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Distributional Effects of Monetary Policy on Housing Bubbles: Some Evidence

by

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Abstract

Empirical asset pricing has always considered housing only as an investment good. This paper explores empirically the effect of monetary policy on housing bubbles when there exists a duality in housing markets: invest (own) vs. consume (rent). Using both simple and time-varying structural vector autoregression (SVAR and TVC-SVAR) with the U.S. housing market data between 1983-2017, this paper studies monetary transmission separately in the homeowners' market and the renters' market. Major findings are: (i) house price is sticky in that it takes more than 2.5 years for the full impact of monetary policy to occur; (ii) there is heterogeneity in the two housing markets: house price dynamic is more consistent with its fundamental in the renters' market rather than in the homeowners' market. This suggests that the two markets differ in their vulnerability to housing bubbles. (iii) monetary policy can play a useful role in stabilizing housing bubbles. Results are robust to alternative identifications of monetary policy shock.

Keywords: monetary policy, house price booms, preference for housing services, time varying coefficients, stochastic volatility, SVAR.

JEL Classifications: E31, E44, E52.

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1 Introduction

"*At the heart of the theoretical framework is the intertemporal household decision problem with housing as both asset and consumption good*"

(Handbook of Macroeconomics; 2016)

Crisis has taught us hard and painful lessons that history should not be allowed to repeat itself again in the future. While the 2008-2009 crisis has been associated with housing market where the depth and persistence it generates is arguably more severe than other types of bubbles, e.g. equity bubbles, the only explanation provided so far in the literatures to explain this distinction of stock price and house price crisis has to do with *credit*.[1] Current policy design intended to control housing bubbles, thus, often done through credit channel, e.g. loan-to-value (LTV) ratio.

Given a clear distinction between crisis generated by housing market and equity market, more explanation should be provided and challenged. This paper studies empirically this issue through the role of monetary policy. Specifically, while monetary policy is a major tool of the central bank, its role in controlling asset prices is unclear.[2] Debate has been going on, whether "leaning against the wind" monetary policy is appropriate in controlling asset price bubbles. This paper extends the debate by studying the effect of monetary policy on housing bubbles when there are friction in housing markets, particularly the decision for housing tenure choice (own vs. rent).[3] The rationale for studying separately market for homeowners and market for renters are as follows.

From an empirical perspective, housing bubbles have always been studied through aggregate data where there is single market for housing. Specifically, asset pricing theory generally views housing only as an investment good, housing bubbles are part of house price that is unexplained by fundamentals, and pays limited attention to another role of housing as a consumption good.

[1] Along this venue, bubbles are classified either into "leveraged" or "unleveraged" bubbles. Financial risks posed by unleveraged bubbles are limited while the burst of credit boom bubbles is more severe. Housing bubbles are always considered of the latter type, credit financed bubbles, making their burst more severe. See, e.g. Kiyotaki and Moore (1997), Geanakoplos (2009), Farhi and Tirole (2011), Martin and Ventura (2012), Jordá *et al.* (2015).

[2] Some have argued that central bank should take an active view in stabilizing asset prices (Cecchetti, 2000; Borio *et al.*, 2001). Others have argued that such policy can have more de-stabilizing effects that monetary policy should focus on price stability (Bernanke and Gertler, 2001).

[3] Handbook of Macroeconomics (2016) has outlined that there are three major sources of friction in housing markets: (I) credit constraint (II) incomplete housing markets that give rise to market for renters (III) transaction costs. The first and the third channel focus on credit which has always been explored. This paper; instead, chooses to focus on the second channel and studies the question when there are duality in housing markets.

Aggregate housing data has been associated with empirical puzzle whereby housing dividend (aggregate rent price) increases in response to tightening monetary policy.[4] This puzzle is not only at odds with the theoretical prediction, but also inconsistent with dividend from other types of asset, e.g. stock price of which its dividend decreases in response to tightening monetary policy.

From the theoretical perspective, however, there exists a duality in housing markets, own vs. rent, which has important insights to housing bubbles. Duality in housing markets is referred to in the literature as *housing tenure choice* or *preference for housing services*. The literature on housing tenure choice is pioneered by Henderson and Ioannides (1983) in a partial equilibrium model. More recently, Chambers *et al.* (2009), Sommer *et al.* (2013), and Duarte and Dias (2017) have extended this work.

The idea of housing tenure choice is that, unlike other assets that have one single market, there exists a duality in housing markets: a homeowners' market and a renters' market. Each landlord can choose whether he/she will become a homeowner or a renter, depending on individual's preference for housing services. High-preference-for-housing-service individual will choose to rent out a house and consume housing dividend today as a consumption good. Low-preference-for-housing-service individual, however, becomes homeowner as they prefer to consume housing return in the future and would rather treat housing similar to other financial assets (investment good).

The importance of the duality in housing markets led the BLS, since 1983, to conduct an extra survey that separates the U.S. shelter cost of living (in U.S. Consumer Price Index calculation) in order to capture the distinction between housing as a consumption and housing as an investment good. However, empirical work has largely abstracted from the presence of this duality in the housing market and focused only on the single-market dimension of housing market.[5]

Recent theoretical work highlights the importance of duality in housing markets to housing bubbles. Huber (2017a) developed an overlapping generation (OLG) model for rational housing bubbles when there is an exogenous preference for housing services. The result shows that lower preference for housing services makes the economy more vulnerable to housing bubble. The paper shows the channel through which it operates that is highly intuitive and tractable: higher preference for housing services (relative to other consumption) implies larger discounted stream of dividend for housing services, or the fundamental value of housing. Thus, less room is left for the development of housing bubbles.

[4] See, e.g. Duarte and Dias (2017)

[5] See, e.g. Campbell *et al.* (2009), Iacoviello(2005), Iacoviello and Neri (2010), Iacoviello and Pavan (2013).

The linkage between preference for housing service and housing bubble is important because it moves beyond the "credit" channel in ascessing financial stability. It thus deserves to be explored empirically. Although recent theoretical studies or implementation of LTV macroprudential policy has always taken homeownership into account [6], empirical work that considers policy role under a duality in housing market is not widespread.[7] This paper makes a preliminary progress by analyzing direct evidence on the role of this duality using U.S. housing market data.

This paper addresses three main questions (i) Is there heterogeneity between homeowners and renters in the residential housing market that is important for the consideration of housing bubbles? (ii) Can we better understand rent puzzle from a duality in housing market? (iii) To what extent can monetary policy influence housing bubbles dynamics? in a favorable manner that it could stabilize housing bubbles or not?

The analysis will focus on comparison between the market for homeowners and the market for renters. The study begins with a simple structural vector autoregression (SVAR) following the conventional monetary policy shock identification of Christiano *et al.* (2005) and extended to allow for time-variation in the coefficient and volatility. The motivation for using time-varying model (TVC-SVAR) here is to account for possible structural changes in housing markets that could not be studied through simple SVAR estimation.

This paper contributes to the existing literatures as follow. First, this paper provides an empirical evidence of monetary transmission mechanism on housing bubbles that considers separately the market for homeowners and the market for renters. Second, while previous studies have already studied the effect of monetary policy shock on house price though time-varying model [8], this paper is the first to consider it together with the time-varying dynamics of housing dividends which is crucial for understanding dynamics of housing bubbles. Finally, this paper provides an additional historical perspective of the U.S. housing market which has encountered both housing boom and bust since 1983.

Three key findings stand out. First, there is significant heterogeneity between the market for homeowners and the market for renters which is particularly important when considering the issue of housing bubbles. The evidence provided here show that house price dynamic is more consistent with its fundamental in the renters' market rather than in the homeowners' market. I consider this evidence as consistent with

[6] See, e.g. Gete and Reher (2015).

[7] Up to my knowledge, Huber (2017b) is the first to pointed out from 18 OECD cross-country house price data that preference for housing services is negatively correlated with homeownership rate, frequency and intensity of housing boom.

[8] See, e.g. Del Negro *et al.* (2007), Aastveit (2017)

Huber (2017a, 2017b) which proposed that preference for housing services matters for the countries' vulnerability to housing bubbles.

Second, while the literature has pointed out the *rent puzzle* whereby rent price increases in response to tightening monetary policy, looking at the more disaggregated dividend series we are able to point out that the puzzle occurs mainly in the homeowners' market.

Finally, the finding that tightening monetary policy helps to drive house price down to their fundamental dividend value suggests that monetary policy can play a useful role in stabilizing housing bubbles. The results are robust to alternative identifications of monetary policy shocks.

This paper is organized as follows: Section (2) describes that definition and assumption of bubbles used in this paper. Section (3) provides the description of the data used. Empirical SVAR and TVC-SVAR model are described in Section (4). Section (5) presents the results of impulse response function and the discussions are provided in Section (6). Section (7) concludes.

2 Rational Bubbles: Definition and Assumption

Following the theoretical model of partial equilibrium rational asset pricing, asset price, Q_t is interpreted to be the sum of the "fundamental component (Q_t^F)" and the "bubble component (Q_t^B)",

$$Q_t = Q_t^F + Q_t^B \tag{1}$$

The bubble component here is modeled as part of the house price,[9] rather than the shortage of the assets in the economy. The fundamental component is defined as the present discounted value of future dividends,

$$Q_t^F \equiv \mathrm{E}_t\Big\{ \sum_{k=1}^{\infty} \Big(\prod_{j=0}^{k-1} (1/R_{t+j}) \Big) D_{t+k} \Big\}. \tag{2}$$

where R_t is (gross) riskless real interest rate and D_t is real housing dividend.

The effect of monetary policy shock is modeled as follows. Let ϵ_t^m be the monetary policy shock. With the assumption of sticky price where nominal shocks could influence real prices, partial derivative of Equation (1), (log) real house price with respect to monetary policy shocks could be described as follows (lowercase letters denote log of

[9] This definition of bubbles is common under infinite sequence of finite-lived agents model where the transversality condition does not hold. Other attempt, e.g. Bernanke and Gertler (2000, 2001), generally modeled asset price as contain the *ad-hoc* deviation part from the fundamental value.

the original variables).

$$\frac{\partial q_{t+k}}{\partial \epsilon_t^m} = (1-\gamma_{t-1})\frac{\partial q_{t+k}^F}{\partial \epsilon_t^m} + \gamma_{t-1}\frac{\partial q_{t+k}^B}{\partial \epsilon_t^m} \tag{3}$$

where $\gamma_t = Q_t^B/Q_t$ denotes the bubble share in the asset price in each period of time.

Similarly, log linearizing definition of the fundamental component from Equation (2), we would arrive at the following equation.

$$q_t^F = const + \sum_{j=0}^{\infty} \Lambda^j[(1-\Lambda)E_t\{d_{t+j+1}\} - E_t\{r_{t+j}\}]$$

Thus,

$$\frac{\partial q_{t+k}^F}{\partial \epsilon_t^m} = \sum_{j=0}^{\infty} \Lambda^j \left((1-\Lambda)\frac{\partial d_{t+k+j+1}}{\partial \epsilon_t^m} - \frac{\partial r_{t+k+j}}{\partial \epsilon_t^m}\right) \tag{4}$$

where Λ is the ratio of (gross) rates of dividend growth over interest rate along the balance growth path ($\Lambda < 1$).

In the empirical part to be described in Section (4), we need a reliable path of the fundamental component to be able to back out the bubbles dynamics which is our main interest. However, I will avoid modeling precisely the impulse response function of the fundamental component as a discounted stream of expected future dividends as described in Equation (4). This is because, unlike the thoretical method, such calculation is uneasy empirically and is likely that doing so will mask original dyanamics of housing dividend impulse response.

To proceed empirically, I make the following simplifying assumption that the effect of monetary policy on (gross) riskless interest rate approaches zero in the long-run horizon.

$$\lim_{k\to\infty} \frac{\partial r_{t+k+j}}{\partial \epsilon_t^m} \to 0, \qquad \text{for all } j$$

Considering Equation (4) at any single long-run horizon with the above assumption, it would follow that

$$\lim_{k\to\infty} \frac{\partial q_{t+k}^F}{\partial \epsilon_t^m} = (1-\Lambda)\lim_{k\to\infty}\sum_{j=0}^{\infty} \Lambda^j \frac{\partial d_{t+k+j+1}}{\partial \epsilon_t^m} \approx \lim_{k\to\infty} \frac{\partial d_{t+k+1}}{\partial \epsilon_t^m} \tag{5}$$

As shown, in the long-run horizon, the "dynamics over time" of housing dividends impulse response function is a potential proxy for the "dynamics over time" of the fundamental component of house price in a similar horizon.

Therefore, in analyzing the fundamental component of house price, I will focus on the evolution of rent price impulse response function, particularly at the long-run horizon, and downplay the importance of those in the short-run horizon. I believe this strategy is consistent with the actual dynamics of riskless interest rate, consistent with practitioners' method in monitoring bubbles through price-dividend ratio, and unnecessarily constrain us to manipulate the actual evolution of housing dividend data.

3 Data Description

To give an overview of the data used, this section presents simple statistics of cyclicalities of housing market variables, both real house price and real housing dividends.

3.1 U.S. Real House Price

Real house price used here is the U.S. residential house price index (all-transaction index) [10], deflated by GDP deflator. All data series cover the period between 1983Q1-2017Q1 due to the availability of U.S. rent of primary residence in 1983.

Figure 1 shows movements of real house price and real GDP cyclical properties with NBER recession shading at quarterly frequency. Both series are detrended by Hodrick-Prescott filter ($\lambda = 1600$)

We can see from Figure 1 that housing cycles tend to be accompanied by key economic variable. House price is highly correlated with GDP, which justifies interest among policy makers in stabilizing housing boom-bust cycle. Statistics from Table 4 of Appendix B. shows that procyclicality and high volatility of real house price are consistent across most of the sampled OECD countries.

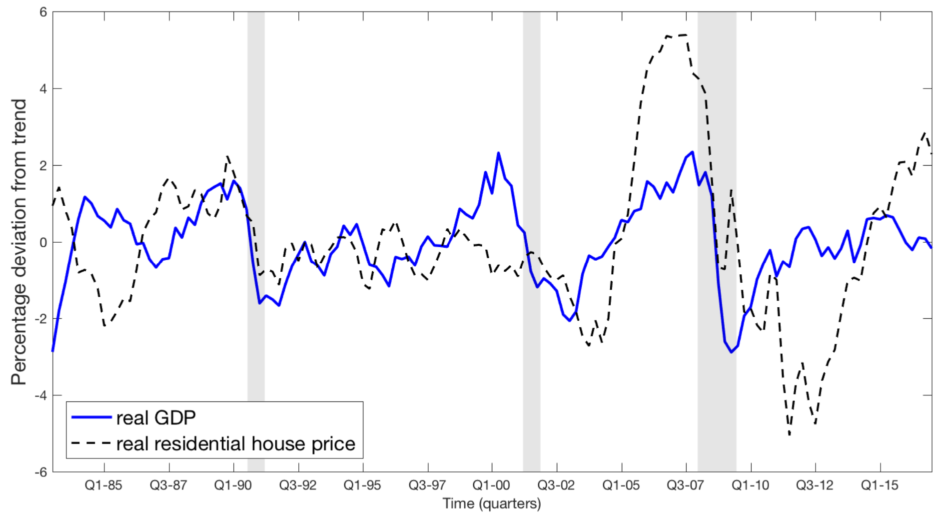


Figure 1: U.S. real house price at business cycles frequencies (1983Q1-2017Q1)

[10] Source: Federal Housing Finance Agency (FHFA). Actual data series are shown in Figure 12 of Appendix A.

3.2 U.S. Real Rent Price: Duality in Housing Markets

With dual housing markets, housing can be either consumption goods or investment goods depending on individuals' preference for housing services. Household with lower preference for housing services will be homeowners and consider housing as an investment, while household with higher preference for housing services will be renters and consider housing as a consumption good.

Let me first describe the unique characteristic of U.S. rent price data which allows us to distinguish between homeowners' housing dividend and renters' housing dividend.

Prior to 1983, U.S. rent price inflation is calculated differently from what is done today. In that period, shelter cost for housing included both consumption and investment aspects. Until February 1983, shelter cost which accounts for 32% share in Consumer Price Index (CPI) is separated into three major components: (i) owners' equivalent rent (OER) of primary residences, (ii) rent of primary residences, (iii) other shelter costs. Each account for approximately 24%, 6%, and 2% in CPI respectively.

The largest component, OER of primary residence, is the rental price of owners-occupied house which is first calculated in 1983. The BLS has suggested to separate out this price index by asking how much rent would homeowner has to pay if he/she were to rent his/her own house. OER thus reflects implicit return for owning a house.

The second largest component, rent of primary residence, is the rental price of tenant-occupied house which represents the actual rent tenants pay to his/her landlord. To avoid confusion, I will refer to rent of primary residence as the"tenant rent" throughout the paper.

Rent price, either OER imputed rent or tenant rent, are used here to capture fundamental components of house price, similar to dividend of stock price. Time-series of OER and tenant rent are reported below in Figure 2.[11] Both series are deflated by GDP deflator.

The cyclicalities of housing dividends are also reported below in Figure 3. Both series, (log) real OER and (log) real tenant rent, are detrended by Hodrick-Prescott filter ($\lambda = 1600$). We can see from Figure 3 that, unlike real house price which is highly procyclical and highly volatile altogether, both real OER and real tenant rent are countercyclical and less volatile than the business cycle. To be more explicit, the numbers are reported in Table 2 where we can see that the tenant rent appears to be more countercyclical and more volatile than the OER imputed rent.

[11] Source: Bureau of Labour Statistics (BLS)'s consumer price index.

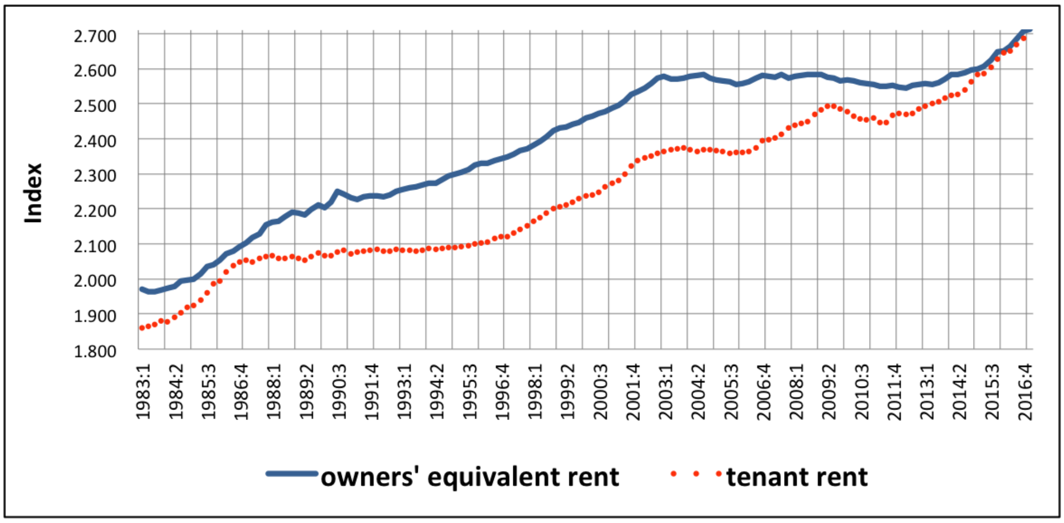


Figure 2: BLS real housing dividend price index (OER vs. tenant rent)

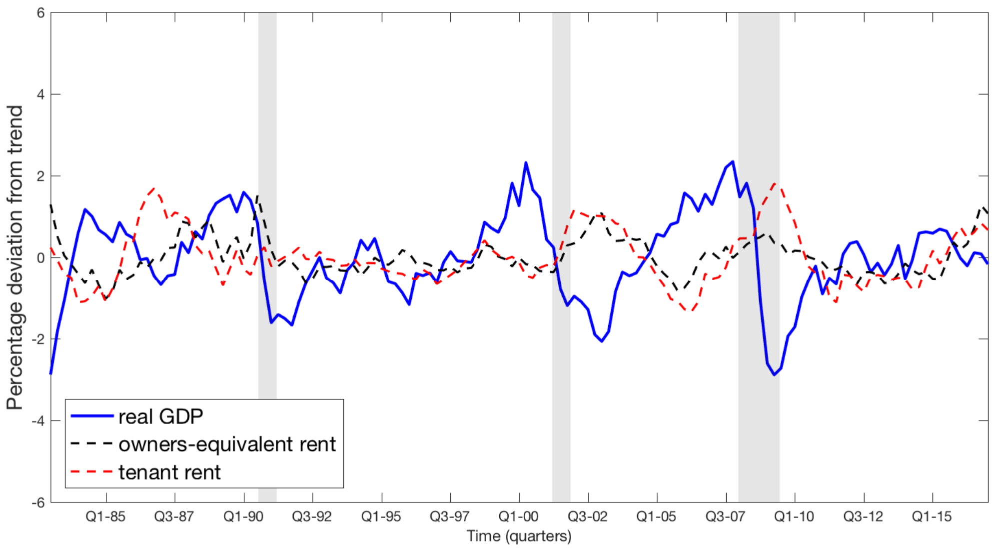


Figure 3: U.S. real rent at business cycles frequencies (1983Q1-2017Q1)

	correlation with business cycles	std. relative to GDP
real house price	0.42	1.89
real OER	-0.26	0.45
real tenant rent	-0.45	0.64

Table 1: Static cyclical properties of U.S. housing market variables (1983Q1-2017Q1)

4 Empirical Model

In studying monetary transmission mechanism, structural vector autoregression (SVAR) model has been widely used. Section (4.1) describes the baseline SVAR empirical model. Time varying version of the model will be described in Section (4.2).

4.1 SVAR

The present section describes the empirical model, structural vector autoregression (SVAR), used in studying the response of house price to monetary policy shock.

Define $x_t \equiv [\triangle y_t, \triangle p_t, \triangle d_t, \triangle p_t^c, i_t, \triangle p_t^h]$ where y_t, p_t, d_t, p_t^c, i_t, p_t^h denote (log) output, (log) price level, (log) real housing dividend, (log) commodity price index, short term interest rate, and (log) real house price index respectively.[12] Details of the data used are reported in Appendix A. Augmented Dickey Fuller test reveals that all log variables are I(1); therefore, I consider first difference VAR with lag order set to p=4 as suggested by BIC Information Criterion.

The model takes the form of an autoregressive (AR) model as follows:

$$x_t = A_0 + A_1 x_{t-1} + A_2 x_{t-2} + ... + A_p x_{t-p} + u_t$$

where u_t is the vector of reduced form innovation, white noise Gaussian process with zero mean and covariance matrix Σ. u_t is assumed to follow a linear transformation of the structural shocks, ϵ_t, where $u_t \equiv \mathrm{S}_t \epsilon_t$, $\mathrm{E}\{\epsilon_t \epsilon_t'\} = I$, $\mathrm{E}\{\epsilon_t \epsilon_{t-k}'\} = 0$ for all t and $k \geq 1$, $\mathrm{S}_t \mathrm{S}_t' = \Sigma$

The identification of monetary policy shock follows the conventional one of Christiano *et al.* (CEE, 2005): monetary policy shock does not affect GDP, real rents, or inflation contemporaneously. Moreover, it is assumed that central bank do not respond contemporaneously to house price innovations.[13] This follows naturally as S_t is a Cholesky matrix of Σ where monetary policy shock ϵ_t^m is ordered fifth in ϵ_t. We make no attempt to interpret the remaining "structural" shocks.

4.2 TVC-SVAR

Following from equation (3), the response of house price to monetary policy shock is a function of the relative size of the bubble (γ_t) which can be changing over time.

[12] Empirical setup here is close to Galí and Gambetti (2015) which study monetary transmission on stock price bubbles. The focuses are on different kinds of asset markets (stock price vs house price) that should be considered a complement to their work. Any difference found should be allowed to be attributable to asset-specific characteristic itself.

[13] Alternative monetary shock identifications that relax this assumptions are performed as a robustness check in Appendix D.

To account for this possibility, this section will utilize the time-varying coefficients structural vector autoregression (TVC-SVAR) model.

Building upon the SVAR described in Section (4.1), the model can be described as,

$$x_t = A_{0,t} + A_{1,t}x_{t-1} + A_{2,t}x_{t-2} + ... + A_{p,t}x_{t-p} + u_t$$

where TVC-SVAR allows for time-varying coefficient, $[A_{0,t}, A_{1,t}, ..A_{p,t}]$, and covariance matrix, Σ_t

Let the VAR's time-varying parameters be collected in a vector $\theta_t = vec(A_t')$ where $A_t = [A_{0,t}, A_{1,t}, ..A_{p,t}]$ and vec is the column stacking operator. We assume θ_t follows the following law of motion:

$$\theta_t = \theta_{t-1} + \omega_t$$

where ω_t is a Gaussian white noise process with zero mean and constant covariance Ω, and independent of u_t at all leads and lags.

The time varying covariance matrix Σ_t is factored as $\Sigma_t = F_t D_t F_t'$, where F_t is a lower triangular matrix with ones on the main diagonal, and D_t is a diagonal matrix. Let σ_t be the vector containing a diagonal elements of $D_t^{1/2}$ and $\phi_{i,t}$ a column vector with the nonzero elements of the (i+1)-th row of F_t^{-1} with i = 1,...5. Reduced-form shock can thus be written as $u_t = F_t D_t^{1/2} \epsilon_t$. Eigenvalue-eigenvector decomposition of covariance matrix is assumed to follows the following law of motion,

$$\begin{aligned} \log\sigma_t &= \log\sigma_{t-1} + \zeta_t \\ \phi_{i,t} &= \phi_{i,t-1} + \nu_{i,t} \end{aligned}$$

where ζ_t and $\nu_{i,t}$ are zero mean constant covariance (Ψ_i and Ξ) white noise Gaussian process. $\nu_{i,t}$ is assumed to be independent of $\nu_{i,t}$, for $j \neq i$ and $\omega_t, \epsilon_t, \zeta_t$ and $\nu_{i,t}$ (for i = 1,...5) are mutually uncorrelated at all leads and lags.

To define monetary impulse response function, rewrite the above AR model into a companion form as:

$$\tilde{x}_t = \tilde{\mu}_t + \tilde{A}_t \tilde{x}_{t-1} + \tilde{u}_t$$

where $\tilde{x}_t \equiv [x_t', x_{t-1}', ...x_{t-p+1}']$, $\tilde{\mu}_t \equiv [A_{0,1}', 0, ...0]'$, $\tilde{u}_t \equiv [u_t', 0, ...0]'$, $\tilde{A}_t$ is the $np \times np$ companion matrix of the form:

$$\tilde{A}_t \equiv \begin{bmatrix} A_{1,t} & A_{2,t} & ... & A_{p-1,t} & A_{p,t} \\ I_n & 0 & \cdots & 0 & 0 \\ 0 & I_n & \cdots & 0 & 0 \\ \vdots & & \ddots & & \vdots \\ 0 & \cdots\cdots & & I_n & 0 \end{bmatrix}$$

We use local approximation method of dynamic response to a t period shock. The median IRFs to exogenous shocks are then collected as:

$$\frac{\partial x_{t+k}}{\partial u_t'} = \left[\tilde{A}_t^k\right]_{6,6} \equiv \mathbf{B}_{t,k}$$

for k= 1,2,... where $[\mathbf{M}]_{6,6}$ represents the first six rows and six columns of and matrix $\mathbf{M}$, where $\mathrm{B}_{t,0} \equiv I$. Thus, monetary policy impulse response functions are given by

$$\frac{\partial x_{t+k}}{\partial \epsilon_t^m} = \mathbf{B}_{t,k}\mathrm{S}_t^{(5)} \equiv \mathbf{C}_{t,k}$$

for k= 0,1,2,... and $\mathrm{S}_t^{(5)}$ denotes the fifth column of S_t.

The model is estimated with Bayesian method. In order to characterize joint posterior distribution of the model parameters, Gibbs sampling algorithm is used. The algorithm works as follows. Parameters are divided into seven subsets. Parameters in each subsets are drawn conditional on a particular value of the remaining parameters. The new draw is used to draw subsets of parameters.[14] The procedure is repeated for 22,000 times discarding the first 20,000. Parameter convergence is assessed using trace plots. Results from TVC-SVAR will be reported in the next section.

4.3 Empirical Setup: Duality in Housing markets

In this paper, I utilize this unique feature of the U.S. rent price described in Section (3.2) to model different housing dividends in the dual housing markets: own vs. rent.

Depending on individual's preference for housing services, households are characterized either as homeowners or renters. These two types of households received different types of dividends for housing. Homeowners receive "owners' equivalent rent" (p_t^{oer}) for owning a house, while renters received "tenant rent" (p_t^{trent}) for renting a house.[15] A country aggregate rent price thus can be modeled as

$$d_t = (1-\omega)p_t^{oer} + \omega p_t^{trent}$$

where ω is a fraction of continuum households with high preference for housing services.

With this framework, this paper studies empirical SVAR model under two extreme scenarios: when all households are homeowners (ω=0) and when all households are renters (ω=1).

Model 1: low preference for housing services.

[14] See Appendix C. for details of the algorithm used.
[15] See Appendix A. for details of the data used.

In this setting, a country is characterized only by households with low preference for housing services (ω=0). All households (landlords) are owners. SVAR model can thus be defined as

$$x_t \equiv [\triangle y_t, \triangle p_t, \triangle p_t^{oer}, \triangle p_t^c, i_t, \triangle p_t^h]$$

Model 2: high preference for housing services
Similarly, this setting assumes households have high preference for housing services (ω=1) that all landlords are renters. The model for SVAR thus become

$$x_t \equiv [\triangle y_t, \triangle p_t, \triangle p_t^{trent}, \triangle p_t^c, i_t, \triangle p_t^h]$$

As Duarte and Dias (2017) has pointed out their results in which the *rent puzzle*, rent price increases in response to tightening monetary policy. This is in contrast to the response of house price to monetary policy shock which decreases persistently in response to tightening monetary policy. By focusing on more disaggregated housing dividend series, not only does it has a theoretical implication for understand housing bubbles under different preference for housing services, but also help improves understanding regarding the dynamics of housing dividends.

5 Results : Impulse Response Function

In this section, I present the impulse response function results from the above described empirical simple SVAR and TVC-SVAR models. For simple SVAR, the sample is restricted to 1983Q1-2007Q4 due to the impact of the zero lower bound which started from 2008 onwards, full sample estimation will be perform in TVC-SVAR.

Here, the results for homeowners' market and renters' market are compared.

$$x_t \equiv [\triangle y_t, \triangle p_t, \triangle d_t, \triangle p_t^c, i_t, \triangle p_t^h] \text{ where } d_t = \{p_t^{oer}, p_t^{trent}\}$$

The rest of the model and shock identification follows from the description in Section (4).

Monetary policy impulse response functions (IRF) are reported in Figure 4 for homeowners and Figure 5 for renters. The solid blue line is the estimated response to policy shock while the two dashed red lines are the 84% confidence interval.

Impulse response function of output and GDP deflator show a correct sign that both series fall in response to tightening monetary policy. The results reveal that (log) real house price falls in response to tightening monetary policy, however, it is sticky in that it responds slowly toward monetary policy shock (Figure 4.f and Figure 5.f). In both models, IRFs are more or less similar for all variables with slight difference

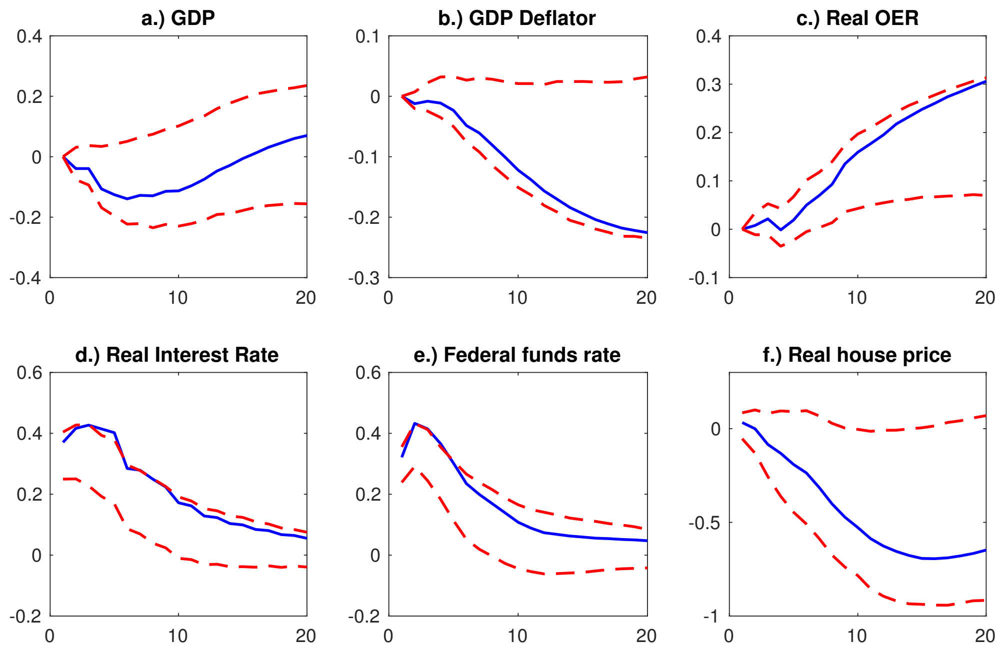


Figure 4: SVAR cumulated IRF from monetary policy shock for **homeowners** (low preference for housing services)

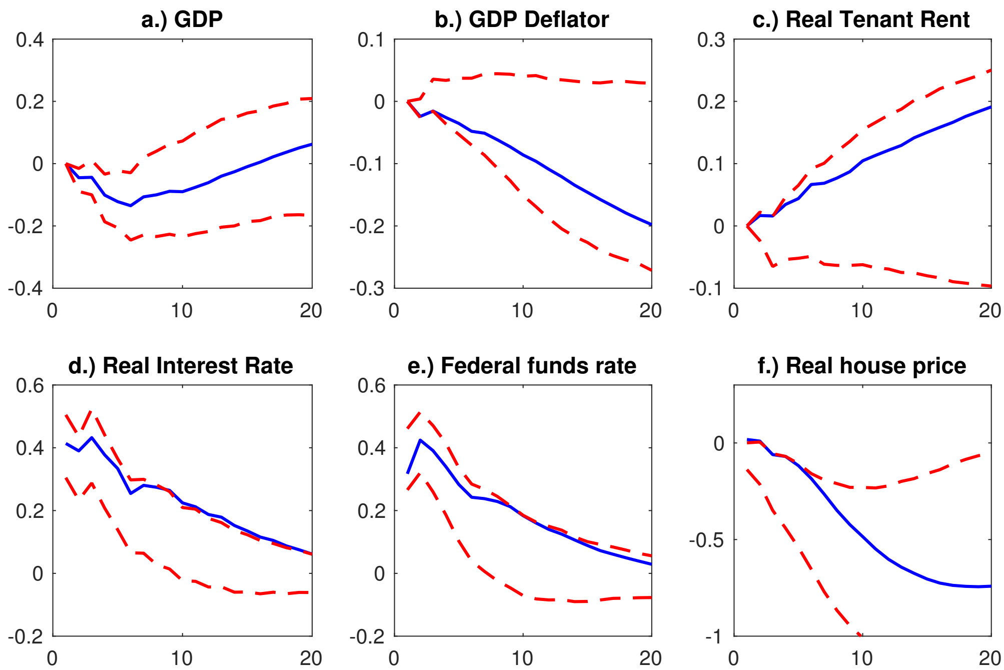
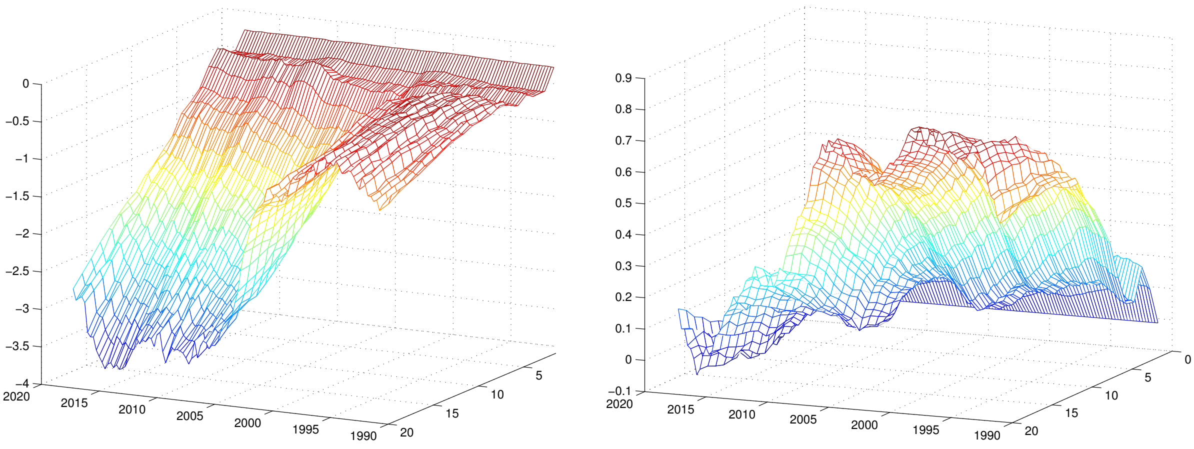
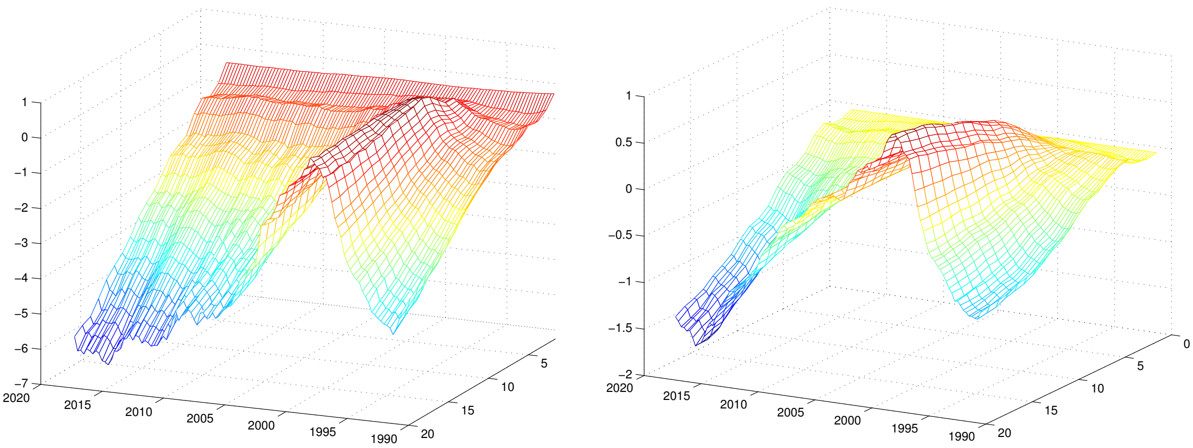


Figure 5: SVAR cumulated IRF from monetary policy shock for **renters** (high preference for housing services)



(a) Real house price (b) Real OER

Figure 6: Model 1 (low preference for housing services). TVC-SVAR monetary IRF



(a) Real house price (b) Real tenant rent

Figure 7: Model 2 (high preference for housing services). TVC-SVAR monetary IRF

for housing dividends. Real OER shows a clear increase in response to tightening monetary policy shock. However, sign of the tenant rent IRF is unclear as its confidence band is not always positive (Figure 5.c).

The results from SVAR seems to be consistent with past works in that housing dividends increase in response to tightening monetary policy and we are unable to characterize the difference between real OER and real tenant rent dynamics. To further investigate this issue and to account for the possible structural changes that could generate instability of SVAR parameters, let us consider the time-varying impulse response function results reported here in Figure 6 and Figure 7.

Due to space considerations, I report here only the time-varying IRFs of real house price and real rent price which are the variables of interest. Overall, the direction of IRFs are consistent with those from the simple SVAR model, reflecting robustness of the results. I defer a complete analysis and policy implications to Section (6).

6 Discussion of the Results

6.1 Sticky House Price

Before turning to the discussion of the main questions of this paper in Section (6.2) and (6.3), let me first highlight one salient fact from the above impulse response functions which has been overlooked in most empirical evidence and theoretical modeling. In contrast to stock price, house price is sluggish and do not respond contemporaneously to conventional demand shock, e.g. monetary policy shock, in the SVAR impulse response function. The evidence here, Figure 4.f and 5.f, show that house price is sticky that it takes longer than 2.5 years to reach its full impact. The results are robust to both constant and time-varying models.

In the literatures, there are two general directions in demonstrating the sluggishness of aggregate price level in response to aggregate shocks. One simply study this question directly through price impulse response, e.g. SVAR, FAVAR.[16] The first method, however, is sometimes criticised as it is hard to identify appropriate exogenous demand shock. This give rise to the second strand of the literatures that turn to micro-level price data in measuring price stickiness instead of the aggregate one.[17]

Following the second method in displaying price rigidity, I report here the persistence of house price inflation along with the persistence of other asset price inflation in Table 2. To be precise, I estimate AR(1) model to first difference of log real house price, log real rent price, and log real stock price. The estimated AR(1) coefficient, used to signify the degree of inflation persistence, are reported along with the standard deviation of AR(1) innovations which is used to measure volatility. Simple statistics here confirm that while both house price and stock price are highly volatile, rigidities exist only in the housing market.[18] AR(1) coefficients of real house price are clearly

[16] See, e.g. Bils *et al.* (2003), Biovin *et al.* (2008), Christiano *et al.* (2005), Mackowiak *et al.* (2009).

[17] Recent empirical work; however, has shown that although prices are found to be highly volatile at the micro-level, this could be driven by temporary sales price change, e.g. durable prices, not the regular price change. One interesting work by Wu (2016) using U.S. micro-level CPI prices has documented that, as long as price change is driven by temporary sales, price change in cumulative impulse response function could be large and persistence.

[18] except Austria of which its data has become unavailable in the beginning and the result is not statistically significant. To give the benchmark number for comparison with Table 2, Bills and Klenow

	real residential house price		real rent (aggregate)		real stock price	
Country	AR(1) coeff.	Std. of innovations	AR(1) coeff.	Std. of innovations	AR(1) coeff.	Std. of innovations
	ξ	σ_ϵ	ξ	σ_ϵ	ξ	σ_ϵ
U.S.	0.69 (0.05)	0.88	0.45 (0.07)	0.56	0.31 (0.07)	1.67
Japan	0.76 (0.05)	1.07	0.59 (0.06)	0.67	0.36 (0.07)	1.70
Germany	0.63 (0.06)	0.63	0.19 (0.07)	0.70	0.37 (0.07)	1.81
France	0.60 (0.06)	2.20	0.47 (0.06)	0.56	0.35 (0.07)	2.14
Italy	0.83 (0.04)	0.80	0.31 (0.07)	1.11	0.37 (0.07)	2.22
UK	0.67 (0.06)	2.53	0.35 (0.07)	1.72	0.26 (0.07)	2.07
Canada	0.77 (0.05)	1.86	0.44 (0.07)	1.54	0.28 (0.07)	1.75
Spain	0.42 (0.07)	2.12	0.92 (0.03)	0.54	0.29 (0.09)	2.26
Finland	0.71 (0.05)	2.01	0.27 (0.07)	1.21	0.38 (0.07)	2.96
Ireland	0.64 (0.06)	2.03	0.42 (0.07)	1.82	0.38 (0.07)	2.26
Netherlands	0.40 (0.07)	2.91	0.48 (0.07)	3.87	0.28 (0.07)	1.99
Norway	0.65 (0.06)	1.90	0.17 (0.07)	2.00	0.25 (0.09)	2.66
New Zealand	0.52 (0.06)	2.04	0.27 (0.08)	1.52	0.19 (0.07)	1.75
Sweden	0.83 (0.04)	1.46	0.25 (0.07)	1.84	0.37 (0.07)	2.71
Switzerland	0.75 (0.05)	1.35	0.61 (0.07)	1.14	0.29 (0.07)	1.89
Australia	0.37 (0.07)	1.79	0.63 (0.06)	1.02	0.22 (0.07)	2.06
Belgium	0.61 (0.06)	1.69	0.78 (0.05)	0.59	0.34 (0.09)	1.73
Denmark	0.44 (0.07)	1.60	0.02 (0.08)	0.79	0.47 (0.07)	1.80
Austria	-0.35 (0.12)	2.07	0.49 (0.06)	0.99	0.40 (0.07)	2.19

Table 2: International evidence of asset price persistence and standard deviation. Persistence (with standard error reported in parenthesis) and standard deviation of inflation for real house price, real rent price, and real stock price. Note: first difference of log real house price, real rent price, and real stock price are fitted to the AR(1) model. $dp_t = \xi dp_{t-1} + \epsilon_t$ where ϵ_t is i.i.d. with standard deviation σ_ϵ. Source: Author's calculation, OECD Economic Outlook (OEO) database.

higher than those of real stock price while standard deviation of AR(1) innovations are high for both asset prices.

Sticky price is always an issue in macroeconomics. It is widely perceived that monetary policy will have a neutral effect on real variables if prices are all flexible but will have large and significant effect if prices are sticky (monetary non-neutrality).[19]

From the perspective of this paper, the work by Barsky *et al.* (2003, 2007) regarding the importance of price stickiness of durable goods is particularly relevant. They employ sticky-price general equilibrium model to argue that in order to understand the transmission of monetary policy shock, pricing behavior of durable goods sector (whether it is sticky or not) is more crucial than pricing behavior of non-durable goods sector. In particular, if price of durable goods (e.g. house price) are flexible while price of nondurable goods are sticky, tightening monetary policy will increase durable goods production and exactly decrease nondurable goods production; leaving neutral effect on aggregate output and production under the perfect financial market assumption. On the other hand, if price of durables are sticky, then even a small durable goods sector can cause the model to behave as if most/all prices are sticky.

(2004) reported that persistence of U.S. aggregate inflation is only 0.2 with s.d. 0.63.

[19] See, e.g. Christiano *et al.* (1999), Romer and Romer (2004)

Despite the importance of housing and sticky price in monetary economic modeling, the role of house price stickiness is not widely discussed but assumed fully flexible in monetary/business cycle modeling as it is highly volatile.[20] The fact that house price is sticky, while stock price is flexible, is consistent with the observed long-lasting effect of the crisis generated by house price collapse. In designing a proper policy, clear-cut understanding of rigidities in housing sector and further attempts in modeling it are thus necessary.

6.2 Heterogeneity in Housing Dividends IRFs Homeowners vs. Renters

Duarte and Dias (2017) has pointed out from constant coefficient SVAR with aggregate price-rent data that rent price increases in response to tightening monetary policy which is quite surprising.

By eparating homeowners' market from renters' market, the results obtained from constant parameter SVAR in Figure 4.c and 5.c are consistent with Duarte and Dias (2017) where rent price increases in response to tightening monetary policy. The difference among the two models in the constant SVAR; however, is still unclear.

In this section, we investigate further using the time-varying SVAR. I report here time-varying IRFs of housing market variables at *selected horizons* in Figure 8 and Figure 9. Figure 8 shows IRFs of real house price and housing dividend of model 1 for homeowners at selected horizons while Figure 9 shows the results of model 2 for renters. With the benefit of time-variation, the analysis here will utilize the distinction of dynamics both across *times (x-axis)* and across *IRF horizons*.

Two interesting observations that show how analyzing separately the two housing markets, together with the application of time-varying model, could help improve our understanding on rent price dynamics are as follows.

Observation 1: Sign of housing dividend IRFs

From both conventional wisdom and economic theory, rent price which is a component of the CPI basket is expected to decrease in response to tightening monetary policy like other price/inflation. The fact that rent price increases in response to tightening monetary policy is thus surprising. Looking at the time-varying results of housing dividends dynamics, we can observe a clear heterogeneity between real OER and real tenant rent which has been obscured in the simple SVAR results.

Comparing Figure 8.b to Figure 9.b, the rent puzzle, rent price increases in response to tightening monetary policy, is more pronounced in homeowners' market. To be

[20] See, e.g. Iacoviello (2005), Iacoviello and Neri (2010).

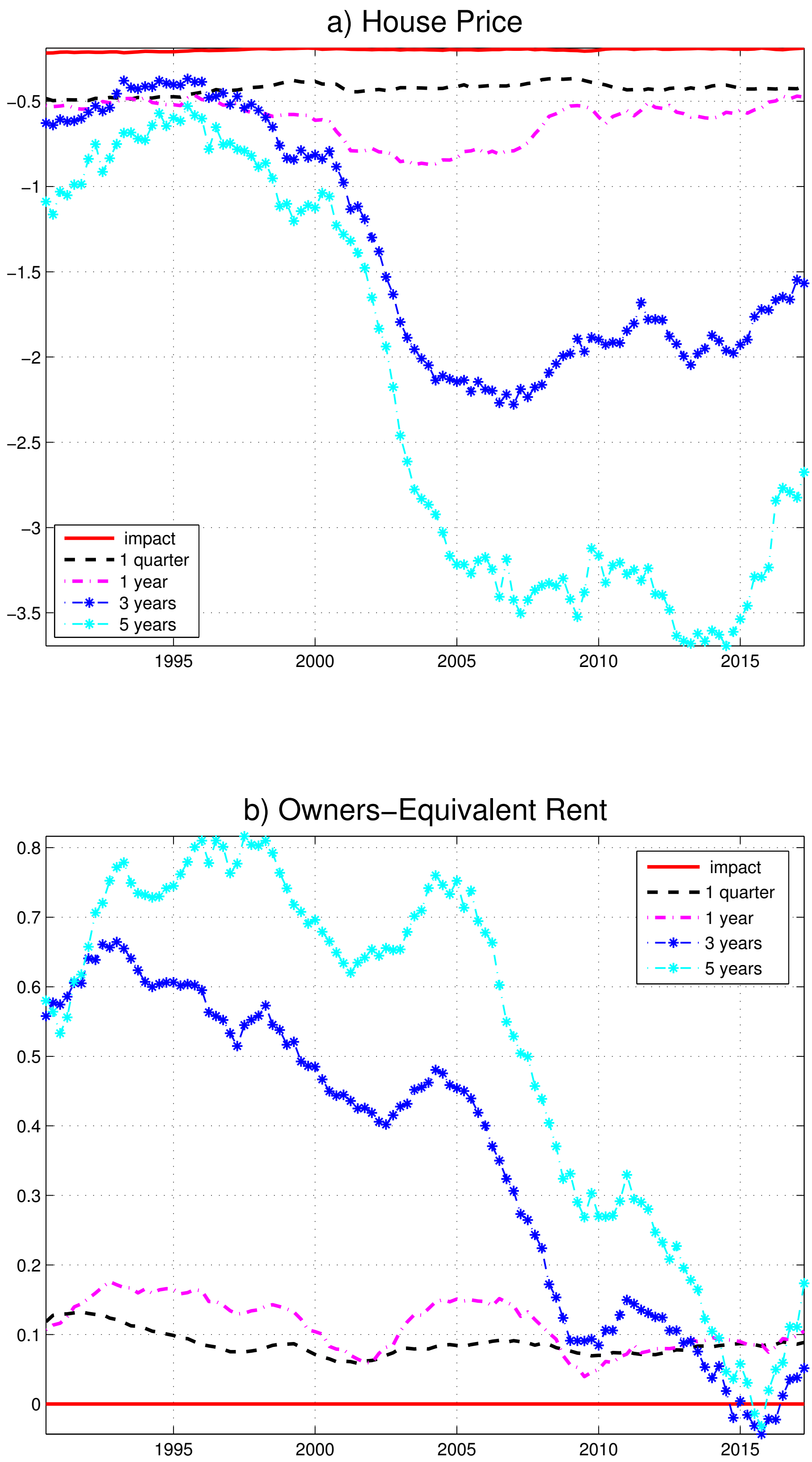


Figure 8: Homeowners' market.

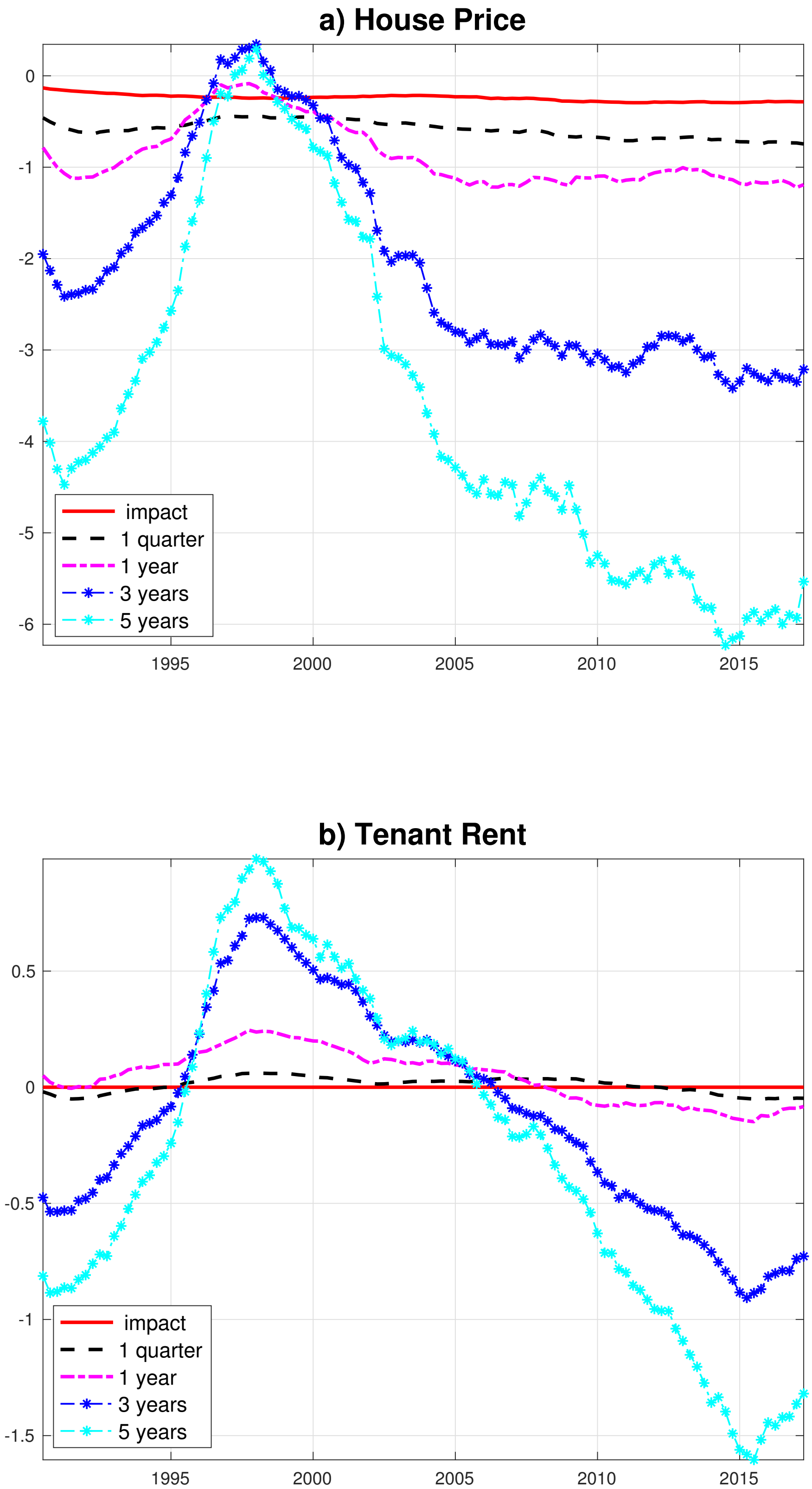


Figure 9: Renters' market.

precise, owners' equivalent rent increases in response to tightening monetary policy in all periods of the study (Figure 8.b). However, tenant rent increases in response to tightening monetary policy only in a brief period during 1995-2005 (Figure 9.a).

Observation 2: Dynamics over time of housing dividend IRFs

Conceptually, we would like to study the dynamics over time of housing bubbles in both the homeowners' market and the renters' market. However, measuring bubbles is not easy empirically.

To proceed, I consider the dynamics over time of house price IRF together with those of the rent price IRF with the assumption that the dynamics of the fundamental component of house price will be captured in the dynamics of the rent price. This follows from what we have discussed earlier in Section (2) that, in the long-run, the rent price dynamics can better reflect the fundamental component of house price rather than in the short-run. The analysis here will thus concentrate on IRFs' dynamics over time only at the long-run horizons (longer than one year).

The results reveal that, in the renters' market, the dynamics across time of house price IRF (Figure 9.a) at longer than one-year horizon are consistent with the dynamics of its fundamental IRF (Figure 9.b; tenant rent) in the sense that the local peaks and troughs of both series are similar. Such pattern consistency between price-fundamental dynamics, however, could not be observed in the homeowners' market (Figure 8). The dynamics across time of house price IRF (Figure 8.a) are significantly different from those of the fundamental component (Figure 8.b; owners' equivalent rent).

Together, these two observations confirm that there is a clear heterogeneity between the homeowners' market and the renters' market which cannot be observed from aggregate data alone. By using data at the more disaggregated levels and tying the results closely to the theoretical framework, we could improve our understanding on the dynamics of housing dividend.

In addition, these two observations suggest that the dynamics of house price is more consistent with the renters' fundamental component rather than the homeowners' fundamental component. This sheds light to the fact that the two market differs in their vulnerability to housing bubbles and it is likely that the homeowners' market is more vulnerable to housing bubbles than the renters' market.[21]

[21] This potential explanation could be seen clearer by looking at Equation (3) which suggests that similar dynamics between house price IRF and the fundamental component IRF in the long-run horizon is explained by larger fundamental share $(1-\gamma_t)$. Our result here thus likely suggests that the fundamental component is larger in the renters' market rather than in the homeowners' market, or equivalently, the renters' market is less vulnerable to housing bubbles than the homeowners' market.

This explanation supports the theoretical prediction of Huber (2017a) and the cross-country evidence of Huber (2017b) in which both suggest that the market for renters (higher preference for housing services environment) has higher share of the fundamental component and the system is less vulnerable to housing bubbles compared to the market for homeowners. Regarding the U.S. housing markets, the fact that owners' equivalent rent accounts for the largest share of the U.S. shelter index at 24% while tenant rent makes up only 6% thus implies that housing market is not highly fundamental driven by nature.

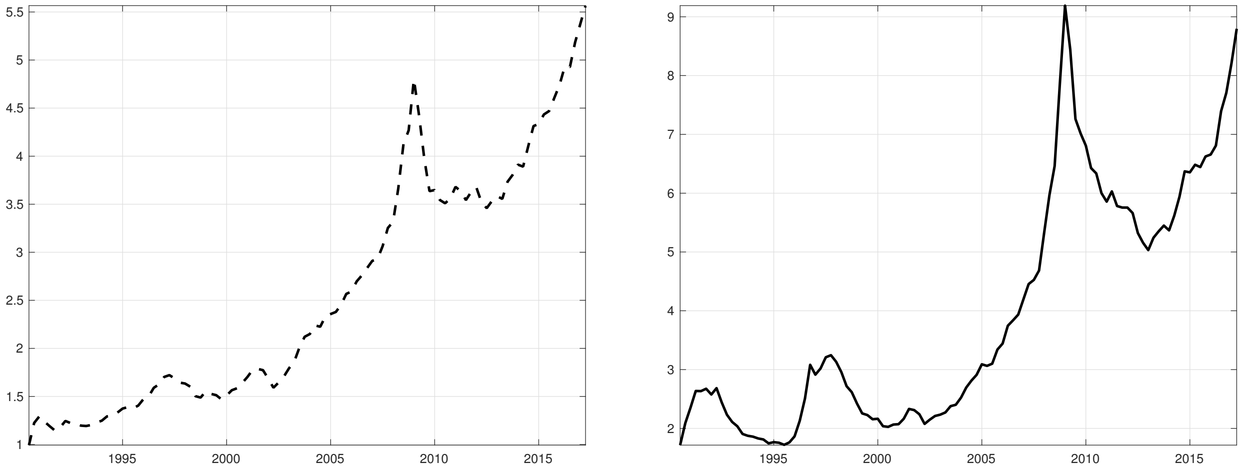
Insights here have important policy implications to housing bubbles. Existing measures intended to curb housing bubbles have focused exclusively on credit. The most widely accepted policy measure to control housing bubbles is the loan-to-value (LTV) ratio, which limits the amount of credit used to finance house purchases. The empirical findings here where the degree of vulnerability to bubbles differs between the homeowners and the renters (different levels of preference for housing services) thus support the idea that there are room for other non-conventional policy, beyond the conventional credit channel, to influence housing bubbles through individual's preference for housing services, e.g. policy to promote homeownership/home investment, rental subsidies.

These types of policy have been implemented differently in several countries. For the U.S., tax-payers can benefit from lower interest rate on home mortgages and various incentives by states and local authorities to support lower-income home-buyers. Other policies around the world include government-subsidized home purchase saving account, program allowed early withdrawal from pension funds for home purchase (Canada), etc. An exception to all these countries is Germany where most government policy focus on rental subsidies, not homeownership (Campbell; 2013). Empirical results here thus raise a concern to the stability issue that the benefit of homeownership could comes with the risk to bubbles and should be taken into consideration.

6.3 The Stabilisation Role of Monetary Policy

In this section, we turn to the role of monetary policy in stabilizing housing bubbles for both the market for homeowners and the market for renters. The previous section has already investigated the dynamics across time of house price and rent price IRFs. In analyzing the effectiveness of monetary policy, this section focuses on the dynamics across horizons of both IRFs.

Figure 8 and Figure 9 reveal that, in both the market for homeowners and the market for renters, monetary policy could play a useful role in stabilizing housing bubbles. To be precise, tightening monetary policy helps to drive house price down to



(a) Model for Homeowners

(b) Model for Renters

Figure 10: Dynamics of total variance of house price explained by monetary policy shock.

its fundamental dividend value, thus, bridge the gap between house price and dividend ratio. The result is more pronounced in the homeowners' market which we have argued in the previous subsection to be more vulnerable to housing bubbles.

However, the fact that SVAR is a linear model makes the effect of monetary policy shock to be symmetric for both tightening and loosening monetary policy. This thus implies that loosening monetary policy would increase the value of house price in the sense that house price becomes more diverge from its fundamental dividend value; thus, could increase the market's fragility to housing bubbles.

To further gauge the importance of monetary policy shock on the housing market variables, let us also look at the total variation of house price generated by monetary policy shock both *over time* and *over horizons.*

Considering Figure 10, [22] we can see that the total variance of house price explained

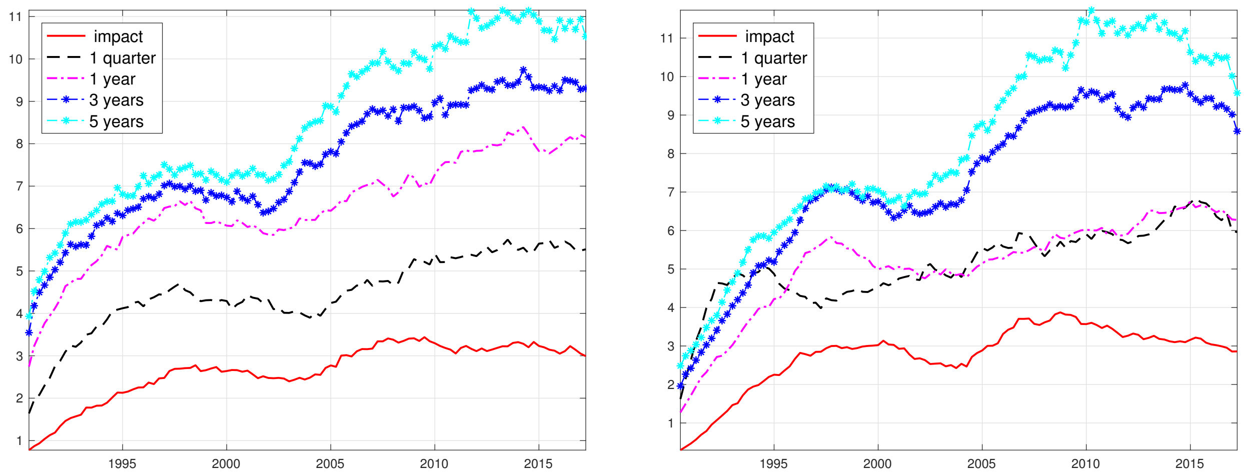
[22] Given that SVAR model can be described as,

$$\begin{bmatrix} \Delta y_t \\ \Delta p_t \\ \Delta d_t \\ \Delta p^c_t \\ i_t \\ \Delta p^h_t \end{bmatrix} = \begin{bmatrix} C^{11}(L) & C^{12}(L) & C^{13}(L) & C^{14}(L) & C^{15}(L) & C^{16}(L) \\ C^{21}(L) & C^{22}(L) & C^{23}(L) & C^{24}(L) & C^{25}(L) & C^{26}(L) \\ C^{31}(L) & C^{32}(L) & C^{33}(L) & C^{34}(L) & C^{35}(L) & C^{36}(L) \\ C^{41}(L) & C^{42}(L) & C^{43}(L) & C^{44}(L) & C^{45}(L) & C^{46}(L) \\ C^{51}(L) & C^{52}(L) & C^{53}(L) & C^{54}(L) & C^{55}(L) & C^{56}(L) \\ C^{61}(L) & C^{62}(L) & C^{63}(L) & C^{64}(L) & C^{65}(L) & C^{66}(L) \end{bmatrix} \begin{bmatrix} \epsilon^1_t \\ \epsilon^2_t \\ \epsilon^3_t \\ \epsilon^4_t \\ \epsilon^5_t \\ \epsilon^6_t \end{bmatrix}$$

where ϵ^5_t is identified to be monetary policy shock (ϵ^m_t). Variance of house price conditional on monetary policy shock can thus be calculated according to,

$$var(\Delta p^h_t|m) = \sum_{k=0}^{\infty}(C^{6m}_k)^2$$

Overall dynamics of house price fluctuation among the two models (Figure 10.a and 10.b) show



(a) Model for Homeowners

(b) Model for Renters

Figure 11: Percentage of house price variance explained by monetary policy shock in each horizon.

by monetary policy is low during the driving up of the boom period (1997-2005Q4) and increased significantly after. This is contrary to the belief that has blamed the unexpectedly low monetary policy to be the cause of house price increase during 2002-2006 (see, e.g. Taylor, 2007; Himmelberg *et al.*, 2005) and more consistent with the opposite (see, e.g. Campbell *et al.*, 2009). One assumption here is that the effect of monetary policy occurs with years of lags.

To support this assumption, we also look at "house price variance explained by monetary policy shock" as a percentage of the "total variance of house price". This is done on the basis of variance decomposition dynamics shown in Figure 11. In the short-run, monetary policy shock could explain very little fraction of the total house price variation. However, the effect becomes more sizable, especially after one year, that the fraction of total house price variance explained by monetary policy shock increase up to 12%. I interpret this number as a sizable fraction given that house price is affected by many other shocks, e.g. income shock, mortgage market shocks.

To conclude the section, when considering the effect of monetary policy on asset price bubbles, the characteristic of asset price itself should be taken into consideration. In contrast to stock price, house price is sticky, the effect of monetary policy on house price variation is limited in the short-run, but sizable in the long-run. This thus suggests that while monetary policy could influence housing bubbles in a useful manner, other tools beyond monetary policy to directly control housing bubbles should

similar pattern across time. The fact that house price variance conditional on monetary policy shock is similar across the two models increases the robustness of the results that it differs only in terms of housing dividend's response.

also be considered.

7 Conclusion

During the past decade, housing has played a very important role in the macroeconomy that it was considered the origin of the past global financial crises. The collapse of house price is arguably deeper and longer than other assets. This prompts interests among policy makers and researchers to better understand its dynamics and study how best we should deal with housing bubbles.

Several attempts have been done to incorporate housing sector into monetary model to study the effect of monetary policy on housing markets. In these models, house price is always assumed to be fully flexible. This paper, however, documents one stylized fact found here that house price is sticky and do not respond contemporaneously to conventional monetary policy shock.

By studying separately the market for homeowners and the market for renters, clear distinction among the two housing markets can be made. The results here show that house price dynamic is more consistent with the fundamental component in renters' market rather than homeowners' market, supporting the theoretical prediction that the two markets differ in their vulnerability to housing bubbles.

Regarding the stabilization role of monetary policy, the evidence here shows that tightening monetary policy can help stabilize housing bubbles in the sense that it drives house price down to the fundamental component of house price. The stabilization effect of monetary policy is particularly pronounced in the homeowners' market which is likely to be more vulnerable to housing bubbles than the renters' market.

This favorable effect of monetary policy on housing bubbles should not make monetary policy be viewed as optimal to target housing bubbles. The unique characteristic of house price that is sticky makes house price uneasy to control: the effect of monetary policy is limited in the short-run but can go far beyond expectation in the long-run. Moreover, the salient effect of loosening monetary policy that it could generate the accumulation of risk in the housing markets should also be taken into account.

This paper so far is just one small further step into the literature on the distributional effects of monetary policy in housing markets. The link between the distributional effect of macroeconomic policy and housing bubbles should be high on further research agenda.

A Appendix : Data Sources

Series	Notes	Sample period	Source
Real GDP	Expenditure approach. Millions of national currency, volume estimates, annual level, quaterly and seasonally adjusted, index based in 2010 (Measure: VOBARSA).	1983Q1-2017Q1	OECD
Price level/GDP deflator	Nominal GDP/Real GDP. nominal GDP is calculated from expenditure approach, millions of national currency, current prices, annual level, quarterly and seasonally adjusted (Measure: CARSA).	1983Q1-2017Q1	OECD
Commodity price index	Non-energy commodity price index.	1983Q1-2017Q1	World Bank
Real owners' equivalent rent	Owners' equivalent rent of primary residence, deflated by GDP deflator.	1983Q1-2017Q1	BLS
Real tenant rent	Tenant rent of primary residence, deflated by GDP deflator.	1983Q1-2017Q1	BLS
Interest rate	3-month policy rate.	1983Q1-2017Q1	FRED
Real House price	All transaction residential house price index, deflated by GDP deflator.	1983Q1-2017Q1	FHFA

Table 3: Data Source.

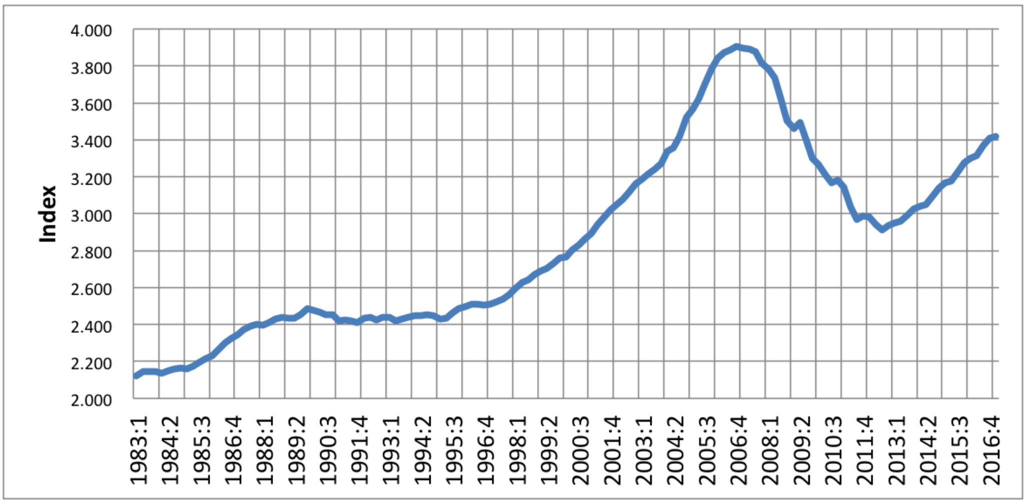


Figure 12: FHFA All-transaction real house price index

B Appendix: Cyclical Properties

	hp-filter		first-difference	
	x = real house price		x = real house price	
Country	Corr.	Relative s.d.	Corr.	Relative s.d.
	$\rho(x,y)$	$\frac{\sigma_x}{\sigma_y}$	$\rho(x,y)$	$\frac{\sigma_x}{\sigma_y}$
U.S.	0.590	1.686	0.251	1.477
Japan	0.500	2.509	0.431	1.456
Germany	0.352	0.959	0.174	0.871
France	0.210	6.080	0.094	4.929
Italy	0.528	1.972	0.313	1.583
UK	-0.339	3.704	-0.080	3.635
Canada	0.523	4.604	0.321	3.427
Spain	0.281	2.844	0.150	2.827
Finland	0.249	2.464	0.142	2.023
Ireland	0.232	2.325	0.045	1.334
Netherlands	0.452	4.148	0.170	2.760
Norway	0.198	3.860	0.147	1.976
New Zealand	0.218	2.959	0.099	1.472
Sweden	0.300	3.669	0.176	2.143
Switzerland	0.585	3.425	0.334	3.323
Australia	0.340	3.282	0.130	2.082
Belgium	0.302	3.525	0.140	2.876
Denmark	0.240	2.101	0.091	1.513
Austria	0.117	1.516	-0.154	3.187

Table 4: International Evidence on cyclical properties of real residential house price (y = real output).

C Appendix: Estimation of TVC-SVAR

This Appendix summarizes the estimation of TVC-SVAR model. The approach here follows Del Negro and Primiceri (2015), Galí and Gambetti (2015). The algorithm draws sets of coefficients from known conditional posterior distributions. The draws converge to draw from the joint posterior after a burn-in period under some regularity conditions. Conditional distributions used are reported below:

1. $p(\sigma^T|x^T, \theta^T, \phi^T, \Omega, \Xi, \Psi, s^T)$
2. $p(\phi^T|x^T, \theta^T, \sigma^T, \Omega, \Xi, \Psi)$
3. $p(\theta^T|x^T, \sigma^T, \phi^T, \Omega, \Xi, \Psi)$
4. $p(\Omega|x^T, \theta^T, \sigma^T, \phi^T, \Xi, \Psi)$
5. $p(\Xi|x^T, \theta^T, \sigma^T, \phi^T, \Omega, \Psi)$
6. $p(\Psi_i|x^T, \theta^T, \sigma^T, \phi^T, \Omega, \Xi)$, i=1,2,3,4
7. $p(s^T|x^T, \theta^T, \sigma^T, \phi^T, \Omega, \Xi, \Psi)$

Prior distributions for initial states θ_0, ϕ_0, $log\sigma_0$ are normal and the prior for Ω, Ξ, Ψ are inverse Wishart. Specifically, $\theta_0 \sim N(\hat{\theta}, 4\hat{V}_\theta)$, $log\sigma_0 \sim N(log\hat{\sigma}_0, I_n)$, $\phi_{i0} \sim N(\hat{\phi}_i, \hat{V}_{\phi i})$ and $\Omega^{-1} \sim W(\underline{\Omega}^{-1}, \underline{\rho}_1)$, $\Xi^{-1} \sim W(\underline{\Xi}^{-1}, \underline{\rho}_2)$ $\Psi^{-1} \sim W(\underline{\Psi}^{-1}, \underline{\rho}_3)$

Gibbs Sampling Algorithm

MCMC is used here to draw realization from posterior density. This section describe Gibbs Sampling Algorithm which works in an iterative way. Each iteration is done in seven steps to draw set of parameters conditional on the value of the remaining parameters.

<u>*Step 1*</u>: $p(\sigma^T|x^T, \theta^T, \phi^T, \Omega, \Xi, \Psi, s^T)$

Draw σ^T conditional on $\theta^T, \phi^T, \Omega, \Xi, \Psi, s^T$, using Kim Shephard and Chib (1989; KSC) algorithm.

Let $x_t^* \equiv \mathrm{F}_t^{-1}(\mathrm{x}_t - \mathrm{W}_t\theta_t) = \mathrm{D}_t^{1/2}\mathrm{u}_t$, where $\mathrm{u}_t \sim N(0, \mathrm{I}_n)$, $\mathrm{W}_t = (\mathrm{I}_n \otimes \mathrm{W}_t)$, $\mathrm{W}_t = [1 \ \mathrm{x}'_{t-1}...\mathrm{x}'_{t-1}]$. Therefore, by squaring and taking logs, we obtain the following state-space representation:

$$\begin{aligned} \mathrm{x}_t^{**} &= 2\mathrm{r}_t + \nu_t \\ \mathrm{r}_t &= \mathrm{r}_{t-1} + \zeta_t \end{aligned}$$

where $\mathrm{x}_{i,t}^{**} = \log(\mathrm{x^*}_{i,t}^2)$, $\nu_{i,t} = \log(\mathrm{u}_{i,t}^2)$, $\mathrm{r}_t = \log\sigma_{i,t}$.

Following KSC, we use a mixture of normal with 7 densities with competent probabilities q_j, means m_j -1.2704, and variances v_j^2 $(j = 1, ...7)$ to approximate the system with Gaussian one, where $\{q_j, m_j, v_j^2\}$ are chose to match the moments of the $\log\chi^2(1)$ distributions. The value used are:

j	q_j	m_j	χ_j^2
1	0.0073	-10.1300	5.7960
2	0.1056	-3.9728	2.6137
3	0.0000	-8.5669	5.1795
4	0.0440	2.7779	0.1674
5	0.3400	0.6194	0.6401
6	0.2457	1.7952	0.3401
7	0.2575	-1.0882	1.2626

In practice, the algorithm of Carter and Kohn (1994; CK) is used to draw r_t from $N(\mathrm{r}_{t|t+1}, \mathrm{R}_{t|t+1})$ where $\mathrm{r}_{t|t+1}$ and $\mathrm{R}_{t|t+1}$ are the conditional mean and variance obtained from the backward recursion equations.

<u>*Step 2*</u>: $p(\phi^T|x^T, \theta^T, \phi^T, \Omega, \Xi, \Psi, s^T)$

To draw ϕ^T, let $\hat{\mathrm{x}}_t = \mathrm{x}_t - \mathrm{W}_t\theta_t$. The i+1-th (i = 1,...n-1) equation of the system $\mathrm{F}_t^{-1}\hat{\mathrm{x}}_t = \mathrm{D}^{1/2}\mathrm{u}_t$ can be written as: $\hat{\mathrm{x}}_{i+1,t} = -\hat{\mathrm{x}}_{[1,i],t}\phi_{i,t} + \sigma_{i,t}\mathrm{u}_{i+1,t} \quad i = 2, ..., n$

The above equation is the observable equation of the state-space model where states are $\phi_{i,t}$. Moreover, since $\phi_{i,t}$ and $\phi_{j,t}$ are independent for $i \neq j$, we apply CK algorithm to draw $\phi_{i,t}$ from $N(\phi_{i,t|t+1}, \Phi_{i,t|t+1})$

<u>*Step 3*</u>: $p(\theta^T|x^T, \theta^T, \phi^T, \Omega, \Xi, \Psi, s^T)$

Conditional on all other parameters and all the observables, we have

$$\begin{aligned} x_t &= Z_t'\theta_t + \epsilon \\ \theta_t &= \theta_{t-1} + \omega_t \end{aligned}$$

Draw θ from $N(\theta_{t|t+1}, \mathrm{P}_{t|t+1})$, where $\theta_{t|t+1} = E(\theta_t|\theta_{t+1}, \mathrm{x}_t, \sigma^T, \phi^T, \Omega, \Psi, \Xi)$ and $\mathrm{P}_{t|t+1} = Var(\theta_t|\theta_{t+1}, \mathrm{x}_t, \sigma^T, \phi^T, \Omega, \Psi, \Xi)$ are obtained from CK algorithm.

<u>*Step 4*</u>: $p(\Omega|x^T, \theta^T, \phi^T, \Omega, \Xi, \Psi, s^T)$

Draw Ω, $i = 1,...,5$. As above, $\Omega = (\mathrm{MM}')^{-1}$ where M is an $(n^2p+n)\times\rho_1$ matrix whose columns are independent draws from a $N(0, \Omega^{-1})$ where $\bar{\Omega}_i = \underline{\Omega} + \sum_{t=1}^{T} \Delta\theta_{i,t}(\Delta\theta_{i,t})$

<u>*Step 5*</u>: $p(\Xi|x^T, \theta^T, \phi^T, \Omega, \Xi, \Psi, s^T)$

Draw Ξ, $i = 1,...,5$. As above, $\Xi = (\mathrm{MM})^{-1}$ where M is an $i \times \bar{\rho}_2$ matrix whose columns are independent draws from a $N(0, \Xi^{-1})$ where $\bar{\Xi} = \underline{\Xi} + \sum_{t=1}^{T} \Delta log\sigma_{i,t}(\Delta log\sigma_{i,t})$

<u>*Step 6*</u>: $p(\Psi|x^T, \theta^T, \phi^T, \Omega, \Xi, \Psi, s^T)$

Draw Ψ_i, $i = 1,...,5$. As above, $\Psi_i = (\mathrm{MM})^{-1}$ where M is an $i \times \bar{\rho}_{3i}$ matrix whose columns are independent draws from a $N(0, \Psi^{-1})$ where $\bar{\Psi}_i = \underline{\Psi} + \sum_{t=1}^{T} \Delta\phi_{i,t}(\Delta\phi_{i,t})$

<u>*Step 7*</u>: $p(s^T|x^T, \theta^T, \phi^T, \Omega, \Xi, \Psi, s^T)$

Draw s^T, each $s_{i,t}$ is independently sampled from $Pr(s = j|x_{i,t}^{**}, r_{i,t}) \propto q_j f_N(x_{i,t}^{**}|2r_{i,t} + m_j - 1.2704, v_j^2)$, where $f_N(x|\mu, \sigma^2)$ denotes the Normal pdf with mean μ and variance σ^2, and q_j is the probability associated to the j-th density.

D Sensitivity Analysis

The fact that house price is ordered last in the SVAR setup implies that central bank has a clear goal in stabilizing output-inflation variability tradeoff and do not response contemporaneously to house price risk by construction.[23] However, Aastveit *et al.* (2017) has estimated the FED monetary policy stance and found that the FED has actually responded to house price movements, especially after the GFC.

This section relaxes this assumption and conduct the robustness check of alternative monetary policy shock identifications. To be precise, I simulate alternative identifications of monetary policy shock that allow policy rate to respond contemporaneously to house price at different levels: {0%, 1%, 2%, 3%}.

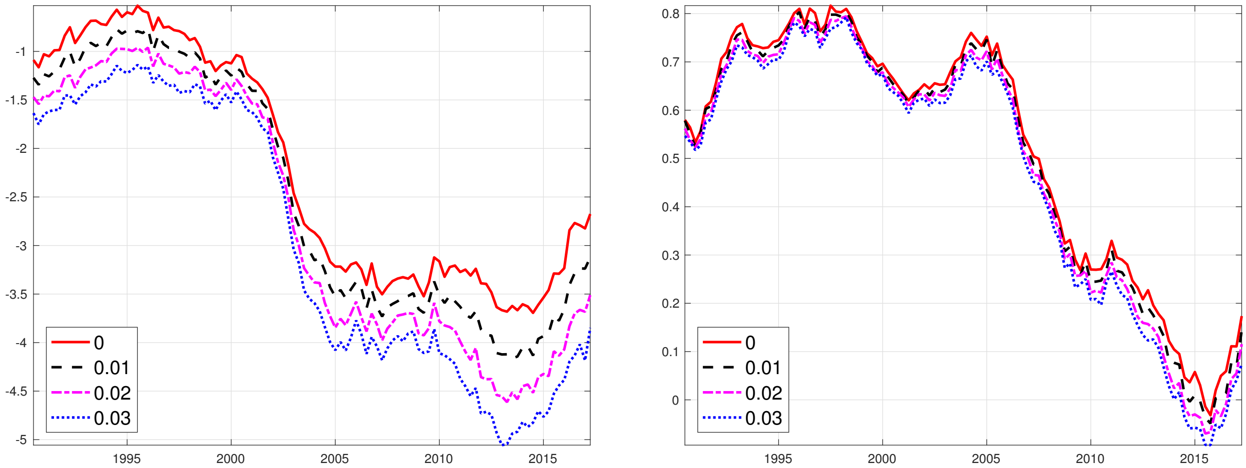
Steps for alternative identification simulations are:

(I) Conditional on TVC-SVAR estimated coefficients, all structural shocks are left unchanged at their estimated historical values, except endogenous response of monetary policy to house price dynamics.

(II) Rescaling monetary policy endogenous response to house price dynamics in such a way that house price enters interest rate rule with coefficients {0%, 1%, 2%, 3%}.

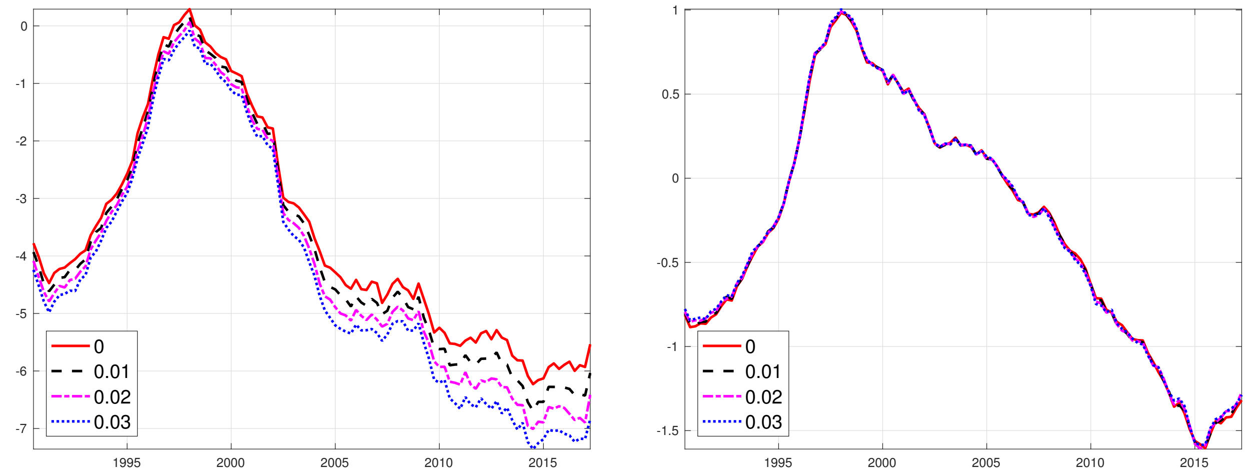
Figure 13 and Figure 14 shows IRF in both the homeowners' and the renters' markets for different calibrations of house price coefficient in the policy rule Results are reported only for the 5-year horizon where impact reaches its fullest magnitude. We can see here that the conclusions from the main text, regarding both the sign and the dynamics across time of housing market variables, are robust to alternative identifications of monetary policy shock.

[23] This follows from the FED Greenbook Forecast which has stated that the FED do not target directly at house price. Therefore, house price is ordered last in the setup of empirical SVAR.



(a) House Price (b) Owners-Equivalent Rent

Figure 13: Estimated response at 5-year horizon to alternative endogeneous policy response in **homeowners' market**



(a) House Price (b) Tenant Rent

Figure 14: Estimated response at 5-year horizon to alternative endogeneous policy response in **renters' market**

References

[1] Aastveit, A.K., Furlanetto, F., and F. Loria. 2017. "Has the FED responded to Stock Price and House Price? A Time-Varying Analysis." Banco de Espana Working Paper No.1713

[2] Barsky, R., House, C.L. and M. Kimball. 2003. "Do Flexible Durable Goods Prices Undermine Sticky Price Models?" NBER Working Paper No. 9832.

[3] Barsky, R.B., House, C.L. and M. Kimball. 2007. "Sticky-price models and durable goods." *The American Economic Review* 97(3): 984-998.

[4] Bernanke, B. and M. Gertler. 2000. "Monetary policy and asset price volatility." NBER Working Paper No. 7559.

[5] Bernanke, B. and M. Gertler. 2001. "Should Central Banks Re- spond to Movements in Asset Prices?." *American Economic Review* 91 (2): 253-257.

[6] Bils, M., Klenow, P.J. and O. Kryvtsov. 2003. "Sticky prices and monetary policy shocks." *Federal Reserve Bank of Minneapolis. Quarterly Review-Federal Reserve Bank of Minneapolis* 27(1): 2.

[7] Boivin, J. and M. Giannoni. 2008. "Global forces and monetary policy effectiveness" NBER Working Paper No. 13736.

[8] Borio, C.E. and P.W. Loewe. 2002. "Asset prices, financial and monetary stability: exploring the nexus." BIS Working Paper.

[9] Campbell, J.Y.. 2012. "Mortgage market design" *Review of finance* 17(1): 1-33.

[10] Campbell, S.D., Davis, M.A., Gallin, J. and R.F. Martin. 2009. "What moves housing markets: A variance decomposition of the rentprice ratio" *Journal of Urban Economics* 66(2): 90-102.

[11] Canova, F. and L. Gambetti. 2009. "Structural changes in the US economy: Is there a role for monetary policy?" *Journal of Economic Dynamics and Control* 33(2): 477-490.

[12] Carter, C.K. and R. Kohn. 1994. "On Gibbs sampling for state space models." *Biometrika* 81(3): 541-553.

[13] Cecchetti, S. 2000. "Making monetary policy: Objectives and rules." *Oxford Review of Economic Policy* 16(4): 43-59.

[14] Chambers, M.S., Garriga, C. and D. Schlagenhauf. 2009. "The loan structure and housing tenure decisions in an equilibrium model of mortgage choice." *Review of Economic Dynamics* 12(3): 444-468.

[15] Christiano, L.J., Eichenbaum, M. and C.L. Evans. 1999. "Monetary policy shocks: What have we learned and to what end?" *Handbook of Macroeconomics* 1: 65-148.

[16] Del Negro, M. and C. Otrok. 2007. "99 Luftballons: Monetary policy and the house price boom across US states." *Journal of Monetary Economics* 54(7): 1962-1985.

[17] Del Negro, M. and G.E. Primiceri. 2015. "Time varying structural vector autoregressions and monetary policy: a corrigendum." *The Review of Economic Studies* 82(4): 1342-1345.

[18] Duarte, J.B., D. Dias. 2017. "Housing And Monetary Policy In The Business Cycle: What Do Housing Rents Have To Say?" *Mimeo.*

[19] Farhi, E., and J. Tirole. 2011. "Bubbly liquidity." *The Review of Economic Studies* 79(2): 678-706.

[20] Galí, J. 2014. "Monetary Policy and Rational Asset Price Bubble." *The American Economic Review* 104(3): 721-752.

[21] Galí, J. 2017. "Monetary Policy and Bubbles in a New Keynesian Model with Overlapping Generation." *Mimeo.*

[22] Galí, J., and L. 2015. Gambetti. "The effects of monetary policy on asset prices bubbles: Some evidence." *American Economic Journal: Macroeconomics* 7(1): 233-257.

[23] Geanakoplos, J. 2010. "The leverage cycle." *NBER Macroeconomics Annual* 24(1): 1-66.

[24] Gete, P. and M. Reher. 2016. "Two Extensive Margins of Credit and Loan-to-Value Policies." *Journal of Money, Credit and Banking* 48(7): 1397-1438.

[25] Henderson, J. Vernon, and Yannis M. Ioannides. "Dynamic aspects of consumer decisions in housing markets." *Journal of Urban Economics* 26, no. 2 (1989): 212-230.

[26] Himmelberg, C. Mayer, C., and T. Sinai. 2005. "Assessing high house prices: bubbles, fundamentals, and and misperceptions." *Journal of Economic Perspectives* 19(4): 67-92.

[27] Huber, S. 2017a. "Preference for housing services and rational house price bubbles". *Mimeo.*

[28] Huber, S. 2017b. "Housing Booms and Busts - Convergence and Divergence in OECD countries". *Mimeo.*

[29] Huang, K.X. and Z. Liu. 2005. "Inflation targeting: What inflation rate to target?." *Journal of Monetary Economics* 52(8): 1435-1462.

[30] Kim, S., Shephard, N. and S. Chib. 1998. "Stochastic volatility: likelihood inference and comparison with ARCH models." *The Review of Economic Studies* 65(3): 361-393.

[31] Iacoviello, M. 2005. "House prices, borrowing constraints, and monetary policy in the business cycle." *The American Economic Review* 95(3): 739-764.

[32] Iacoviello, M. and S. Neri. 2010. "Housing market spillovers: evidence from an estimated DSGE model." *American Economic Journal: Macroeconomics* 2(2): 125-164.

[33] Jordá, O., M. Schularick and A. M. Taylor. 2012. "When credit bites back: Leverage, Business Cycle, and Crises" *Journal of Money, Credit, and Banking* 45(s2): 3-28.

[34] Jordá, O., M. Schularick and A. M. Taylor. 2015. "Leveraged Bubbles." *Journal of Monetary Economics* 76: S1-S20.

[35] Kiyotaki, N. and J. Moore. 1997. "Credit cycles." *Journal of political economy* 105(2): 211-248.

[36] Martin, A. and J. Ventura. 2016. "Managing credit bubbles." *Journal of the European Economic Association* 14(3): 753-789.

[37] Makowiak, B., Moench, E. and M. Wiederholt. 2009. "Sectoral price data and models of price setting." *Journal of Monetary Economics* 56: S78-S99.

[38] Piazzesi, M. and M. Schneider. 2016. "Housing and Macroeconomics." *Handbook of Macroeconomics* 2: 1547-1640.

[39] Primiceri, G.E. 2005. "Time varying structural vector autoregressions and monetary policy." *The Review of Economic Studies* 72(3): 821-852.

[40] Sargent, T.J. 1979. "Estimating vector autoregressions using methods not based on explicit economic theories." *Quarterly Review* (Sum).

[41] Sommer, K., Sullivan, P. and R. Verbrugge. 2013. "The equilibrium effect of fundamentals on house prices and rents." *Journal of Monetary Economics* 60(7): 854-870.

[42] Taylor, J. 2007. "Housing and Monetary Policy." NBER Working Paper No. w13682.

[43] Wu, W. 2016. "Monetary Policy, Durable Goods and Nominal Rigidity." *Mimeo* (JMP).