Monetary Policy and Housing Bubbles:  
Some Evidence when House Price is Sticky  

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Abstract  
The assumption of fully flexible house prices is widely applied in general equilibrium monetary models. This paper documents new stylized facts arguing that rigidities do exist in house price movements. I show that such rigidities in house prices are important in rationalizing the effect of monetary policy on housing bubbles. Specifically, unlike stock prices, nominal house price does not respond contemporaneously to a tightening of monetary policy, regardless of a falling fundamental value. However, once it starts declining after some time lag, the downward price decrease will be highly persistent, leading to negative bubbles that last for several years. Using time-varying coefficient structural vector autoregression (TVC-SVAR), this paper shows that the persistent long-run response of house price to a monetary policy tightening is driven by non-fundamental factors, which in turn contribute to a protracted recovery in the real output. The results are consistent with theoretical prediction of Galí (2017) that, under assumptions of rational bubbles and sticky asset prices, monetary policy may unintendedly cause bubble-driven output fluctuations due to the persistent effect of (negative) bubbles on real sector.

*First draft of this paper is the author’s master thesis at Barcelona GSE, previously circulated under the title “Sticky House Price?”, of which the analysis and methodology were quite different. This version is written while the author is a researcher at Puey Ungphakorn Institute for Economic Research, Bank of Thailand. Email: voradal@bot.or.th

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1 Introduction

Crisis has taught us hard and painful lessons that history should not be allowed to repeat itself again in the future. Asset price bubbles which are often considered a major source of macroeconomic instability have been seriously studied since then. Although theory of rational bubbles has been long developed \(^1\), empirical evidence is arguably limited that, up to the present, our understanding on how best should we deal with bubbles remains far from perfect.

Monetary policy, a major tool of the central bank, has been facing several questions regarding its role in controlling asset prices. \(^2\) While the debate is still going on, whether “leaning against the wind” monetary policy is appropriate in controlling asset price bubbles, discussions through monetary model and hard empirical evidence are not prevalent. One explanation could be that study of monetary policy is often conducted through Dynamic Stochastic General Equilibrium (DSGE) model where bubbles are often ruled out by construction.

Until recently, Galí (2017) has studied, on the theoretical ground, linkages between bubbles and monetary policy in the New Keynesian model with overlapping generations (OLG) of finite-lived agents that allows for existence of rational bubbles in equilibrium. In that model, the assumption of sticky price is highlighted that not only does it allow monetary policy to influence the bubble size, but also for bubble size fluctuation to influence aggregate demand. These linkages are interesting that they leave room for monetary policy to affect real variables through bubble-driven output fluctuation.

History has shown that not all bubbles are alike, this paper chooses to focus mainly on housing bubbles due to several reasons. First, 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, very little attention has been given and the only explanation provided so far in the literature has to do with credit. \(^3\) Along this venue, bubbles are classified either into “unleveraged” or “credit boom” bubbles. Financial risks posed by unleveraged bubbles are limited while the burst of credit boom bubbles is more severe. Credit financed housing bubbles are considered of the latter type. Given a clear distinction between crisis generated by housing market and equity market, more explanation should be provided and challenged.

Second, this paper shows the new stylized fact, contrary to conventional wisdom,\(^1\) See, e.g. Tirole (1982, 1985), Allen and Gale (2000), Martin and Ventura (2016).
\(^2\) 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).
\(^3\) See, e.g. Farhi and Tirole (2011), Martin and Ventura (2012), Jorda et al. (2015)
arguing that stickiness does exist in house price. This finding makes housing market unique and provides perfect ground to study the role of monetary policy in generating non-fundamental driven output fluctuations as proposed in Galí (2017). Importance of sticky house price can go far beyond an interest of this paper, especially in terms of monetary modeling, that it might deserve more considerations and discussions.  

In this paper, I study the dynamic effect of monetary policy on house price and show how sticky house price assumption could improve our understanding on monetary transmission mechanism. The study begins with simple structural vector autoregression (SVAR) following the conventional monetary policy shock identification of Christiano et al. (2005) and eventually extended to allow for time-variation in coefficient and standard deviation. Using time-varying coefficient structural vector autoregression (TVC-SVAR) with U.S. housing market data, this paper studies such question empirically and ties the results closely to Galí and Gambetti (2015) partial equilibrium rational asset pricing model.

While baseline empirical setup here follows those of Galí and Gambetti (2015), 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. Though both papers yield one similar conclusion that questions leaning against the wind monetary policy, underlying intuitions and transmission mechanisms clearly differ. To be precise, comparing house price here to previous work of stock price allows us to point out two unique characteristics of housing market that are in stark contrast to the conventional view: (I) house price is sticky while stock price is flexible (II) rent price increases, while stock dividend decreases, in response to tightening monetary policy. The fact that the nature of crisis generated from house price and stock price is different makes their heterogeneity always an interest among researchers.

The motivation of using time-varying model here is for several purposes. First, it allows us to examine the evolution of cyclicalities of housing markets variables, house price and rent price. Cyclicalities of these variables are always an interest among researchers; however, no previous work has studied their second moments from the dynamic perspective. Time-varying nature of the model thus allows us to deepen our understanding on structural changes that have been going on in housing markets. Second, with the concern for possible structural changes in housing markets that could biased our one-time estimation, e.g., impulse response response function, time-varying nature of the model could help ease that concern. Finally, and most important for the conclusion of this paper, time-varying model opens door for the interpretation of

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4 Further discussions will be provided in Section (6).
5 See, e.g. Primiceri (2005), Galí and Gambetti (2009, 2015) for example of time-varying SVAR.
changing bubble size. More specifically, not only do the model allows for the possibility of monetary policy to affect change in bubble size ‘across impulse response horizons’, but also help detect changing dynamic of bubble size fluctuation ‘across times’ which are highly crucial for detecting non-fundamental driven period and be able to draw conclusion regarding the non-neutrality of monetary policy.

Major findings are as follows. First, the results question the effect of tightening monetary policy to stabilize housing bubbles and point to the fact that monetary policy might end up increasing bubbles’ volatility in the long-run. To be precise, while house price is sticky and do not respond contemporarily to tightening monetary policy, its fundamental component has already fallen. In the long-run, the effect can be deep and persistent as house price continued to be downward rigid while fundamental component has already recovered from interest rate shock. As a result, house price will eventually fall below fundamental price making bubbles turn negative that it could become damaging in the long run. Second, the evidence here point to the persistent effect of monetary policy on bubble-driven output fluctuation. Combining this finding with theoretical concept and the previous finding that monetary policy can influence bubble size fluctuation, it could be inferred to the persistent effect of bubble size fluctuation on output fluctuation which is consistent with what we observed in the bust that the effect of bubbles on real sector lasts for several years.

The organization of this paper is as follows: Section (2) first presents some evidence on sticky house price that has motivate the focus of this study. Rational bubbles model is described in Section (3) while empirical SVAR and TVC-SVAR model are described in Section (4). Descriptive statistics and the cyclical behavior of housing market variables are reported in Section (5). Section (6) presents the result of impulse response function and the results are discussed in Section (7). Section (8) focuses the analysis on the relationship of bubbles and monetary non-neutrality. Section (9) concludes.

2 Some Thoughts on Sticky House Price

This section discusses some evidence and literatures of the uniqueness of house price which is sticky, and discuss its importance in monetary transmission mechanism which has been the motivation of this paper in focusing specifically on housing bubbles.

House price is widely assumed to be flexible as it is notoriously volatile. However, simple statistics from Table 1 reveals that house price that is both highly volatile and persistence altogether. In Table 1, I follows the sticky-price literature by fitting first difference of log real house price and real rent price to AR(1) model. Coefficient of AR(1) model signifying the degree of inflation persistence are reported along with
Table 1: Persistence (with standard error reported in parenthesis) and standard deviation of inflation for real house price and real rent price. Note: first difference of log real house price and real rent price are fitted to the AR(1) model. $dp_t = \varepsilon_t + \delta dp_{t-1}$ where $\varepsilon_t$ is i.i.d. with standard deviation $\sigma_\varepsilon$.

<table>
<thead>
<tr>
<th>Country</th>
<th>AR(1) coeff. $\xi$</th>
<th>Std. of innovations $\sigma_\varepsilon$</th>
<th>AR(1) coeff. $\xi$</th>
<th>Std. of innovations $\sigma_\varepsilon$</th>
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<tr>
<td>U.S.</td>
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<td>0.88</td>
<td>0.45 (0.07)</td>
<td>0.56</td>
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<td>0.59 (0.06)</td>
<td>0.70</td>
</tr>
<tr>
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<td>0.63</td>
<td>0.19 (0.07)</td>
<td>0.70</td>
</tr>
<tr>
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<tr>
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<tr>
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<td>0.92 (0.03)</td>
<td>0.54</td>
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<tr>
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<td>Ireland</td>
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<tr>
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<tr>
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<tr>
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<td>0.02 (0.08)</td>
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<tr>
<td>Austria</td>
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<td>0.49 (0.06)</td>
<td>0.99</td>
</tr>
</tbody>
</table>

standard deviation of AR(1) innovations which is used to measure volatility.

We can see the characteristic of real house price that is both highly persistent and highly volatile for all sampled countries 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 easier comparison with Table 2, Bills and Klenow (2004) reported that persistence of U.S. aggregate inflation is only 0.2 with s.d. 0.63.

To gain more insights, I review the importance of sticky house price in the workhorse monetary model in Section (2.1) and provide a survey of existing literatures that could point to stickiness in house price to support the idea in Section (2.2).  

2.1 Importance of Sticky House Price in Monetary Model

Before turning to the evidence that could lead to downward rigidity in house price, let me first briefly discuss the importance of durable goods (housing) in general equilibrium monetary model. Despite the importance of housing to the whole economy and the leading role of sticky price in monetary business cycle analysis, the role of house price rigidities is unclear and has gone unchallenged but assumed fully flexible in most

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6 Although the evidence is scattered and ambiguous as the idea of sticky house price has never been seriously considered, I try to collect the evidence that this idea could possibly be hidden behind.

7 Existing conclusions reached are, i.e. it is optimal for monetary policy to stabilize price in the one-sector NK model (e.g. Woodford (2003)), monetary policy should stabilize price in the sticky price sector if there are both sticky price and flexible price sector in the NK model (e.g. Aoki (2001); Benigno (2004); Huang and Liu (2005)), or monetary policy should not stabilize house price as its fluctuation is an efficient response movement (e.g. Bernanke and Gertler (1999)).
monetary model.  

Sticky price is always an explanation to key concern among macroeconomists: the extent to which demand shocks could affect real variables such as output and employment. It is widely perceived that monetary policy have neutral effect on real variables if prices are all flexible but will have large and significant effect if prices are sticky. The latter phenomenon is known as “monetary non-neutrality”.

The assumption of sticky price; however, has been challenged by recently available micro-level prices data as prices change too frequently in the micro-level than otherwise assumed in the canonical business cycle model.

One provocative work regarding the importance of price stickiness of durable goods is done by Barsky, House, and Kimball (2003, 2007). 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 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.

According to their work, if house price were to be flexible, this would present a serious co-movement puzzle: flexibly priced durables would contract in response to monetary expansion. They shows that the puzzle is highly robust. The co-movement puzzle from the model is, however, contrary to the evidence observed. Despite such argument, house price has always been assumed fully flexible as it is highly volatile.

There has been several attempts in modeling general equilibrium monetary model to reconcile this puzzle while assuming house price to be fully flexible incorporating other rigidities instead. Barsky et at (2003) has suggested two possible solutions for this co-movement puzzle by incorporating one of the two rigidities into the model: nominal wage stickiness (supply side) and financial imperfection from credit constraint (demand side).

By incorporating nominal wage stickiness, monetary policy tightening will increase real wage, reduced the desired output from durable-good firms. Studies in this direction can be found in, i.e. Erceg et al. (2000), Carlstrom and Fuerst (2006).

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8 See, e.g. Icaoviello (2005), Icaoviello and Neri (2010)
9 See, e.g. Christiano et al. (1999), Romer and Romer (2004)
11 Erceg and Levin (2005) employs VAR model to show that durable goods production decline in response to increase in interest rate.
An alternative is to incorporate credit constraints, this direction of studies include, i.e. Monacelli (2005), Carlstrom and Fuerst (2010). The intuition is that by incorporating credit frictions into NK model with durables as a collateral constraint, borrowing constraint will act as a substitute for nominal rigidities in the price of durable goods.

According to an argument made in Barsky et al. (2003, 2007), importance of sticky house price thus can go beyond an interest of this paper on the transmission of monetary policy on housing bubbles. To be precise, it confirms that sticky-price is not of little importance in monetary model even if so many goods are flexibly priced at the micro-level. In the next subsection, I will document some evidence that could lead to the idea that house price is rigid, arguing against this conventional wisdom.

2.2 Survey of Sticky House Price

While evidence regarding rigidities in house price is unclear in the literatures, it is widely assumed to be fully flexible in most monetary model. Although prices are posted in advance, the fact that they are notoriously volatile and can be negotiated between sellers and buyers provide reasons to believe that house price is flexible.

According to one of the most cited work on sticky price by Bils and Klenow (2004) that has investigated frequencies of price adjustment from over 350 categories of goods and services, durable goods have higher frequency of price adjustment compared to non-durable goods. However, it is arguable in the literatures that durable goods here do not include “long-lived” durables, such as house price which is typically excluded from CPI construction. Further evidence and analysis are thus needed before concluding from their work that house price is flexible.

In this section, I will provide a survey of existing literatures that the idea of sticky house price could possibly be hidden behind. Although the evidence is scarce and ambiguous that its importance has always been overlooked, some part of these evidence do point to the conclusion that rigidities exist in house price movements.

Some researchers, however, recognize that house price is downward rigid: whenever excess supply or demand occurs in housing market, house price does not immediately move to clear the market, instead, sellers tend not to sell houses as their expected price that is higher than the buyers’ expected price during the recession.

DiPasquale and Wheaton (1994) was among the first to argue strongly that price stickiness is crucial to understand the behavior of house price. Specifically, they develop a structural model of single family market employing U.S. annual data from 1960s to 1990s to explicitly test how rapid house price adjusts to equilibrium. They found that it takes several years for U.S. house price to clear the market, returning to long-run steady state, even though it is possible for housing market to be in equilibrium.
in every period. The paper thus suggested that it is more important to study gradual 
dynamic adjustment of house price and construction level instead of focusing only on 
equilibrium level. The model is later applied to Chinese housing market in Chow et 
al.(2008) and similar conclusion of gradual house price adjustments are reached.

Supporting DiPasquale et al. (1994), Riddel (2002) applied the same set of U.S. 
data to the two-sided disequilibrium model, supply and demand side disturbances. The 
results show that U.S. housing market is characterised by periods of disequilibrium 
which results from slow price adjustment in clearing the market.

Case (1994) presented the result supporting the fact that if nominal price does not 
move to clear the market, then it is expected that the market will be “quantity clear-
ing”. He presented statistics of the U.S. housing market in different cities, showing 
that housing boom made sales dropped dramatically, unsold inventories reached the 
highest point, but house price fell only slightly. Strong evidence of house price stick-
iness can be found in the statistics of inventory (unsold house) which rise invariably 
at the onset of every recession. Supporting the view of quantity clearing in housing 
market, Leamer (2007) also claim that as housing has the volume cycle not the price 
cycle; thus, housing is crucial in explaining business cycle/recession.

Another evidence can be found from Case and Shiller (1988, 2003) where they 
conduct a questionnaire survey for nearly two decades during the slow market and 
show that very few fraction of the respondents are willing to lower their house price 
to get them sold in the sluggish economy period, most of them has lower reservation 
price that they are willing to wait.

Price rigidity is a kind of market inefficiency and downward price stickiness means 
that house price adjusts asymmetrically, empirical evidence on asymmetric house price 
adjustment can be found in Tsai and Chen (2009). They employ GJR-GARCH model 
to demonstrate that the volatility in U.K. house price series are asymmetric. When 
bad news occur, the variance decreases and price is sticky downward. Gao et al. (2009) 
apply autoregressive mean reversion (ARMR) model to U.S dataset and found that 
house price is likely to overshoot the equilibrium, its serial correlation is higher, in the 
appreciation period than the declining period; in other words, house price tends to 
adjust asymmetrically that it grows fast but decreases slow.

More stylized evidence on (asymmetric) stickiness of real house price can be found 
in the relationship between inflation and real house price adjustment. Girouard et al. 
(2006) employs the data from 18 OECD countries and shows that scattered plot be-
tween average annual inflation rate and duration of decreased real house price exhibits 
a negative trend in their correlation. Put differently, it takes longer time for house 
price to adjust in low inflation (recession) period, while less time in high inflation 
period. Also, they present the plot showing the negative relationship between average
annual inflation rate and average percentage change in real house price: real house price adjusts less, in percentage, during the low inflation period (recession) compared to high inflation period.

Another explanation of house price being very sticky downward comes from behavioral economics: loss aversion. Sellers are averse to loss and expected price at least what they have paid for in the past. According to Genesove and Mayer (2001), Engelhardt (2003), there exist an evidence of nominal loss aversion in housing market. Dobrynskaya (2008) presents the result from his behavioral model that as loss aversion exist among the behavior of real estate traders, house price downward rigidities should also exist.

3 Theoretical Issues of Rational Bubbles

This section lays out theoretical model of rational asset pricing. Following Galí and Gambetti (2015) partial equilibrium model where agents are assumed to be risk neutral.

Asset price, $Q_t$, is interpreted to be the sum of “fundamental component ($Q^F_t$)” and “bubble component ($Q^B_t$),

$$Q_t = Q^F_t + Q^B_t$$

where the fundamental component is defined as the present discounted value of future dividends: $Q^F_t \equiv \left\{ \sum_{k=1}^{\infty} \left( \prod_{j=0}^{k-1}(1/R_{t+j}) \right) D_{t+k} \right\}$. Log linearizing this equation would become:

$$q^F_t = \text{const} + \sum_{k=1}^{\infty} \Lambda^k[(1 - \Lambda) E_t\{d_{t+k+1}\} - E_t\{r_{t+k}\}]$$

where $\Lambda = \Gamma/R < 1$ with $\Gamma$ and $R$ are denoting, respectively, the (gross) rates of dividend growth and interest along a balanced growth path.

How does these variables affected by monetary policy shock. Let $\epsilon^m_t$ be monetary policy shock, we have

$$\frac{\partial q_{t+k}}{\partial \epsilon^m_t} = (1 - \gamma_{t-1}) \frac{\partial q^F_{t+k}}{\partial \epsilon^m_t} + \gamma_{t-1} \frac{\partial q^B_{t+k}}{\partial \epsilon^m_t}$$

where $\gamma_t = Q^B_t/Q_t$ denotes the bubble share in the asset price and from the definition of the fundamental component, we get

$$\frac{\partial q^F_{t+k}}{\partial \epsilon^m_t} = \sum_{j=0}^{\infty} \Lambda^j \left( (1 - \Lambda) \frac{\partial d_{t+k+j+1}}{\partial \epsilon^m_t} - \frac{\partial r_{t+k+j}}{\partial \epsilon^m_t} \right)$$
Both theory and evidence agree on the fact that in response to monetary contraction, interest rate will increase while dividend will decrease $r_{t+k} > 0$ and $d_{t+k} \leq 0$ for $k = 0,1,2,...$. Therefore, following equation (4), asset price will decline in response to monetary contraction $m_{t+k} > 0$ for $k = 0,1,2,...$.

The response of rational bubble component to monetary policy shock, however, is unclear. As we know that $Q_t R_t = E_t \{ D_{t+k} + Q_{t+k} \}$, it follows that the definition of fundamental component satisfies

$$Q^F_t R_t = E_t \{ D_{t+1} + Q^F_{t+1} \}$$

where it could be checked that the bubble component will satisfy:

$$Q^B_t R_t = E_t \{ Q^B_{t+1} \}$$

log-linearizing yields:

$$E_t \{ \Delta Q^B_{t+1} \} = r_t$$

I will refer to equation (7) later in the paper as the first channel that interest rate can affect the bubble component: higher interest rate increases expected growth of the bubble or bubble expected return, where under risk neutrality assumption it must be equal to interest rate.

The second channel, through which it is possible for the interest rate to affect the bubble component: a possible systemic comovement between (indeterminate) innovation in the bubble with the surprise component of the interest rate. To see this, reevaluating equation (8) and eliminating the expectation would obtain:

$$\Delta q^B_t = r_{t-1} + \xi_t$$

where $\xi_t \equiv q^B_t - E_{t-1} \{ q^B_t \}$ is an arbitrary process satisfying $E_{t-1} \{ \xi_t \} = 0$ for all $t$. Note that the innovation in the size of the bubble, $\xi_t$ may or may not related to innovation in the interest, $e_t$. Thus,

$$\xi_t = \psi_t (r_t - E_{t-1} \{ r_t \}) + \xi_t^*$$

$\psi_t$ is a (possibly random) parameter of which both its sign and size cannot be pinned down by theory, $\{ \xi_t^* \}$ is a zero mean martingale difference process. Therefore, the dynamic response of the bubble component to interest shock is given by

$$\frac{\partial q^B_{t+k}}{\partial e^m_t} = \begin{cases} \psi_t \frac{\partial q^F_{t+1}}{\partial e^m_t}, & k = 0 \\ \psi_t \frac{\partial q^F_{t+1}}{\partial e^m_t} + \sum_{j=0}^{k-1} \frac{\partial q^B_{t+j}}{\partial e^m_t}, & k = 1, 2, ... \end{cases}$$

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As we can see, the theory of rational bubble opens doors for different predictions: the initial response of the bubble to interest rate is captured by $\psi_t$ which is indeterminate both sign and size. The long-run impact of monetary policy shock on the bubble size, $\lim_{t \to \infty} \frac{\partial q_t^B}{\partial \psi_t^n}$, will be positive or negative depending on whether the persistence of real interest rate response is sufficient to offset the initial impact.

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 $x_t = [\Delta y_t, \Delta p_t, \Delta p^r_t, \Delta p^c_t, i_t, p^h_t]$ where $y_t, p_t, p^r_t, p^c_t, i_t, p^h_t$ denote (log) output, (log) price level, (log) real rent, (log) commodity price index, short-term interest rate, and (log) real house price index respectively. Details of the data used are reported in the next section. Augmented Dickey Fuller test reveals that all log variables are of I(1); therefore, I consider first difference VAR in the next subsection. Cointegration test will be performed later in the following section.

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

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

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

The identification of monetary policy shock follows the conventional one of Christiano, Eichenbaum, and Evans (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.

Letting the monetary policy shock be the fifth element of $\epsilon_t$ and to satisfy the above identification, let $S_t$ be the Cholesky factor of $\Sigma_t$. 
4.2 TVC-SVAR

Noted here that one can rewrite equation (3) as:

$$\frac{\partial q_{t+k}}{\partial \varepsilon_t} = (1 + \gamma_{t-1} - \rho_k^2) + \gamma_{t-1} \left( \psi_t + \frac{1 - \rho_k^2}{1 - \rho_k} \right)$$

(11)

Following equation (11), we are concerned that the response of house price to monetary policy shock, depends on the relative size of the bubble ($\gamma_t$) and its response ($\psi_t$). These two variables can be changing over time. Time-varying considerations here have motivated for the use of time-varying coefficients structural vector autoregression (TVC-SVAR) model in this paper.

Building upon SVAR described in Section (4.1), let $\theta_t = vec(A_t)$ where $A_t = [A_{0,t}, A_{1,t}, ..., A_{p,t}]$ and $vec$ is the column stacking operator. We assume $\theta_t = \theta_{t-1} + \omega_t$ where $\omega_t$ is a Gaussian white noise process with zero mean and constant covariance $\Omega$, and independent of $u_t$ at all leads and lags.

TVC-SVAR allows for time variation in $\Sigma_t$. Let $\Sigma_t = F_tD_tF_t^f$ where $F_t$ is lower triangular matrix with ones on the main diagonal, and $D_t$ is a diagonal matrix. Let $\sigma_t$ be the vector containing a diagonal elements of $D_t^{-1}$ and $\phi_{i,t}$ a column vector with the nonzero elements of the $(i+1)$-th row of $F_t^{-1}$ with $i = 1, ..., 5$, while

$$\log \sigma_t = \log \sigma_{t-1} + \zeta_t$$

$$\phi_{i,t} = \phi_{i,t-1} + \nu_{i,t}$$

where $\zeta_t$ and $\nu_{i,t}$ are zero mean constant covariance ($\Psi$ and $\Xi$) 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.

The model is estimated with Bayesian methods. 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.

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.

12 See Appendix D. for detailed of the algorithm used.
5 Data Description and Cyclical Properties

To give an overview of the data used, this section presents simple statistics of cyclicalities of housing market variables: house price and rent price. The analysis will begin with the static version of U.S. housing market cyclicalities and move on to the dynamic version which is calculated from the TVS-SVAR model.$^{13}$

5.1 Static Properties

Figure 1 and Figure 2 show movements of real house price and real rent price cyclical properties with NBER recession shading at quarterly frequency between 1971Q1 and 2016Q2. Rent price is used here to capture fundamental components, similar to dividend of stock price. Both series, (log) real house price and (log) real rent price,

![Figure 1: U.S. real house price at business cycles frequencies (1971Q1-2016Q2)](image1)

![Figure 2: U.S. real rent at business cycles frequencies (1971Q1-2016Q2)](image2)

$^{13}$ See Appendix A. for detail of data used.
Table 2: Unconditional cyclical components of real house price and real rent in international countries (y = real output)

are detrended by Hodrick-Prescott filter \((\lambda = 1600)\).

Figure 1 suggests that housing boom-bust tends to be accompanied by key economic variable, GDP, which made it unsurprisingly an interest among policy makers in stabilizing its boom-bust cycle. Statistics from Table 2 has made it clearer that real house price is procyclical (cross correlation with GDP business cycle is 0.59) and highly volatile (sd. is 1.686 times of real GDP), while real rent price is countercyclical (cross correlation with business cycle is -0.2152) and less volatile for the U.S. data. Note here that these characteristics of real house price, procyclalities and high volatilities, are found to be consistent across other 19 OECD countries as shown in Table 2; however, the conclusion is unclear for the case of real rent price.

### 5.2 Dynamic Properties

Now we move on to the dynamic properties of U.S. housing market variables estimated from the TVC-SVAR. Although previous studies have already investigate cyclicalities of house price and rent price, there has been no work that applies the time-varying model to improve understanding on dynamic properties of the data series and their comovements over time. Studying cyclicalities from the dynamic perspective would undoubtedly improve our understanding on structural change that has happened in U.S. housing markets.
5.2.1 Time-Varying Standard Deviation

Figure 3 shows the evolution of unconditional standard deviation of U.S. housing market variables; including house price, rent price, and real output. Several important facts are worth noted.

First, standard deviation of all housing variables and GDP declined significantly during 1980 and 1985 which is consistent with the period of U.S. “Great Moderation”. This inference could be made clearer when ones look further at the standard deviation of all three variables (house price, rent price, and real output) conditional on deflator (price) shock. For all three variables, standard deviation conditional on deflator shock explain the majority of its unconditional standard deviation and is a major driver for observed significant decline during 1980 and 1985. This finding thus supports the assumption that the stability in all three housing market variables during the Great Moderation could be related to stability of the U.S Great Inflation in the late 1970s.

Comparing among three variables, house price is much more volatile than real GDP while rent price shows more stability throughout the studying period. While GDP and rent price are relatively more stable after the Great Moderation, upward trend however can be observed in house price volatility.

![Figure 3: Time-varying unconditional standard deviation for U.S. housing market variables: house price and rent price.](image)

14 Conditional standard deviation is shown in Appendix E. Figure 11-13.
This can be seen from Figure 4 where standard deviation of house price and rent price are shown both relative to standard deviation of GDP. House price becomes more volatile relative to the U.S. business cycle after the Great Moderation in contrary to rent price of which its cyclicality remains relatively stable.

5.2.2 Time-Varying Correlation

From the theoretical perspective, the two-sector monetary business cycle model where durable goods price (house price) is assumed flexible and nondurable goods price is assumed sticky would give rise to the co-movement puzzle between durables and non-durables after monetary policy shock. To be precise, monetary expansion while typically results in increased output, it will contract demand for flexibly-priced sector and expand demand for sticky-priced sector. As a result, theory would predict that price of durable goods (assumed flexible here) will decrease as demand contract and comove negatively with output in response to tightening monetary policy, while price of nondurable goods (assumed sticky) will increase and comove positively with output.

In this section, I will assess this prediction empirically from the time-series perspective and will provide some results that could possibly lead to the opposite assumption the two-sector New-Keynesian model predicts.

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15 This co-movement puzzle was first pointed out by Barsky et al. (2003, 2007)
While Table 2 has already shown that house price is procyclical, some might argue that such positive correlation is driven by other types of shocks beyond monetary policy innovations. To be more precise with the role of monetary policy and to test the model’s prediction regarding the stickiness in house price, it would be more intuitive to look at the correlation conditional on monetary policy shock and ask how monetary policy would affect their correlation.

Building upon TVC-SVAR estimated results, this section shows below the evolution of correlation between house price and GDP conditional on monetary policy shock, along with its unconditional correlation. 16 Therefore, according to the theoretical prediction, if house price is flexible, we would expect its correlation with output conditional on monetary policy shock to be negative.

As seen in Figure 5, unconditional correlation between house price and GDP calculated from TVC-SVAR (red solid line) is positive around 0.25, close to those reported

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16 Appendix B describes detail of the calculation for conditional correlation.
in Table 2. Our interest here in this section is instead on conditional correlation. As we can see, house price and output are positively correlated conditional on monetary policy shock (dashed black line). This evidence is in stark contrast to the prediction from the two-sector monetary model briefly described above in this section that house price is fully flexible and is, therefore, more consistent with the conclusion that rigidities do exist in house price movements.

Their correlation is quite symmetric with recession period slightly more procyclical than the expansion period. This can be seen from Table 3 where the degree of asymmetry in boom-bust cycles, calculated from the difference between average correlation of house price and GDP during the expansion and average correlation during recession period, are reported.

6 Impulse Response Function

6.1 Results

Here, I present the impulse response function result from the above SVAR models. In this section, \( x_t = [\Delta y_t, \Delta p_t, \Delta p_f^t, \Delta p_c^t, i_t, \Delta p_h^t] \). The rest of the model and shock identification follow from what describe above.

Figure 6 presents the impulse response function (IRF) to monetary policy shock. The solid blue line is the estimated response to policy shock while the two dashed red lines are the 84% confidence interval.

Tightening monetary policy will increase both real and nominal interest rate, lower (log) real GDP, and eventually lower (log) GDP deflator. (Log) real rent; however, increases in response to monetary policy shocks. The results are consistent for other OECD countries except UK, Norway and Belgium.

In the previous version of this paper, I referred to the situation where real rent increases in response to contractionary monetary policy, which is at odds with the theoretical prediction, as rent puzzle. It also inconsistent with dividend from other types of asset, i.e. stock price, which decrease in response to tightening monetary policy. Recent paper by Duarte and Dias (2016) has nicely studied this puzzle. They proposed the hypothesis that monetary policy could have on housing tenure

\[ \text{corr}(x_t, z_t) = \sum_{i=1}^{6} \lambda_i \text{corr}(x_t, z_i), \]

where \( \lambda \equiv (\sigma(x_t)\sigma(z_t))/\sigma(x_t)\sigma(z_t) \).

18 MBBQ Algorithm (Harding and Pagan (2002)) is used to identified GDP expansion-recession period.

19 Detail of identification can be found in Christiano, et al. (1999) or Galí and Gambetti (2013).

20 See Appendix F. Figure 14-16.

21 Galí and Gambetti (2013) showed that stock dividend declines in response to exogenous monetary policy tightening, consistent with conventional analysis.
Figure 6: Cumulated IRF from monetary policy shock (U.S data, VAR in difference)

Figure 7: IRF from monetary policy shock (U.S data, VAR in level) Note here that the solid blue line is the mean of the bootstrapped based IRF, not the median.
decisions (own vs rent). Specifically, if prices do not adjust quickly enough, people might switch from one type, either own or rent, to another. Tightening monetary policy will increase the cost of owning a house, making people switch to rental market and increase rent price.

Following an accounting identity of Section (3) partial equilibrium rational asset pricing model, impulse response function of fundamental component is calculated according to equation (4) is reported in Figure 6.g where fundamental component of house price falls immediately in response to monetary contraction, consistent with both the theory and evidence. Response of the proxy for bubble, shown in Figure 6.i, is calculated as the gap between house price IRF and fundamental IRF according to equation (3) as,

\[
\frac{\partial(q_t+k - q_t^F)}{\partial e_t^m} = \gamma_{t-1}(\frac{\partial q_t^{B}}{\partial e_t^m} - \frac{\partial q_t^{F}}{\partial e_t^m})
\]

(12)

Since all variables in \(x_t\) : (log) real output, (log) real rent, (log) price level, (log) commodity price index, (log) real house price index, are I(1), differenced VAR as in the previous section is an appropriate solution.

For robustness of the result, I test whether there exist cointegrating relationship among variables. Johansen cointegration test reveals that there are at least two cointegrating vectors, estimating VAR in levels thus seem to be justified. \(^{22}\) I thus estimates VAR in levels and show the result in Figure 7. \(^{23}\) Here, we can see that the analysis does not change much from VAR in difference. Moreover, as Johansen cointegration test is highly sensitive to the number of lag chosen, I therefore choose to work with VAR in difference in later analysis throughout the paper for consistency in comparison with the literatures. \(^{24}\)

Time-varying version of the impulse response function as described in Section (4.2) are also reported here in Figure 8. Before turning to a complete analysis of monetary impulse response function to Section (7), I will first point out some preliminary observations of these impulse response function in Section (6.2).

### 6.2 Relations to Price Rigidities

In demonstrating the sluggishness of aggregate price level in response to aggregate shock, there are two main directions in the literatures. One simply study this question

\(^{22}\) Details of Johansen Cointegration test is reported in Table 4, Appendix C.
\(^{23}\) Note here that, only real output is expressed in log unit.
\(^{24}\) The effect of monetary policy on other asset price, e.g. stock price, has been done in differenced VAR (Galí and Gambetti, 2013). For ease of comparison with the literatures, I thus kept the analysis in the differenced VAR form.
directly, e.g., through vector autoregression. \(^{25}\) This first strand of literature, however, is criticised as it is hard to identify appropriate exogenous demand shock and the bias it could generate from one-time estimation. This give rise to the second strand of the literatures that turn to micro-level price data instead of the aggregate one.

In this section, I follows the first strand of the literature by pointing out that house price is sticky in response to conventional shock, e.g. monetary policy shock, through benchmark SVAR model impulse response function.

Figure 5.f, which is our main interest in this section, reveals that (log) real house price falls in response to monetary policy tightening, consistent with the fact that it is procyclical; however, it is sluggish that it responds slowly toward monetary policy

\(^{25}\) See, e.g., Bils et al. (2003), Mackowiak et al. (2009).
Combining with the importance of sticky house price discussed in the previous section (Section (2.2)), the empirics here thus implies that sticky house price is not of little importance in monetary model despite the evidence that not a few goods’ prices in the economy are sticky.

Supporting the assumption that house price is sticky at the international level, Figure 15 of Appendix F. presents the impulse response of empirical SVAR model for 19 OECD countries. Results are consistent with the conclusion here that house price does not fall immediately in response to monetary policy tightening, instead, it

To reconcile the result with the literatures, examples can bee seen in Barsky et al. (2003). Under the sticky-price general equilibrium model, they show the simulated impulse response function of durable prices in response to monetary policy shock with different degree of durable price rigidities. The result shows that durable price jumps immediately in response to monetary policy shock if the assumption behind is “flexible durable prices”, while the response is close to zero in the beginning if the assumption is “sticky durable prices”. 

26
is sticky and adjusts slowly towards monetary shocks.

Showing price rigidities through SVAR is simple, yet conventional in the literatures. The result that price adjusts slowly in response to monetary policy shock is often referred to in the literatures as “real rigidities” (e.g. Ball and Romer, 1990). This paper is not the first to study the effect of monetary policy on house price through SVAR exercise, but it raises here for the first time that they are rigid and will show later in this paper that their rigidities are important for monetary transmission mechanism.

Comparing to other assets, e.g. the response of stock price to monetary policy shock in Gali and Gambetti (2013): even though both house price and stock price are highly volatile, the two types of assets and their bubbles behave differently in response to monetary policy shock. Moreover, rigidities and rent puzzle exists only in housing markets.

I leave the discussion of Figure 6.g, 6.h, 6.i to Section (7) and will show later in this paper how the findings here can bring new insights that help us better understand the effect of monetary policy on asset price bubbles.

7 Discussion of the Results

7.1 Housing Bubbles

This present section focuses the analysis on the response of proxy for house price bubble to monetary policy shock from TVC-SVAR model result, calculated according to equation (12). Figure 6.i and 8.h have made clear that the response of the gap between house price and its fundamental component (proxy for bubbles) to interest rate shock is non zero. For clarity of the time-varying IRF graph, Figure 9.a report here again IRF of house price minus fundamental from Figure 7.h at selected horizons in.

Two facts can be drawn when combining such observation with equation (12). First, bubble component does exist in housing markets ($\gamma_t \neq 0$). Second, housing bubble and its fundamental component respond differently to monetary policy shock ($\frac{\partial q_t^B}{\partial \tau_t} \neq \frac{\partial q_t^F}{\partial \tau_t}$).

One might argue that it is unlikely, by model construction, that the calculated gap will be exactly zero. For robustness of the positive gap observed, I also consider the bootstrapped based probability that the gap between house price and fundamental response to monetary policy shock will be positive in Figure 9.b. We can see that, for immediate impact, the probability of observing a positive gap (red solid line: contemporaneous effect) is well above 90 percent. This increase our confidence in the

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27 See Bils et al. (2003), Barsky et al. (2003).
uncertainty of the result that bubble exist to begin with.

7.2 Theoretical Discussion of the Empirical Result

In this section, I provide a discussion of the impulse response function generated from SVAR and TVC-SVAR, based on partial equilibrium model described in Section (3). The analysis will first consider contemporaneous effect in response to tightening monetary policy in Section (7.2.1) and move to long-run effect in Section (7.2.2).

7.2.1 Contemporaneous Effect

Reconsidering equation (3) at contemporaneous time \((k = 0)\):

\[
\frac{\partial q_{t+k}}{\partial \epsilon_t} = \frac{1 - \gamma_{t-1}}{1 - \Lambda \rho_r} + \gamma_{t-1} \psi_t
\]

Theory and evidence (Figure 7.g) both suggest that fundamental component responds negatively to positive monetary policy shock \((\frac{\partial q_{t+k}^F}{\partial \epsilon_t^m} < 0, k = 0)\). However, Figure 7.f reveals that house price is sticky that it adjusts slowly toward tightening monetary policy in the beginning \((\frac{\partial q_{t+k}^F}{\partial \epsilon_t^m} \approx 0, k = 0)\).

By rationalizing these two findings with equation (13), it is necessary that housing bubbles grow with the interest rate on impact \((\psi_t > 0 \text{ and } \gamma_{t-1} > 0)\). 28 This results

\[
28 \text{ Here, I ignore the case that } \psi_t < 0 \text{ and } \gamma_{t-1} < 0 \text{ as it is unlikely that policy makers will tighten monetary policy when price has already fallen below fundamental.}
\]
in observed positive gap between the response of house price and its fundamental component to monetary policy shock, displayed in Figure 7.h.

Therefore, the short-run impact would be that housing bubbles inflate with tightening monetary policy, contrary to the “conventional” wisdom which says that tightening monetary policy can help stabilize the bubble. We discuss further the long-run effect in the next subsection.

7.2.2 Long-Run Effect

A first look at Figure 7.h, where the difference between IRF of house price and its fundamental turns negative in the long-run (blue dashed-starred line in Figure 9.b shows that it would be negative with 60 percent bootstrapped-based probability), is tempting to conclude that tightening monetary policy can stabilize housing bubbles in the long-run. However, in this section, I will show that the results might not seem so when ones try to understand them from the theoretical perspective.

Again, I reconsider equation (3) in longer run \((k \to \infty)\):

\[
\lim_{k \to \infty} \frac{\partial q_{t+k}}{\partial \epsilon_i^m} = (1 - \gamma_{t-1}) \lim_{k \to \infty} \frac{\partial q_{t+k}^F}{\partial \epsilon_i^m} + \gamma_{t-1} \lim_{k \to \infty} \frac{\partial q_{t+k}^B}{\partial \epsilon_i^m}
\]

\[
= (1 - \gamma_{t-1}) \lim_{k \to \infty} \left( -\frac{\rho_r^k}{1 - \Lambda \rho_r} \right) + \gamma_{t-1} \left( \psi_t + \frac{1}{1 - \rho_r} \right)
\]

\[(14)\]

In the long-run, Figure 7.g shows that the effect of monetary policy shock on fundamental component does not persist \((\lim_{k \to \infty} \frac{\partial q_{t+k}^F}{\partial \epsilon_i^m} = \lim_{k \to \infty} -\frac{\rho_r^k}{1 - \Lambda \rho_r} = 0)\). With downward rigid house price \((\lim_{k \to \infty} \frac{\partial q_{t+k}^B}{\partial \epsilon_i^m} < 0)\) observed in Figure 7.f, it follows that the second term on the right hand side variable of equation (14) or the long-run response of housing bubble to monetary policy shock must be negative.

As \(\psi_t\) captures the unexpected change in the size of the bubble and is pinned down to be positive by the response on impact (Section (7.2.1)), it must be the case that bubbles turn negative \((\gamma_{t-1} < 0)\) in the long-run.

Although the case of negative bubble share \((\gamma_{t-1} < 0)\) has never been seriously discussed, the model is flexible to this possibility and negative bubble is possible under downward rigid house price. To be precise, in the long run, if house price were to be

Moreover, rewriting equation (13) under the negative bubble case where \(\frac{\partial q_{t+k}^B}{\partial \epsilon_i^m} \approx 0\) would yield:

\[
\psi_t \approx \frac{1 - \gamma_{t-1}}{\gamma_{t-1}} \left( \frac{1}{1 - \Lambda \rho_r} \right)
\]

\[
\approx \frac{-1}{1 - \Lambda \rho_r} + \frac{1}{\gamma_{t-1}(1 - \Lambda \rho_r)} < \frac{-1}{1 - \Lambda \rho_r} < 0
\]

Therefore, observed empirical evidence will be consistent with asset pricing theoretical perspective if and only if \(\psi_t\) is non-normally negative \((\psi_t < -\frac{1}{1 - \Lambda \rho_r})\) which is an extreme case.
downward rigid that it falls below fundamental price, it could endogenously generate
damaging negative bubbles.

Negative bubble is not new in the literature. Allen and Gale (2000) has discussed
the initiation of negative bubble that it could occur from various reasons i.e. positive
bubble burst, new information, or banks are forced to liquidate assets in rigid market.
These negative bubbles lead to collapse in asset price which they viewed as a source
of banking crisis.

Note here that one should not only view sticky house price assumption as a reason
for the observed negative gap in Figure 7.h, observed result should also be considered
as an evidence supporting the assumption of downward rigid house price as well, at
least for the case of U.S. shown here.

This section has so far suggested the analysis of the empirical TVC-SVAR results
from the theoretical perspective of rational asset price bubbles. To gain deeper un-
derstanding regarding this point, I will further discuss the analysis of time-varying
impulse response function result at selected horizons in Section 7.3.

7.3 A Closer Look at Selected Horizons

As stated in the previous section, the effect of monetary policy on housing bubble is
rather unpredictable: bubbles grow with the interest rate contemporaneously, while in
the long run, it could become deeply negative. To improve our understanding on this
theoretical issue, I discuss here some observations from further contemplating at the
previous time-varying impulse response functions.

Time-varying impulse response functions of housing market variables at selected
horizons are shown in Figure 10. With the benefit of time-variation, the analysis here
will utilize both distinction of dynamics both across time dimensions and across IRF
horizon dimensions.

According to Figure 10.a, house price decreases in response to positive monetary
policy shock. In the short run (less than 1-year horizon), while the magnitude of
price decrease has gained its intensity over horizons, patterns remain stable over time
and over horizons. Changing patterns across time; however, could be observed in the
long-run response (3-year horizon) of house price.

Notice here that turning points of house price response at 3-year horizon around
the beginning of the 1990s and the end of 2005 coincide with the considered high
bubble period from the U.S. Case-Shiller house price index, implying that monetary
policy affect house price in the long-run somewhat similar to housing cycle. Moreover,
we could observe that long-run response can go far beyond expectation that house
price is particularly sensitive during the high bubble period (around 1989Q4 and 2005Q4) and the depth of house price decrease has gained its intensity every considered high bubble period that has passed.

To structurally explain reasons behind the changing patterns of house price IRF at
longer than 3-year horizon, following equation (3) would allow us to hypothesize that it could be explained by either of the following three channels: (I) IRF of fundamental (II) IRF of the bubble component (III) bubble share.

By looking at Figure 10.b, one would be able to argue that the observed changing patterns across horizons of house price IRF could not be explained by the first channel, IRF of fundamental component. To be precise, while the response of fundamental component to monetary policy shock has decreased its intensity over horizons, patterns over time of fundamental IRF at long-run horizon rarely changed and is similar to those at the short-run horizon. Therefore, I could ignore the first channel and argue that change in house price IRF at long-run horizon has to do with bubbles rather than fundamental and it should be explained by either change in response of the bubble IRF over horizons, or change in sign of the bubble share from positive to negative as horizons pass.

To gain deeper intuitions which of the two channels is in effect, I further look at the response of rent price to monetary policy shock in Figure 10.c. Comparing Figure 10.a to 10.c, one could observe similar changing pattern across time period between IRF at the 3-year horizon of house price (starred blue line of Figure 10.a) and those at 1-year horizon of rent price (dashed pink line in Figure 10.c). Notice here that the response of rent price not only appears at earlier horizon, but also at earlier time period. This shed light to the fact that the response of rent price to monetary policy shock in the short-run could imply us pattern of house price IRF in later period.

The fact that movements over time of house price IRF at 3-year horizon shows

Figure 10 (continued): IRF of housing market variables at selected horizons.
similar pattern to those of the rent price at 1-year horizon allows us to rule-out the second channel suggested by equation (3): changing pattern of long-run response of house price should not be explained by change in IRF of bubble component across horizons. This follows from the fact that factors affecting change in the rent price IRF at 1-year horizon would not influence IRF of bubble component at 3-year horizon. The intuition would be clearer when ones compare equation (2) to equation (3). Equation (2) shows that asset price IRF is a function of fundamental IRF and interest rate response, while equation (3) would imply that these variables affect rent price in earlier horizon.

From all the evidence presented, we still could not rule-out the third channel that could affect changing patterns of house price IRF at 3-year horizon, bubble share. Moreover, the observed similar pattern but delayed response of house price at 3-year horizon compared to rent price at 1-year horizon points to the fact that house price is sticky. If this is the case, the third channel is likely the result from delayed response of house price. Therefore, the conclusion here is supportive to the fact that the observed negative long-run response of the gap between house price and its fundamental is a result of positive bubble turning negative in the long run as proposed in Section 7.2.

7.4 Understanding House Price Fluctuations from Time-Varying Second Moments

The previous sections have already tried to understand monetary policy impulse response function of housing market variables both from the theoretical prediction and from the qualitative pattern detection. While conclusion from both analysis suggest that it is likely that bubbles are the major drivers of long-run house price response to monetary policy shock, we are still unable to draw causality or correlation of house price and bubbles. This section tries to improve on that missing linkages by focusing on the analysis of time-varying second moments.

Figure 11 shows the time-varying variance of house price conditional on monetary policy shock. While the exact meaning and constructions differ, implication of Figure 11 is similar to Figure 10.a that house price is less volatile in the short run but appears to be highly volatile in the longer run. This conditional variance of house price can be written as the sum of ‘house price vs fundamental covariance conditional on monetary policy shock’ and ‘house price vs bubble covariance conditional on monetary policy shock’ as follow,
Using time-varying coefficients estimated from TVC-SVAR model, I shown below time-varying covariance conditional on monetary policy shock of ‘house price vs. fundamental’ and ‘house price vs. proxy for bubbles’ in Figure 12.

While Figure 12.a has shown that importance of fundamental component in house price is decreasing over monetary shock horizons, Figure 12.b shows that bubbles gain more importance as horizons passed. We can see here that in the sufficiently long horizon, say after 1 year, when conditional covariance of house price and bubbles start to become positive, house price started to becoming more volatile in response to monetary policy shock.

It is interesting to note here that covariance of house price and bubbles conditional on monetary policy shocks is highest on 2005 which is the year that house price peak before its collapse and start the the period of the Great Financial Crisis. Take the 5-year horizon of year 2005 as an example, we could observe high conditional covariance of house price and bubbles but near zero covariance of house price and fundamental. This would suggest that tightening monetary policy at the peak of the house price cycle, intending to control the bubbles at that time, would generate persistent bubble-driven house price fluctuation in the future. Combining this with the theoretical prediction that bubbles turn negative in the long run implies that monetary policy
generates persistent negative bubbles in the long-run.

Considering both theoretical discussion and empirical analysis at selected horizons, this exercise not only calls into question “leaning against the wind” monetary policy, particularly when asset price is sticky and its business cycle is tied closely to important macro variables like house price, but this exercise also helps improve our understanding regarding the transmission mechanism of monetary policy in stabilizing housing bubbles. As shown, controlling housing bubble is an uneasy task for monetary policy and it is likely that monetary policy will increase variability of bubbles in the long-run, particularly during the high price periods.

8 Bubbles and Monetary Non-Neutrality

Previous section has already analyzed the effect of monetary policy on asset (housing) market from several dimensions. One conclusion reached is that monetary policy could influence house price through bubble size fluctuation and the effect is persistent.

The finding here is consistent with the theoretical prediction of Galí (2017) that sticky price allows monetary policy to influence bubble size fluctuation. Beyond this, he shows theoretically that, with sticky price, bubble fluctuations are allowed to generate fluctuation in aggregate demand (output and employment) through implied wealth effect on consumption. There are thus room for monetary policy to influence bubble-driven fluctuation of real variables. This section aims to provide an empirical evidence to this newly proposed channel of monetary transmission mechanism.
Similar to the previous section, covariance of output and bubbles conditional on monetary policy shock explains how much can monetary policy affect bubble-driven output fluctuations. Figure 13 shows the output variance conditional on monetary policy shock and Figure 14 shows how much this fluctuation could be explained by bubbles.
Figure 15: IRF of (a) GDP and (b) proxy for bubble, both at 5-year horizon.

We can see here that output fluctuation increases with horizons after being in influenced by monetary policy shock, similar to its covariance with bubbles conditional on monetary policy shock. Figure 15 shows the dynamics over time of output and bubbles impulse response function at arguable long horizon (5 years) and we can see here that dynamic of output IRF (Figure 15.a) is arguably “proportional” to the proxy for bubbles (Figure 15.b). This thus implies that monetary policy can affect bubble-driven output fluctuation, similar to the theoretical prediction discussed earlier, and the effect is stronger in the long run.

Beyond the non-neutrality of monetary policy through bubble-driven fluctuations, evidence here can infer us linkages between bubbles and real sector. Given the evidence that monetary policy can influence fluctuation in the bubble size in the long run and the conclusion that monetary policy can influence bubble-driven output fluctuation, this would thus suggest that bubbles fluctuation could affect real variables in the long run. The fact that we choose 5-year to represent long horizon thus implies that the effect is highly persistent.

Linkages between bubbles and real sector is highly important, especially in the context of sticky prices. It is unarguable that crisis generated by housing bubbles is much
deeper and lasts longer than other asset price bubbles, e.g. stock price bubbles. The only explanation widely accepted in the literature has to do with credit-fueled bubbles, e.g. Jordá et al (2015) 29. Sticky house prices, where the response of house price lasts for several years, thus could be another potential explanation for the deep and long-lasting effect of the financial crisis witnessed. Moreover, it provides an explanation that differentiate the characteristic of housing bubbles from equity price bubbles that could make its effect on the whole financial system differs.

9 Conclusion and Discussion

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 asset market that this prompts interests among policy makers and researchers to better understand its dynamics and study how best should we response to housing bubbles. Several attempts have been done to incorporate housing sector into monetary model to study the effect of monetary policy on housing markets.

One important issue centered in the literature of monetary modeling has to do with sticky price. It is well accepted that nominal monetary policy shock could have real effect on the economy only if prices are sticky; otherwise, monetary policy would become neutral to the real sector. 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. This paper documents and raises awareness regarding the existence of stickiness in house price which is highly important when one think of the role of monetary policy in controlling asset price bubbles and, beyond the focus of this paper, support the fact that sticky price is not of little importance in monetary model. In designing a proper policy, clear-cut understanding of rigidities in housing sector and further attempts in modeling it is thus necessary.

Using rational asset price bubble theory to understand empirical results from both the standard and time-varying SVAR model, this paper shows a hard evidence that housing bubbles exist and respond differently from its fundamental component to tightening monetary policy.

The results point to several unique characteristics of house price which differ significantly from the “conventional” view and other asset prices. While the conventional

29 They argue that if bubbles are not fueled by credit boom, their effects on macroeconomy will be limited. However, if bubbles were credit-financed, like the one emerged in housing markets, there will be a positive feedback between asset price, credit growth, and debt accumulation of which the bursting of the bubbles will weakens economic activity and increases macroeconomic risk in credit markets.
view would predict that asset price bubble will decrease in response to tightening monetary policy, similar to both asset price and its fundamental components, house price differs from this prediction both in the short run and in the long run. The results here show that (I) house price is sticky, in contrast with stock price which is flexible and (II) rent price increases in response to higher exogenous change in interest rate, opposite direction with stock dividend’s response. These two characteristics have made the transmission mechanism of monetary policy to housing bubbles differs. In the short run, house price is downward rigid that it rarely change while fundamental component has already decreased. This give rise to the possibility of housing bubbles inflate contemporaneously to monetary policy tightening. In the long run, house price can be highly downward rigid that it falls below fundamental value. The result here point to the fact that the effect could be persistent, and under the rational bubble assumption, the role of monetary policy in stabilizing housing bubbles should be viewed with skeptic.

The fact that house price is sticky and monetary policy could influence bubble size fluctuation in the long-run is consistent with the theoretical prediction of monetary model that allows for sticky asset price (Galí, 2017). Empirical result here that dynamics of long-run response of housing bubble to monetary policy shock is similar to output implies that there is channel for monetary policy to influence bubble-driven output fluctuation. The finding here is interesting that it leads to channel for potential persistent effect of bubbles on real output which could serve as another potential explanation for the observed persistent effect after the crisis.

In sum, this paper highlights the importance of asset-specific characteristic when one thinks of monetary policy role in stabilizing asset price bubbles. So far, the effect of bubbles on real sector is inferred from related evidence and theoretical prediction. Future work that could directly identify bubble fluctuation and study its real effect are highly encouraged.
A Appendix : Data

The list of 19 countries include: Austria, Australia, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Spain, Sweden, Switzerland, UK., and the US. The sample period is 1971Q1-2016Q2. The following paragraph provides detailed of the data used. All data are downloaded from OECD stat websites.

**Real GDP**: expenditure approach. Millions of national currency, volume estimates, annual level, quarterly and seasonally adjusted, index based in 2010 (Measure: VO-BARSA).

**Real Rent Price**: nominal rent price deflated by GDP deflator. Nominal rent price is obtained from OECD. All data is quarterly and seasonally adjusted (index based in 2010).

**Price Level/ GDP Deflator**: calculated from nominal GDP/real GDP where nominal GDP is calculated from expenditure approach, millions of national currency, current prices, annual level, quarterly and seasonally adjusted (Measure: CARSA).

**Consumer Price Index**: CPIs are presented as an index where the year 2010 is the base year. The data is quarterly and unadjusted.

**Short term interest rate**: Short term rates are usually either the three month interbank offer rate attaching to loans given and taken amongst banks for any excess or shortage of liquidity over several months, or the rate associated with Treasury bills, Certificates of Deposit or comparable instruments, each of three month maturity. For Euro Area countries the 3-month “European Interbank Offered Rate” is used from the date the country joined the euro.

All data are quarterly and unadjusted. Downloaded from OECD website and UPF data streaming. Sources: OECD, Main Economic Indicators - complete database.

**Real House Price Index**: index is quarterly and seasonally adjusted (index based in 2010).

30 except the following countries due to data availability of historical short term interest rate: Norway (1979Q1-2016Q2), New Zealand (1974Q1-2016Q2), Sweden (1980Q1-2016Q2), Switzerland (1974Q1-2016Q2), Australia (1972Q3-2016Q2), Belgium (1976Q2-2016Q2), Denmark (1979Q2-2016Q2)
B Appendix: Conditional Correlation Estimators

In calculating the impulse response function, we can express

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

where \( \epsilon^5_t \) is identified to be monetary policy shock (\( \epsilon^5_m \)). Correlation conditional on monetary policy shock between real GDP and real house price can be obtained by:

\[
\rho(\Delta y_t, \Delta p''_t | m) = \frac{\sum_{j=0}^{\infty} C_{j}^{1m} C_{j}^{6m}}{\sqrt{\text{var}(\Delta y_t | m) \text{var}(\Delta p''_t | m)}}
\]

where \( \text{var}(\Delta y_t | m) = \sum_{j=0}^{\infty} (C_{j}^{1m})^2 \) and \( \text{var}(\Delta p''_t | m) = \sum_{j=0}^{\infty} (C_{j}^{6m})^2 \) are conditional variance of real GDP and real house price respectively. Also, correlation conditional on monetary policy shock between real GDP and real rent can be calculated in the same manner.

\[
\rho(\Delta y_t, \Delta p'_t | m) = \frac{\sum_{j=0}^{\infty} C_{j}^{1m} C_{j}^{2m}}{\sqrt{\text{var}(\Delta y_t | m) \text{var}(\Delta p'_t | m)}}
\]

where \( \text{var}(\Delta p'_t | m) = \sum_{j=0}^{\infty} (C_{j}^{2m})^2 \) is conditional variance of real rent price.

C Appendix: Johansen Cointegration (Trace) Test

<table>
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<th>rank</th>
<th>h</th>
<th>stat</th>
<th>cValue</th>
<th>pValue</th>
<th>eigVal</th>
</tr>
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<td>135.0794</td>
<td>95.7541</td>
<td>0.0010</td>
<td>0.3085</td>
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<tr>
<td>At most 1</td>
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<td>69.8187</td>
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<td>0.2113</td>
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<td>At most 2</td>
<td>1</td>
<td>59.8964</td>
<td>47.8564</td>
<td>0.0032</td>
<td>0.1876</td>
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<td>At most 3</td>
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<td>0.0948</td>
<td>0.0763</td>
</tr>
<tr>
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<td>15.4948</td>
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<td>0.0610</td>
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<td>At most 5</td>
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<td>4.9399</td>
<td>3.8415</td>
<td>0.0263</td>
<td>0.0310</td>
</tr>
</tbody>
</table>

Table 4: Johansen Cointegration Test (MATLAB), lag=4, U.S. data
Appendix: Estimation of TVC-SVAR

This Appendix summarizes the estimation of TVC-SVAR model. The approach here follows Del Negro and Primiceri (2013), Galí and Gambetti (2015).

Prior distributions for initial states $\theta_0$, $\phi_0$, $\log \sigma_0$ are normal and the prior for $\Omega$, $\Xi$, $\Psi$ are inverse Wishart. Specifically, $\theta_0 \sim N(\hat{\theta}, 4\hat{V}_\theta)$, $\log \sigma_0 \sim N(\log \hat{\sigma}_0, I_n)$, $\phi_0 \sim N(\hat{\phi}_0, \hat{V}_\phi)$ and $\Omega^{-1} \sim W(\Omega^{-1}, \rho)$, $\Xi^{-1} \sim W(\Xi^{-1}, \rho)$, $\Psi^{-1} \sim W(\Psi^{-1}, \rho)$. 

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.

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

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

Let $x^*_t \equiv F_t^{-1}(x_t - W_t \theta_t) = D_t^{1/2}u_t$, where $u_t \sim N(0, I_n)$, $W_t = (I_n \otimes W_t)$, $W_t = [1 \ x_{t-1} \ x_{t-1}']$. Therefore, by squaring and taking logs, we obtain the following state-space representation:

$$
\begin{align*}
x_t^* &= 2r_t + \nu_t \\
r_t &= r_{t-1} + \zeta_t
\end{align*}
$$

where $x_t^* = \log(x_{i,t}^2)$, $\nu_{i,t} = \log(u_{i,t}^2)$, $r_t = \log \sigma_{i,t}$.

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

<table>
<thead>
<tr>
<th>$j$</th>
<th>$q_j$</th>
<th>$m_j$</th>
<th>$\nu_j^2$</th>
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</thead>
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<td>-10.1300</td>
<td>5.7960</td>
</tr>
<tr>
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<td>-3.9728</td>
<td>2.6137</td>
</tr>
<tr>
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<td>0.0000</td>
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</tr>
<tr>
<td>4</td>
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<td>0.6401</td>
</tr>
<tr>
<td>6</td>
<td>0.2457</td>
<td>1.7952</td>
<td>0.3401</td>
</tr>
<tr>
<td>7</td>
<td>0.2575</td>
<td>-1.0882</td>
<td>1.2626</td>
</tr>
</tbody>
</table>

In practice, the algorithm of Carter and Kohn (1994; CK) is used to draw $r_t$ from $N(r_{t|t+1}, R_{t|t+1})$ where $r_{t|t+1}$ and $R_{t|t+1}$ are the conditional mean and variance obtained from the backward recursion equations.
To draw $\phi_t$, let $\hat{x}_t = x_t - W_t \theta_t$. The $i+1$-th ($i = 1,...,n-1$) equation of the system $F_t^{-1} \hat{x}_t = D^{1/2} u_t$ can be written as: $\hat{x}_{i+1,t} = -\hat{x}_{[i,t],t} \phi_{i,t} + \sigma_{i,t} u_{i+1,t},$ $i = 2, ..., n$.

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 $N(\phi_{i,t|t+1}, \Phi_{i,t|t+1})$.

**Step 3**: $p(\theta_t | x_t, \theta_{t+1}, \phi_t, \phi_{t+1}, \Omega, \Xi, \Psi, s^T)$

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

$$x_t = Z_t \theta_t + \epsilon_t$$

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

Draw $\theta$ from $N(\theta_{t|t+1}, P_{t|t+1})$, where $\theta_{t|t+1} = E(\theta_t | \theta_{t+1}, x_t, \sigma_T, \phi^T, \Omega, \Xi)$ and $P_{t|t+1} = Var(\theta_t | \theta_{t+1}, x_t, \sigma_T, \phi^T, \Omega, \Xi, \psi)$ are obtained from CK algorithm.

**Step 4**: $p(\Omega | x_t, \theta_T, \phi_T, \phi_{T+1}, \Xi, \Psi, s^T)$

Draw $\Omega, i = 1,...,5$. As above, $\Omega = (MM)^{-1}$ where $M$ is an $(n^2p+n) \times \rho_1$ matrix whose columns are independent draws from a $N(0, \Omega^{-1})$ where $\Omega_i = \Omega + \sum_{i=1}^{T} \Delta \theta_{i,t} (\Delta \theta_{i,t})$.

**Step 5**: $p(\Xi | x_T, \theta_T, \phi_T, \Omega, \Psi, s^T)$

Draw $\Xi, i = 1,...,5$. As above, $\Xi = (MM)^{-1}$ where $M$ is an $i \times \rho_2$ matrix whose columns are independent draws from a $N(0, \Xi^{-1})$ where $\Xi_i = \Xi + \sum_{i=1}^{T} \Delta log \sigma_{i,t} (\Delta log \sigma_{i,t})$.

**Step 6**: $p(\Psi | x_T, \theta_T, \phi_T, \Omega, \Xi, \Psi, s^T)$

Draw $\Psi_i, i = 1,...,5$. As above, $\Psi_i = (MM)^{-1}$ where $M$ is an $i \times \rho_3$ matrix whose columns are independent draws from a $N(0, \Psi^{-1})$ where $\Psi_i = \Psi + \sum_{i=1}^{T} \Delta \phi_{i,t} (\Delta \phi_{i,t})$.

**Step 7**: $p(s^T | x_T, \theta_T, \phi_T, \Omega, \Xi, \Psi, s^T)$

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

**E Appendix: Conditional and Unconditional Standard Deviation**

This appendix reports the evolution of unconditional standard deviation of each housing market variables and standard deviation conditional on five shocks from TVC-SVAR. Here, the $5^\text{th}$ is identified to be monetary policy shock, the $2^\text{nd}$ shock can be identified to be price shock.

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Figure 11: Standard deviation of GDP: unconventional (red line) and conditional on each shock (dashed line).

Figure 12: Standard deviation of house price: unconventional (red line) and conditional on each shock (dashed line).

Figure 13: Standard deviation of rent price: unconventional (red line) and conditional on each shock (dashed line).
Appendix: Cumulative Impulse Response to monetary policy tightening in international country

F.1 Real GDP

Figure 14: Real GDP response to monetary policy tightening
F.2  Real House Price

Figure 15: Real house price response to monetary policy tightening
F.3 Real Rent

Figure 16: Real rent price response to monetary policy tightening
F.4 Price minus Fundamental

Figure 17: Gap between house price and fundamental component
References


