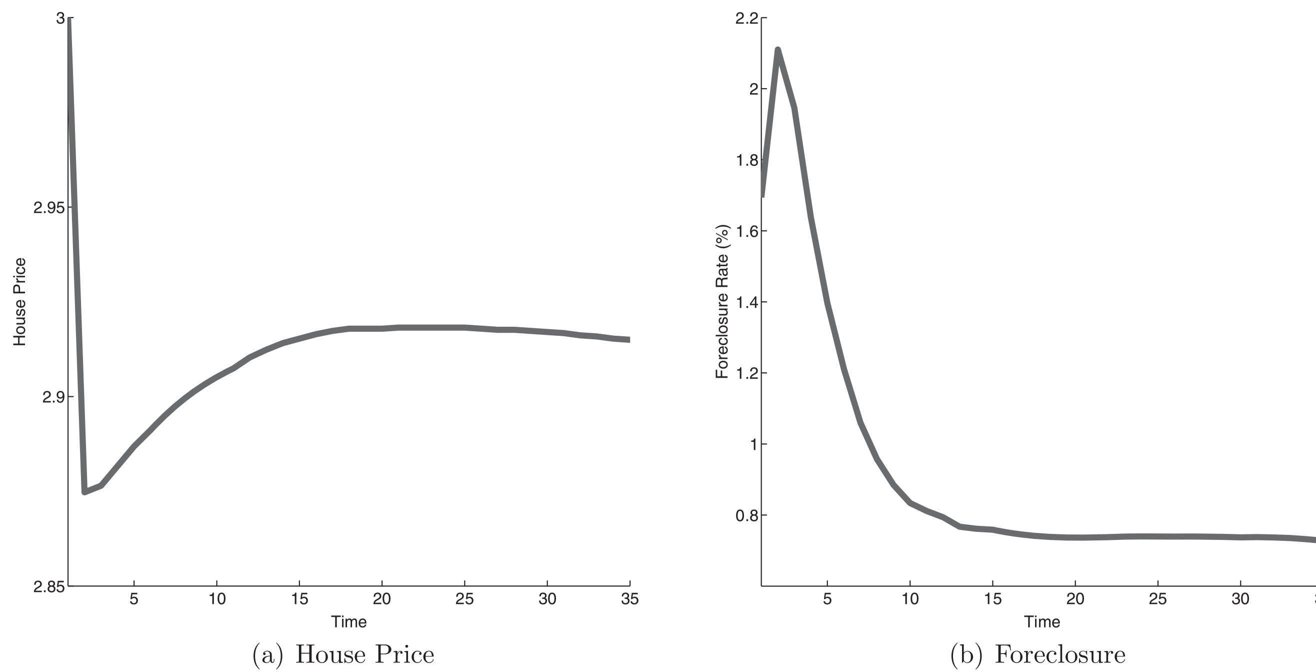


FIG. 5. Transition in Response to Unemploygment Shock.

NOTES: The figures show the evolution of the house price and the foreclosure rate in response to an unexpected and permanent increase in the unemployment rate from 5% to 6%.

response of the lenders increases the average down-payment in the economy and gradually decreases the foreclosure rate to its final steady-state levels.

Transition with all three shocks together

In the previous simulations, we studied the effects of an interest rate shock, an unemployment shock, and a financial shock separately. However, in reality all of them could have happened together during the crisis. In particular, we study the transition where the interest rate increases from 2% to 3%, the minimum down-payment requirement increases from 0% to 20%, and the unemployment rate increases from 5% to 6%.

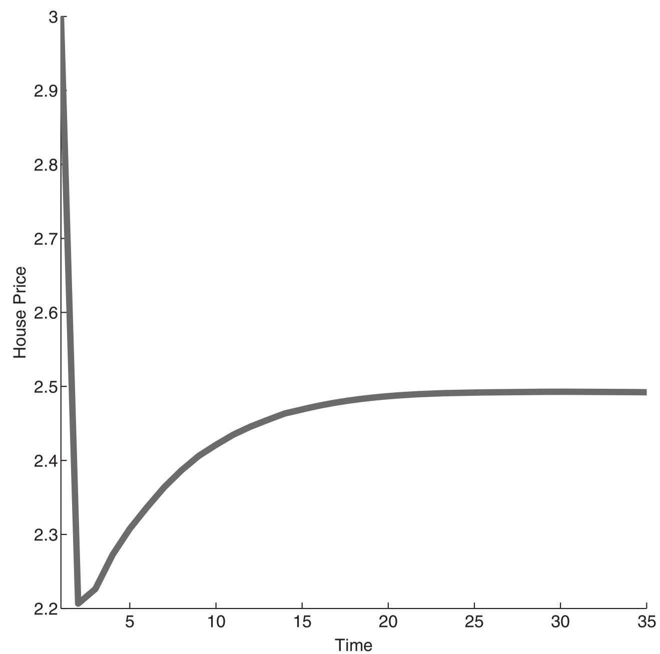
Figure 6(a) plots the path of the house price, and Figure 6(b) plots the path of the foreclosure rate when all shocks hit the economy together. As would be predicted, the response of both house prices and foreclosures are larger. The house price declines around 27% on impact (from 3 to 2.2). The second steady state of the house price is around 17% lower than the first steady state (from 3 to 2.49). The foreclosure rate initially jumps to the levels around 4.5%, and gradually declines to the levels of the final steady state, 0%. Our results show that these three shocks all together can provide a relevant explanation to the large responses of house prices and foreclosures during the latest financial crisis.

3.1 Feedback Mechanism between Foreclosures and House Prices

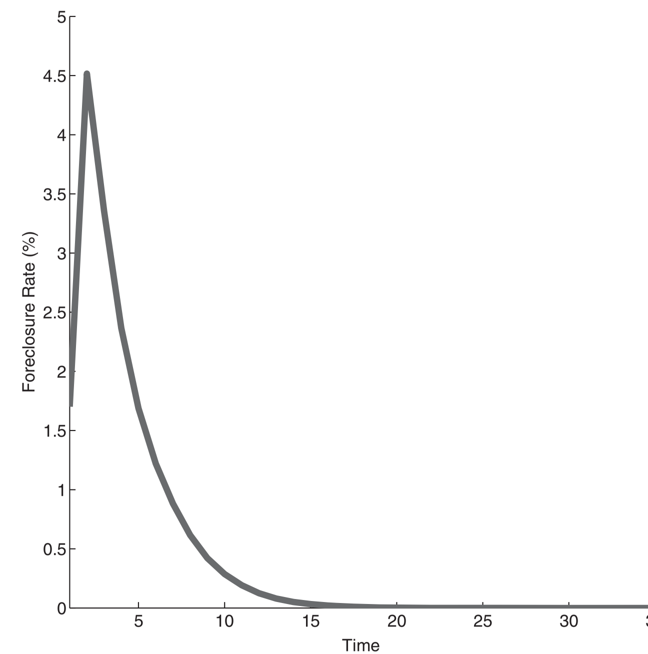
The main reason behind the sharp decline of the house price on impact of the shocks is the feedback mechanism between the foreclosures and the house price. A fall in the house price initiates an increase in the foreclosure rate since some homeowners who end up having negative equity in their houses choose to default. This increases the effective house supply. That extra supply pushes the house price even lower, which in turn increases the incentives to foreclose due to more people ending up with negative equity. Moreover, households who choose to default are excluded from the market. This fact decreases the effective demand for houses, which in turn decreases the house price even further. As a consequence of these feedback mechanisms the house price falls sharply after the shock. When the house price dips, it starts gradually to appreciate to its new steady-state value. As the house price starts to appreciate, the foreclosure rate starts to decline.

To quantify this feedback mechanism, we follow two different routes. In a simple way, one can think of the additional drop in the house on the impact of the shock compared to its change between the steady-state levels as the contribution of the feedback mechanism generated by the foreclosures. If we follow this route, this will imply that in the case of all three shocks, foreclosures cause the house prices to drop from 3 to 2.2 on impact instead of from 3 to 2.49 between steady states. This means that foreclosures generate around 60% further decline in the house price (17% versus 27% decline).

As a second alternative, following Chatterjee and Eyigungor (2014), we recalibrate our economy with the assumption of no foreclosures. One can think of this economy as the one with infinite utility cost of defaulting (i.e., $\gamma_d = -1$). We recalibrate the ownership premium, discount factor, and moving probability for his economy to



(a) House Price



(b) Foreclosure

Fig. 6. Transition in Response to All Three Shocks.

Notes: The figures show the evolution of the house price and the foreclosure rate in response to an unexpected and permanent increase in the risk-free rate from 2% to 3%, an increase in the minimum down-payment requirement from 0% to 20% and an increase in the unemployment rate from 5% to 6%.

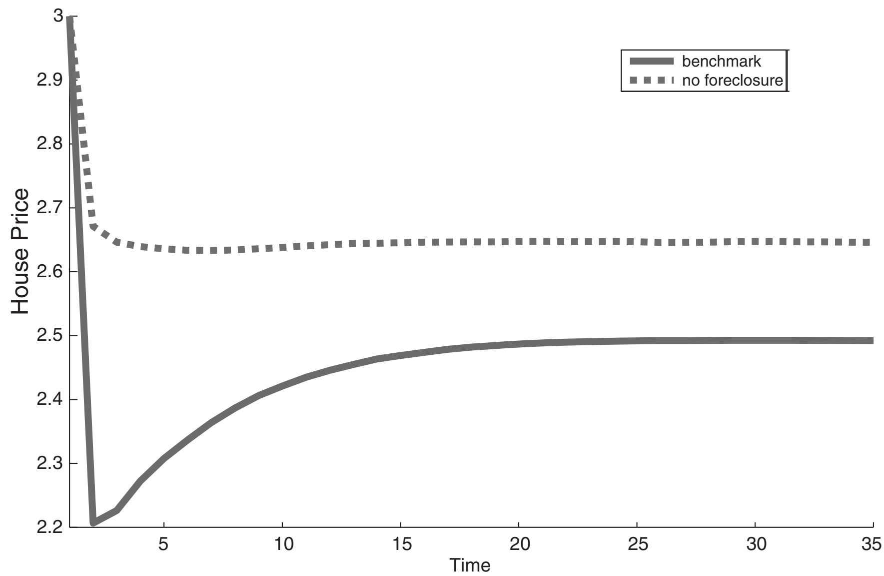


FIG. 7. Transition without Foreclosures.

NOTES: The figure shows the comparison of the evolution of house prices in response to an unexpected and permanent increase in the risk-free rate from 2% to 3%, an increase in the minimum down-payment requirement from 0% to 20%, and an increase in the unemployment rate from 5% to 6% between the benchmark model and the model without foreclosures.

match the homeownership rate, wealth–income ratio, and moving rate of homeowners. This calibration results $\gamma_h = 0.69$, $\beta = 0.92$, and $\psi = 5.7\%$. Then, we analyze the response of this economy to all the three shocks as in the benchmark model. Figure 7 shows the comparison of the evolution of house prices between the benchmark economy and the one without foreclosures. Three observations are in order. First of all, across the steady states, the presence of the foreclosures generates 47% further drop in the house price (a decrease from 3 to 2.65 versus from 3 to 2.49). Second, on impact, the drop of the house price in the economy without foreclosures is from 3 to 2.67, while it is from 3 to 2.2 with foreclosures. This means, on impact, the presence of foreclosures results in almost a 150% further drop in the house price. Finally, the presence of foreclosures generates a larger drop in the house price on the impact of the shock compared to its final steady-state level. However, in the model without foreclosures the house price drops gradually to its final steady-state level; that is, we do not observe a swing in the house price. These observations show how strong the feedback mechanism between the foreclosures and the house price can be.

4. POLICY EXPERIMENTS

In the remaining parts of the paper, we study how two specific policies would affect the transition dynamics. In particular, we study an *ex post* monetary policy and an *ex ante* macroprudential policy. As a monetary policy, we consider the Fed's low interest rate policy. As a macroprudential policy, we consider imposing a higher minimum down-payment requirement. We study how the model dynamics would change during the transition in response to these two policies.

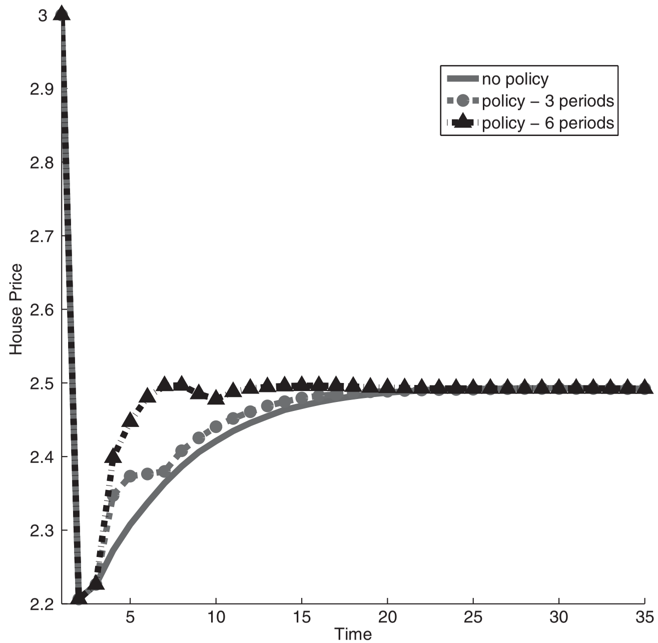
4.1 Monetary Policy

As a response to the financial crisis, the Fed decreased the funding rate. In addition to that policy, the Fed also stated that the policy rate will stay low for a prolonged period of time. As of now, in the policy statements, it is mentioned that the policy rate would be low until mid-2015. In this part of the paper, we analyze the potential implications of this policy on housing prices and foreclosures along the transition. In particular, we assume that in response to the shocks that we studied above, the Fed lowers the risk-free interest rate to 0.5% and commits to this policy for a predetermined period of time. Consequently, agents in our economy know that the low interest rate policy of the Fed will be transitory. We also study how the length and timing of the Fed's low interest rate policy affect the transitional dynamics. In particular, we first assume that the policy takes place in two periods after the shocks are realized and continues either for three or six periods (a period corresponds to a year). In the next step, we also analyze the timing of the policy by assuming that the policy takes place as soon as the shocks are realized. In all these experiments, we analyze the effectiveness of the monetary policy in response to all three shocks.

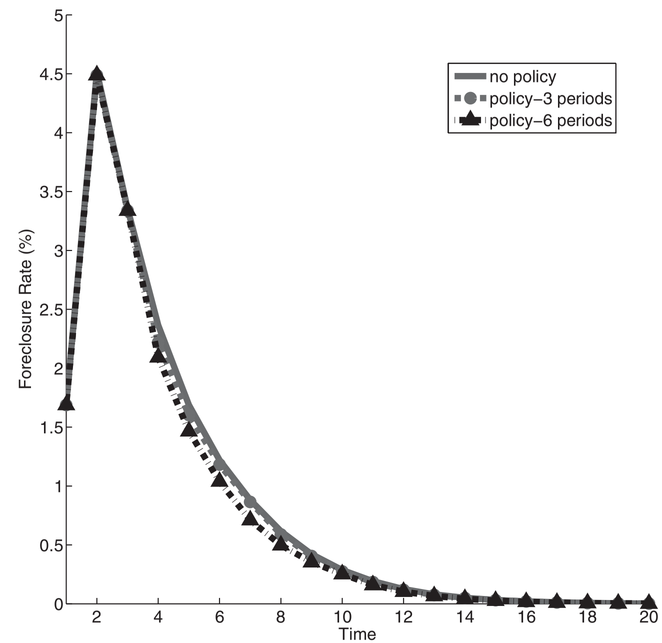
In Figures 8(a) and 8(b), we plot the responses of the house price and the foreclosure rate during the transition when the Fed implements the above policy in response to all three shocks. We assume that two periods after economy is hit by the shocks, the Fed lowers the risk-free interest rate to 0.5% and commits to this policy for six periods starting in the third period. As a response to the Fed's announcement, the house price appreciates and then declines gradually to the low levels as policy end date becomes closer. However, the magnitudes are limited considering such a low interest rate policy. The main reason is that even if the risk-free interest rate is lowered to 0.5% temporarily, the presence of high minimum down-payment requirement and high unemployment risk makes mortgages and houses less affordable. So, households cannot respond much to the policy in this case. Again, due to the timing of the Fed policy and lower response of the house price, the foreclosure rate essentially does not change apart from a very small decrease after the policy is implemented.

We also experiment with shortening the length of the policy action. In Figures 8(a) and 8(b), we can also see the effect of the policy if the Fed commits to this policy for only three periods instead of six periods. Not surprisingly, in this case, the Fed policy becomes even less effective on both the house price and the foreclosure rate.

In addition, we also analyze the effects of the timing for the Fed policy. In Figures 9(a) and 9(b), we see the effect of the Fed policy with two different timing assumptions. In these figures, the solid line is the benchmark case with no Fed policy. The line with the label "policy in 2 periods" shows the effect of the Fed policy once it takes place two periods after the shocks are realized. Finally, the line with the label "policy on impact" shows the effect of the Fed policy if it takes place as soon as the



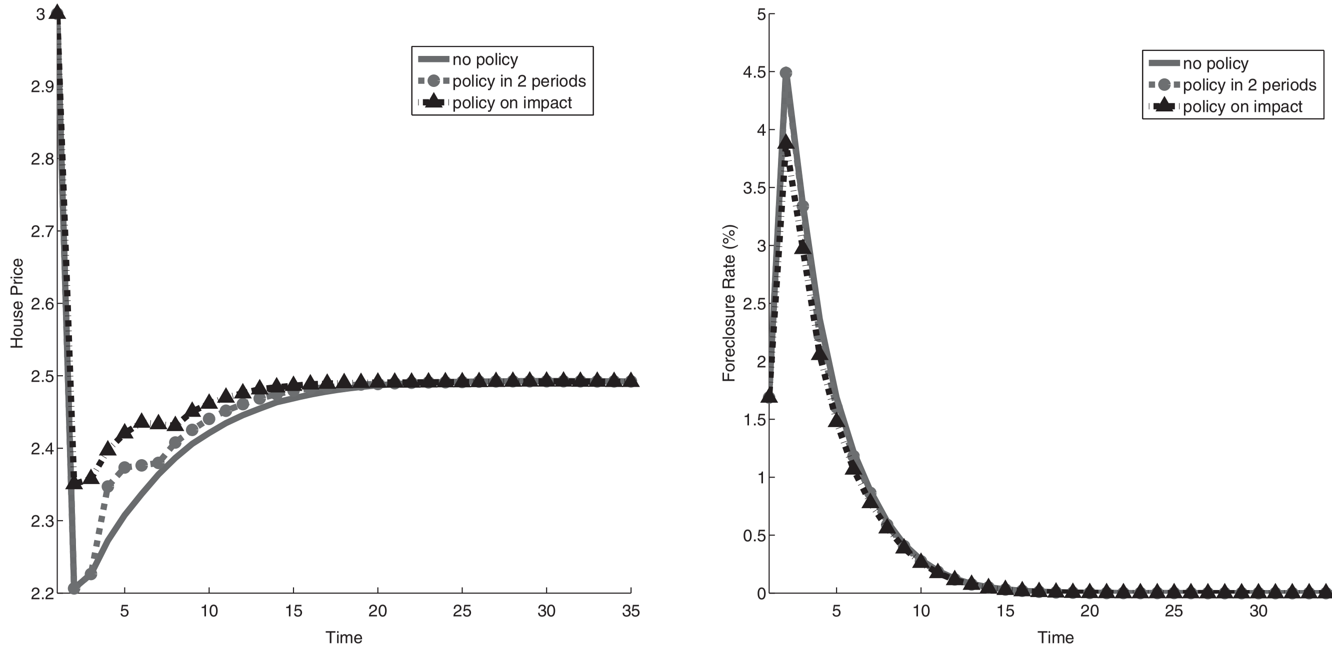
(a) House Price



(b) Foreclosure

FIG. 8. The Effect of Monetary Policy in Response to All Three Shocks.

NOTES: The figures show the evolution of the house price and the foreclosure rate in response to an unexpected and permanent increase in the risk-free rate from 2% to 3%, increase in the minimum down-payment requirement from 0% to 20%, and increase in the unemployment rate from 5% to 6% together with a Fed intervention after two periods of the shock. The Fed decreases the risk-free interest rate to 0.5% and commits to this policy for a specific amount of time. We both analyze the commitment for three and six periods.



(a) House Price (b) Foreclosure

Fig. 9. The Effect of Monetary Policy in Response to All Three Shocks.

Notes: The figures show the evolution of the house price and the foreclosure rate in response to an unexpected and permanent increase in the risk-free rate from 2% to 3%, increase in the minimum down-payment requirement from 0% to 20%, and increase in the unemployment rate from 5% to 6% together with a Fed intervention. We analyze the case when the Fed intervenes to the market by decreasing the risk-free interest rate to 0.5% both as soon as the unexpected shocks are realized, and two periods after the shocks are realized. In both cases, the Fed commits to its policy for the next three periods.

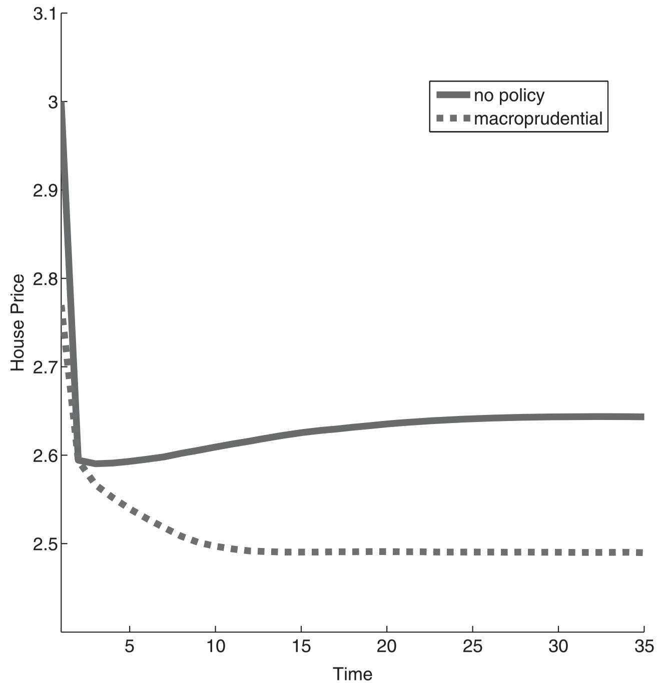
shocks are realized. In this case, the drop in the house price and the increase in the foreclosure rate are lower. However, again the effects are not significant due to the presence of high down-payment requirement and high unemployment risk.

4.2 Macroprudential Policy

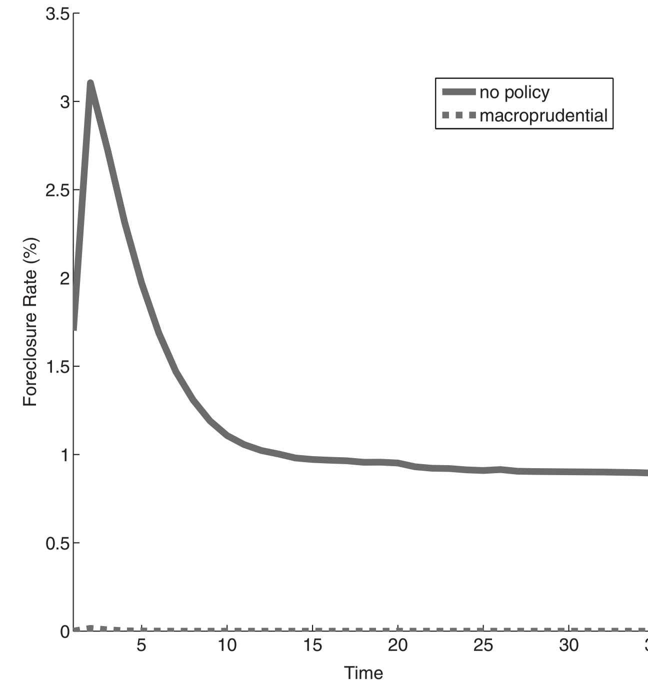
In the previous section, we showed that a policy similar to the Fed's interest rate policy has limited effects on our main variables of interest. Another possible policy is an *ex ante* macroprudential policy. The regulatory authority can easily enforce a minimum down-payment requirement. In the following figures, we depict our analysis of how the transition would look like if there was a 20% minimum down-payment requirement before the shocks. We assume that the risk-free interest rate increases from 2% to 3%, and the unemployment rate increases from 5% to 6%. In order to isolate the effect of the macroprudential policy, we assume that in the benchmark case the minimum down-payment requirement does not change and stays at 0%. However, with the macroprudential policy in place, we assume that the minimum down-payment is 20% all along.

Our results show that both the decline in the house price and the increase in the foreclosure rate are much smaller with the macroprudential policy. Without the policy, the house price drops by 14% on impact (12% across the steady states), whereas with the *ex ante* macroprudential policy the house price drops by 6% on impact (10% across the steady states). The house price still drops significantly but by a smaller magnitude in the presence of the macroprudential policy, because with the higher interest rate and higher unemployment risk, mortgages become less affordable and the demand for houses decreases. This is the same mechanism working in the case without policy. As can be seen from Figure 10(b), the increase in the foreclosure rate is significantly lower in the case with *ex ante* macroprudential policy (0.02% versus 3.1% on impact). The lower increase in the foreclosure rate with *ex ante* macroprudential policy is due to the higher minimum down-payment requirement. Owing to the *ex ante* macroprudential policy, when the economy is hit with the shocks, households have higher home equity compared to the case without the policy. As a result, the effect of a drop in the house price on the foreclosure rate is not very effective once the *ex ante* macroprudential policy is in place. So, the feedback mechanism between the foreclosures and house prices is muted, and the drop in the house price is lower and gradual with *ex ante* macroprudential policy.

We should mention that even though the cost of the shocks to the economy is smaller, it does not mean that the welfare is higher with this policy. Obviously, *ex ante* macroprudential policy decreases the welfare of the homeowners *ex ante* by putting an additional borrowing constraint on them. However, it improves their welfare *ex post* when an unexpected shock hits the economy. Due to the feedback mechanism between foreclosures and house prices, it is possible to obtain welfare-improving-macroprudential policies. The mechanism behind this reasoning is that as individual consumers are price takers they do not internalize how their housing



(a) House Price



(b) Foreclosure

FIG. 10. The Effect of Macroprudential Policy in Response to Shocks.

NOTES: The figures show the evolution of the house price and the foreclosure rate in response to an unexpected and permanent increase in the risk-free rate from 2% to 3%, and an increase in the unemployment rate from 5% to 6% together with and without *ex ante* macroprudential policy. The *ex ante* macroprudential policy we consider here is a 20% minimum down-payment requirement to purchase a house.

decisions affect house prices. But a social planner can internalize it and implement some policies to improve welfare. This is a topic for future research.

5. CONCLUSION

The causes of the recent financial crisis and policies to mitigate the effects of the crisis have become an important area of research for economists. In this paper we, too, deal with these questions. We do this by utilizing an incomplete market life-cycle model with housing, where we model mortgage contracts in detail. We believe incorporating both life-cycle structure and detailed mortgage contracts are crucial for this sort of analysis. It is imperative for the analysis of the mortgage default to know the specifics of the mortgage contract, savings, and income of the mortgage holders. Our model can deal with such complexities.

One of the main findings from this paper is that the transitional dynamics in response to an unexpected and permanent shock can be quite different than the dynamics across the steady states. Along the transitions, the responses of house prices and foreclosures are much stronger. More importantly, foreclosures can be very low (around 0) at the steady states, but they can be very large especially after the initial realization of the shocks. Moreover, the feedback mechanism between the house prices and foreclosures is substantial. Finally, we use the model to understand the implications of monetary and macroprudential policies on the house price and foreclosures. Our analysis shows that although the timing and the duration of monetary policy actions can matter, their effects on house prices and foreclosures are quite limited. However, *ex ante* macroprudential policy can be more effective on the house price and foreclosure dynamics.

Our results come with some caveats. Throughout our analysis, we only focus on the effects of the shocks on house prices and foreclosures through their effects on the demand for owner-occupied units. Obviously, with a flexible supply of owner-occupied units and housing stock, there will be further effects of these shocks on the house price through supply dynamics. It is an ambitious and a quite interesting research question to analyze these supply effects along with the effect of flexible rental prices.

Another interesting dimension for further research is the effect of the shocks on lender's balance sheets, and its feedback to the housing and mortgage market. Lenders make losses on the impact of the shocks. We ignore these losses in our analysis. However, these losses will deteriorate the balance sheet of the lenders, and this will have a feedback effect on newly issued mortgages, which in turn will affect house prices.

Finally, we omit the welfare implications of monetary and macroprudential policies. Especially, since an *ex ante* macroprudential policy seems quite effective in mitigating the effects of aggregate shocks, it would be fruitful to extend the analysis to examine the potential *ex ante* and *ex post* welfare implications of this policy tool.

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