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What Drives the Owner-Occupied and Rental Housing Markets? Evidence from an Estimated DSGE Model

Most dynamic stochastic general equilibrium (DSGE) models with a housing market do not explicitly include a rental market and assume a tight mapping between house prices and rents over the business cycle. However, rents are much smoother than house prices in the data. We match this feature of the data by adding both an owner-occupied housing market and a rental market in a standard DSGE model. The intertemporal preference shock accounts for more than half of the variation in house prices and contributes to residential investment fluctuations through the liquidity constraint, and nominal rigidity in rental contracts captures the variation in the price-rent ratio.

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IN THE U.S. ECONOMY, HOUSE PRICES fluctuate more than rental prices, and the difference in volatility is especially prominent during the past two decades. Figure 1 plots the Federal Housing Finance Agency (FHFA) repeat-transactions house price index together with the Bureau of Labor Statistics (BLS) rental index of primary residence, deflated by the implicit price index for the nonfarm business sector. Both series are in logarithmic form and normalized to be zero at the beginning of the sample period. Between 1997 and 2006, real house prices increased by 63% whereas real rental prices rose by 18% only. The drop in house prices that followed was also not matched by much movement in rents. Why does the price-rent

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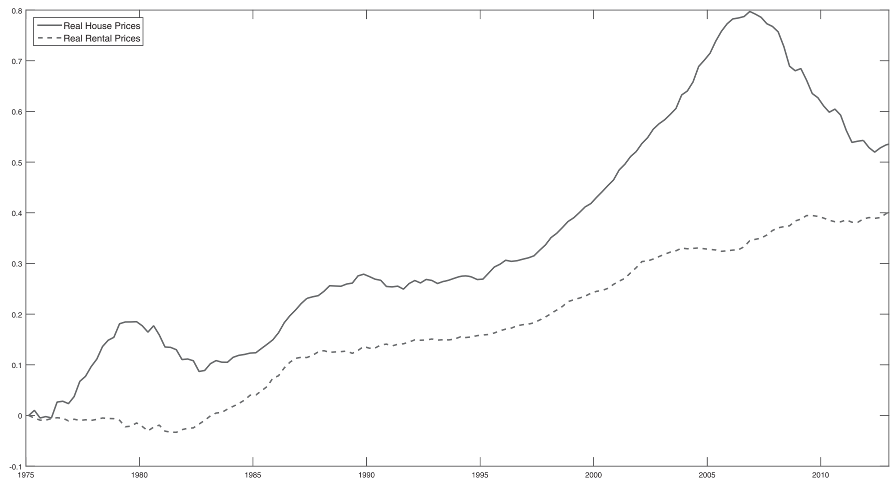

FIG. 1. U.S. National House Prices and Rental Prices: 1975:Q1–2013:Q4.

ratio move so much over time? We answer this question with a dynamic stochastic general equilibrium (DSGE) model.

We take the borrower-lender model of Iacoviello and Neri (2010) as our baseline model and explicitly model a rental market. We do not focus on individual household behaviors, and we consider a representative household that obtains shelter services both through homeownership and via the rental market.[1] We allow both house prices and rental prices to be determined endogenously and allow for nominal rigidity in rental contracts. The objective of this paper is to understand the equilibrium effects of a set of structural shocks on housing market dynamics.

We assume that owner-occupied housing and rental housing are substitutes in households' utility functions, and we include a unique housing preference (or demand) shock to capture households' demand for housing.[2] By imposing collateral constraints on both entrepreneurs and constrained households, we capture not only the comovements between house prices and consumption studied in Iacoviello and Neri (2010) but also the comovements between the price-rent ratio and output as in Miao, Wang, and Zha (2014). We find that the housing preference shock explains about 35% of the variation in real rents but does not contribute much to house price dynamics. Instead, the intertemporal preference shock drives more than 50% of the fluctuations in house prices.[3] Working through entrepreneurs' borrowing capacity,

1. The paper of Iacoviello and Neri (2010) is based on the literature of neoclassical dynamic equilibrium models with nominal rigidities, including Christiano, Eichenbaum, and Evans (2005) and Smets and Wouters (2007).

2. The housing preference shock in this paper is unique. We do not separately impose preference shocks on owner-occupied housing and rental housing.

3. Liu, Wang, and Zha (2013), however, find that the housing preference shock contributes to 90% of the variation in house prices (or land prices in their paper) in a framework without a rental market.

the intertemporal preference shock induces a substantial fraction of the variation in residential investment. Nominal rigidity in rental contracts is found to play an important role in capturing the smoothness of rents and the large variation in the price-rent ratio. Finally, we try to understand what the two preference shocks capture by regressing them on a set of observables, and we find that both are strongly correlated with consumer sentiment, policy uncertainty, employment ratio, and age structure.

This paper belongs to the growing literature on DSGE models with housing markets. Iacoviello and Neri (2010) estimate a DSGE model and explain the comovements between house prices and consumption expenditure. They find that the housing demand shock explains a large fraction (about 25%) of the volatility of housing investment and house prices. However, the demand shock cannot explain the observed price-rent ratio dynamics, as the shock moves both house prices and rental prices by similar amounts. Without explicitly modeling a rental market, their model implies a tight mapping between house prices and rental prices at the business cycle frequency; see footnote 15 in their paper.[4] We relax this assumption in this paper and explain the observed dynamics of the price-rent ratio as shown in Figure 1.

Miao, Wang, and Zha (2014) notice that the price-rent ratio not only displays high volatility, but also moves together with output. To account for these two phenomena, they add a rental market and develop a transmission mechanism through the liquidity premium—the difference between the house price and the discounted present value of future house rents—and estimate a medium-scale structural model. A rise in the liquidity premium relaxes the firm's liquidity constraint and raises aggregate total factor productivity. They find that a small but persistent shock to the stochastic discount factor (SDF) is able to generate large fluctuations in the price-rent ratio. We also find the SDF shock (which is the same as the intertemporal preference shock in this paper) to be important, and we extend their work by adding rent rigidity and allowing monetary policy to play a role. We find rent rigidity to be crucial (as in Genesove 2003) but that monetary policy only has a small impact on housing markets.

This paper is also related to another literature that focuses on the change of house prices relative to rental prices. Among others, Campbell et al. (2009), Piazzesi and Schneider (2009), Favilukis, Ludvigson, and Van Nieuwerburgh (2013), Fairchild, Ma, and Wu (2015), and Sun and Tsang (2015), mostly using vector autoregression (VAR) models, study the dynamics of the price-rent ratio with a linearized present value model. The price-rent ratio is decomposed into the expected present value of all future real housing returns, the expected present value of all future real rent growth, and a residual which is usually named "the pricing error." The two expected present

Their argument does not work for the rental market because the housing preference shock drives as much variation in rents as in house prices while the data show that rents are much smoother than house prices.

4. By modeling both an owner-occupied housing market and a rental market, we are able to examine the validity of the simple present value model which assumes that a house price is the discounted present value of all future rents. We find that the present value model does not hold in the case of heterogenous households and the discrepancy is largely attributable to the intertemporal preference shock. This result is presented in Online Appendix C.

value components are estimated via a VAR model that consists of real housing return and real rent growth, as well as a set of macroeconomic observables. Empirical results suggest that the pricing error accounts for a large fraction of the variation in the price-rent ratio. There are at least two possible reasons: First, expectations are not rational, and second, VAR models do not include all useful information. The structural model in this paper and our multivariate regression analysis of the preference shocks shed light on this finding in the VAR literature. We show that consumer sentiment, policy uncertainty, employment ratio, and age structure explain a considerable fraction of the variation in the estimated preference shocks. Including those variables in VAR models may improve the goodness-of-fit and reduce the pricing error.

The paper is organized as follows. In Section 1, we construct a model economy that features both an owner-occupied housing market and a rental market with nominal rigidity. Section 2 presents the empirical results from taking the model to data. In Section 3, we fully explore the economic implications of the model. In particular, we examine the determinants of the dynamics of housing markets and compare our model with existing models in the literature. Section 4 provides a further understanding of both the intertemporal and the housing preference shocks. Section 5 concludes the paper.

1. THE MODEL ECONOMY

Based on Iacoviello and Neri (2010) and an earlier work Iacoviello (2005), we construct a model economy that features both an owner-occupied housing market and a rental housing market. On the demand side, there are two types of households—unconstrained (i.e., lenders) and constrained (i.e., borrowers)—with different discount factors. On the supply side, entrepreneurs produce consumption goods and new houses. Another role that entrepreneurs play in this model is to provide rental services. A linear technology is available that transforms one unit of housing stock into one unit of rental services. Both entrepreneurs and constrained households borrow from unconstrained households using their housing stock as collateral assets.

1.1 Entrepreneurs

There is a continuum of measure one of entrepreneurs who accumulate capital and own land. They hire labor and purchase intermediate goods to produce wholesale goods Y and new houses IH. Entrepreneurs maximize their lifetime utility:

$$V = E_0 \sum_{t=0}^{\infty} (\beta)^t z_t \frac{1-\epsilon}{1-\beta\epsilon} \ln(c_t - \epsilon c_{t-1}) \tag{1}$$

subject to a budget constraint

$$\frac{Y_t}{X_t} + \frac{r_t H_{r,t}}{X_{r,t}} + q_t[IH_t - (H_{r,t} - (1-\delta_r)H_{r,t-1})] + b_t$$
$$= c_t + \frac{R_{t-1}b_{t-1}}{\pi_t} + \frac{k_{c,t} - (1-\delta_{kc})k_{c,t-1}}{a_{k,t}} + \left(k_{h,t} - (1-\delta_{kh})k_{h,t-1}\right)$$
$$+ k_{b,t} + p_{l,t}(l_t - l_{t-1}) + \sum_{i=c,h} w'_{i,t}n'_{i,t} + \sum_{i=c,h} w''_{i,t}n''_{i,t} + \Phi_t, \tag{2}$$

and a collateral constraint (see Kiyotaki and Moore 1997):

$$b_t \leq mE_t\left(q_{t+1}(1-\delta_r)H_{r,t}\frac{\pi_{t+1}}{R_t}\right), \tag{3}$$

where the capital adjustment cost Φ_t follows:

$$\Phi_t = \frac{\phi_{kc}}{2}\left(\frac{k_{c,t}}{k_{c,t-1}} - 1\right)^2 k_{c,t-1} + \frac{\phi_{kh}}{2}\left(\frac{k_{h,t}}{k_{h,t-1}} - 1\right)^2 k_{h,t-1}. \tag{4}$$

In above equations, c, b, k_c, k_h are consumption, borrowing, and capital in the consumption and housing sectors. The term a_k captures the investment-specific shock and represents the marginal cost of producing capital used in the consumption sector. Loans are set in nominal terms and yield a riskless nominal return R. Money inflation in the consumption sector is π. Entrepreneurs hire labor n'_c, n''_c for the production of consumption goods and n'_h, n''_h for the production of new houses from unconstrained and constrained households. Real wages paid to these four sector-household combinations are denoted w'_c, w''_c, w'_h, w''_h. Real house prices and real rental prices are denoted q and r. The term H_r stands for the stock of housing for rental purposes. Entrepreneurs sell consumption goods and provide rental services to households indirectly via retailers who purchase wholesale goods and rental services from entrepreneurs and sell them at markups X and X_r. The existence of retailers brings price rigidity into the model. Intermediate inputs, land, and land prices are denoted k_b, l, and p_l. The term z_t in the utility function captures the shock to intertemporal preferences as in Primiceri, Schaumburg, and Tambalotti (2006) and it follows an AR(1) process:

$$\ln z_t = \rho_z \ln z_{t-1} + \varepsilon_{z,t}, \tag{5}$$

where ρ_z is the autoregressive parameter and $\varepsilon_{z,t}$ is an independently and identically distributed innovation with mean zero and variance σ_z^2.

Entrepreneurs use their housing stock as a collateral asset to borrow and their maximum amount of borrowing is bounded by a portion (usually called the loan-to-value ratio or simply the LTV ratio) of the expected present value of their housing stock; see equation (3). The LTV ratio tied to entrepreneurs is not of our primary interest. We assume this ratio is fixed at m. This borrowing constraint indicates that entrepreneurs are able to borrow more when house prices are expected to become higher. Any factors that affect house prices also alter entrepreneurs' borrowing capacity and influence their investment and production decisions. The parameters β and ϵ characterize entrepreneurs' discount factor and habits in consumption. Rental housing depreciates at a rate of δ_r. The capital depreciation rates in the consumption and housing sectors are denoted δ_{kc} and δ_{kh}, respectively. The capital adjustment costs are measured by parameters ϕ_{kc} and ϕ_{kh}.

Entrepreneurs use Cobb–Douglas technologies with constant returns to scale in both sectors. The production functions follow:

$$Y_t = \left(a_{c,t}(n'_{c,t})^{\alpha}(n''_{c,t})^{1-\alpha}\right)^{1-\mu_c}(k_{c,t-1})^{\mu_c}, \tag{6}$$

$$IH_t = \left(a_{h,t}(n'_{h,t})^{\alpha}(n''_{h,t})^{1-\alpha}\right)^{1-\mu_h-\mu_b-\mu_l}(k_{h,t-1})^{\mu_h}k_{b,t}^{\mu_b}l_{t-1}^{\mu_l}, \tag{7}$$

where a_c and a_h measure productivity in the consumption sector and the housing sector, respectively. The parameter α measures the labor income share of unconstrained households. μ_c, μ_h, μ_b, and μ_l are production function parameters.

Technology processes are modeled as

$$\ln a_{c,t} = \rho_{AC}\ln a_{c,t-1} + \varepsilon_{c,t}, \tag{8}$$

$$\ln a_{h,t} = \rho_{AH}\ln a_{h,t-1} + \varepsilon_{h,t}, \tag{9}$$

$$\ln a_{k,t} = \rho_{AK}\ln a_{k,t-1} + \varepsilon_{k,t}, \tag{10}$$

where $\varepsilon_{c,t}$, $\varepsilon_{h,t}$, and $\varepsilon_{k,t}$ are independently and identically innovations with mean zero and variances σ^2_{AC}, σ^2_{AH}, and σ^2_{AK}.

1.2 Households

There is a continuum of measure one of agents in each of the unconstrained and constrained groups. Within each group, a representative household maximizes the lifetime utility:

$$\begin{aligned} V' = E_0\sum_{t=0}^{\infty}(\beta')^t z_t\Bigg[&\frac{1-\epsilon'}{1-\beta'\epsilon'}\ln(c'_t-\epsilon' c'_{t-1}) \\ &+\frac{j_t}{1-\vartheta'}\ln\left(\omega'_h h'^{1-\vartheta'}_{o,t}+(1-\omega'_h)h'^{1-\vartheta'}_{r,t}\right) \\ &-\frac{\tau_t}{1+\eta'}\left(n'^{1+\xi'}_{c,t}+n'^{1+\xi'}_{h,t}\right)^{\frac{1+\eta'}{1+\xi'}}\Bigg], \end{aligned} \tag{11}$$

$$V'' = E_0 \sum_{t=0}^{\infty} (\beta'')^t z_t \left[\frac{1-\epsilon''}{1-\beta''\epsilon''} \ln(c''_t - \epsilon'' c''_{t-1}) + \frac{j_t}{1-\vartheta''} \ln\left(\omega''_h h''^{1-\vartheta''}_{o,t} + (1-\omega''_h) h''^{1-\vartheta''}_{r,t}\right) - \frac{\tau_t}{1+\eta''} \left(n''^{1+\xi''}_{c,t} + n''^{1+\xi''}_{h,t}\right)^{\frac{1+\eta''}{1+\xi''}} \right], \tag{12}$$

where variables and parameters with a single prime refer to unconstrained households and those with double primes refer to constrained households. The variables j_t and τ_t capture the housing preference shock and the labor supply shock, and they follow:

$$\ln \tau_t = \rho_\tau \ln \tau_{t-1} + \varepsilon_{\tau,t}, \tag{13}$$

$$\ln j_t = (1-\rho_j) \ln j + \rho_j \ln j_{t-1} + \varepsilon_{j,t}, \tag{14}$$

where ρ_i ($i = \tau$ or j) is the autoregressive parameter; j is the steady-state value of the preference shock; $\varepsilon_{i,t}$ ($i = \tau$ or j) is an independently and identically distributed innovation with mean zero and variance σ_i^2.

We assume that owner-occupied housing and rental housing are substitutes to both types of households and we allow for constant elasticity of substitution between these two types of housing, captured by $1/\vartheta'$ and $1/\vartheta''$ where both ϑ' and ϑ'' are between 0 and 1. Therefore owner-occupied housing and rental housing are perfect substitutes when ϑ' and ϑ'' approach zero. The coefficients ω'_h and ω''_h are share parameters. This specification is able to capture a representative household's demand for housing, it might, however, be neglecting some important aspects of individual household behaviors.[5] In our setup, a unique shock that characterizes households' demand for housing is driving the dynamics of the owner-occupied and rental housing markets. The specification of the disutility of labor allows for less than perfect labor mobility between sectors, characterized by the parameters ξ', ξ'', η', and η''.

Unconstrained households maximize their lifetime utility subject to the following budget constraint:

5. Both Iacoviello and Pavan (2013) and Sommer, Sullivan, and Verbrugge (2013) model individual households' choice between owning and renting. Their model specifications are more successful in capturing microeconomic evidence, including, for example, that homeowners change house size infrequently but in large amounts or among discrete sizes, and renters may change house size more often or rent a small unit of shelter. In this paper, we do not focus on individual household behaviors and consider a representative household that obtains shelter services both through homeownership and via the rental market.

$$c'_t + q_t(h'_{o,t} - (1-\delta_o)h'_{o,t-1}) + r_t h'_{r,t} + \frac{R_{t-1}b'_{t-1}}{\pi_t}$$
$$= \frac{w'_{c,t}n'_{c,t}}{X_{wc,t}} + \frac{w'_{h,t}n'_{h,t}}{X_{wh,t}} + DIV'_t + b'_t, \tag{15}$$

where

$$DIV'_t = \frac{X_t - 1}{X_t}Y_t + \frac{X_{r,t}-1}{X_{r,t}}r_t H_{r,t} + \frac{X_{wc,t}-1}{X_{wc,t}}w'_{c,t}n'_{c,t} + \frac{X_{wh,t}-1}{X_{wh,t}}w'_{h,t}n'_{h,t}, \tag{16}$$

which denotes the lump-sum dividends received from retailers (owned by unconstrained households) and labor unions. Owner-occupied housing depreciates at a rate of δ_o.

Constrained households use their housing stock as a collateral asset and maximize their lifetime utility subject to a budget constraint:

$$c''_t + q_t((h''_{o,t} - (1-\delta_o)h''_{o,t-1}) + r_t h''_{r,t} + \frac{R_{t-1}b''_{t-1}}{\pi_t}$$
$$= \frac{w''_{c,t}n''_{c,t}}{X_{wc,t}} + \frac{w''_{h,t}n''_{h,t}}{X_{wh,t}} + DIV''_t + b''_t, \tag{17}$$

and a borrowing constraint:

$$b''_t \leq m'' E_t\left(\frac{q_{t+1}(1-\delta_o)h''_{o,t}\pi_{t+1}}{R_t}\right), \tag{18}$$

where the dividends come from labor unions only:

$$DIV''_t = \frac{X_{wc,t}-1}{X_{wc,t}}w''_{c,t}n''_{c,t} + \frac{X_{wh,t}-1}{X_{wh,t}}w''_{h,t}n''_{h,t}. \tag{19}$$

1.3 Price and Wage Rigidities

We allow for sticky prices in the consumption sector and sticky wages in both sectors. Price stickiness in the consumption sector is introduced by assuming monopolistic competition at the retail level, implicit costs of adjusting nominal prices following Calvo-style contracts (see Calvo 1983), and partial indexation to lagged inflation of those prices that cannot be reoptimized (see Smets and Wouters 2003). The resulting Phillips curve is

$$\ln\pi_t - \iota_\pi \ln\pi_{t-1} = \beta'(E_t \ln\pi_{t+1} - \iota_\pi \ln\pi_t)$$
$$-\frac{(1-\theta_\pi)(1-\beta'\theta_\pi)}{\theta_\pi}\ln\left(\frac{X_t}{X}\right) + \varepsilon_{p,t}, \tag{20}$$

where θ_π is the fraction of retailers that cannot set prices optimally; $\varepsilon_{p,t}$ is an exogenous cost-push shock with mean zero and variance σ_p^2. As in Smets and Wouters (2005), equation (20) indicates that current inflation depends on past and expected future inflations and on the current marginal cost. This equation reverts to the standard forward-looking Phillips curve when the degree of indexation ι_π is zero.

Wage stickiness is modeled similarly. Under Calvo-style pricing with partial indexation to inflation in the previous period, we have the following wage Phillips curves:

$$\ln\left(\frac{\pi_t w'_{i,t}}{w'_{i,t-1}}\right) - \iota_{wi}\ln\pi_{t-1} = \beta'\left(E_t\ln\left(\frac{\pi_t w'_{i,t+1}}{w'_{i,t}}\right) - \iota_{wi}\ln\pi_t\right) - \frac{(1-\theta_{wi})(1-\beta'\theta_{wi})}{\theta_{wi}}\ln\left(\frac{X_{wi,t}}{X_{wi}}\right), \tag{21}$$

$$\ln\left(\frac{\pi_t w''_{i,t}}{w''_{i,t-1}}\right) - \iota_{wi}\ln\pi_{t-1} = \beta''\left(E_t\ln\left(\frac{\pi_t w''_{i,t+1}}{w''_{i,t}}\right) - \iota_{wi}\ln\pi_t\right) - \frac{(1-\theta_{wi})(1-\beta''\theta_{wi})}{\theta_{wi}}\ln\left(\frac{X_{wi,t}}{X_{wi}}\right), \tag{22}$$

where $i = c, h$, which denote the consumption sector and the housing sector, respectively. The parameter θ_{wi} characterizes the wage stickiness in sector i and $X_{wi,t}$ is the corresponding wage markup.

In order to capture the feature in the data that rental prices fluctuate less than house prices, we also specify Calvo-type rental contracts and allow for stickiness in nominal rental prices. We obtain a rental price Phillips curve similarly:

$$\ln\left(\frac{\pi_t r_t}{r_{t-1}}\right) - \iota_r\ln\pi_{t-1} = \beta'\left(E_t\ln\left(\frac{\pi_{t+1} r_{t+1}}{r_t}\right) - \iota_r\ln\pi_t\right) - \frac{(1-\theta_r)(1-\beta'\theta_r)}{\theta_r}\ln\left(\frac{X_{r,t}}{X_r}\right), \tag{23}$$

where θ_r denotes the fraction of rental contracts that cannot be reoptimized in a given period. This assumption is in line with the evidence of substantial nominal rigidity among housing rents in the United States provided by Genesove (2003).

1.4 Monetary Policy

The central bank sets the nominal interest rate according to a classic Taylor rule that responds to the money inflation and the GDP growth:

$$\ln R_t = \gamma_R\ln R_{t-1} + (1-\gamma_R)\gamma_\pi\ln\pi_t + (1-\gamma_R)\gamma_Y\ln\left(\frac{GDP_t}{GDP_{t-1}}\right) + (1-\gamma_R)\ln\overline{rr} + \varepsilon_{R,t} - s_t, \tag{24}$$

where $\varepsilon_{R,t}$ is an independently and identically distributed monetary shock with mean zero and variance σ_R^2 and $\overline{rr}$ is the steady-state real interest rate. The AR(1) stochastic process $s_t = \rho_s s_{t-1} + \epsilon_{s,t}$ captures long-lasting deviations of inflation from its steady-state level, where $\epsilon_{s,t}$ is an independently and identically distributed innovation with mean zero and variance σ_s^2.

1.5 Market Clearing

The market clearing conditions are

$$C_t + IK_{c,t}/a_{k,t} + IK_{h,t} + k_{b,t} = Y_t - \Phi_t, \tag{25}$$

$$\begin{aligned}(h'_{o,t} + h''_{o,t}) - (1-\delta_o)(h'_{o,t-1} + h''_{o,t-1}) + (h'_{r,t} + h''_{r,t})\\ - (1-\delta_r)(h'_{r,t-1} + h''_{r,t-1}) = IH_t,\end{aligned} \tag{26}$$

$$h'_{r,t} + h''_{r,t} = H_{r,t}, \tag{27}$$

$$b_t + b'_t + b''_t = 0, \tag{28}$$

where $C_t = c_t + c'_t + c''_t$, $IK_{c,t} = k_{c,t} - (1-\delta_{kc})k_{c,t-1}$, and $IK_{h,t} = k_{h,t} - (1-\delta_{kh})k_{h,t-1}$. Above equations characterize the clearing conditions of the consumption goods market, the owner-occupied housing market, the rental market, and the loan market (Walras' law). Later in the estimation, we match the sum of $c_t + c'_t + c''_t$ and $r_t(h'_{o,t} + h''_{o,t} + h'_{r,t} + h''_{r,t})$ to private consumption data in the National Income and Product Accounts (NIPA), since NIPA private consumption includes an imputed value for rents from owner-occupied housing.[6] Our definition of GDP sums consumption data (including rents and imputed rents) and investment data by their steady-state shares.

2. EMPIRICAL RESULTS

2.1 Data Description

Our model features a central bank that sets the nominal interest rate according to a Taylor rule. However, the nominal interest rate has been around the zero lower bound since a large drop in the last quarter of 2008. The zero bound on the nominal interest rate introduces nonlinearity into the model. It is an interesting topic but is beyond the scope of this paper. We therefore choose to use data that range from 1975:Q1 to 2008:Q3. The data set contains 11 variables: real consumption, real

6. Without specifying a rental market, Iacoviello and Neri (2010) ignore the imputed rents. We are able to match the model variables with the data series more accurately.

TABLE 1

Calibrated Parameters

Parameter	Value	Parameter	Value	Parameter	Value
β	0.9825	μ_l	0.10	m	1.20
β'	0.9925	j	0.12	m''	0.85
β''	0.95	δ_o	0.008	X	1.15
μ_c	0.35	δ_r	0.016	X_r	1.15
μ_h	0.10	δ_{kc}	0.025	X_{wc}, X_{wh}	1.15
μ_b	0.10	δ_{kh}	0.030	ρ_s	0.95

business investment, real residential investment, real house prices, the price-rent ratio, inflation rate, hours and wage inflation in the consumption sector, hours and wage inflation in the housing sector, and nominal 3-month interest rate.

Real consumption, real business investment, and real residential investment are obtained from the Bureau of Economic Analysis (BEA), expressed in per-capita term; inflation rate is the percent change of the consumer price index for all items less shelter; real house prices are obtained from the FHFA house price index, deflated with the implicit price deflator for the nonfarm business sector; housing rents come from rent of primary residence published by the BLS; hours and wage inflations are also obtained from BLS; the nominal short-term interest rate is the 3-month Treasury Bill Rate at secondary market from Board of Governors of the Federal Reserve System. We use microdata from the 2000 Decennial Census of Housing (DCH) to benchmark the price-rent ratio in 2000; see Davis, Lehnert, and Martin (2008) and Campbell et al. (2009) for a detailed procedure.

Unlike Iacoviello and Neri (2010), we do not model linear trends in this paper and remove them from all data series prior to estimation.

2.2 Calibration

We calibrate the discount factors (β, β', and β''), the technology parameters (μ_c, μ_h, μ_b, and μ_l), the depreciation rates (δ_o, δ_r, δ_{kc}, and δ_{kh}), the LTV ratios (m and m''), the steady-state value of the preference shock (j), the steady-state gross price and wage markups (X, X_r, X_{wc}, and X_{wh}), and the persistence of the inflation objective shock (ρ_s); see Table 1.

The model implies a zero inflation rate, that is, $\overline{\pi} = 1$, in the steady state. We set $\beta' = 0.9925$, implying a steady-state quarterly nominal interest rate of around 0.75%, as the sample average of the 3-month Treasury Bill Rate. We choose $X = X_r = X_{wc} = X_{wh} = 1.15$ as an usual markup on prices (see Corsetti et al. 2013). The depreciation rates are set at $\delta_o = 0.008$, $\delta_r = 0.016$, $\delta_{kc} = 0.025$, and $\delta_{kh} = 0.03$. The condition $\delta_r > \delta_o$ means that housing occupied by a renter depreciates more rapidly than owner-occupied housing.[7] We fix the discount factor of entrepreneurs β at

7. The difference in depreciation rates can be interpreted from a moral hazard perspective, as in Chambers, Garriga, and Schlagenhauf (2009). The moral hazard problem occurs in the rental market when renters decide how intensively to use the dwelling.

0.9825 and the relevant LTV ratio m at 1.2. These numbers are calibrated to pin down the steady-state value of the price-rent ratio, which is around 40 in the data (see Online Appendix B for the derivation of the steady state). Following Iacoviello (2005), we choose the discount factor of constrained households β'' to be 0.95 in order to guarantee an impatience motive for constrained households large enough that they are arbitrarily close to the borrowing limit.[8] The LTV ratio tied to constrained households is set at $m'' = 0.85$. The steady-state value of the preference shock is chosen to be $j = 0.12$. The value of j is consistent with the calibration of Iacoviello and Neri (2010). The calibrated parameter values imply that consumption, business investment, and housing investment account for around 81%, 15%, and 4% of GDP, as the data suggest.[9] Finally, we fix the persistence parameter ρ_s. The Taylor rule in equation (24) features two shocks, an i.i.d. shock $\epsilon_{R,t}$ and an AR(1) shock s_t. Fixing ρ_s helps identify these two shocks separately.

2.3 Prior and Posterior Distributions

The prior distributions of the structural parameters and shock processes are presented in the left panels of Tables 2 and 3. The labor income share of unconstrained households (α), the consumption habit parameters (ϵ, ϵ', and ϵ''), the working disutility parameters (η' and η''), the hour substitution parameters (ξ' and ξ''), the capital adjustment cost parameters (ϕ_{kc} and ϕ_{kh}), the indexation parameters (ι_π, ι_{wc}, ι_{wh}, and ι_r), the Taylor rule parameters (γ_R, γ_π, and γ_Y), the Calvo price and wage parameters (θ_π, θ_{wc}, θ_{wh}, and θ_r), and all of the shock process parameters have the same prior distributions as in Iacoviello and Neri (2010). In order to allow for less-than-perfect substitutes between two types of housing, we set a prior on ϑ' and ϑ'' of around 0.5 with standard deviation 0.2. We do not have much prior knowledge about the share parameters ω_h' and ω_h'', we therefore choose a beta prior with mean 0.5 and standard deviation 0.2. Notice that ϑ', ϑ'', ω_h', and ω_h'' all have quite loose prior distributions.

The right panels report the posterior mean, median, and 90% probability intervals. The estimate of α, the labor income share of credit-unconstrained households, is 0.86, which implies a share of labor income accruing to credit-constrained households of around 14%. Though this value is close to the estimate in Jappelli (1990) based on the 1983 Survey of Consumer Finances, we have to acknowledge that the share of credit-constrained households has been understated due to the exclusion of the recent recession from the sample. For example, Guerrieri and Iacoviello (2015a) show that the tightening of collateral constraints during the recession accounts for a large fraction of the business cycle fluctuations and they find a considerably larger fraction

8. Guerrieri and Iacoviello (2015b) provide an easily applied toolkit for dealing with inequality constraints that bind occasionally. We do not consider occasionally binding constraints in this paper but simply follow Iacoviello and Neri (2010) and assume that constrained households and entrepreneurs are impatient enough so that they always borrow the highest amount they qualify.

9. Given our definition of GDP, consumption (including rents and imputed rents), business investment, and housing investment in the data account for 81.47%, 14.81%, and 3.72% of GDP. These ratios implied by our model are 80.87%, 15.49%, and 3.63% in the steady state.

TABLE 2

PRIOR AND POSTERIOR DISTRIBUTION OF THE STRUCTURAL PARAMETERS

	Prior distribution			Posterior distribution			
Parameter	Distribution	Mean	SD	Mean	5%	Median	95%
α	Beta	0.65	0.05	0.8611	0.8347	0.8604	0.8861
ϵ	Beta	0.5	0.075	0.5191	0.4438	0.5181	0.5737
ϵ'	Beta	0.5	0.075	0.2880	0.2414	0.2891	0.3249
ϵ''	Beta	0.5	0.075	0.5362	0.4747	0.5373	0.6052
η'	Gamma	0.5	0.1	0.4254	0.3501	0.4245	0.4859
η''	Gamma	0.5	0.1	0.4769	0.4042	0.4772	0.5435
ϑ'	Beta	0.5	0.2	0.1294	0.0112	0.1030	0.2788
ϑ''	Beta	0.5	0.2	0.0115	0.0026	0.0101	0.0196
ω_h'	Beta	0.5	0.2	0.7784	0.6795	0.7812	0.8804
ω_h''	Beta	0.5	0.2	0.4701	0.4693	0.4699	0.4709
ξ'	Normal	1	0.1	0.8294	0.7142	0.8363	0.9201
ξ''	Normal	1	0.1	0.9710	0.8781	0.9767	1.0675
ϕ_{kc}	Gamma	10	2.5	20.8439	18.7136	20.7585	23.6022
ϕ_{kh}	Gamma	10	2.5	13.1083	10.9219	13.1863	14.9015
ι_π	Beta	0.5	0.2	0.7525	0.5941	0.7493	0.9042
ι_{wc}	Beta	0.5	0.2	0.0469	0.0106	0.0442	0.0767
ι_{wh}	Beta	0.5	0.2	0.2167	0.1338	0.2113	0.3120
ι_r	Beta	0.5	0.2	0.1210	0.0160	0.1151	0.2000
γ_R	Beta	0.75	0.1	0.6983	0.6557	0.7000	0.7411
γ_π	Normal	1.5	0.1	1.5542	1.4972	1.5527	1.6077
γ_Y	Normal	0	0.1	0.2410	0.1707	0.2395	0.3207
θ_π	Beta	0.667	0.05	0.7811	0.7416	0.7806	0.8320
θ_{wc}	Beta	0.667	0.05	0.8504	0.8322	0.8502	0.8702
θ_{wh}	Beta	0.667	0.05	0.9502	0.9408	0.9502	0.9594
θ_r	Beta	0.667	0.05	0.7056	0.6805	0.7057	0.7293

TABLE 3

PRIOR AND POSTERIOR DISTRIBUTION OF THE SHOCK PROCESSES

	Prior distribution			Posterior distribution			
Parameter	Distribution	Mean	SD	Mean	5%	Median	95%
ρ_{AC}	Beta	0.8	0.1	0.9743	0.9600	0.9754	0.9901
ρ_{AH}	Beta	0.8	0.1	0.9796	0.9630	0.9814	0.9956
ρ_{AK}	Beta	0.8	0.1	0.9774	0.9615	0.9781	0.9930
ρ_j	Beta	0.8	0.1	0.9356	0.9099	0.9374	0.9584
ρ_τ	Beta	0.8	0.1	0.9196	0.8942	0.9194	0.9482
ρ_z	Beta	0.8	0.1	0.9877	0.9826	0.9881	0.9922
σ_{AC}	Inv. Gamma	0.001	0.01	0.0100	0.0090	0.0100	0.0109
σ_{AH}	Inv. Gamma	0.001	0.01	0.0147	0.0133	0.0147	0.0161
σ_{AK}	Inv. Gamma	0.001	0.01	0.0147	0.0132	0.0147	0.0160
σ_j	Inv. Gamma	0.001	0.01	0.0125	0.0107	0.0125	0.0138
σ_τ	Inv. Gamma	0.001	0.01	0.0268	0.0229	0.0264	0.0307
σ_z	Inv. Gamma	0.001	0.01	0.0359	0.0265	0.0353	0.0449
σ_r	Inv. Gamma	0.001	0.01	0.0038	0.0033	0.0038	0.0043
σ_p	Inv. Gamma	0.001	0.01	0.0092	0.0077	0.0091	0.0109
σ_s	Inv. Gamma	0.001	0.01	0.0005	0.0004	0.0005	0.0006
σ_{NH}	Inv. Gamma	0.001	0.01	0.1756	0.1675	0.1750	0.1833
σ_{WH}	Inv. Gamma	0.001	0.01	0.0057	0.0050	0.0057	0.0065

NOTE: In order to guarantee that the number of shocks is more than or equal to the number of data series, we impose measurement errors on hours and wage inflation in the housing sector, with their standard errors being denoted σ_{NH} and σ_{WH}.

TABLE 4
STANDARD DEVIATION COMPARISON OF MODEL VARIABLES AND DATA SERIES

		Model	
Variable	Data	Median	95% Probability Interval
Consumption	0.0247	0.0349	[0.0225, 0.0561]
Inflation	0.0080	0.0096	[0.0078, 0.0126]
Housing investment	0.1561	0.1558	[0.1038, 0.2310]
Business investment	0.0828	0.0941	[0.0651, 0.1478]
House price	0.0782	0.0516	[0.0317, 0.0949]
Price-rent ratio	0.0710	0.0443	[0.0263, 0.0798]
Nominal interest rate	0.0075	0.0079	[0.0058, 0.0116]
GDP	0.0336	0.0420	[0.0288, 0.0666]

(about 40%) of credit-constrained households.[10] Entrepreneurs and both types of households exhibit a moderate degree of habit formation in consumption ($\epsilon = 0.52$, $\epsilon' = 0.29$, and $\epsilon'' = 0.54$). The estimates of η' and η'', the labor supply elasticities, are around 0.43 and 0.48, not very different from their prior means. The parameters ξ' and ξ'' are estimated to be 0.83 and 0.97, implying that hours in the two sectors are imperfect substitutes. The estimates of adjustment cost parameters are $\phi_{kc} = 20.84$ and $\phi_{kh} = 13.11$. The Calvo price and wage parameter estimates are similar to those in Iacoviello and Neri (2010). The Taylor rule parameter estimates are consistent with previous evidence too. The estimate of $\theta_r = 0.71$ indicates that rental contracts are less sticky than price and wage contracts. Rents are reoptimized about every three to four quarters, and this estimate is close to the microevidence of four quarters in Genesove (2003). Both estimates of ϑ' and ϑ'' are not too far from zero, while ϑ' is slightly larger. This indicates that two types of housing are almost perfect substitutes to constrained households but imperfect substitutes to unconstrained households. The share parameters ω_h' and ω_h'' are estimated to be around 0.78 and 0.47, implying that unconstrained households weigh owner-occupied housing more than constrained households do. All AR(1) shocks are quite persistent.

2.4 Cyclical Properties

In order to evaluate the performance of our estimated DSGE model in capturing the business cycle properties of data series, we simulate the model 1,000 times and compare the standard deviation of model variables with the standard deviation of data series (in logarithmic form) in Table 4. In each simulation repetition, we generate artificial time series of length equal to the length of data. The summary statistics in the table are computed across 1,000 simulation repetitions. As the table shows, all of the 95% probability intervals computed from the model simulations successfully

10. Other factors affecting the α estimate may include the nonlinearity of the model. In a recent working paper, Sun and Tsang (2015) also find a larger fraction of credit-constrained households by allowing for regime switches in the volatility of structural shocks and in the monetary policy parameters.

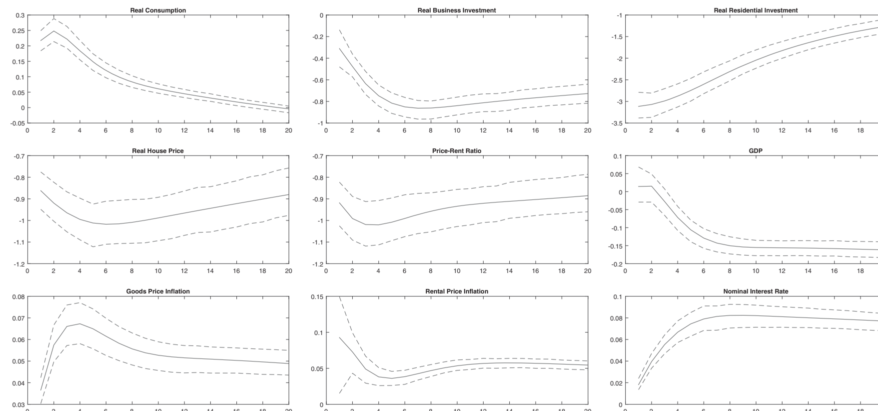

FIG. 2. Impulse Responses to a One Standard-Error Intertemporal Preference Shock.

NOTE: The *y*-axis measures the percent deviation from the steady state. The solid lines represent the estimated responses and the dotted lines demarcate the 90% confidence intervals.

cover the true standard deviations of data series. We therefore comfortably conclude that the model replicates the business cycle properties of the data well.

3. ECONOMIC IMPLICATIONS

In this section, we consider the economic implications of the model. First, we show that the intertemporal preference shock and the housing preference shock are crucial in explaining the housing market dynamics. These two shocks have different impacts on rents and house prices though. Then, we explain why rigidity in rental contracts is necessary to capture the smoothness of rents and show that our model can reproduce two important comovements observed in the data.

3.1 Impulse Responses

We plot the impulse responses of nine key variables—real consumption, real business investment, real residential investment, real house prices, the price-rent ratio, real GDP, price inflation in the consumption sector, price inflation in the rental market, and the nominal interest rate—to the intertemporal preference, housing preference, housing technology, and monetary policy shocks.

Figure 2 indicates that a positive shock to the intertemporal preference encourages consumption but heavily weakens the incentive to invest, especially in the housing sector. House prices drop by a significant amount, but rental prices do not change much. Therefore, the price-rent ratio decreases. Due to the shrinkage of investment, GDP falls. Mild inflation pops up in the rental market and weakens over time. The shock has a slight impact on the goods price inflation, which strengthens gradually

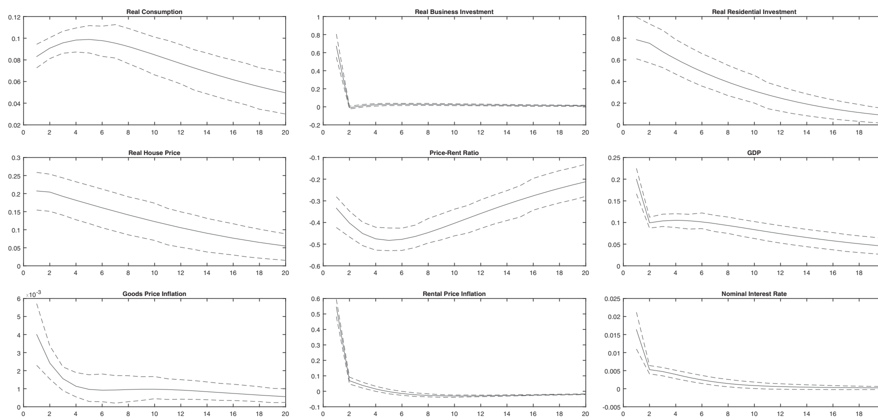

FIG. 3. Impulse Responses to a One Standard-Error Housing Preference Shock.

NOTE: The *y*-axis measures the percent deviation from the steady state. The solid lines represent the estimated responses and the dotted lines demarcate the 90% confidence intervals.

and reaches the peak about four quarters later. The positive impact on the nominal interest rate is also negligible.

As Figure 3 shows, a positive housing preference shock stimulates investment in the housing sector and has a temporary influence on business investment. This shock raises both house prices and rents, with a larger effect on the later. Therefore, the price-rent ratio decreases. A higher house price increases the collateral capacity of entrepreneurs and constrained households and allows them to consume more. As a result of the increase in consumption and investment, GDP increases. Therefore, central bank raises the nominal interest rate as a response. While the housing preference shock has a negligible impact on price inflation in the consumption sector, it causes a significant price adjustment in the rental market.

The housing preference shock is the only one among nine structural shocks that induces larger fluctuations in rents than in house prices. Facing a positive preference shock, both unconstrained and constrained households would choose to own or rent more housing so that both house prices and rents increase. The two types of households behave differently, however. At a higher level of house prices, constrained households qualify for a larger amount of borrowing and they choose to own more and rent more, simultaneously. In contrast, unconstrained households choose to own less and rent more because making loans to constrained households is attractive, due to the assumption that loans are riskless. Therefore, house prices fluctuate less than rental prices after a shock to the housing preference.

Figure 4 shows that all components of aggregate demand fall after a positive monetary policy shock. The largest drop happens in residential investment, followed by business investment, and then by consumption. Rents drop in the short run and owning a house becomes relatively cheaper. Inflation in the consumption sector

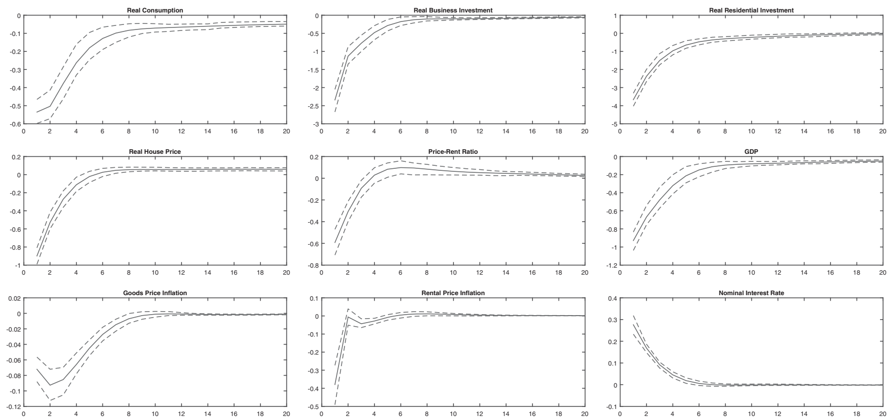

FIG. 4. Impulse Responses to a One Standard-Error Monetary Shock.

NOTE: The *y*-axis measures the percent deviation from the steady state. The solid lines represent the estimated responses and the dotted lines demarcate the 90% confidence intervals.

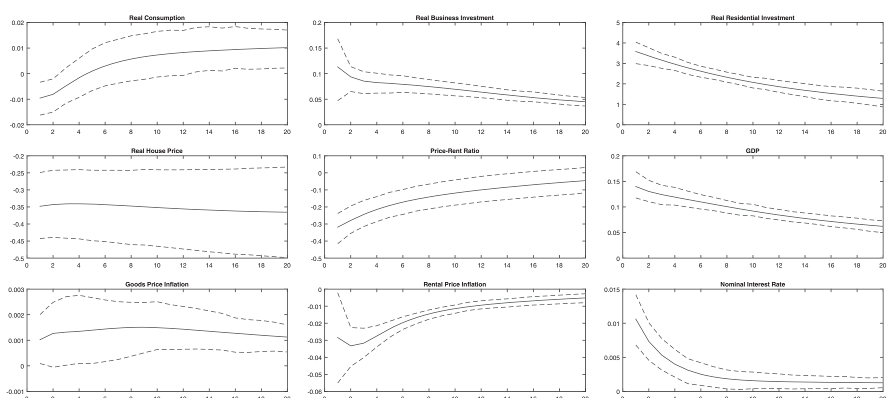

FIG. 5. Impulse Responses to a One Standard-Error Housing Technology Shock.

NOTE: The *y*-axis measures the percent deviation from the steady state. The solid lines represent the estimated responses and the dotted lines demarcate the 90% confidence intervals.

declines as the Phillips curve suggests. Drastic downward price adjustments occur in the rental market within the first two quarters.

As is shown in Figure 5, a positive technology shock in the housing sector leads to a considerable increase in residential investment. Due to a technological progress and, hence, a fall in construction costs, house prices decrease over a long time horizon. Rents drop gradually over time so that renting becomes more expensive relative to owning after a technology shock. The housing technology shock does not have considerable impacts on goods price inflation or rental price inflation.

TABLE 5

Variance Decomposition of the Forecast Errors

Variable	ε_c C Tech.	ε_h IH Tech.	ε_k IK Tech.	ε_j Resi. Pref.	ε_τ Lab. Sup.	ε_z Inter. Pref.	ε_r Mon. Policy	ε_p Cost Push	ε_s Inf. Targ.
Real consumption	40.04	0.01	0.87	0.83	31.31	2.02	6.03	11.21	7.69
Real business investment	8.70	0.09	41.06	0.42	8.09	9.59	7.13	17.83	7.08
Real residential investment	6.34	32.53	0.11	1.05	10.75	31.68	7.74	2.60	7.21
Real house prices	17.82	5.93	0.54	1.03	9.29	53.92	4.00	5.94	1.53
Real rental prices	16.35	4.94	0.29	34.10	14.87	0.27	1.38	25.38	2.43
Price-rent ratio	5.39	1.84	0.52	11.50	0.27	68.82	2.33	8.36	0.97
Inflation	2.37	0.00	0.34	0.00	1.46	5.16	2.84	44.62	43.22
GDP	30.50	0.85	7.67	0.73	26.50	1.46	8.46	14.22	9.62
Nominal interest rate	2.84	0.04	1.47	0.05	3.75	13.53	17.05	23.22	38.04

3.2 Relative Importance of the Shocks

Table 5 presents results from the conditional variance decomposition of the forecast errors at the business cycle frequency. The intertemporal preference shock ε_z drives 50% of the variation in house prices. Working through entrepreneurs' credit constraints, the intertemporal preference shock causes 10% of the fluctuations in business investment and a substantial fraction (about 30%) of fluctuations in residential investment. The variation in GDP is not heavily affected by the intertemporal preference shock because 80% of GDP is accounted for by consumption (according to our definition).

The housing preference shock ε_j explains about 35% of the variation in real rents. Since the preference shock does not affect house prices much, it does not alter entrepreneurs' or constrained households' borrowing capacity and hence does not drive fluctuations in business investment or residential investment.

The monetary policy shock ε_r contributes little to the price side of housing markets. The cost-push shock drives almost half of the variation in inflation. Since around 70% of the rental contracts cannot be reoptimized in each period, but are indexed to previous period inflation, the cost-push shock explains about a quarter of the variation in real rents.

For each of the three variables of most interest—real GDP, real house prices, and real rental prices, we conduct a historical shock decomposition in Figure 6. As Panel (a) shows, the technology shock in the consumption sector ε_c is the primary driving force of the fluctuations in real GDP. After all, consumption accounts for about 80% of the aggregate demand. Panel (b) shows that the intertemporal preference shock ε_z drives most of the fluctuations in real house prices. Most of the fluctuations in real rental prices, however, are driven by the housing preference shock ε_j and the cost push shock ε_p, as shown in Panel (c).

Estimated variance decomposition results and the historical shock decomposition show that the intertemporal preference shock explains half of the variation in house prices and the housing preference shock is the primary driving force of the fluctuations

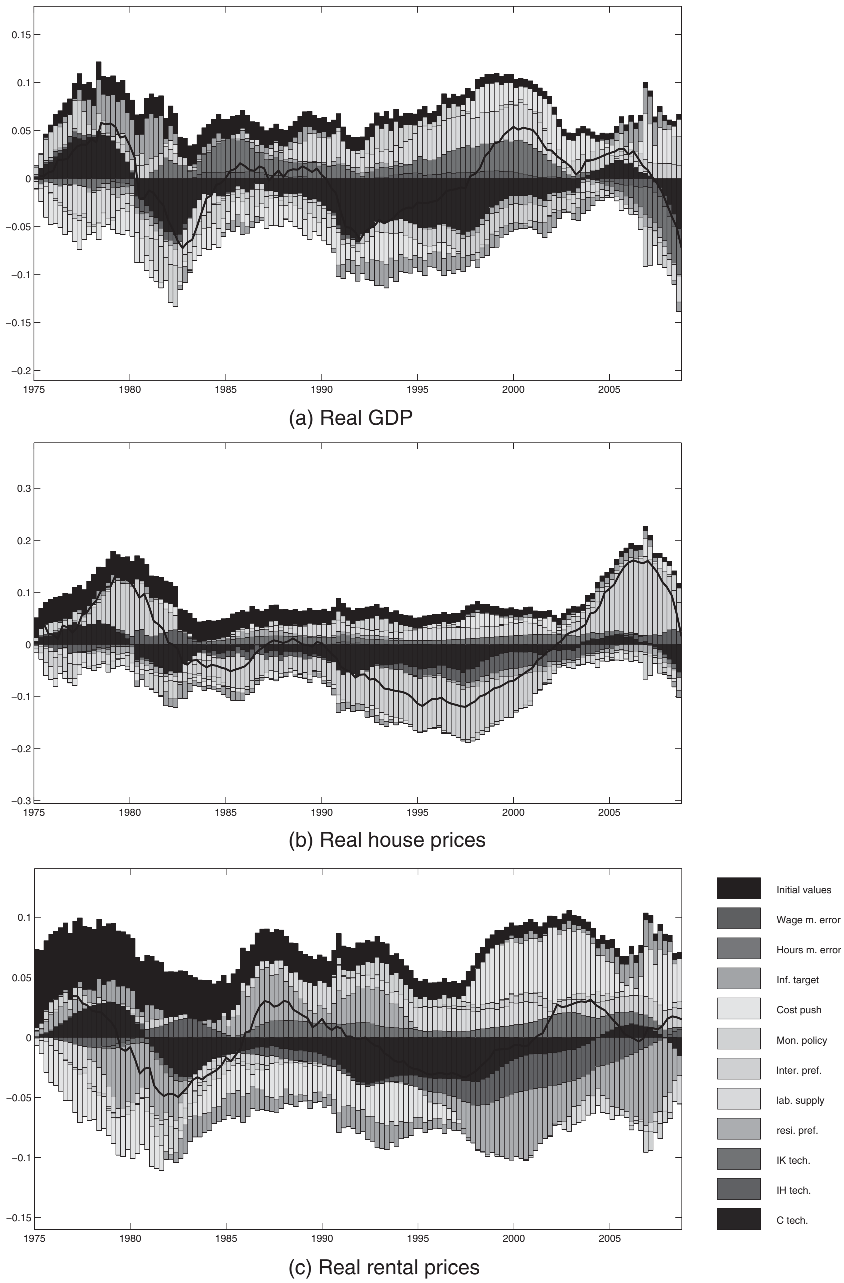

FIG. 6. Historical Decomposition of Key Variables.

NOTE: The solid lines plot model variables, expressed in percentage deviation from their steady-state values. The bars show the contributions of the estimated structural shocks.

in rental prices. Liu, Wang, and Zha (2013), however, find that the housing preference shock contributes to 90% of the variation in house prices (or land prices in their paper) in a framework without a rental market. Iacoviello and Neri (2010) find that the housing preference shock explains one quarter of the fluctuations of house prices. How and why is our result different from theirs?

To illustrate an economic intuition, we take a closer look at the Euler equations associated with house prices and rental prices (see online Appendix A for the derivation of Euler equations). Here, we take unconstrained households as an example:

$$\left(\frac{1-\epsilon'}{1-\beta'\epsilon'}\right)\left(\frac{z_t}{c'_t-\epsilon' c'_{t-1}}-\frac{\beta'\epsilon' z_{t+1}}{c'_{t+1}-\epsilon' c'_t}\right)q_t=\frac{z_t j_t \omega'_h h'^{-\vartheta'}_{o,t}}{\omega'_h h'^{1-\vartheta'}_{o,t}+(1-\omega'_h)h'^{1-\vartheta'}_{r,t}}$$
$$+\beta'(1-\delta_o)E_t\left(\left(\frac{1-\epsilon'}{1-\beta'\epsilon'}\right)\left(\frac{z_{t+1}}{c'_{t+1}-\epsilon' c'_t}-\frac{\beta'\epsilon' z_{t+2}}{c'_{t+2}-\epsilon' c'_{t+1}}\right)q_{t+1}\right), \quad (29)$$

and

$$\left(\frac{1-\epsilon'}{1-\beta'\epsilon'}\right)\left(\frac{z_t}{c'_t-\epsilon' c'_{t-1}}-\frac{\beta'\epsilon' z_{t+1}}{c'_{t+1}-\epsilon' c'_t}\right)r_t=\frac{z_t j_t(1-\omega'_h)h'^{-\vartheta'}_{r,t}}{\omega'_h h'^{1-\vartheta'}_{o,t}+(1-\omega'_h)h'^{1-\vartheta'}_{r,t}}, \quad (30)$$

which, when habit formation is not present (i.e., $\epsilon'=0$), reduce to

$$\frac{z_t}{c'_t}q_t=\frac{z_t j_t \omega'_h h'^{-\vartheta'}_{o,t}}{\omega'_h h'^{1-\vartheta'}_{o,t}+(1-\omega'_h)h'^{1-\vartheta'}_{r,t}}+\beta'(1-\delta_o)E_t\left(\frac{z_{t+1}}{c'_{t+1}}q_{t+1}\right), \quad (31)$$

and

$$\frac{z_t}{c'_t}r_t=\frac{z_t j_t(1-\omega'_h)h'^{-\vartheta'}_{r,t}}{\omega'_h h'^{1-\vartheta'}_{o,t}+(1-\omega'_h)h'^{1-\vartheta'}_{r,t}}. \quad (32)$$

House prices are much more volatile than consumption in the data. As in Liu, Wang, and Zha (2013), the housing preference shock (ϵ_j that causes a change in j_t) is able to drive large fluctuations in house prices without requiring consumption also to be highly volatile. However, equations (31) and (32) suggest that the housing preference shock drives as much variation in rents as in house prices. As mentioned in the introduction, rental prices fluctuate much less than house prices. Equation (31) indicates that the intertemporal preference shock (ϵ_z that causes a change in z_t) can drive large fluctuations in house prices without requiring consumption or rents to fluctuate as much. This intertemporal preference shock cancels out at both sides of equation (32), leaving the housing preference shock to generate fluctuations in rental prices.

Even the housing preference shock is found not as important as it is in Liu, Wang, and Zha (2013), it still drives about 35% of the variation in rental prices. What does the preference shock stand for? Liu, Wang, and Zha (2013) provides two interpretations. One interpretation is that the housing preference shock represents shifts in household

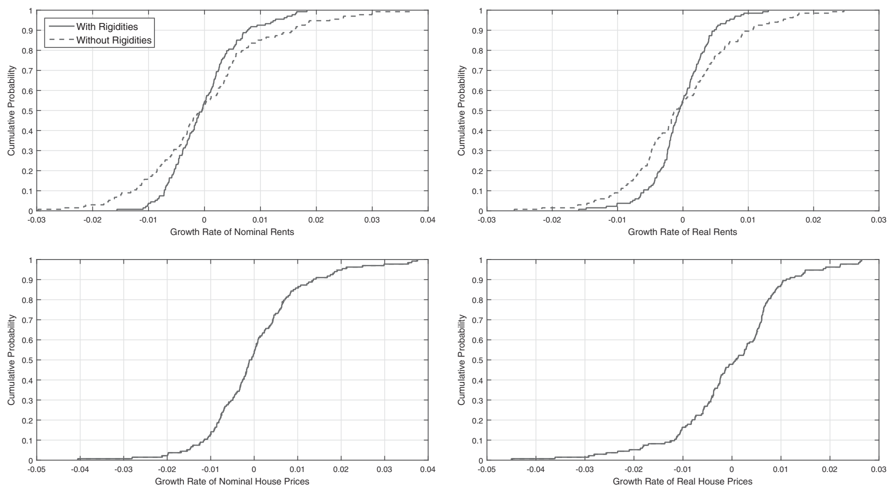

FIG. 7. Empirical Cumulative Distribution Function of Rent and Price Growth Rates.

tastes for housing. The other interpretation is that the housing preference shock is simply a catchall of frictions or deeper shocks that are omitted in the model. Later in this paper, we conduct multivariate regression analyses on both the intertemporal and housing preference shocks.

3.3 Nominal Rigidity in Rental Contracts

An important feature of our model is the nominal rigidity in rental contracts. It is also a primary aspect that our model differs from Miao, Wang, and Zha (2014). In each period, a fraction θ_r of rental contracts cannot be reoptimized but are indexed to inflation in the previous period. This fraction is estimated to be $\theta_r = 0.71$, that is, nominal rents are significantly sticky in the data. What if rental contracts are not sticky?

Figure 7 shows the empirical cumulative distribution function of the quarterly growth rates of house and rental prices under sticky nominal rents and flexible nominal rents between 1975:Q1 and 2008:Q3. As the upper left panel indicates, under sticky rental contracts, 90% of the time nominal rents fluctuate less than 1% and the largest quarterly fluctuation in nominal rents does not exceed 2% over the entire sample period. When flexibility is assumed instead, nominal rents become much more volatile and around 40% of the time the fluctuation exceeds 1%. Consistent with the microevidence in Genesove (2003), we find that rent rigidity is essential to capture the smoothness of rents.

Nominal rigidity in rental contracts also makes real rents smoother (see the upper right panel) but does not affect the smoothness of nominal or real house prices (see the lower panels). Therefore, it plays an important role in capturing the observed variation in the price-rent ratio.

Not surprisingly, we also find that rents are much more responsive to the intertemporal preference, housing preference, and monetary policy shocks when nominal rigidity is not present.

3.4 *Observed Comovements in Data*

U.S. data suggest that house prices are positively correlated with consumption expenditure and the price-rent ratio moves together with output. During the period 1975:Q1–2008:Q3, the empirical correlation coefficients are 0.38 between house prices and consumption and 0.31 between the price-rent ratio and output. Iacoviello and Neri (2010) explain the correlation between house prices and consumption expenditure by imposing a collateral constraint on one type of households. They find that collateral effects on household borrowing amplify the response of nonhousing consumption to given changes in fundamentals. Miao, Wang, and Zha (2014) construct an economy where firms are subject to a collateral constraint which is directly influenced by the liquidity premium—the difference between the house price and the discounted present value of house rents. They find that a small shock to the SDF leads to a large price-rent ratio fluctuation and generates the comovement between the price-rent ratio and output.

We impose collateral constraints on both households and entrepreneurs in this paper so that we capture both comovements studied in Iacoviello and Neri (2010) and Miao, Wang, and Zha (2014). The median values of correlation coefficients between house prices and consumption and between price-rent ratio and output are 0.56 and 0.22 from 1,000 simulations of the model. Our model performs quite well in capturing the comovement between the price-rent ratio and output but overstates the comovement between house prices and consumption to some extent, because we assume that the collateral constraints are binding and the LTV ratios are time-invariant. When constrained households choose not to use up their borrowing capacity, the model would imply a weaker correlation.

4. UNDERSTANDING THE PREFERENCE SHOCKS

As demonstrated in the last section, the intertemporal and housing preference shocks, ε_z and ε_j, account for a large fraction of housing market fluctuations. Since explaining phenomena with taste change is not explanation at all, we treat the preference shocks mostly as measures of the inability of the DSGE model to fit the data well. However, we can learn more about what is missing in the model by studying these preference shocks.

What explains the movements in household preferences? In order to address this concern, we conduct a standard multivariate time-series analysis, following Evans (1992). We choose a set of omitted factors, denoted **x**, that potentially change consumer tastes and investigate the following specification:

$$\varepsilon_{z,t} = B_z \mathbf{x}_t + \nu_{z,t}, \tag{33}$$

$$\varepsilon_{j,t} = B_j \mathbf{x}_t + \nu_{j,t}, \tag{34}$$

where B_z and B_j are coefficient vectors; ν_z and ν_j are independently and identically distributed error terms.[11]

The main determinants of household preferences are demographic. But other factors, like income, price of housing, cost and availability of credit, consumer preferences, investor preferences, price of substitutes, and price of complements, all play a role. Some of these determinants have already been included in our model. We include several variables out of the model in the list of regressors. These regressors are: the University of Michigan Index of Consumer Sentiment, the Economic Policy Uncertainty Index, the employment-to-population ratio, the population share between ages 16 and 19, the population share between ages 20 and 24, and the population share above age 55.[12] The trends in data, if exist, are all removed prior to estimation. All variables are in logarithm. The estimation results of equations (33) and (34) are presented in Table 6.

The selected regressors are considerably strong explanatory variables for the preference shocks. In particular, about 20% of the variation in the intertemporal preference shock and 15% of the variation in the housing preference shock can be explained by the regressors. Consumer sentiment is statistically significant and has the expected sign in both regressions. As households become more confident about the economic prospects, they switch from renting to owning.[13] The economic policy uncertainty significantly promotes household willingness of owning but not renting. Among these regressors, the employment-to-population ratio affects household preference to the largest extent. As a larger fraction of the population becomes employed, the demand for rental services decreases and the demand for homeownership increases. Age structure also has important implications for the housing demand. As the population share between 16 and 19 and that between 20 and 24 increase, households switch

11. Iacoviello and Neri (2010) conduct similar analysis to understand the preference shock $u_{j,t}$ using the original framework of Evans (1992):

$$u_{j,t} = A(L)u_{j,t-1} + B(L)\mathbf{x}_{t-1} + \nu_t,$$

where ν_t is a mean zero independently and identically distributed random variable, $A(L)$ and $B(L)$ are polynomials in the lag operator L, and $\mathbf{x}$ is a list of potential explanatory variables for housing demand. However, this setup contradicts their model assumption that $u_{j,t}$ is an independently and identically distributed random variable. In our regressions, we exclude the lags of each relevant dependent variable from the list of regressors, in order to be consistent with the assumptions in Section 1.

12. Data sources are as follows. Consumer Sentiment Index: Thomson Reuters/University of Michigan Surveys of Consumers; Uncertainty Index: Economic Policy Uncertainty; Employment-to-Population Ratio and Population Shares: Federal Reserve Bank of St. Louis.

13. According to the impulse response results, a negative impact on the intertemporal preference shock induces households to own more housing and a positive impact on the housing preference shock induces households to rent more.

TABLE 6

UNDERSTANDING THE INTERTEMPORAL AND HOUSING PREFERENCE SHOCKS

	(1) Intertemporal preference shock	(2) Housing preference shock
Consumer sentiment	−0.105**	−0.0216**
	(0.0226)	(0.00767)
Uncertainty index	−0.0551**	0.00836
	(0.0205)	(0.00696)
Employment-to-population ratio	−0.365	−0.158*
	(0.201)	(0.0681)
Population share b/w 16 and 19	−0.230**	−0.0624**
	(0.0555)	(0.0188)
Population share b/w 20 and 24	−0.213	−0.0823*
	(0.116)	(0.0392)
Population share above 55	0.329	0.127*
	(0.184)	(0.0625)
N	135	135
adj. R^2	0.192	0.156

NOTE: Standard errors in parentheses; $^*p < 0.05$, $^{**}p < 0.01$; constant terms are not reported.

from renting to owning, which suggests that households with children prefer owning a house. The elderly population seems to prefer renting.

5. CONCLUSION

Most DSGE models with a housing market do not explicitly include a rental market and assume a tight mapping between house prices and rents over the business cycle. However, rents are much smoother than house prices in the data. We match this feature of the data by adding both an owner-occupied housing market and a rental market with nominal rigidity in a standard DSGE model. The housing preference shock explains 35% of the variation in rents but does not contribute much to the dynamics of house prices. The intertemporal preference shock accounts for more than half of the variation in house prices and contributes significantly to residential investment fluctuations through the liquidity constraint. The monetary policy shock explains little of the fluctuations in the price-rent ratio. Nominal rigidity in rental contracts plays an important role in capturing the smoothness of rents and the variation in the price-rent ratio.

To understand the preference shocks, we conduct multivariate regressions on a variety of potential explanatory variables that are not explicitly included in our model. Regression results suggest that consumer sentiment, policy uncertainty, employment ratio, and age structure are considerably strong explanatory variables for both the intertemporal preference shock and the housing preference shock, suggesting possible directions of improving the DSGE model to better understand housing market dynamics.

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