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Abstract

We consider which factors determined the price-rent ratio for the housing market in 18 U.S. metropolitan areas (MSAs) and at the national level over the period of 1975 to 2012. Based on a present-value framework, our proposed empirical model separates the price-rent ratio for a given market into unobserved components related to the expected real rent growth and the expected housing return, but is modified from standard present-value analysis by also including a residual component that captures non-stationary deviations of the price-rent ratio from its present-value level. Estimates for the modified present-value model suggest that the present-value residual (PVR) component is always important and sometimes very large at the national and regional levels, especially for MSAs that have experienced frequent booms and busts in the housing market. In further analysis, we find that house prices in MSAs that have larger PVR components are more sensitive to mortgage rate changes. Also, comparing our results with a recent statistical test for periodically-collapsing bubbles, we find that MSAs with large estimated PVR components are the same MSAs that test positively for explosive sub-periods in their price-rent ratios, especially during the 2005-2007 subsample. Our approach allows us to estimate the correlation between shocks to expected rent growth, the expected housing return, and the PVR component. We find that the expected housing return and movements in the PVR component are highly positively correlated in the pre-2006 sample period, implying an impact of the expected housing return on house prices that is different than what a standard present-value model would imply, although this correlation declined significantly in the post-2006 sample period. Our results also show that most of the variation in the present-value component of the price-rent ratio arises due to the variation in the expected housing return.

JEL Classification: E31, G12, R31.

Keywords: Price-Rent Ratio, Unobserved Component Model, Present-Value Model.

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1 Introduction

The financial crisis of 2008-2009 had its roots in the boom and the bust of the U.S. housing market. The collapse of house prices led to the overall decline in financial and macroeconomic stability, starting with a big decline in the stock market.[1] The sustained increase in house prices prior to 2007 attracted widespread attention from the empirical researchers. A big portion of the housing market literature has focused on the price-rent ratio as a metric to measure the extent of overvaluation in the housing market. Most of these empirical studies have used some version of the present-value model of house prices to examine the sources of variation in the price-rent ratio and have found a mixture of results depending on which market is considered.[2]

The present-value model of house prices is based on Campbell and Shiller's (1988) model for asset prices, which has been applied extensively in the finance and exchange rate literature. The housing market version of this model implies that the current price-rent ratio reflects households' expectations about future rent growth and future housing returns. In particular, the price-rent ratio according to the conventional present-value model has the following representation:

$$p_t - r_t = \frac{\kappa}{1-\rho} + \sum_{j=1}^{\infty} \rho^{j-1} E_t(\triangle r_{t+j} - h_{t+j})$$

where $p_t - r_t$ is the log of the price-rent ratio, $\triangle r_t$ is rent growth, h_t is the housing return, ρ is the discount factor and κ is a constant. The above model suggests that the log of the price-rent ratio can be expressed as the expected discounted sum of future rent growth minus future housing returns. If expected rent growth and the expected housing return are both stationary, then the price-rent ratio should also be stationary. Intuitively, this implies that if there is any deviation from the long-run equilibrium value, the price-rent ratio should self-correct. An upward surprise in price-rent ratio today must correspond to news that future housing returns will be higher or to a

[1] It has been estimated that the net worth of the U.S. households declined by $13 trillion dollars between 2007-2009 (Flow of funds data).

[2] Using a present-value model, Gallin (2004) and Case and Shiller (2003) argue that the U.S. housing market in 2004 was over-valued because the price-rent ratio was significantly above its historical average. However, Himmelberg, Mayer and Sinai (2005) find no evidence of a bubble in 2004 in any of the regional markets. Using data from Northern California, Meese and Wallace (1994) reject both constant and time-varying discount rate versions of the housing price present value relation in the short run. Long-run results are consistent with the housing price present value relation when they adjust the discount factor for changes in both tax rates and borrowing costs for their 1970-1988 sample period.

downward revision in expected rent growth. The conventional analysis of the housing market takes this approach and assumes that the price-rent ratio is stationary.

The evidence, however, clearly suggests that price-rent ratio is non-stationary. Table 1 shows results for unit root tests of the log of price-rent ratio for 18 U.S. metropolitan areas (MSAs) and the nation.[3] The results overwhelmingly support the presence of a unit root in the price-rent ratio.[4] This finding is not driven by the presence of unit root in either rent growth or the housing return, as these "fundamental variables" are stationary.[5] One explanation of the non-stationarity of the price-rent ratio is that there are some other factors that drive the variation in price-rent ratio and these factors are non-stationary. This is consistent with the nature of the U.S. housing markets. Unlike stock markets, the functioning of the housing markets in the U.S. is characterized by illiquidity, high transaction costs, differential tax regimes, and zoning laws. To take into account these features of the housing market, we propose a modified present-value model that decomposes the price-rent ratio into the present-value of expected house price growth, the present-value of expected rent growth, and a present-value residual (PVR) component that captures non-stationary factors.

We take an unobserved component approach to estimate a modified present-value model for the United States and each of the 18 MSAs. Our framework explicitly takes into account the fact that the price-rent ratio may move due to changes in expected return to housing, expected rent growth variation, and a PVR component that cannot be accounted for by a conventional model.[6] We treat expected rent growth, expected housing return, and the PVR component as unobserved (to the econometrician) variables that follow exogenously-specified time series processes. In particular, we assume a parsimonious AR(1) specification for both expected rent growth and expected housing return and a random walk specification for the PVR component. Because these latent variables are estimated using the Kalman filter, by construction we use information from

[3]The 18 MSAs in our study are Atlanta, Boston, Chicago, Cleveland, Dallas, Denver, Houston, Los Angeles, Miami, Milwaukee, Minneapolis, New York, Philadelphia, Pittsburgh, Portland, San Francisco, Seattle and St. Louis. Our MSA sample is based on data availability for rent from the BLS for our sample period (1975-2012).

[4]The table shows the results for Ng-Perron unit root test. Other unit root tests also provide us the same results.

[5]Unit root tests overwhelmingly rejects the null of unit root in realized rent growth and realized housing return for all the MSAs and the nation in our sample.

[6]Present-value models have also been studied extensively in finance and exchange rate literature to study the behavior of equity market and exchange rates. For example, Balke and Wohar (2002) apply a state-space/present-value model of stock prices to estimate what drives low-frequency movements in the price-dividend ratio. Binsbergen and Koijen (2008) follow a similar approach to estimate the expected stock returns, and apply it to predict stock returns. For application of present-value models to exchange rates, see Engel and West (2004, 2005) among others.

the whole history of past realized rent growth, realized housing return, and price-rent ratio when making inferences. We express realized variables as the sum of an expected component and an error term that is unforecastable. Only a few other papers have used present-value model to examine the determinants of the price-rent ratio for housing. Notably, Campbell et al. (2009) employ a reduced-form VAR approach to explain the movements in price-rent ratio. They measure expectations by fixed coefficient VAR model. The VAR is used to directly compute expected future housing returns and then use an accounting identity to identify expected future rents as a residual given data on rent-price ratios. In other related work, Ambrose et al. (2013) use 355 years of data for Amsterdam and find that deviations of house prices from their fundamentals are long-lasting and persistent.[7]

Our approach has several advantages over more conventional analysis. First, we are not aware of any study that takes into account the non-stationarity of the price-rent ratio and modifies the present-value model accordingly. Moreover, because future rent growth and housing return are unobserved to econometricians, an unobserved component model is more suitable to model the housing market than an approach that assumes they are observable. Third, as pointed out by Cochrane (2008), a structural state-space model is able to capture individually small but possibly important moving average error terms in the long run. Another important contribution of our work is that our approach allows us to estimate the correlation between expected rent growth, expected housing return and the PVR component.

Our empirical estimates suggest that the PVR component is significant both at the national and regional levels. This is especially true for MSAs that have experienced frequents booms and busts in the housing market. Our results show that this deviation was biggest in Boston, Los Angeles, Miami, New York, San Francisco and Seattle, whereas it was between 0-8% of the price-rent ratio in MSAs like Atlanta, Chicago, and Dallas, Denver, Houston, Philadelphia, Pittsburgh, Portland and St. Louis. In further analysis, we find a negative relationship between the PVR component and mortgage interest rates. This negative relationship is large and significant for all MSAs for the 1991-2005 sample period. Moreover, we also find that the MSAs that display larger deviations from their present-value levels are more sensitive to mortgage rate changes.

[7] Recently, Fairchild, Ma and Wu (2012) use a dynamic factor model in the present-value framework and estimate the relative share of national and local share in variation of price-rent ratio. They find that a large fraction of the variation is based on local factors.

For comparison, we also consider the supADF (SADF) test of Phillips et al. (2011). This test gives rise to a dating strategy which identifies points of origination and termination of possible bubbles that may reflect exuberation or herd behavior. Overall, the results from the SADF test and our model seem to indicate that the MSAs that had large PVR components are the same MSAs that witnessed explosive sub-periods in their price-rent ratios, especially during the 2005-2007 subsample.

Our approach also allows us to estimate the correlation between expected rent growth, expected housing return and the PVR component. We find that shocks to the expected housing return and shocks to the non-stationary PVR component are highly positively correlated in the pre-2006 sample period. This positive correlation may imply that, if there is a positive shock to the PVR component, the expected housing return may not increase by the 'full' amount right away. This is equivalent to saying that there is a slow adjustment of the expected housing return in response to a shock to the PVR component. Notably, this correlation declined significantly in the post-2006 sample. One could think of the shock to this PVR component arising from some regulatory changes or through monetary policy actions. We also find positive correlation between expected rent growth and expected housing return. This positive correlation is intuitive since a shock to expected housing return is also expected to lead to an increase in expected rent growth. This positive correlation between the rent growth and the housing return is consistent with what other researchers have found for the stock market. For example, Bernanke and Kuttner (2005) and Campbell and Ammer (1993) find that shocks to expected dividend growth and equity premia are positively correlated. We also perform variance decomposition of the stationary present-value component. The results show that most of the variation in the present-value component of the price-rent ratio arise due to variation in the expected housing return.

The plan of this paper is as follows: Section 2 proposes a modified present-value model. Section 3 describes the data. Section 4 discusses the empirical results. Section 5 compares results from our model with Phillips et al. (2011) explosive bubble test. Section 6 concludes.

2 Model Specification

2.1 An Unobserved Component Approach to Estimate a Modified Present-Value Model of House Prices

In this section, we present a modified present-value model of the price-rent ratio in the spirit of Campbell and Shiller (1988) and Binsbergen and Koijen (2010). In contrast to Campbell et al. (2009), we assume that the expected house price return and expected real rent growth are latent variables and there is a non-stationary deviation from the long-run stationary value of price-rent ratio represented by the conventional present-value model. Therefore, we can express the log price-rent ratio as the sum of three pieces: the future expected housing return[8], rent growth, and a non-stationary residual term:

$$p_t - r_t = \frac{\kappa}{1-\rho} + \sum_{j=1}^{\infty} \rho^{j-1} E_t(\triangle r_{t+j} - h_{t+j}) + pvr_t \tag{1}$$

We assume that expected rent growth and expected housing return are latent variables. We follow a parsimonious modeling strategy by modeling expected rent growth and expected housing return as AR(1) processes, while we assume that the PVR component follows a random walk process:

$$\triangle r^e_{t+1} = \gamma_0 + \gamma_1(\triangle r^e_t - \gamma_0) + \varepsilon^{r^e}_{t+1} \tag{2}$$

$$h^e_{t+1} = \delta_0 + \delta_1(h^e_t - \delta_0) + \varepsilon^{h^e}_{t+1} \tag{3}$$

$$pvr_{t+1} = pvr_t + \varepsilon^{pvr}_{t+1} \tag{4}$$

where

$$h^e_t = E_t[h_{t+1}]$$

$$\triangle r^e_t = E_t[\triangle r_{t+1}]$$

The realized rent growth and realized housing return are equal to the expected rent growth and expected housing return plus an idiosyncratic shock:

$$\triangle r_{t+1} = \triangle r^e_t + \varepsilon^r_{t+1} \tag{5}$$

$$h_{t+1} = h^e_t + \varepsilon^h_{t+1} \tag{6}$$

[8] Note that $h_{t+1} \equiv \log\left(\frac{P_{t+1}+R_{t+1}}{P_t}\right)$.

Plugging equations (4-6) in equation (3) and solving, we get:

$$p_t - r_t = \frac{\kappa}{1-\rho} + \frac{\gamma_0 - \delta_0}{1-\rho} + \frac{\triangle r_t^e - \gamma_0}{1-\rho\gamma_1} - \frac{h_t^e - \delta_0}{1-\rho\delta_1} + pvr_t \tag{7}$$

which can be written as

$$p_t - r_t = A + B_1(\triangle r_t^e - \gamma_0) - B_2(h_t^e - \delta_0) + pvr_t \tag{8}$$

where $A = \frac{\kappa}{1-\rho} + \frac{\gamma_0 - \delta_0}{1-\rho}$, $B_1 = \frac{1}{1-\rho\gamma_1}$, $B_2 = \frac{1}{1-\rho\delta_1}$. The log price-rent ratio is linear in the expected rent growth r_t^e, and expected housing return h_t^e and the residual term pvr_t. The loadings ($B_1$and B_2) depend on the persistence of rent growth and the housing return. There are five shocks in the model, a shock to expected rent growth ($\varepsilon_{t+1}^{r^e}$), a shock to expected housing return ($\varepsilon_{t+1}^{h^e}$), a shock to the PVR component (ε_{t+1}^{pvr}), a shock to realized rent growth (ε_{t+1}^{r}), and a shock to the realized housing return (ε_{t+1}^{h}). These shocks have mean zero and have the following general variance-covariance matrix:

$$\sum = var \begin{bmatrix} \varepsilon_t^r \\ \varepsilon_t^h \\ \varepsilon_t^{r^e} \\ \varepsilon_t^{h^e} \\ \varepsilon_t^{pvr} \end{bmatrix} = \begin{bmatrix} \sigma_r^2 & \sigma_{rh} & \sigma_{rr^e} & \sigma_{rh^e} & \sigma_{rpvr} \\ \sigma_{rh} & \sigma_h^2 & \sigma_{hr^e} & \sigma_{hh^e} & \sigma_{hpvr} \\ \sigma_{rr^e} & \sigma_{hr^e} & \sigma_{r^e}^2 & \sigma_{r^e h^e} & \sigma_{r^e pvr} \\ \sigma_{rh^e} & \sigma_{hh^e} & \sigma_{r^e h^e} & \sigma_{h^e}^2 & \sigma_{h^e pvr} \\ \sigma_{rpvr} & \sigma_{hpvr} & \sigma_{r^e pvr} & \sigma_{h^e pvr} & \sigma_{pvr}^2 \end{bmatrix}$$

As suggested by Cochrane (2008), we need to impose restrictions on the covariance structure in the above state space model to achieve identification.[9] We follow Binsbergen and Koijen (2010) identification strategy and assume that covariance between shocks to realized variables are uncorrelated with shocks to unobserved state variables. Also, we assume that shocks to realized rent growth and realized housing return are uncorrelated. Our approach allows us to estimate the correlation between shocks to the PVR component and shocks to the expected rent growth and the expected housing return.

2.2 State Space Representation

The present-value model of house price-rent ratio has three latent variables: expected rent growth, $\triangle r_t^e$, expected housing return, h_t^e, and the residual term pvr_t. We define the demeaned state

[9] Also, see Morley et al. (2003) on identification of unobserved components models with a general variance-covariance matrix.

variables as:

$$\triangle r_t^e = \gamma_0 + \widehat{\triangle r_t^e}$$

$$h_t^e = \delta_0 + \widehat{h_t^e}$$

There are three transition equations associated with above demeaned latent variables:

$$\widehat{\triangle r_{t+1}^e} = \gamma_1 \widehat{\triangle r_t^e} + \varepsilon_{t+1}^{r^e}$$

$$\widehat{h_{t+1}^e} = \delta_1 \widehat{h_t^e} + \varepsilon_{t+1}^{h^e}$$

$$pvr_{t+1} = pvr_t + \varepsilon_{t+1}^{pvr}$$

and three measurement equations:

$$\triangle r_{t+1} = \gamma_0 + \widehat{\triangle r_t^e} + \varepsilon_{t+1}^r$$

$$h_{t+1} = \delta_0 + \widehat{h_t^e} + \varepsilon_{t+1}^h$$

$$p_t - r_t = A + B_1(\triangle r_t^e - \gamma_0) - B_2(h_t^e - \delta_0) + pvr_t$$

We can estimate the above state space model using maximum likelihood via the Kalman filter. To take into account the big changes in the housing market in 2006-2012 sample period, we also allow the transition equation variance-covariance matrix to have two regimes: one for the 1975-2005 sample period and the other for the 2006-2012 sample period. Admittedly, there are only 27 observations in the second sample period. However, as we will see, it is still possible, despite this small number of observations, to gain some insight into the changes that took place in the housing market during the global financial crisis.

2.3 Variance Decomposition of the Present-Value Level

The stationarity of the present-value components of the price-rent ratio allows us to perform a variance decomposition using equation (8). The variance decomposition of the present-value level of the price-rent ratio is defined as

$$var(p_t^* - r_t^*) = B_1^2 var(\triangle r_t^e) + B_2^2 var(h_t^e) - 2B_1B_2 cov(r_t^e, h_t^e)$$

$$var(p_t^* - r_t^*) = \frac{(B_1\sigma_{r^e})^2}{1-\gamma_1^2} + \frac{(B_2\sigma_{h^e})^2}{1-\delta_1^2} - \frac{2B_1B_2\sigma_{r^e h^e}}{1-\gamma_1\delta_1}$$

where $p_t^* - r_t^*$ corresponds to the present-value level of the price-rent ratio $p_t - r_t$. The above formula implies that proportion of variation of present-value level of the price-rent ratio explained by expected rent growth is $\frac{(B_1 \sigma_{r^e})^2}{1-\gamma_1^2}$, and percentage of variation explained by housing return is $\frac{(B_2 \sigma_{h^e})^2}{1-\delta_1^2}$. It may also be possible that the covariance explains a bigger percentage of variation in the stationary component of the price-rent ratio.

3 Data Description

We use quarterly data and our sample runs from 1975:Q1 through 2012:Q3. The data on house prices are from Freddie Mac. Rent data is the rent of primary residences from the BLS. Some researchers have used owner's equivalent rent of residences as a measure of rent, but the sample period of this series begins only in 1982. We convert the nominal rent growth and house price growth to real growth rates by deflating nominal rents and house prices by CPI of each MSAs and the nation. The quarterly data for CPI and the rent have been computed by taking the monthly averages. The monthly data are not available for all the MSAs in our sample, so we take the average of available month within the quarter to calculate the quarterly estimate. For example, if data for only January and March are available, we take the average of January and March for the first quarter. In a few MSAs, only semi-annual data were available in the initial sample period. In these cases, we use the same CPI and the rent level for two quarters. However, we do not need to make this approximation for most of the MSAs. Our MSA sample is based on data availability for rent from the BLS for our sample period. The growth rate is calculated as the quarterly change of the log level and is annualized. The mortgage rate is 30-year conventional rate and has been obtained from the FRED data base.

4 Empirical Results

As shown in the introduction of the paper, we find strong evidence in support of the presence of unit root in price-rent ratio. Our findings are not surprising as visual inspection of the price-rent ratios in the United States and the MSAs in Figure 1 shows that the ratio is extremely persistent in every case. To estimate the modified present-value model, we cast equations (2)-(8) into a state space form and apply Kalman filter to estimate the hyperparameters of the model.[10] The estimated hyperparameters are shown in tables 2-3. The unconditional mean of expected rent growth and expected housing return (γ_0 and δ_0) vary across different MSAs. For example, the mean of expected housing return in the United States is 6.6%, whereas it is 0.2% for the expected rent growth. It can be clearly seen that the mean of expected real rent growth is much smaller in magnitude than the expected housing return implying that in all the MSAs and the United States, rents have grown roughly at the same rate as the overall inflation. The results suggest that persistence parameter (AR coefficient δ_1) of expected housing return is much higher than the expected rent growth. The high persistence of expected housing return is similar to what researchers have found for expected financial asset returns in the finance literature.[11]

To take into account the high volatility in the housing market since 2006, we allow the variance-covariance matrix of the transition equations to have 2 regimes in our study: one for the pre-2006 sample period and the other for the 2006-2012 sample period. The results presented in Table 2 show the estimated standard deviations of expected rent growth (σ_{r^e}), expected housing return (σ_{h^e}) and the PVR component (σ_{pvr}). There are two main findings: within each time period, the standard deviation of shocks to the PVR component is much larger than the standard deviation of the expected housing return, which in turn is higher than the standard deviation of the expected rent growth. The smaller magnitude of the shocks to expected rent growth is not surprising since the rent series for all the MSAs and the United States do not exhibit huge variation. Secondly, we find that there are significant differences in the variances of these unobserved series across the two sample periods.

Our approach also allows us to estimate the correlation between state variables of the present-value model. The results are shown in Table 3. As discussed above, we estimate these correlations for both the pre-2006 and the 2006-2012 sample period. The results suggest that there is positive correlation ($\rho_{r^e h^e}$) between expected rent growth and expected housing return. This positive correlation is intuitive since a shock to expected housing return is also expected to lead to an increase in expected rent growth. This positive correlation between the rent growth and the housing return

[10] Measurement and transition equations for the state space model are provided in the Appendix.

[11] For example, Binsbergen and Koijen (2010), Fama and French (1988), Pastor and Stambaugh (2009) among others have also found expected return on stocks to be highly persistent.

is consistent with what other researchers have found for the stock market. For example, Bernanke and Kuttner (2005), Campbell and Ammer (1993) found that shocks to expected dividend growth and equity premia are positively correlated. The positive correlation between expected future rent growth and housing return that we document could simply indicate that rents do not increase by "enough" during periods of rising house price growth, which mechanically implies a contemporaneous increase in housing return. We find that the shock to expected housing return and shock to PVR component is highly positively correlated ($\rho_{r^e pvr}$) in the pre-2006 sample period, whereas this correlation declines significantly in the post-2006 sample period. Even though the correlation is more than 0.89 for all the MSAs and the United States, the degree of correlation is lowest for Atlanta, Chicago, Cleveland, Dallas, Houston and Philadelphia. These are also the MSAs where the PVR component is low as compared to the other MSAs. This positive correlation may imply that there is a positive shock to the PVR component, expected housing return may not increase by its 'full' amount right away. This is equivalent of saying that there is a slow adjustment of expected housing return in response to a shock to the PVR component.

One question that naturally arises is that what is the source of these shocks to the PVR component. Because we have motivated this component through the institutional, regulatory and macroeconomic changes, one could think of the shock to this residual term arising from some regulatory changes or through monetary policy actions which the past behavior of rent growth, housing return, and the price-rent ratio cannot predict. The historical evolution of the U.S. housing finance system is a clear example of regulatory change, the impact of which may not have been foreseen by the past price-rent ratios.

The high positive correlation between shocks to expected rent growth and shocks to the PVR component is not surprising since we also find positive $\rho_{r^e h^e}$ and $\rho_{r^e pvr}$. We find that the correlation between expected housing return and shocks to the PVR component declined significantly in the 2006-2012 sample period implying that expected housing return has become less sensitive to changes in the economy that could have affected the PVR component.

Because the present-value level of the price-rent ratio is stationary, we can perform a variance decomposition to examine the relative importance of rents and housing return in driving the price-rent ratio. Table 4 shows the results for this exercise for both the pre-2006 and the 2006-2012 sample period. We find that most of the variation in the present-value component is explained by expected changes in housing return. In fact, for all the MSAs as well as for the United States, the percentage of variation explained by expected rent growth is never higher than 2 percent. This is true for both sample periods. In fact, the share of expected housing return is higher than 100%. The negative share of the covariances dampen the overall variation in price-rent ratio. The share of the covariance between r^e and h^e is negative because the loading on expected housing return in equation (8) is negative. The results are consistent with Glaeser (2013) who argues that there are many similarities between the most recent boom and previous booms in the United States where rising prices reflected optimistic expectations.

Once the state space model is estimated using maximum likelihood via the Kalman filter, we can also examine the extent of deviation of the price-rent ratio from the level implied by the conventional present-value model. Figures 2 and 3 show the estimated deviation from the present-value level for the 18 MSAs and for the United States from the corresponding unobserved component models. The vertical axis represents the percentage deviation from the level of price-rent ratio implied by the present-value model. First, we find that there was a build up in the PVR component prior to 2006 and then a big decline that coincided with the housing market collapse. This result is uniform across all the MSAs. The magnitude of the increase and decline, however, varies across different MSAs. One the one hand,there are MSAs like Boston, Los Angeles, Miami, New York, Seattle and San Francisco where the PVR component was higher than 20% during the boom. At the same time, there are MSAs like Cleveland, Dallas, Houston and Pittsburgh where the deviation was very small and ranged from 3-10%. We also have MSAs like Atlanta, Chicago, Denver, Milwaukee, Minneapolis, Philadelphia, Portland and Saint Louis where the PVR component was somewhere in the middle. The estimated deviation is consistent with observed volatility in the housing market in these MSAs. Historically, housing market has not witnessed much volatility in MSAs like Atlanta, Cleveland, Chicago, Dallas, Denver, Houston as compared to the other MSAs in our sample. Not surprisingly, we find that at the national level, the PVR component is somewhere in the middle. At the height of the boom in housing market, the price-rent ratio in our model was 10-15% higher than the level implied by the present-value components. We should point out that a deviation of 10-15% is not akin to saying that housing market was overvalued by 10-15% at the height of the housing market boom. It should also be noted that the overvaluation may also arise from variation in the present-value component. What our results suggest is that a big portion of the overall variation in the price-rent ratio cannot be explained by the present-value model itself. In fact, Campbell et al. (2009) show that for the recent run-up in the housing market, the present-value model is not able to capture a big portion of the increase in price-rent ratio. Therefore, we need to modify the present-value model to allow for a deviation that takes into account the shocks that can have permanent impact on the level of price-rent ratio. It may be tempting to consider this residual term as reflecting some form of 'bubble' in the housing market, although this is not necessarily the case. Our paper is similar to the strand of literature in finance where the focus is on the empirical test of the present-value models and not necessarily on the existence of bubbles.

4.1 Deviations from the Present-Value Level and Mortgage Rates

Our method modifies the present-value model and allows us to estimate the deviation from the present-value level. In this section, we examine the relationship between interest rates and the PVR component. A significant amount of literature has suggested that a very accommodative stance of the monetary policy was responsible for the run-up in the housing prices (see Taylor (2007) among others). Taylor (2007) argues that monetary policy did play a significant role in the run-up of the house prices. One drawback of this argument is that there was a big variation in the increase in house prices across different MSAs and states. Therefore, easy monetary policy cannot be the single factor that can explain the housing market boom.

To explore the relationship between the housing market and interest rates, we examine whether the deviation component in our model is also related to the interest rates. This exercise is similar in flavor to Brunnermeier and Julliard (2008), who argue that inflation and nominal interest rates explain a larger share of mispricing in the housing market. They consider a behavioral approach to motivate the decomposition of the price-rent ratio into a rational component and a mispricing term and show that the mispricing term is highly correlated with nominal interest rate and inflation. They attribute this behavior to 'money illusion'. To examine the relationship between nominal interest rate and the PVR component, we run a simple OLS regression of the deviation component on 30-year nominal mortgage rate. There are two econometric issues in this regression that the readers should be aware of. First, there may be a "generated regressor' problem with the use of the estimated PVR component. Secondly, because this PVR component is non-stationary, we need the mortgage rate to be non-stationary for a cointegrating relationship to exist between these variables to avoid the problem of spurious regression. For our sample period, evidence clearly supports non-stationarity of the mortgage rate.

We examine the relationship for four sample periods: 1976-2012, 1976-2005, 1991-2005 and 2006-2012. In addition to the full sample period, we also break the sample in 1991 and 2006. Because our model is estimated on the basis of a break in 2006, we re-estimate the regression for this break. In addition, we also perform the analysis for 1991-2005 sample period. We choose this sample period because this was the period of the recent housing market boom and we want to investigate whether the relationship between interest rates and the PVR component was different during this period.

The results are presented in Table 5. Newey-West HAC P-values are in parenthesis. We find substantial variation in the estimates across different sample periods. However, except the last sample period (2006-2012), the sign on the coefficient is negative. This implies that a fall in mortgage rate is associated with an increase in the PVR component. For the full sample period, we find that the coefficient on mortgage rate is insignificant in half of the MSAs. However, for 1976-2005 sample period, the relationship between mortgage rate and the PVR component is significant. For example, the results suggest that a one percent decline in mortgage rate is associated with 0.3 percent increase in PVR component in the case of the United States. We also find insignificant relationship between these two variables for the last sample period and the sign of the coefficient is also counterintuitive. Smaller sample size may play a role in higher variances. The sample period 1991-2005 yields the most interesting results. As can be seen, there is a clear cut relationship between the magnitude of the deviation from the present-value model and its sensitivity to mortgage rate. The results suggest that MSAs which have the highest deviation from the present-value level are also the MSAs that are most sensitive to mortgage rate changes. On the one hand, a one percent decline in mortgage rate is associated with 7.6% increase in deviation from PV model in Miami. On the other hand, this estimate is only 0.8% for Dallas. The results presented here show that low interest rates may have played a role in the housing market boom after all, but only for those MSAs that were more sensitive to the changes in the interest rates. This result is consistent with the studies that document possibly divergent sensitivities of disaggregate housing markets to a monetary-policy shock.[12]

[12] See Carlino and Defina (1998), Fratantoni and Schuh (2003) among others.

5 Comparison with a Test of Explosive Bubbles and Date Stamping

In a recent paper, Phillips et al. (2011) have developed a recursive method for testing for explosive bubbles. The method involves the recursive implementation of a right-side unit root test and a sup test. Right sided unit root tests, as shown in Phillips et al. (2011), are informative about mildly explosive or submartingale behavior in the data. This procedure gives rise to a date stamping strategy which identifies points of origination and termination of a bubble. This test procedure is shown to have discriminatory power in detecting periodically collapsing bubbles, thereby overcoming a weakness in earlier applications of unit root tests for economic bubbles. The explosive behavior may reflect exuberation and herd behavior. Even though our paper does not make a claim about existence of bubbles in the price-rent ratio, it is an interesting exercise to compare the estimated PVR component with these bubble tests. In particular, we are interested in examining whether periods of big PVR components coincide with the periods of explosive bubbles according to a test. For this purpose, we perform the supADF test as explained in Phillips et al. (2011).[13] Table 6 reports the supADF statistic for all the MSAs, as well as for the United States. The results show that in 12 out of 19 cases, the supADF statistics exceed their respective 5% right-tail critical values giving strong evidence that price-rent ratio had explosive subperiods. The critical values are obtained from Monte Carlo simulation with 10,000 replications and sample size of 15. The smallest window size has 40 observations (10 years). The results clearly show that the MSAs that had high PVR components are also the cities that had exploding price-rent ratios. We find that MSAs like Dallas, Houston, Cleveland, and Pittsburgh that have small PVR components did not witness exploding price-rent ratios.

To locate specific bubble periods, we compare the backward supADF statistic sequence with a 90% SADF critical value sequence. The results are shown in Figures 4 and 5. The findings suggest that for most of the MSAs with a high PVR component, the explosive bubble period started around 2005:Q1 and terminated at the end of 2007. This is also the period when the PVR component was highest for these MSAs. For Boston, however, the SADF test shows that the explosive bubble was in

[13] For very large sample size, Phillips et al. (2013) develop a generalized SADF test to test for multiple bubbles. Our study only has 37 years of data and therefore, we ended up using the SADF test.

the late 1980s. This is also consistent with the boom and the bust of the housing market in Boston in the late 1980s and the early 1990s. We also find that for New York City, Philadelphia and the U.S., there were two periods of explosive sub-periods. In addition to the explosive subperiod in 2005-2007, there was also an explosive sub-period in the 1980s. Not surprisingly, we find that Chicago, Cleveland, Dallas, Houston and Pittsburgh do not have the explosive sub-periods according to this recursive SADF test. Overall, the results from the SADF tests and our model seem to indicate that the MSAs that had large PVR components are also the MSAs that witnessed explosive sub-periods in their price-rent ratios, especially during the 2005-2007 sample period.

6 Concluding Remarks

In this paper, we have proposed a modified present-value model that decomposes the price-rent ratio into expected real rent growth, expected housing return, and a residual term that represents the deviation of the price-rent ratio from its conventional present-value level. This residual term takes into account the fact that price-rent ratio at the national and the MSA levels is non-stationary, whereas the conventional present-value model approach assumes that this ratio is stationary. To estimate this modified present-value model, we use the unobserved component approach. We treat expected rent growth, expected real interest rates, expected housing premia, and the residual as unobserved variables that follow exogenously-specified time series processes.

Our findings suggest that the residual term representing the deviation of the price-rent ratio from its present-value model is important both at the national and the regional levels. This is especially true for the MSAs that have experienced frequent booms and busts in the housing market. We also find that the MSAs that display larger deviations from the present-value model are more sensitive to mortgage rate changes. Our approach also allows us to estimate the correlation between expected rent growth, expected housing return and the deviation component. We find that a shock to the expected housing return and a shock to the residual term are highly positively correlated in the pre-2006 sample period. We also find positive correlation between expected rent growth and the expected housing return. We perform a variance decomposition of the stationary present-value components. The results show that most of the variation in the present-value level of the price-rent ratio arises due to the variation in the expected housing return.

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Appendix

State Space Representation of the Present-Value Model

Equations (2-8) can be represented in a state-space form. The measurement equation can be written as:

$$\begin{bmatrix} \triangle r_t \\ h_t \\ p_t - r_t \end{bmatrix} = \begin{bmatrix} \gamma_0 \\ \delta_0 \\ A \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ B_1 & -B_2 & 1 \end{bmatrix} \left[\begin{bmatrix} \widehat{\triangle r_t^e} \\ \widehat{h_t^e} \\ pvr_t \end{bmatrix} \right] + \begin{bmatrix} \varepsilon_t^r \\ \varepsilon_t^h \\ 0 \end{bmatrix}$$

Transition equation is represented as:

$$\begin{bmatrix} \widehat{\triangle r_t^e} \\ \widehat{h_t^e} \\ pvr_t \end{bmatrix} = \begin{bmatrix} \gamma_1 & 0 & 0 \\ 0 & \delta_1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \widehat{\triangle r_{t-1}^e} \\ \widehat{h_{t-1}^e} \\ pvr_{t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_t^{r^e} \\ \varepsilon_t^{h^e} \\ \varepsilon_t^{pvr} \end{bmatrix}$$

Variance-Covariance matrix of the transition equation errors are:

$$Q = var \begin{bmatrix} \varepsilon_t^{r^e} \\ \varepsilon_t^{h^e} \\ \varepsilon_t^{pvr} \end{bmatrix} = \begin{bmatrix} \sigma_{r^e}^2 & \sigma_{r^e h^e} & \sigma_{r^e pvr} \\ \sigma_{r^e h^e} & \sigma_{h^e}^2 & \sigma_{h^e pvr} \\ \sigma_{r^e pvr} & \sigma_{h^e pvr} & \sigma_{pvr}^2 \end{bmatrix}$$

Variance-Covariance matrix of the measurement equation errors are:

$$R = var \begin{bmatrix} \varepsilon_t^r \\ \varepsilon_t^h \end{bmatrix} = \begin{bmatrix} \sigma_r^2 & \sigma_{rh} \\ \sigma_{rh} & \sigma_h^2 \end{bmatrix}$$

In our model, we allow the variance-covariance matrix to have two regimes: one for the 1975-2005 sample period and the other for the 2006-2012 sample period.

Table 1: Unit Root Test

City	Ng-Perron MZa Statistic	10% critical value
USA	-3.40	-5.70
Atlanta	-5.59	-5.70
Boston	-0.75	-5.70
Chicago	-2.66	-5.70
Cleveland	-2.51	-5.70
Dallas	-2.98	-5.70
Denver	-1.79	-5.60
Houston	-3.03	-5.70
Los Angeles	-1.62	-5.70
Miami	-4.03	-5.70
Milwaukee	-2.77	-5.70
Minneapolis	-3.54	-5.70
New York	-1.00	-5.70
Philadelphia	-2.91	-5.70
Pittsburgh	-4.36	-5.70
Portland	-0.67	-5.70
San Francisco	-1.28	-5.70
Seattle	-0.44	-5.70
St. Louis	-3.40	-5.70

Null hypothesis implies unit root. The test equation includes a constant. The results do not change if we use other unit root tests.

Table 2: Parameter Estimates

	Pre-2006									Post-2006
	σ_{r^e}	σ_{h^e}	σ_{pvr}	γ_0	γ_1	δ_0	δ_1	σ_{r^e}	σ_{h^e}	σ_{pvr}
USA	0.003	0.009	0.045	0.002	0.383	0.066	0.798	0.000	0.008	0.000
Atlanta	0.007	0.014	0.082	-0.003	0.763	0.053	0.821	0.003	0.019	0.107
Boston	0.008	0.011	0.160	0.001	0.420	0.042	0.939	0.006	0.001	0.011
Chicago	0.009	0.013	0.080	0.001	0.588	0.048	0.840	0.006	0.007	0.074
Cleveland	0.010	0.017	0.109	-0.002	0.663	0.050	0.828	0.009	0.009	0.067
Dallas	0.009	0.018	0.094	0.000	0.557	0.056	0.817	0.011	0.008	0.020
Denver	0.004	0.011	0.084	0.000	0.638	0.045	0.871	0.000	0.008	0.013
Houston	0.015	0.019	0.170	0.001	0.660	0.060	0.902	0.000	0.007	0.004
Los Angeles	0.006	0.013	0.075	0.002	0.359	0.039	0.831	0.010	0.013	0.034
Miami	0.003	0.021	0.185	0.000	0.823	0.079	0.898	0.001	0.009	0.043
Milwaukee	0.006	0.019	0.133	-0.001	0.514	0.050	0.854	0.004	0.006	0.013
Minneapolis	0.005	0.014	0.086	0.000	0.400	0.054	0.834	0.005	0.010	0.023
New York	0.004	0.013	0.124	0.001	0.284	0.043	0.899	0.005	0.004	0.012
Philadelphia	0.007	0.011	0.065	0.001	0.488	0.056	0.837	0.006	0.007	0.015
Pittsburgh	0.005	0.015	0.101	-0.001	0.568	0.049	0.851	0.004	0.005	0.012
Portland	0.005	0.018	0.109	0.000	0.415	0.041	0.827	0.004	0.008	0.108
Seattle	0.004	0.014	0.136	0.000	0.533	0.040	0.893	0.004	0.006	0.131
San Francisco	0.011	0.016	0.151	0.002	0.624	0.036	0.905	0.001	0.009	0.016

r^e and h^e refer to expected real rent growth, and expected housing return and pvr is the deviation from the present-value components. γ_0 and δ_0 are the constants in autoregressive process for expected rent growth, real interest rate and housing premia, whereas γ_1 and δ_1 refer to the estimated AR(1) coefficients.

Table 3: Correlation Estimates

	Pre-2006			Post-2006		
	$\rho_{r^e h^e}$	$\rho_{r^e pvr}$	$\rho_{h^e pvr}$	$\rho_{r^e h^e}$	$\rho_{r^e pvr}$	$\rho_{h^e pvr}$
USA	0.612	0.469	0.986	0.991	-0.852	-0.007
Atlanta	0.344	-0.120	0.891	0.992	-0.226	-0.295
Boston	0.003	-0.169	0.985	0.998	-0.067	0.000
Chicago	0.449	0.102	0.935	0.610	0.225	0.842
Cleveland	0.169	-0.223	0.923	0.633	-0.301	0.338
Dallas	0.632	0.403	0.964	0.992	-0.993	-0.208
Denver	0.243	0.051	0.981	-0.992	-0.959	0.153
Houston	0.306	-0.045	0.937	-0.993	-0.521	0.013
Los Angeles	0.589	0.411	0.979	0.991	-0.997	-0.448
Miami	-0.066	-0.182	0.993	-0.992	-0.988	0.232
Milwaukee	0.346	0.218	0.991	0.713	-0.905	-0.033
Minneapolis	0.460	0.317	0.988	0.993	-0.998	-0.268
New York	0.410	0.323	0.996	0.574	-0.912	-0.019
Philadelphia	0.563	0.298	0.957	0.996	-0.999	-0.229
Pittsburgh	0.318	0.163	0.987	0.671	-0.961	-0.054
Portland	0.487	0.373	0.992	-0.262	-0.352	0.993
Seattle	0.074	-0.029	0.995	-0.229	-0.359	0.953
San Francisco	0.464	0.216	0.965	-0.992	0.025	-0.002
St. Louis	0.510	0.367	0.987	0.999	-0.996	-0.215

r^e and h^erefer to expected real rent growth, and expected housing return and pvr is the deviation from the present-value components.
$\rho_{r^e h^e}$ is the correlation between expected rent growth and expected housing return

Table 4: Variance Decomposition of the Present-Value Components

	Pre-2006			Post-2006		
	Var(r^e)	Var(h^e)	cov(r^e,h^e)	Var(r^e)	Var(h^e)	cov(r^e,h^e)
USA	0.005	1.069	-0.074	0.000	1.016	-0.016
Atlanta	0.021	1.026	-0.047	0.052	0.644	0.304
Boston	0.001	0.999	0.000	0.061	1.219	-0.279
Chicago	0.037	1.122	-0.159	0.080	1.255	-0.335
Cleveland	0.061	1.017	-0.078	0.221	1.445	-0.666
Dallas	0.005	1.062	-0.067	0.051	0.672	0.277
Denver	0.011	1.033	-0.043	0.000	1.000	0.000
Houston	0.025	1.055	-0.080	0.000	1.000	0.000
Los Angeles	0.006	1.064	-0.070	0.018	1.201	-0.220
Miami	0.007	0.983	0.010	0.004	0.880	0.116
Milwaukee	0.004	1.030	-0.034	0.017	1.142	-0.160
Minneapolis	0.005	1.045	-0.050	0.010	1.152	-0.162
New York	0.000	1.009	-0.009	0.010	1.056	-0.065
Philadelphia	0.018	1.111	-0.129	0.053	1.384	-0.437
Pittsburgh	0.006	1.037	-0.044	0.055	1.238	-0.294
Portland	0.003	1.040	-0.043	0.008	0.958	0.035
Seattle	0.002	1.003	-0.004	0.009	0.961	0.031
San Francisco	0.012	1.069	-0.082	0.000	0.975	0.025
St. Louis	0.005	1.053	-0.058	0.031	1.286	-0.317

This table presents the variance decomposition of the present-value components of the price-rent ratio. Var(r^e) represents the share explained by expected rent growth and Var(h^e) shows the share explained by expected housing return

Table 5: Relationship Between the Deviation of the Price-Rent Ratio from its Present-Value Level and the Mortgage Rate

	1976:02-2012:03	1976:02-2005:04	1991:01-2005:04	2006:01-2012:03
USA	-0.001 (0.38)	-0.003 (0.08)	-0.026 (0.00)	0.029 (0.00)
Atlanta	0.002 (0.28)	-0.002 (0.14)	-0.017(0.00)	0.039 (0.02)
Boston	-0.002 (0.76)	-0.005 (0.37)	-0.052 (0.00)	0.004 (0.11)
Chicago	-0.003 (0.24)	-0.009 (0.00)	-0.019 (0.00)	0.044 (0.00)
Cleveland	-0.002 (0.38)	-0.008 (0.00)	-0.003 (0.05)	0.013 (0.19)
Dallas	0.003 (0.00)	0.004 (0.00)	-0.008 (0.00)	0.006 (0.42)
Denver	-0.005 (0.00)	-0.007 (0.00)	-0.016 (0.00)	-0.005 (0.46)
Houston	0.005 (0.80)	0.002 (0.30)	-0.010 (0.00)	0.007 (0.61)
LA	-0.006 (0.02)	-0.009 (0.00)	-0.053 (0.00)	0.020 (0.26)
Miami	-0.001 (0.86)	-0.007 (0.22)	-0.076 (0.00)	-0.014 (0.75)
Milwaukee	-0.008 (0.00)	-0.012 (0.00)	-0.031 (0.00)	0.032 (0.00)
Minneapolis	-0.005 (0.01)	-0.008 (0.00)	-0.037 (0.00)	0.024 (0.00)
New York	-0.004 (0.17)	-0.008 (0.02)	-0.048 (0.00)	0.024 (0.00)
Philadelphia	-0.005 (0.00)	-0.007 (0.00)	-0.031 (0.00)	0.023 (0.00)
Pittsburgh	-0.006 (0.00)	-0.008 (0.00)	-0.009 (0.00)	0.001 (0.93)
Portland	-0.012 (0.00)	-0.014 (0.00)	-0.029 (0.00)	0.035 (0.01)
Seattle	-0.011 (0.00)	-0.016 (0.00)	-0.037 (0.00)	0.036 (0.12)
San Francisco	-0.006 (0.11)	-0.013 (0.00)	-0.056 (0.00)	0.007 (0.72)
St. Louis	-0.005 (0.00)	-0.008 (0.00)	-0.022 (0.00)	0.029 (0.00)

This table presents the results for OLS regression of the *pvr* component as a percentage of price-rent ratio on nominal mortgage rate. The entries are coefficients on the mortgage rate. Newey-West P-values are in parentheses.

Table 6: The SADF Test of the Price-Rent Ratio

City	SADF	90% cv	95% cv	99% cv
USA	1.63	0.90	1.23	1.83
Atlanta	1.26	0.90	1.23	1.83
Boston	3.70	0.90	1.23	1.83
Chicago	0.24	0.90	1.23	1.83
Cleveland	0.36	0.90	1.23	1.83
Dallas	0.29	0.90	1.23	1.83
Denver	0.10	0.90	1.23	1.83
Houston	0.22	0.90	1.23	1.83
Los Angeles	1.79	0.90	1.23	1.83
Miami	1.77	0.90	1.23	1.83
Milwaukee	1.10	0.90	1.23	1.83
Minneapolis	3.73	0.90	1.23	1.83
New York	5.34	0.90	1.23	1.83
Philadelphia	2.85	0.90	1.23	1.83
Pittsburgh	-0.48	0.90	1.23	1.83
Portland	2.37	0.90	1.23	1.83
San Francisco	1.90	0.90	1.23	1.83
Seattle	1.42	0.90	1.23	1.83
St. Louis	1.36	0.90	1.23	1.83

Critical Values are obtained from Monte Carlo Simulation with 10,000 replications with sample size of 151. The smallest window size has 40 observations.

Figure 1: Price-Rent Ratio

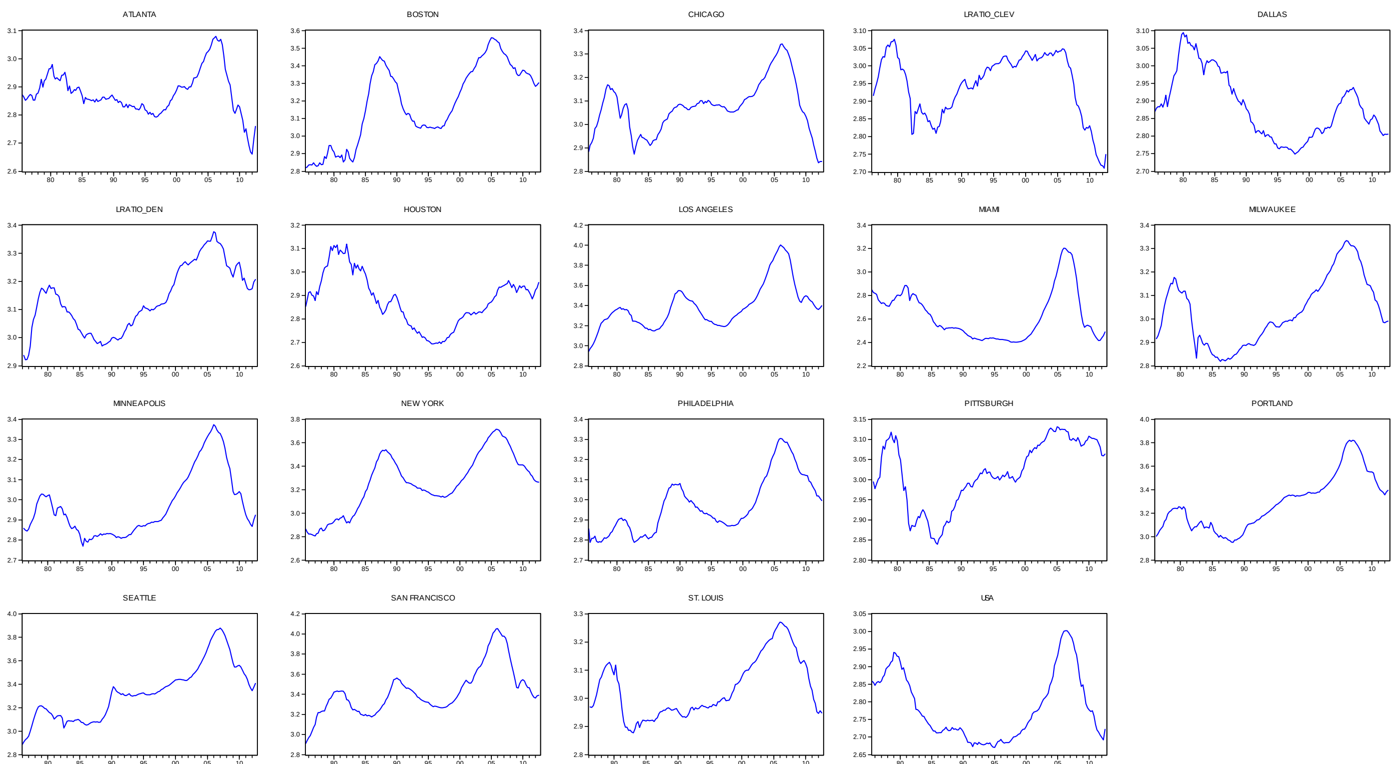

Figure 2: Deviation from Present-Value Components

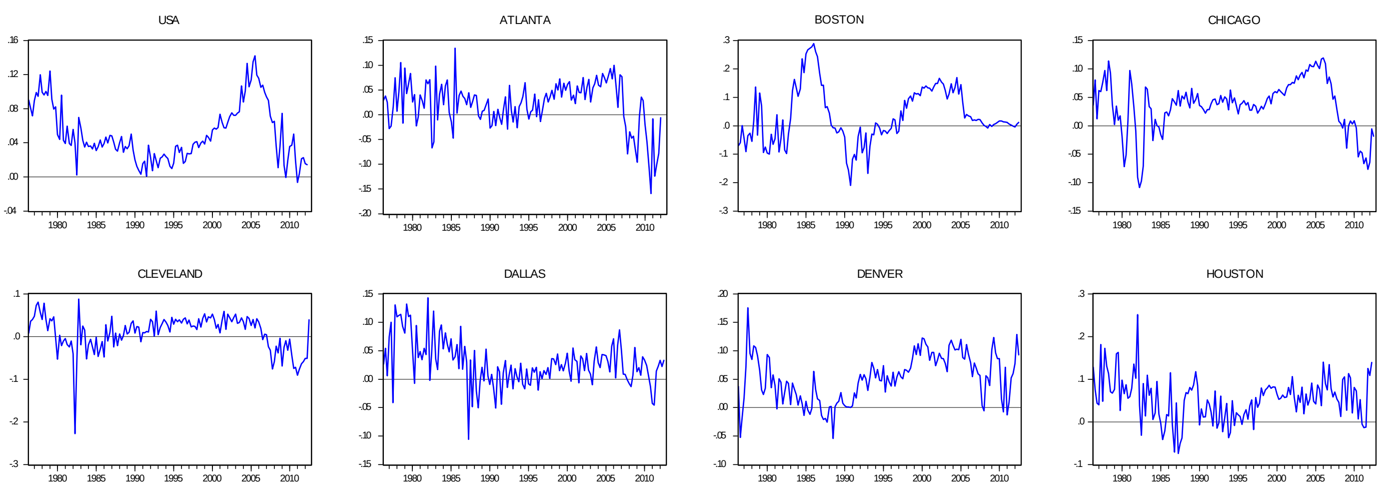

Figure 3: Deviation from Present-Value Components

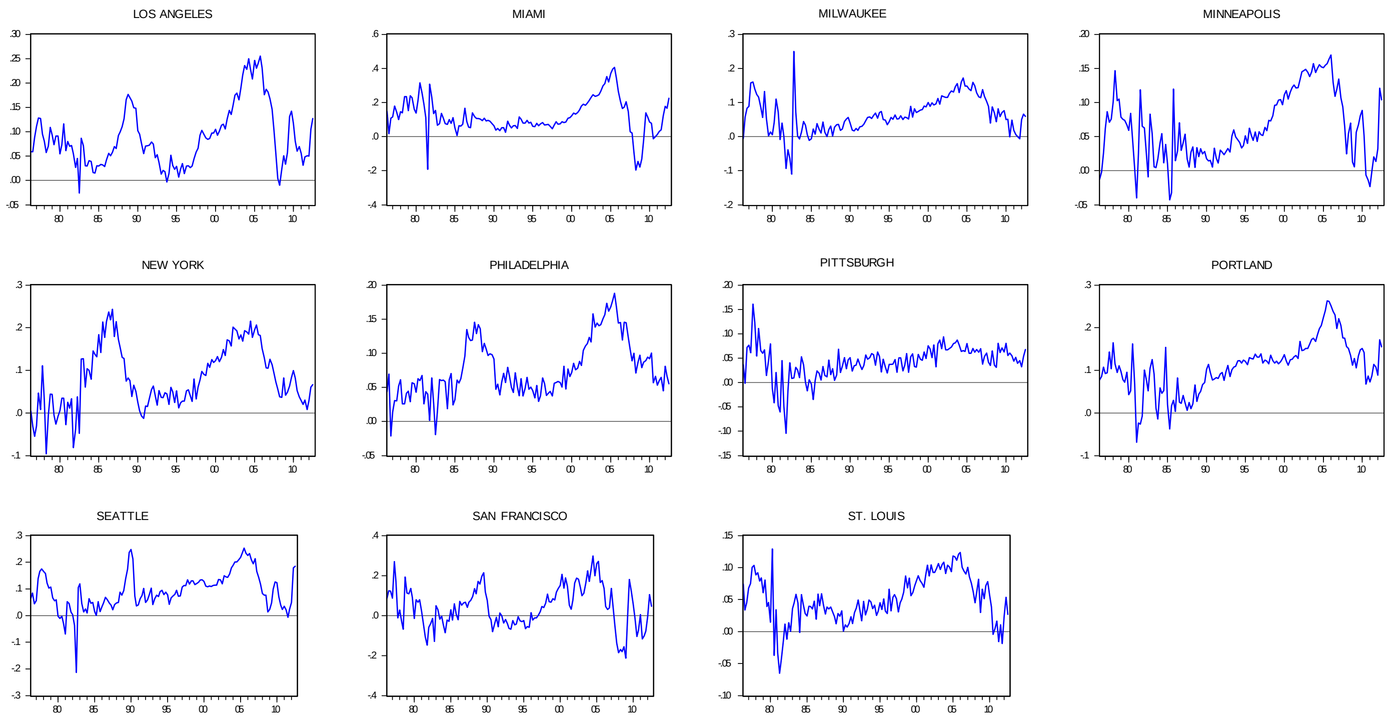

Figure 4: Date-stamping Bubble Periods in the Price-Rent Ratio using the SADF Procedure

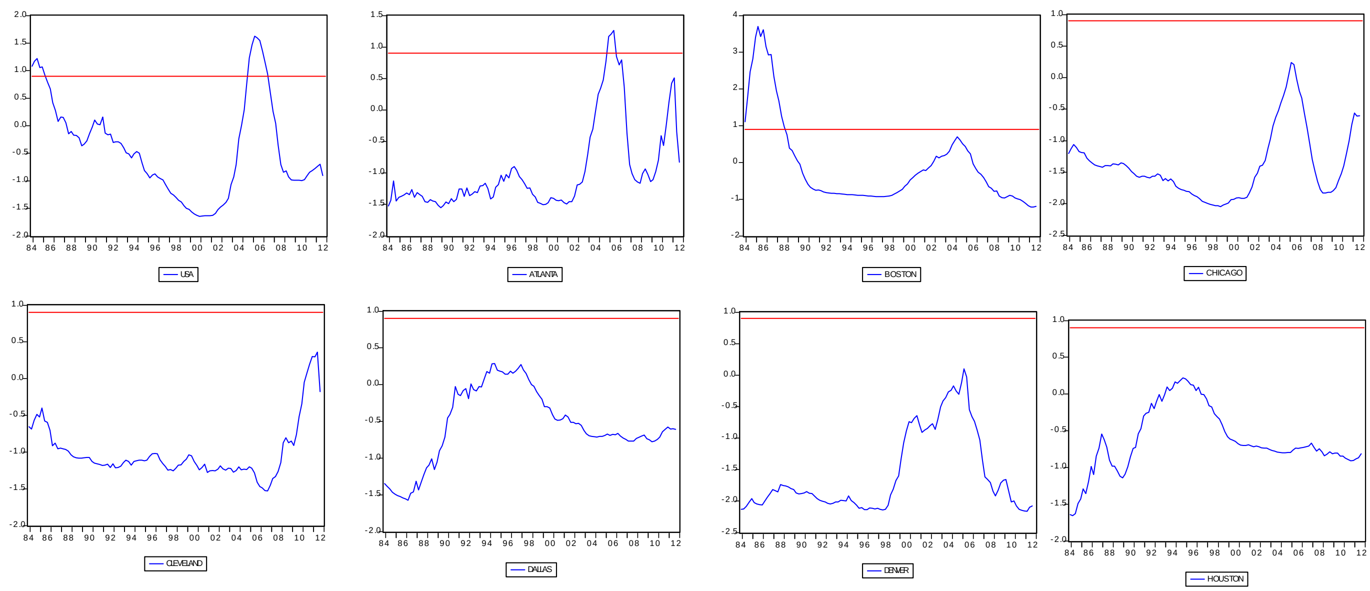

Figure 5: Date-stamping Bubble Periods in the Price-Rent Ratio using the SADF Procedure