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Bubbles in US Regional House Prices: Evidence from House Price/Income Ratios at the State Level

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Abstract

We investigate the presence of bubbles in the US house price-income ratio at the state level by applying the right-tailed unit root test of Phillips, Shi and Yu (2015, PSY) to data from January 1975 to December 2014. Based on a model specification with an intercept, we can identify 'collapse' episodes, 'collapse and recovery' episodes in addition to bubbles. The absence of an intercept in the null leads to identification of only potential bubbles. We find evidence of bubbles in several states in the 1980s (such as California, Hawaii, Massachusetts and New York), which coincides with some existing studies that investigate housing bubbles or booms and busts using a range of alternative approaches. Our results show the existence of a housing bubble that originates in the early 2000s and collapses in the mid-2000s in more than 20 States and the DC. We conclude that this housing bubble was localized and not a national phenomenon and that the bubbles of the 2000s were more widespread than the 1980s. We also found that the exclusion of an intercept in the unit root null hypothesis will affect the asymptotic theory and date-stamping outcomes for the PSY approach which translates empirically to evidence of 'no exuberance' in several of the states' house prices which otherwise would have suggested bubbles.

Keywords

bubbles
generalized sup ADF test
US regional house prices
house price-income ratio

JEL Classifications

C59; R19; R39

'We don't perceive that there is a national bubble,
but it's hard not to see that there are a lot of local bubbles'.
(Alan Greenspan, Economic Club of New York, 2005)

1. Introduction

The United States seems to have a long history of real estate speculation (Glaeser, 2013). The purpose of this paper is to investigate evidence of exuberance by comparing house price changes with changes in income, and whether the outcomes are generic, localized or create regionally constrained spillovers? To consider such questions we will utilize the recently developed bubble detection and date-stamping approach of Phillips, Shi & Yu (2015, PSY). We will add to this approach by considering evidence based on their right-tailed unit root tests both with an without and intercept in the null hypothesis. By making use of the PSY approach, we are able to identify points (in time and space) related to the origination and termination of any bubble event.

Our empirical study focuses on the 1980s and the early 2000s and has three main aims and contributions where it differs from existing studies in several respects. First, a major focus is to examine the econometric evidence for housing bubble(s) during the 1980s with particular emphasis on the States of California, Hawaii, Massachusetts and New York. Several other studies for example, Case & Shiller (1988), Case & Shiller (1994), Case & Shiller (2003), Wheelock et al. (2006) consider US house price booms and busts or bubbles during the 1980s, however, most of these studies describe or graphically inspect some house price measure (e.g., house price, price-income ratio or price-rent ratio) without applying any econometric tests. Thus our paper fills the gap by providing empirical test-based evidence of housing bubbles during the 1980s. Second, more recently, much attention has been paid to the rapid increase in US house prices in the 2000s see for example, Del Negro & Otrok (2007), Goodman & Thibodeau (2008), Shiller (2008), Wheaton & Nechayev (2008), Mayer (2011). A number of States/areas experienced a dramatic boom during the 2000s and thus there is an increasing interest in testing for evidence of housing bubbles during this period using a range of approaches. Del Negro & Otrok (2007) see this recent rapid increase as a national phenomenon, however, Greenspan disagreed stating that: "we don't perceive that there is a national bubble, but it's hard not to see that there are a lot of local bubbles" in 2005. Martin (2011) also concluded that the 2000s US housing bubble was not a national phenomenon. Our second aim will therefore consider whether there is evidence of a national or several local (disconnected) bubbles (or no bubbles at all) at the regional level in the US during the early-mid 2000s. To anticipate, we find evidence of a housing bubble that originates in the early 2000s and collapses in the mid-2000s in more than 20 States and the District of Columbia in our study. Our results show the bubble of the 2000s is not a national phenomenon, but is more widespread than the 1980s. This is perhaps the first empirical study to make a comparison in terms of their magnitude and coverage between the regional housing bubbles in the 1980s with the recent regional bubbles in the 2000s, which also contributes to the novelty of this paper. Third, we also use the US State-level house price-income ratio data to study the importance of model formulation highlighted in Phillips, Shi & Yu (2014) by exploring the role of the intercept in the right-tailed unit root tests of Phillips, Shi & Yu (2015). Based upon the model specification with an intercept, we can identify collapse episode, collapse and recovery episode and the potential bubbles. Whereas without an intercept in the null leads to identification of only potential bubbles (if they exist). An important finding in the unit root null hypothesis without the intercept is that several States do not exhibit any bubble-like behaviors for the whole sample period.

The paper is organised as follows. Section 2 reviews some existing studies on US house price bubbles. Section 3 provides a brief description of the GSADF and SADF tests of Phillips, Shi & Yu (2015) and Phillips, Wu & Yu (2011) and Section 4 describes the data. Section 5 provides empirical results for all the 50 States and the District of Columbia and Section 6 concludes.

2. Literature Review

A large number of studies have tested for the existence of house price bubbles in the US. A house price bubble is defined as a situation when a growth of the price is not supported by changes in its fundamentals e.g., Stiglitz (1990). A 'fundamental' in empirical studies of the housing market is often assumed to be either a rental cost-house price ratio, where the logic is that the rent represents the stream of future income from the housing asset, or a personal income-house price ratio, where the idea is that in the long run house prices cannot exceed the ability to purchase the property or service the debt in the process. These two types of ratio lend themselves to what have become some of the most common forms of analysis of whether house prices deviate from 'fundamentals', which are based on tests for cointegration between the numerator and denominator series. For example, Malpezzi (1999) rejected the null hypothesis of no cointegration between house prices and income in US Metropolitan areas concluding there was no evidence of bubbles. McCarthy & Peach (2004) found little evidence of a bubble in US home prices where in their view the run-up in house values was largely attributable to market fundamentals. This conclusion is similar to Himmelberg et al. (2005), who also find little evidence of housing bubbles. Gallin (2006) provides an excellent example of tests of the relationship between house prices and income in US where using 27 years of US national-level data and finds no evidence of cointegration. As standard cointegration tests are known to have low power in small samples, Gallin (2006) applied several panel cointegration tests to a panel of 95 US Metropolitan areas over a 23 year period and also found no evidence of cointegration. In both cases, a finding of no cointegration relationship suggests evidence of bubbles. Zhou & Sornette (2006) investigated the existence of US housing bubbles at the regional and State levels using quarterly data, 1993-2005 where instead of tests for "market fundamentals" they define a bubble as a 'faster-than-exponential price growth'. They concluded that 22 States exhibited evidence of a fast-growing bubble. Mikhed

& Zemčík (2009) also used a panel test for the price-rent ratio in 23 US Metropolitan areas for the period 1978-2006 and concluded that there was evidence of a bubble. Holly et al. (2010) used Moon & Perron (2004) and Pesaran (2007) panel tests to consider the relationship between real house prices and real per capita disposable incomes in the US at the State level using annual data 1975-2003 and found little evidence of house price bubbles with a few exceptions (e.g., California, New York, Massachusetts, Connecticut, Rhode Island, Oregon and Washington). Zhou (2010) adopted a two-step testing procedure to determine whether house prices and fundamentals are linearly/nonlinearly cointegrated at both the national and city level (i.e., Boston, Chicago, Cleveland, Dallas, Los Angeles, New York, Philadelphia, Richmond, Seattle and St.Louis). Zhou (2010) could not find evidence of cointegration in three cities only (Boston, Los Angeles and New York) and such a finding could be interpreted as evidence of bubbles. Empirical results from Kivedal (2013) suggest that there was a bubble in the US housing market prior to the 2007 subprime financial crisis. Nneji et al. (2013) examined the presence of intrinsic bubbles of a Froot & Obstfeld (1991) type [1] or rational speculative bubbles of a Blanchard & Watson (1982) type in the residential property market in the US between 1960 and 2011. They split the data into two periods (1960-1999) and (2000-2011) and found an intrinsic bubble for the first period and a rational speculative bubble for the second period only. Escobari et al. (2015) proposed a new test to identify house price bubbles, which explored a specific feature of the market such that low tier house prices should appreciate more during the upswing of a growing boom and fall faster during the bust, and found evidence of bubbles in 15 US Metropolitan Statistical Areas. It should be noted, however, that the methodology developed by Escobari et al. (2015) does not consider "market fundamentals" in assessing house price bubbles.

More recently, a series of papers adopt either the SADF test of Phillips, Wu & Yu (2011, PWY) or the GSADF test of Phillips, Shi & Yu (2015, PSY) to examine the presence of bubbles in housing markets. Phillips & Yu (2011) investigated a rental-adjusted house price series (the S&P Case-Shiller Composite-10 index divided by the rental measure) using data from January 1990 to January 2009 and found a significant bubble for the period May 2002-December 2007. Homm & Breitung (2012) confirmed the existence of a bubble in the US Case-Shiller home price index (January 1987-March 2006), the UK house price index (January 1991 to October 2007) and the Spanish house price index (1987Q1-2007Q1) based on the PWY testing procedure. The existence of Chinese house price bubbles has become an issue of great concern in international real estate markets and Chen & Funke (2013) apply the PWY and PSY approaches to the Chinese nationwide house price-to-rent ratio to explore the possibility of bubbles in this market from 2003Q1 to 2011Q4 and find weak evidence of house price bubbles. Greenaway-McGrevy & Phillips (2015) utilised the PSY approach to investigate the presence

[1] Intrinsic bubbles are driven solely by fundamentals (Froot & Obstfeld, 1991).

of housing bubbles in New Zealand using quarterly house prices from 1993-2014 and concluded that there was evidence of a housing bubble that began in 2003 and collapsed mid-2007 to early 2008. Pavlidis et al. (2015) applied the PWY and PSY approaches to examine the explosive behavior of three house price indicators (real house price, price-rent ratio and price-income ratio) for a lager set of countries including the US and found significant periods of exuberance in most countries. Pavlidis et al. (2015) also developed a panel version of GSADF test to draw general conclusions about international housing markets. Shi et al. (2015) used the PSY testing algorithm to examine the presence of bubbles in the house price-rent ratio in Australian capital cities and found evidence of bubbles in several capital cities.

3. Method

Phillips, Wu & Yu (2011) develop a sup ADF (SADF) procedure that can test for evidence of price exuberance and date stamp its origination and collapse. Such a test procedure makes use of a right-tailed unit root and a sup test in a recursive way. One highlight of this new approach is the ability to capture explosive behavior and even the periodically collapsing bubbles of Evans (1991).

The SADF test is recursively applied to the sample data and is implemented as follows. For each time series x_t, we apply the Augmented Dickey-Fuller (ADF) test for a unit root against the alternative of an explosive root (right-tailed). The following autoregressive specification for x_t is estimated by least squares:

$$x_t = \mu_x + \delta x_{t-1} + \sum_{j=1}^{J} \phi_j \Delta x_{t-j} + \varepsilon_{x,t}, \qquad \varepsilon_{x,t} \sim \mathrm{NID}(0, \sigma_x^2), \tag{1}$$

for some given value of the lag parameter J, where NID denotes independent and normally distributed. The null hypothesis of this test is $H_0 : \delta = 1$ and the alternative hypothesis is $H_1 : \delta > 1$. Equation (1) is estimated repeatedly using subsets of the sample data incremented by one additional observation at each pass in the forward recursive regression. Thus the SADF test is constructed by repeatedly estimating the ADF test. Let r_w be the window size of the regression. The window size r_w expands from r_0 to 1, where r_0 is the smallest sample window width fraction and 1 is the largest window fraction (the full sample). The starting point r_1 is fixed at 0, and the end point of each sample (r_2) equals r_w and changes from r_0 to 1. The ADF statistic for a sample that runs from 0 to r_2 is therefore denoted by $ADF_0^{r_2}$. The SADF statistic is defined as the sup value of the ADF statistic sequence:

$$SADF(r_0) = \sup_{r_2 \in [r_0, 1]} ADF_0^{r_2}$$

Unlike the SADF test, the GSADF test is extended by using a more flexible window size. The end point r_2 varies from r_0 (the minimum window size) to 1. The start point r_1 is also allowed to vary from 0 to $r_2 - r_0$. The GSADF statistic is the largest ADF statistic over range of r_1 and r_2. The key difference between the SADF and GSADF is the window size of starting point r_1. The GSADF statistic is therefore defined as:

$$GSADF(r_0) = \sup_{\substack{r_2 \in [r_0, 1] \\ r_1 \in [0, r_2 - r_0]}} ADF_{r_1}^{r_2}$$

Previous applications (e.g., exchange rate market, stock market, housing market and commodity market) of the approach have followed PSY's suggestion to include an intercept in the right-tailed unit root test. As a result, many empirical papers have reported rejections of the null suggesting periods of rapid increase in for example prices or exchange rates associated with a growing bubble, when in fact the data identifies a 'collapse' or a 'collapse and recovery' phase and not a bubble (e.g., Chen et al. (2015), Jiang et al. (2015), Zhao et al. (2015)). Visual inspection can usually resolve these cases, although it also seems that false (positive) bubbles also seem to be reported when an intercept is included. An example of 'collapse episode' and 'collapse and recovery episode' can be seen in Figure 1 below. The backward SADF statistic (blue line) and its 95% critical value (red line) for Figure 1a suggests a number of 'bubbles' as the test statistic exceeds the relevant critical value. However, the plot of the actual data (green line) shows that the data is continuously declining (a collapse period and not a series of bubbles). Figure 1b presents data and test results consistent that relate to a 'collapse and recovery' episode and a genuine 'bubble'. The plot of the actual data makes the classification of these different episodes clear and highlight why the actual data and the test statistic (and relevant critical values) need to be presented on the same graph. Previous empirical studies have either ignored such cases or if they have mentioned them they have provided no explanation of the possible reason for the false test positives. Some empirical papers even obfuscate this issue by plotting only the backward SADF statistic with the 95% critical value sequences and provide no plot of the actual data series in the date-stamping strategy graph. In this paper, we use two different model specifications for the null hypothesis in the right-tailed unit root tests (a model without an intercept [2] as in Equation (2) and a model with an intercept in Equation (3)) to explore the evidence of bubbles and compare the results obtained from both formulations. We will demonstrate and compare the bubble detection results using the aforementioned model specifications. The model specification is explained as follows. A fixed lag order of 3 is used in both formulations. In PWY of Phillips, Wu & Yu (2011), the null hypothesis is:

$$H_{01} : y_t = y_{t+1} + \varepsilon_t, \qquad \varepsilon_{x,t} \sim \text{NID}(0, \sigma^2). \tag{2}$$

[2] When an intercept is excluded, the procedure detects only 'bubbles'.

(a) Collapse episode (b) Collapse and recovery episode and bubble

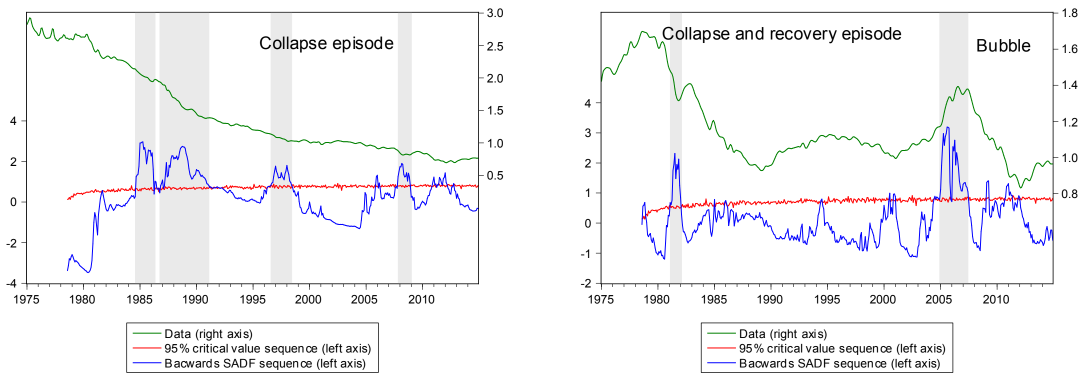


Figure 1: Examples of collapse episode, collapse and recovery episode and bubble.

The second specification for the null is obtained from Diba & Grossman (1988):

$$H_{02} : y_t = \alpha + y_{t+1} + \varepsilon_t, \qquad \text{where } \alpha \text{ is the constant.} \tag{3}$$

4. Data

As US regional housing markets could behave quite differently, we focus here on State level data rather than national data. The monthly Freddie Mac State house price index provides a measure of house price inflation for the US in 50 State indexes and the District of Columbia (DC). All series used are from January 1975 to December 2014 (December 2000=100). Quarterly State personal income for 50 States and the District of Columbia are obtained from the U.S. Bureau of Economic Analysis (BEA). Due to data frequency availability, we use the commonly adopted Chow & Lin (1971) GLS procedure to interpolate the quarterly personal income series to create a monthly series [3]. All monthly personal income series have been rebased to December 2000. We are then able to calculate a house price-income ratio for all States as well as the District of Columbia.

5. Results

We divide our results into several parts. Section 5.1 provides an overview of the bubble detection results for all the States and the District of Columbia. The results for several key States are then

[3] A number of researchers have applied the Chow & Lin (1971) GLS procedure that can provide the best linear unbiased interpolations in house prices or property markets (see, Kenny (1999), Meese & Wallace (2003), Assenmacher & Gerlach (2008), Goodhart & Hofmann (2008), Zhou (2010)).

discussed for example, California in Section 5.2, Massachusetts in Section 5.3, New York in Section 5.4, Nevada in Section 5.5, Hawaii in Section 5.6 and District of Columbia in Section 5.7. We also discuss results for farm and the "Rust Belt" States in Section 5.8 and "Energy-producing" States in Section 5.9.

5.1. General results

The price-income ratio for all the 50 States and the District of Columbia can be classified into two groups: one is oscillating with peaks and troughs (e.g., California, Florida, Hawaii, etc.) and the other exhibits a declining trend (e.g., Indiana, Mississippi, South Carolina, etc.). Figure 2 displays periods of exuberance suggested by the GSADF test at the State level based on a test formulation with an intercept in the null. The shaded area in Figure 2 indicates the bubble periods [4]. Tables 1 and Table 2 present the corresponding date-stamping outcomes and GSADF test statistics for all the 50 States and the District of Columbia [5]. Overall, we find evidence of explosive behaviour in the house price-income ratio for all the States and the District of Columbia except West Virginia. The GSADF statistics for the house price-income ratio of 34 States and the District of Columbia are significant at the 1% level, which indicates strong evidence of explosive periods. The GSADF statistics of 12 States provide evidence of explosive behaviour at the 5% level (i.e. Alaska, Colorado, Iowa, Idaho, Illinois, Indiana, Kansas, Minnesota, New Hampshire, Pennsylvania, South Dakota and Wyoming). The GSADF statistics of price-income ratio for the remaining 3 States exceeds the 10% right-tail critical values (i.e., Louisiana, Oklahoma and Utah).

However, results obtained from the model formulation without an intercept differ from these findings. Figure 3 displays periods of exuberance suggested by the GSADF test at the State level based on the model formulation without an intercept in the null. Figure 7, Figure 9, Figure 11, Figure A.13, Figure A.15, Figure A.17, Figure A.19, Figure A.21, Figure A.23, Figure A.25, Figure A.27 and Figure A.29 compare the backward SADF statistic with the 95% critical value sequences for the price-income ratio based on unit root tests without an intercept. Tables 3 and Table 4 present the corresponding date-stamping outcomes and GSADF test statistics for all the States and the District of Columbia. The GSADF statistics of 8 States and the District of Columbia are significant at the 1% level, which indicates strong evidence of explosive periods (e.g., California, Delaware, Hawaii, Illinois, Maine, New Hampshire, Rhode Island and Virginia). The null hypothesis of no explosive periods is rejected at the 5% level for 11 States (e.g., Alaska, Connecticut, Florida, Massachusetts, Maryland,

[4]We assume that a housing bubble should last at least for 6 months. Thus a bubble episode with shorter period is ignored.

[5]The critical values for the null hypothesis with an intercept: 2.5343 (90%), 2.7960 (95%), 3.4337 (99%). The critical values for the null hypothesis without an intercept: 3.4989 (90%), 3.8319 (95%), 4.5976 (99%).

Minnesota, Montana, New Jersey, New York, Pennsylvania and Vermont). The GSADF statistics of house price-income ratio for New Mexico, Oregon, Washington, Wyoming also exceeds the 10% right-tailed critical values. We find no significant evidence of explosive periods for the remaining States. Comparing Figure 2 and Figure 3 shows that the exclusion of the intercept in the model formulation has affected the theory and date-stamping strategy of the PSY approach.

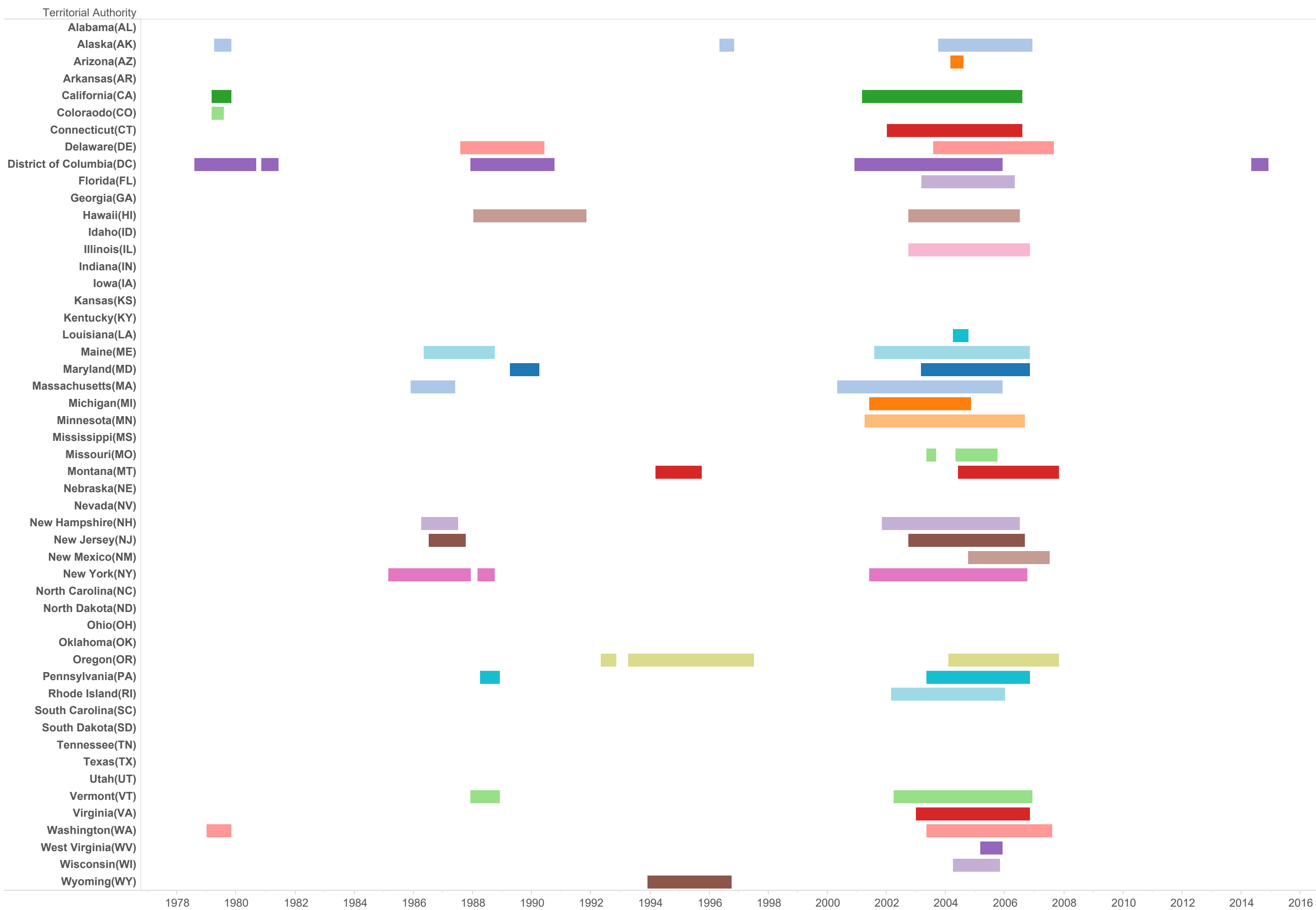
We present results based upon tests of the unit root null with and without an intercept. Based on the above results, the intercept term plays a crucial role in identifying the explosive behaviour as it can potentially affect the date-stamping outcomes from the PSY. Our results suggest that we would find the same date-stamping outcomes for with and without intercept in a particular State if the State data does not have any collapse or collapse and recovery events - only the potential bubbles. Examples of collapse episodes can be seen in Figure 10b, Figure 10d, Figure 10e and etc. Similarly, examples of collapse and recovery episodes may be found in Figure 8a, Figure 8b, Figure 8c, Figure 8d and etc. When the intercept is included in the null hypothesis, we not only detect the collapse episode or collapse and recovery episode, but also the potential bubbles. However, without considering the intercept in the unit root null hypothesis, the PSY approach detects only the potential bubbles. Special attention should be paid to assessing the evidence of the potential bubbles.

Quite different date-stamping outcomes are obtained from the two model specifications (with or without an intercept) if the price-income ratio of a particular State has a declining trend. Most States with a declining trend exhibit strong evidence of collapse episodes under the model specification with an intercept (e.g., Georgia in Figure A.20c, Indiana in Figure A.16b, South Dakota in Figure A.18e, Tennessee in Figure A.24a, etc.), which could give the false indication of bubbles. However, when the intercept term is removed in the unit root null hypothesis, our date-stamping strategies no longer detect the collapse episodes (e.g., Georgia in Figure A.21c, Indiana in Figure A.17b, South Dakota in Figure A.19e, Tennessee in Figure A.25a, etc.), which suggest no evidence of bubbles.

Our empirical evidence demonstrates the practical importance in model specification. Based upon the model specification with an intercept, we can identify collapse episode, collapse and recovery episode and the potential bubbles. When the data exhibits a declining trend, the model specification without an intercept seems to provide more promising results as it identifies only the potential bubbles. We do not try to suggest a particular model specification, which always provides the most reliable way in examining the presence of bubbles. One of the take home messages from our study is that it is useful to try a range of model specifications for assessing evidence of bubbles in right-tailed unit root tests.

Figure 2: Date-stamping strategies based on the model formulation under the null hypothesis with an intercept.

Figure 3: Date-stamping strategies based on the model formulation under the null hypothesis without an intercept.



5.1.1. *Was there a housing bubble in the 1980s?*

Existing studies found the existence of a bubble in several States during the 1980s. As shown by Figure 4, based upon the model without an intercept, our empirical results seem to suggest that only 10 States and the District of Columbia experience a housing bubble in the 1980s. The 10 bubbling States include Delaware, Hawaii, Maine, Massachusetts, Maryland, New Hampshire, New Jersey, New York, Pennsylvania and Vermont. The finding of a housing bubble in the 1980s is in line with several existing studies including Case (1986), Case & Shiller (1988), Case & Shiller (1994), Riddel (1999), Case & Shiller (2003) and Zhou & Sornette (2003). It should be pointed out that California experiences a housing bubble during the 1980s only under the assumption of the unit root null hypothesis with an intercept.

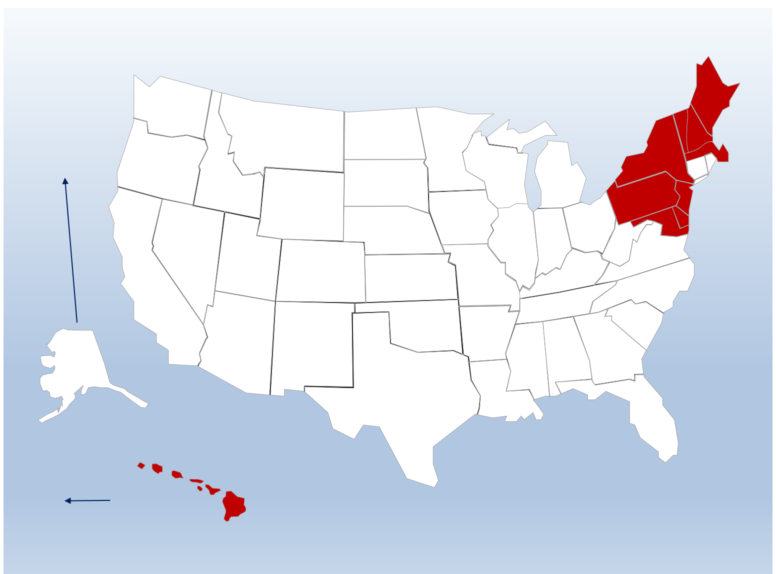


Figure 4: States experiencing a bubble during the 1980s based on the model specification without an intercept.

5.1.2. *Was there a housing bubble in the early 2000s? If so, is it a national bubble?*

Several States experienced a dramatic house price boom in the early 2000s followed by a collapse. Glick et al. (2015) conclude that the States with the largest house price booms from 2002 to 2006 are Hawaii, Florida, Nevada, California, and Arizona and the States with the smallest house price booms are Mississippi, North Dakota, Oklahoma, South Dakota, Kentucky, Colorado, Idaho, Nebraska, Ohio, Indiana and Michigan. Our results seem to support the view that that the States with the largest house price booms are bubbles. The date-stamping strategies of Hawaii in Figure 6e, Florida in Figure A.20b, Nevada in Figure 6d, California in Figure 6a and Arizona in Figure A.26a indicate the presence of bubbles between 2001 and 2006 based on the model formulation with an intercept. A

Table 1: Testing for explosiveness in the US house price-to-income ratio at the State level based on model formulation with an intercept in the null (1).

Territorial Authority	GSADF statistic	Bubble Episode(s)
Alaska(AK)	2.5753** [a]	87M02-88M05, 89M02-90M02, 03M06-06M09, 11M06-12M04
Alabama(AL)	2.8677***	80M09-82M06, 88M08-89M06, 89M10-91M03, 91M10-92M07, 97M10-98M07, 09M12-13M04
Arkansas(AR)	3.4767*** [b]	81M05-82M05, 88M11-90M04, 97M07-98M08, 07M08-09M05, 10M02-13M05
Arizona(AZ)	4.0760***	84M05-90M12, 96M11-98M11, 04M05-05M11, 08M10-09M05
California(CA)	3.9756***	83M07-85M06, 88M05-89M10, 01M02-05M11
Colorado(CO)	2.5833**	83M08-92M01, 97M10-98M08, 06M10-09M03, 10M10-12M05
Connecticut(CT)	2.8532***	86M01-87M08, 01M10-05M10, 10M10-13M04
District of Columbia(DC)	3.8213***	78M08-80M08, 87M10-90M03, 92M12-94M04, 01M02-05M11
Delaware(DE)	3.8356***	87M04-88M03, 90M10-02M01, 02M12-06M10, 08M10-13M02
Florida(FL)	3.7602***	81M02-81M11, 84M09-86M05, 02M04-05M11
Georgia(GA)	4.3743***	83M02-85M06, 88M07-95M05, 07M08-12M12
Hawaii(HI)	4.7460***	88M07-91M07, 96M09-98M02, 02M07-06M06, 08M10-09M06
Iowa(IA)	2.5337**	81M01-81M12, 07M10-09M04, 10M10-13M09
Idaho(ID)	2.5736**	80M09-81M09, 83M12-85M06, 87M07-90M03, 97M05-03M03, 05M05-05M11, 06M02-06M08, 09M06-12M04
Illinois(IL)	2.3791**	81M09-83M02, 97M07-98M06, 07M09-09M04, 10M06-13M03
Indiana(IN)	2.2692**	81M11-83M02, 83M06-85M07, 07M08-09M04, 10M10-13M04
Kansas(KS)	2.6143**	80M10-87M02, 88M08-89M08, 89M10-91M02, 91M09-92M06, 06M10-07M04, 07M09-08M11, 10M10-12M04, 12M08-13M04
Kentucky(KY)	3.0950***	80M10-82M08, 90M01-92M12, 97M08-99M02, 07M08-09M04, 10M03-13M07
Louisiana(LA)	1.9972* [c]	84M05-86M01, 87M07-91M03, 11M06-13M04
Massachusetts(MA)	3.3926***	85M01-87M07, 01M01-05M08
Maryland(MD)	3.3083***	82M02-83M04, 83M10-86M03, 92M11-01M02, 02M05-03M12, 04M02-06M06, 08M08-09M04
Maine(ME)	3.6362***	87M01-88M03, 92M12-93M08, 01M04-05M12
Michigan(MI)	3.8590***	06M06-12M11
Minnesota(MN)	2.2989**	83M10-86M04, 88M12-90M12, 01M11-03M11, 04M11-05M11, 07M08-09M04, 10M06-12M04
Missouri(MO)	3.6546***	88M10-89M07, 90M04-93M03, 07M06-09M04, 10M06-13M04
Mississippi(MS)	3.7950***	81M06-82M03, 87M08-90M10, 10M04-13M03

[a]** indicates significance at the 5% level.
[b]*** indicates significance at the 1% level.
[c]* indicates significance at the 10% level.

Table 2: Testing for explosiveness in the US house price-to-income ratio at the State level based on model formulation with an intercept in the null (2).

Territorial Authority	GSADF statistic	Bubble Period(s)
Montana(MT)	2.9110*** [a]	88M12-90M04, 93M11-95M01, 04M11-06M12, 09M11-12M11
North Carolina(NC)	3.4271***	80M10-82M01, 88M01-90M09, 91M07-93M05, 09M03-13M05
North Dakota(ND)	3.1273***	11M06-12M11
Nebraska(NE)	4.3557***	84M06-85M06, 87M11-89M08, 06M12-09M07, 10M06-13M12
New Hampshire(NH)	2.7671** [b]	80M09-83M04, 86M03-87M04, 90M12-92M07, 01M03-05M10, 07M09-09M04, 10M010-12M11
New Jersey(NJ)	2.8940***	86M01-87M08, 95M11-96M05, 01M11-05M12
New Mexico(NM)	3.0967***	87M09-92M08, 97M10-99M01, 99M09-02M04, 05M05-07M01, 11M06-12M04
Nevada(NV)	4.2925***	82M12-90M09, 91M11-93M06, 03M10-05M02, 07M08-09M04
New York(NY)	3.5519***	85M01-87M11, 94M12-96M06, 01M06-05M11, 11M01-11M08
Ohio(OH)	2.8279***	81M02-82M10, 83M10-85M12, 07M08-14M12
Oklahoma(OK)	2.2009* [c]	81M02-82M05, 84M06-91M08, 07M11-08M11
Oregon(OR)	3.1929***	81M02-82M02, 04M12-07M06
Pennsylvania(PA)	2.5222**	81M06-83M02, 92M05-93M07, 94M11-98M06, 04M11-05M11, 10M10-12M04
Rhode Island(RI)	2.8820***	81M10-82M10, 86M06-87M07, 92M02-93M09, 01M04-05M11
South Carolina(SC)	3.5162***	83M11-85M03, 88M02-89M06, 92M12-93M08, 08M09-14M03
South Dakota(SD)	2.7747**	86M04-87M02, 87M07-92M09, 10M10-12M05
Tennessee(TN)	3.5187***	80M07-81M04, 88M01-95M04, 97M11-98M11, 10M05-13M02
Texas(TX)	2.9688***	84M08-86M05, 86M10-91M02, 96M08-98M06, 07M11-09M01
Utah(UT)	2.2061*	81M05-82M10, 83M08-91M01, 94M01-94M10, 97M10-02M02, 10M09-12M03
Virginia(VA)	3.6578***	80M11-81M08, 82M01-82M11, 90M10-91M05, 91M08-99M06, 03M03-06M06
Vermont(VT)	4.5995***	79M06-80M03, 81M02-82M09, 87M11-88M11, 91M08-00M03, 02M02-06M05, 11M03-12M05
Washington(WA)	2.7979***	95M10-97M05, 05M04-07M03, 10M09-12M06
Wisconsin(WI)	2.9467***	80M10-82M08, 10M06-14M12
West Virginia(WV)	1.8273	81M10-82M12, 01M07-02M02, 08M08-09M04, 10M11-12M04
Wyoming(WY)	2.3944**	80M05-81M04, 84M05-86M04, 94M03-96M04

[a]*** indicates significance at the 1% level.
[b]** indicates significance at the 5% level.
[c]* indicates significance at the 10% level.

Table 3: Testing for explosiveness in the US house price-to-income ratio at the State level based on model formulation without an intercept in the null (1).

Territorial Authority	GSADF statistic	Bubble Episode(s)
Alaska(AK)	3.9690** [a]	79M04-79M11, 96M05-96M11, 03M10-06M12
Alabama(AL)	0.8321	
Arkansas(AR)	0.6238	
Arizona(AZ)	2.7832	04M03-04M08
California(CA)	4.7830*** [b]	79M03-79M11, 01M03-06M08
Colorado(CO)	2.3487	79M03-79M08
Connecticut(CT)	4.2990**	02M01-06M08
District of Columbia(DC)	5.9705***	78M08-80M09, 80M11-81M06, 87M12-90M10, 00M12-05M12, 14M05-14M12
Delaware(DE)	5.1558***	87M08-90M06, 03M08-07M09
Florida(FL)	4.2377**	03M03-06M05
Georgia(GA)	1.3040	
Hawaii(HI)	4.9623***	88M01-91M11, 02M10-06M07
Iowa(IA)	2.0512	
Idaho(ID)	2.3192	
Illinois(IL)	4.2508***	02M10-06M11
Indiana(IN)	0.2466	
Kansas(KS)	1.6406	
Kentucky(KY)	0.8426	
Louisiana(LA)	2.9086	04M04-04M10
Massachusetts(MA)	3.8427**	85M12-87M06, 00M05-05M12
Maryland(MD)	4.0003**	89M04-90M04, 03M03-06M11
Maine(ME)	5.1095***	86M05-88M10, 01M08-06M11
Michigan(MI)	2.8259	01M06-04M11
Minnesota(MN)	4.1407**	01M04-06M09
Missouri(MO)	2.8779	03M05-03M09, 04M05-05M10
Mississippi(MS)	0.8537	

[a] ** indicates significance at the 5% level.
[b] *** indicates significance at the 1% level.

Table 4: Testing for explosiveness in the US house price-to-income ratio at the State level based on model formulation without an intercept in the null (2).

Territorial Authority	GSADF statistic	Bubble Period(s)
Montana(MT)	3.9162**	94M03-95M10, 04M06-07M11
North Carolina(NC)	0.1472	
North Dakota(ND)	1.7347	
Nebraska(NE)	1.7782	
New Hampshire(NH)	5.9468*** [a]	86M04-87M07, 01M11-06M07
New Jersey(NJ)	4.2077** [b]	86M07-87M10, 02M10-06M09
New Mexico(NM)	3.8277* [c]	04M10-07M07
Nevada(NV)	2.4837	
New York(NY)	3.9831**	85M03-87M12, 88M03-88M10, 01M06-06M10
Ohio(OH)	1.2067	
Oklahoma(OK)	1.2085	
Oregon(OR)	3.5237*	92M05-92M11, 93M04-97M07, 04M02-07M11
Pennsylvania(PA)	3.8800**	88M04-88M12, 03M05-06M11
Rhode Island(RI)	4.6938***	02M03-06M01
South Carolina(SC)	0.9467	
South Dakota(SD)	1.6170	
Tennessee(TN)	1.6736	
Texas(TX)	1.0062	
Utah(UT)	2.1127	
Virginia(VA)	4.6772***	03M01-06M11
Vermont(VT)	3.9377**	87M12-88M12, 02M04-06M12
Washington(WA)	3.6748*	79M01-79M11, 03M05-07M08
Wisconsin(WI)	3.1672	04M04-05M11
West Virginia(WV)	3.3261	05M03-05M12
Wyoming(WY)	3.7067*	93M12-96M10

[a]*** indicates significance at the 1% level.
[b]** indicates significance at the 5% level.
[c]* indicates significance at the 10% level.

similar conclusion can also be drawn based on the model formulation without an intercept except in the case of Arizona. On the other hand, the date-stamping strategies of those States with the smallest house price booms suggest no evidence of bubbles between 2001 and 2006 - the exception is Michigan as shown in Figure 9b.

It should be emphasized that the States with a housing bubble are not limited to California, Florida, Hawaii and Nevada as shown in Figure 5. We also find States with a bubble that grows in the early 2000s and collapses in mid-2000s as presented in Table 5 based on two different model formulations. We can see that the housing bubble is not an isolated phenomenon in particular, 22 or 25 States (depending on the model formulation) and the District of Columbia experience a bubble during this period. Although there are some differences in the origination and collapse dates of the bubbles based on the two model formulations, our results provide similar date-stamping outcomes and also confirm the existence of a bubble in these States. According to Martin (2011), the States that experienced a bubble during this period include California, District of Columbia, Florida, Hawaii, Massachusetts, Nevada, Pennsylvania and Rhode Island, which are well aligned with our results. Crucially, our results suggest that the housing bubble in the early 2000s is not a national bubble, as many States experience no bubble activity during this period. This conclusion is consistent with the views of Greenspan in 2005. The States that experience a bubble are mainly located in Northeast or West with the exception of Florida, New Mexico, Montana, Michigan, Missouri, Minnesota and Illinois. Wheelock et al. (2006) also concluded that housing booms and busts in the 1980s and early 2000s are different in terms of their magnitude and coverage where the early 2000s boom appeared more widely spread out than that of the 1980s. Our results allow us to draw an important conclusion - the bubble of the 2000s is more widespread than the 1980s, but is not a national bubble. This phenomenon is clear via close inspection of Figure 3.

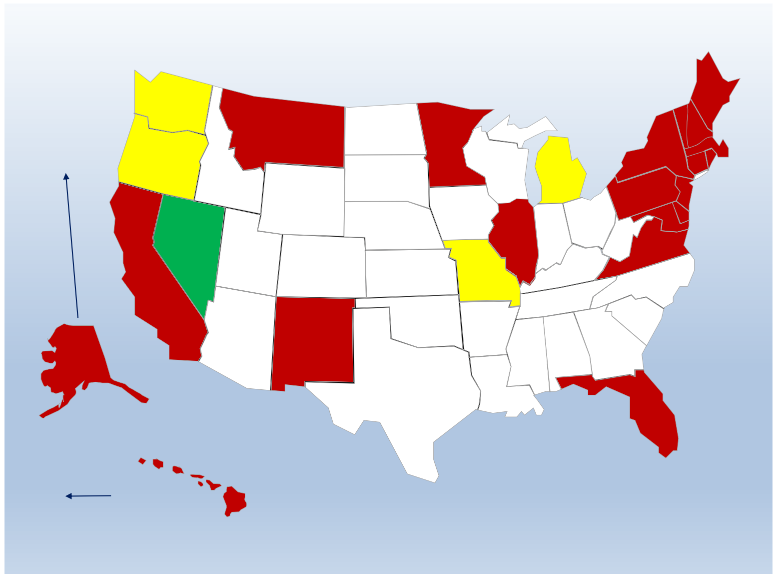


Figure 5: States experiencing a bubble during the early 2000s based on the two model specifications. A State experiencing a bubble under both models is colored in red. A State experiencing a bubble only under the assumption without an intercept is colored in yellow while a State experienced a bubble only under the assumption with an intercept is colored in green.

5.2. California (CA):

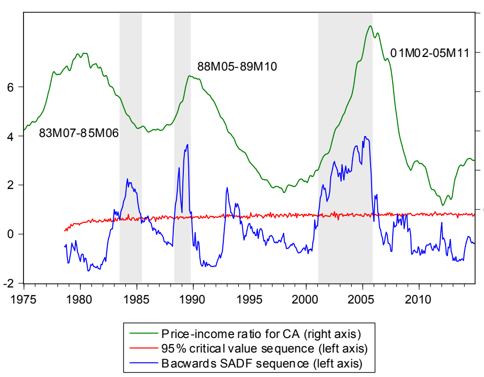
A number of studies focus on the Californian housing market (e.g., Case & Shiller (1994), Gabriel et al. (1999)[6], Riddel (1999) and Riddel (2011)[7].). Our date-stamping strategy results for the Californian price-income ratio are presented as Figure 6a, where the price-income ratio reaches its lowest point in 1984/1985 and starts to climb to a peak in 1989. After 1989/1990, the ratio declines sharply then reaches another peak in 2005/2006. We find several episodes from the price-income ratio for California: 1983M07- 1985M06, 1988M05-1989M10 and 2001M02-2005M11. Case (1986) argues that there is a house price boom in California in 1976-1980, however, our results indicate that such a 'housing boom' was not a bubble.

Based on our analysis, there are two explosive episodes in the 1980s (1983M07-1985M06, 1988M05-1989M10). The first period between 1983M07 and 1985M06 is an example of a collapse episode. The

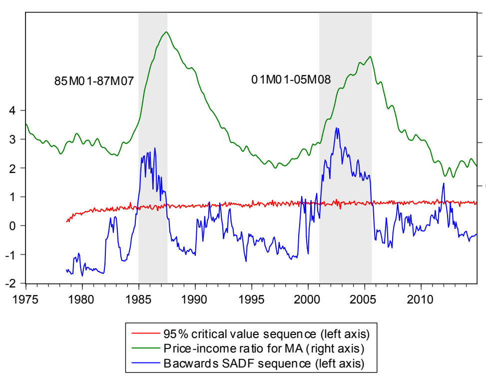
[6]Gabriel et al. (1999) explored the housing price patterns in California's two largest Metropolitan areas (Los Angeles and San Francisco) prior to 2000.

[7]Riddel (2011) estimated an error correction model that spanned 1978Q2 to 2008Q1 using quarterly housing price data for Las Vegas and Los Angeles with both national and regional economic variables. Riddel (2011) provided support for the contagion hypothesis that income and price in Los Angeles contributed to the run-up house values in Las Vegas from 2002-2006.

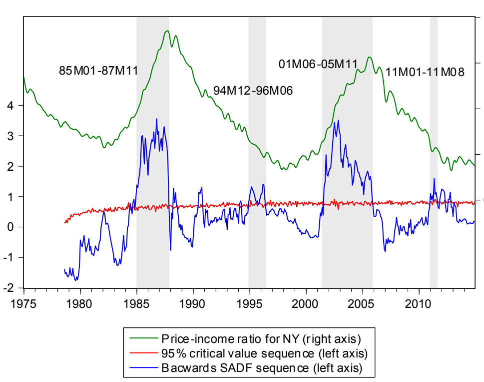
(a) California (CA)



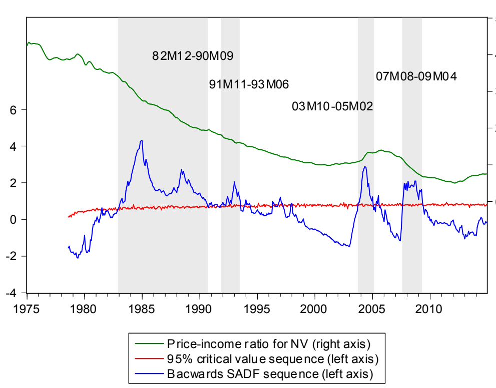
(b) Massachusetts (MA)



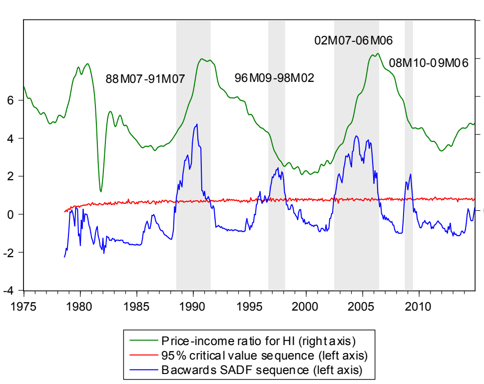
(c) New York (NY)



(d) Nevada (NV)



(e) Hawaii (HI)



(f) District of Columbia (DC)

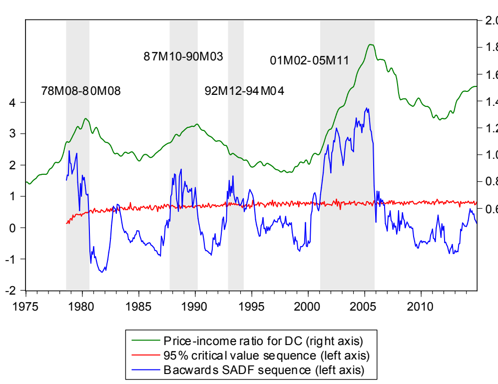
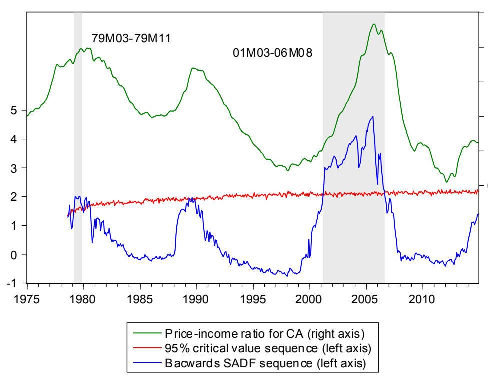
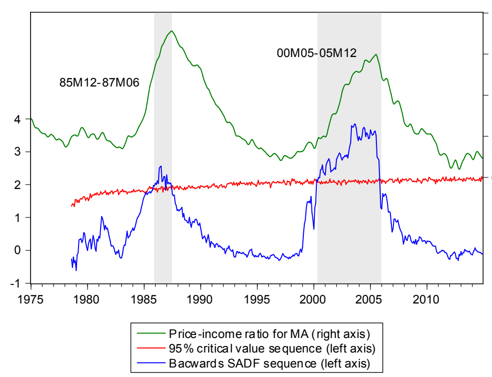


Figure 6: Date-stamping strategy of price-income ratio for several key States based on the model formulation under the null hypothesis with an intercept.

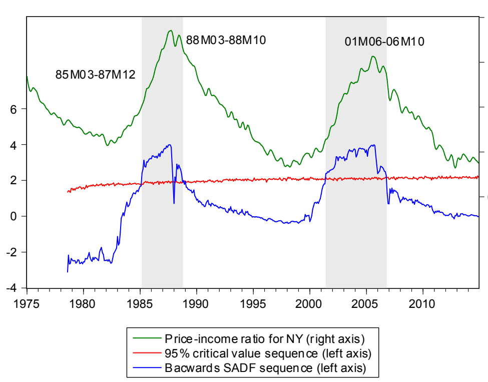
(a) California (CA)



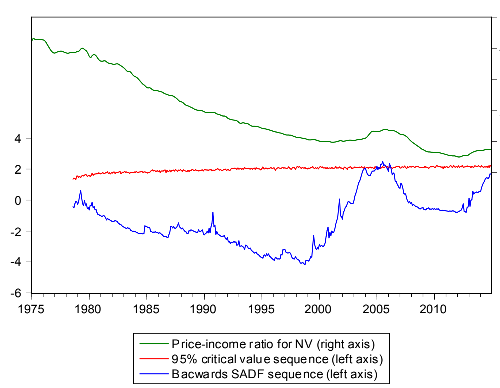
(b) Massachusetts (MA)



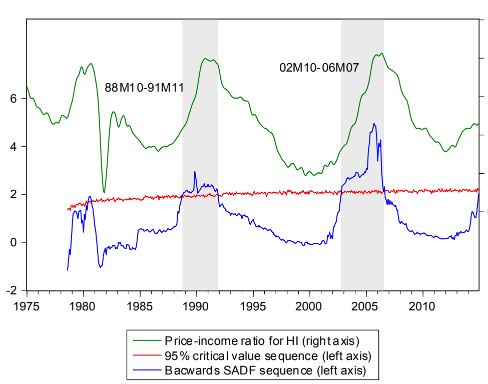
(c) New York (NY)



(d) Nevada (NV)



(e) Hawaii (HI)



(f) District of Columbia (DC)

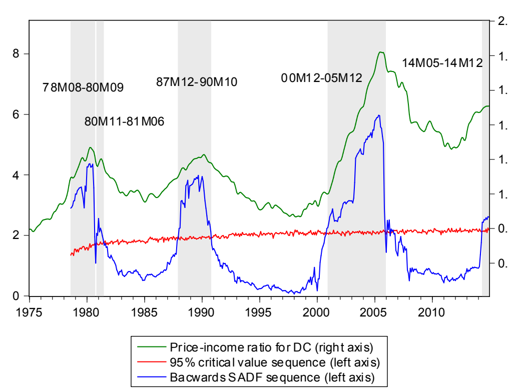


Figure 7: Date-stamping strategy of price-income ratio for several key States based on the model formulation under the null hypothesis without an intercept.

Table 5: States with a bubble during the early 2000s boom.

State	Bubble period under the model with an intercept	Bubble period under the model without an intercept
Alaska	2003M06-06M09	2003M10-06M12
California	2001M02-05M11	2001M03-06M08
Connecticut	2001M10-05M10	2002M01-06M08
District of Columbia	2001M02-05M11	2000M12-05M12
Delaware	2002M12-06M10	2003M08-07M09
Florida	2002M04-05M11	2003M03-06M05
Hawaii	2002M07-06M06	2001M10-06M07
Illinois	2002M04-05M11	2002M10-06M11
Massachusetts	2001M01-05M08	2000M05-05M12
Maryland	2002M05-03M12	2003M03-06M11
	2004M02-06M06	
Maine	2001M04-05M12	2001M08-06M11
Michigan		2001M06-04M11
Minnesota	2001M11-03M11	2001M04-06M09
Missouri		2003M05-03M09
		2004M05-05M10
Montana	2004M11-06M12	2004M06-07M11
Nevada	2003M10-05M02	
New Hampshire	2001M03-05M10	2001M11-06M07
New Jersey	2001M11-05M12	2002M10-06M09
New York	2001M06-05M11	2001M06-06M10
New Mexico	2005M05-07M01	2004M10-07M07
Oregon		2004M02-07M11
Pennsylvania	2004M11-05M11	2003M05-06M11
Rhode Island	2001M04-05M11	2002M03-06M01
Virginia	2003M03-06M06	2003M01-06M11
Vermont	2002M02-06M05	2002M04-06M12
Washington		2003M05-07M08

papers by Case (1994), Case & Shiller (1994), Riddel (1999), Zhou & Sornette (2003) and Gupta & Miller (2012) offer some support for our findings. Case & Shiller (1988) were the first to uncover the role of high expectations in driving up the California boom in late 1980s using a questionnaire survey. Firstly, Case & Shiller (1988), surveyed a sample of 2000 households who bought homes in 1988 in Los Angeles, San Francisco, Boston and Milwaukee. The Los Angeles and San Francisco housing markets were chosen to represent two "boom markets" and Boston was selected as a "post-boom market". Milwaukee was treated as a control market to reflect a 'normal' housing market. A key finding from Case & Shiller (1988) suggests that three housing markets (Los Angeles, San Francisco and Boston) have gone through a house price bubble period. A house price boom in California over the period 1987-1989 is also identified in Case (1994)[8], which coincides with our second episode 1988M05-1989M10. Secondly, Case & Shiller (1994) compared two house price boom/burst cycles in Boston and Los Angeles and they focused on the period post-1983 in Boston and the period post-1985 in Los Angeles. The prices in Los Angeles increased more than 100 percent between 1985 and 1989. They concluded that these two house price booms cannot be fully explained by economic fundamentals. The run-up in prices seem to have be driven by "speculation" as most home buyers paid higher prices for properties and aimed at future capital gains. Moreover, Riddel (1999) concluded that there was a speculative housing bubble from late 1987 to mid-1990 in the Santa Barbara County of California. Zhou & Sornette (2003) also found evidence of a housing bubble that originated around 1984 and burst in 1989 in the California market based on the characteristic of a bubble defined as 'a super-exponential growth' phase. They draw the same conclusion for Los Angeles and San Francisco as these two cities led the Californian market. This finding is consistent with our analysis. Lastly, Southern California experienced a run-up and subsequent fall in house prices during the late 1980s and early 1990s (Gupta & Miller, 2012)[9]. This is due to the fact that California experienced considerable economic growth during 1983-1989 and suffered a major decline in economic activity during the 1990-1991 recession.

House prices in California accelerated again in the early 2000s then declined from their peak in 2005/2006. Our results confirm this period as a bubble. The finding of a bubble during this period coincides with several existing studies in the literature (e.g., Case & Shiller (2003), Gupta & Miller (2012)). For example, Case & Shiller (2003) replicated a questionnaire survey in 2003 for the same markets (e.g., Los Angeles, San Francisco, Boston and Milwaukee). Unlike the first survey in 1988, these three markets were in booms while Milwaukee was a control city. The survey was conducted

[8] Case (1994) reviewed the house prices in the US since the 1950s at national and regional level and discussed the causes of house price behaviours across regions.

[9] Gupta & Miller (2012) explored the cointegration relationships between house prices in eight Southern California Metropolitan statistical areas (MSAs).

among 2000 persons who had bought houses between March and August 2002. They concluded the characteristics of bubbles in these four markets were strong in 2003, but not as strong as in 1988. Results obtained from Case & Shiller (2003) also seem to suggest the existence of bubbles. Moreover, house prices rose dramatically in Southern California MSAs in the early 2000s, peaking in 2005 or 2006 depending on the MSA (Gupta & Miller, 2012). It is interesting that our identified episode (2001M02-2005M11) is in line with the period of run-up and decline in house values in California.

We obtain quite different results, however, using the model specification without an intercept in the null hypothesis. According to Figure 7a, we detect an early episode in 1979, which is not detected under the null hypothesis with an intercept. This finding is consistent with Case (1986), as discussed earlier, who concluded a housing boom at that time in California. No explosive behavior is found in the 1980s as the collapse-only episode between 1983M07 and 1985M06 is not identified. This result does not support the view that California experienced a bubble in the 1980s, which is a key difference between the two models. However, the housing boom in the 2000s is shown to be a bubble.

5.3. Massachusetts (MA):

Based on the model formulation with an intercept, we find significant evidence of explosive bubbles in the price-income ratio for the period 1985M01-1987M07 and 2001M02-2005M08 presented as Figure 6b. The GSADF statistics is 3.3926, which is significant at the 1% level. A series of papers by Case (1986), Case (1994) and Case & Shiller (2003) enable us to understand house price dynamics in Boston during the 1980s. House prices rose rapidly in Boston in 1984 with house prices in the Boston Metropolitan area increasing by 39 percent in 1985 and more than 140 percent in 1988 (Case & Shiller, 2003). House prices in Boston remained unchanged at or near their peak for almost three years from 1987Q2 to 1990Q1. If the price increases in 1994/1995 were maintained, house prices would double approximately every three years in Boston (Case, 1986). Most importantly, Case (1986) concluded that Boston had experienced a housing price bubble as market fundamentals, (e.g., population growth, employment growth, increasing income, mortgage rates, construction costs) did not fully explain the rapid increase in house values. Case (1994) also described several house price booms in the US including the boom in Boston 1983-1987. Therefore, our findings for the first explosive period (1985M01-1987M07) coincide with the historical experiences of house price boom/bubble in Boston from Case (1986), Case (1994) and Case & Shiller (2003). The run-up in house values of Massachusetts in the early 2000s is a bubble, which is consistent with the conclusion drawn by Case & Shiller (2003).

We obtain similar date-stamping outcomes when the intercept term is removed from the model specification in the null hypothesis. As shown in Figure 7b, two episodes (1985M12-87M06 and 2000M05-05M12) are identified. Results based on the two model formulations seem to suggest that Massachusetts experienced a bubble in the 1980s and early 2000s, respectively.

5.4. New York (NY):

As shown in Figure 6c, we find evidence of explosive behavior for the periods 1984M09-1987M12, 1994M12-1996M06, 2001M07-2005M12 and 2011M01-2011M07. Case (1986) also discussed a house price boom in New York in the 1980s, where the median sale prices of existing single-family homes rose by 30 percent in New York in 1985. The rapid increase in house prices in Boston and New York in the mid-1980s doesn't suggest a national house market boom as many cities faced a decline in nominal values (Case, 1986). A house price boom in New York in 1983-1987 is identified in Case (1994). A finding of a bubble period 1984M09-1987M12 from our analysis seems to be in line with house price boom in New York during the mid-1980s. Wheelock et al. (2006) also support a housing boom in New York between 1985Q1 and 1987Q3 and a decline in house price followed [10]. Moreover, based on our results, the rapid appreciation of house price-income ratio between 2001M07 and 2005M12 is a bubble.

We no longer detect the collapse episodes of 1994M12-1996M06 and 2011M01-2011M07 in Figure 7c when the intercept is removed from the model formulation in the null hypothesis. We obtain similar date-stamping outcomes under the null hypothesis without an intercept except for the omission of the two collapse episodes.

5.5. Nevada (NV):

As illustrated by Figure 6d, we find several episodes in the price-income ratio series (e.g., 1982M12-1990M09, 1991M11-1993M06, 2003M10-2005M02, 2007M08-2009M04). Zhou & Sornette (2008) analyzed the real estate market of Las Vegas between June 1983 and March 2005 and argue for the existence of a housing bubble during 2003 to mid-2004 [11]. This finding partially supports our analysis for the episode during 2003M10-2005M02. Riddel (2011) presented the view that contagious price and income growth from the Los Angeles market contributed to the bubble formed in Las Vegas house prices during 2002-2006.

However, a close inspection of the price-income ratio series in Figure 6d shows that the general trend of the price-income ratio is declining. All periods are collapse episodes. When the intercept is removed from the null hypothesis, we find no explosive behavior as the GSADF statistics is much lower than the 10% critical values (2.4837<3.8319). Thus there is no evidence to indicate the presence of bubbles in Nevada for the whole period as suggested by Figure 7d.

[10] Wheelock et al. (2006) summarized that US States experienced 20 house price booms between 1980 and 1999.

[11] Zhou & Sornette (2008) defined a bubble as a price acceleration faster exponential. This definition is the same as Zhou & Sornette (2006).

5.6. Hawaii (HI):

As illustrated by Figure 6e, Hawaii experienced a bubble period between July 1988 and July 1991. As suggested in a series of papers by Miller et al. (1988), Wheelock et al. (2006), Krainer & Wilcox (2011), Krainer & Wilcox (2013), there was rapid growth in Hawaii's real estate market from the late 1980s where the appreciation of house prices was driven by Japanese investors. The house values in Hawaii rose dramatically during the years of the Japanese economy boom in the 1980s and house prices dropped significantly in the early 1990s when the Japanese asset price bubble's collapsed (Krainer & Wilcox, 2013). Our results support the historical house price dynamics in Hawaii during the late 1980s and early 1990s.

When the intercept term is removed from the null hypothesis, the PSY approach no longer detects the collapse episodes (i.e., 1996M09-1998M02 and 2008M10-2009M06). The exclusion of the intercept term has affected the asymptotic theory and date-stamping outcomes of the PSY approach. Overall, based on the two models, our results seem to indicate that Hawaii experienced a bubble during the late 1980s and early 1990s. This finding coincides with the house price boom/bust in Hawaii. Moreover, the housing boom in the early 2000s in Hawaii is also a bubble.

5.7. District of Columbia (DC):

Based upon the assumption 'with an intercept', the data-stamping strategy for the District of Columbia is shown in Figure 6f. The empirical results suggest that the District of Columbia experiences three house price bubbles in 1978M08-1980M08, 1987M10-1990M03 and 2001M02-2005M11. These occurrences are quite unusual as, based upon our results, few other areas experienced a housing bubble between the late 1970s and early 1980s. However, the District of Columbia experiences a housing bubble and the price-income ratio reaches a peak in 1979/1980. A collapse episode is also identified during the period 1992M12-1994M04. The recent run-up in housing prices during the early-mid 2000s is shown to be a bubble.

Moreover, as can be seen in Figure 7f, we obtain similar date-stamping outcomes when the intercept is removed from the unit root null hypothesis, where we are able to identify the following bubbles: 1978M08-1980M09, 1980M11-1981M06, 1987M12-1990M10, 2000M12-2005M12 and 2014M05-2014M12. The most recent episode (2014M05-2014M12) suggests that the District of Columbia is experiencing a new housing bubble, which is of particular interest. Our results, based on tests of the unit root null hypothesis without an intercept, indicate the District of Columbia is the only area experiencing a housing bubble post-2010. This is clearly shown in Figure 3.

5.8. *Farm and "Rust Belt" States: Iowa (IA), Michigan (MI), Wisconsin (WI) and West Virginia (WV):*

The date-stamping strategy for the price-income ratio of the farm and the so-called "Rust Belt" States is presented as Figure 8. The general trend for the price-income ratio in these figures is downward sloping. The null hypothesis of no explosive behavior in the price-income ratio is rejected at the 1%, 5% and 5% level for Iowa, Michigan and Wisconsin, respectively. The GSADF statistics for the house price-income ratio in West Virginia is 1.8273, which is below the 10% level significance.

The house price busts occurred during 1980-1982 in these four States (Wheelock et al., 2006). Of particular interest is whether these house price busts are bubbles. As can be seen in Figure 8a, Figure 8b, Figure 8d and Figure 8c, the price-income ratio reaches a peak or maintains a high level in 1980 for Iowa (IA), Michigan (MI), Wisconsin (WI) and West Virginia (WV). The income of these States relied heavily on older manufacturing industries (e.g., automobiles and steel) where there was a large decline during the early 1980s recession (Wheelock et al., 2006) [12]. Although these States do not experience a high growth in house prices, the PSY approach identifies the collapse and recovery episodes in the early 1980s based (e.g., 1981M01-1981M12 for Iowa, 1982M06-1982M11 for Michigan, 1981M10-1982M12 for West Virginia and 1980M10-1982M08 for Wisconsin).

As shown in Figure 9, quite different results are obtained from the GSADF test under the assumption of no intercept in the null. The null hypothesis of no explosive periods cannot be rejected at the 10% level and we find no significant evidence of bubbles in these four States. We also find no explosive periods during 1980-1982 in these four States, which indicates that the house price busts are not bubbles.

5.9. *Energy-producing States: Alaska (AK), Louisiana (LA), Montana (MT), Oklahoma (OK), Texas (TX) and Wyoming (WY):*

The oil prices rise sharply during the 1970s energy crisis and it reached a peak in 1980 at more than \$35 per barrel before plunging to less than \$10 per barrel in 1986. Wheelock et al. (2006) argue that the house price busts in these energy-producing States was associated with a sharp decline in energy prices. We therefore aim to investigate whether these house price busts during the early-mid 1980s are bubbles. The trend for price-income ratio of these six energy-producing States is downward sloping (see Figure 10). The null hypothesis of no bubbles is rejected for all six States, however, we find significant evidence of 'collapse' episodes and 'collapse and recovery' episodes in Figure 10.

[12] During 1980-82, Iowa, Wisconsin, West Virginia, and Michigan ranked 42nd, 44th, 45th, and 50th, respectively, among all States in real personal income growth, and 45th, 40th, 48th, and 50th in employment growth (Wheelock et al., 2006).

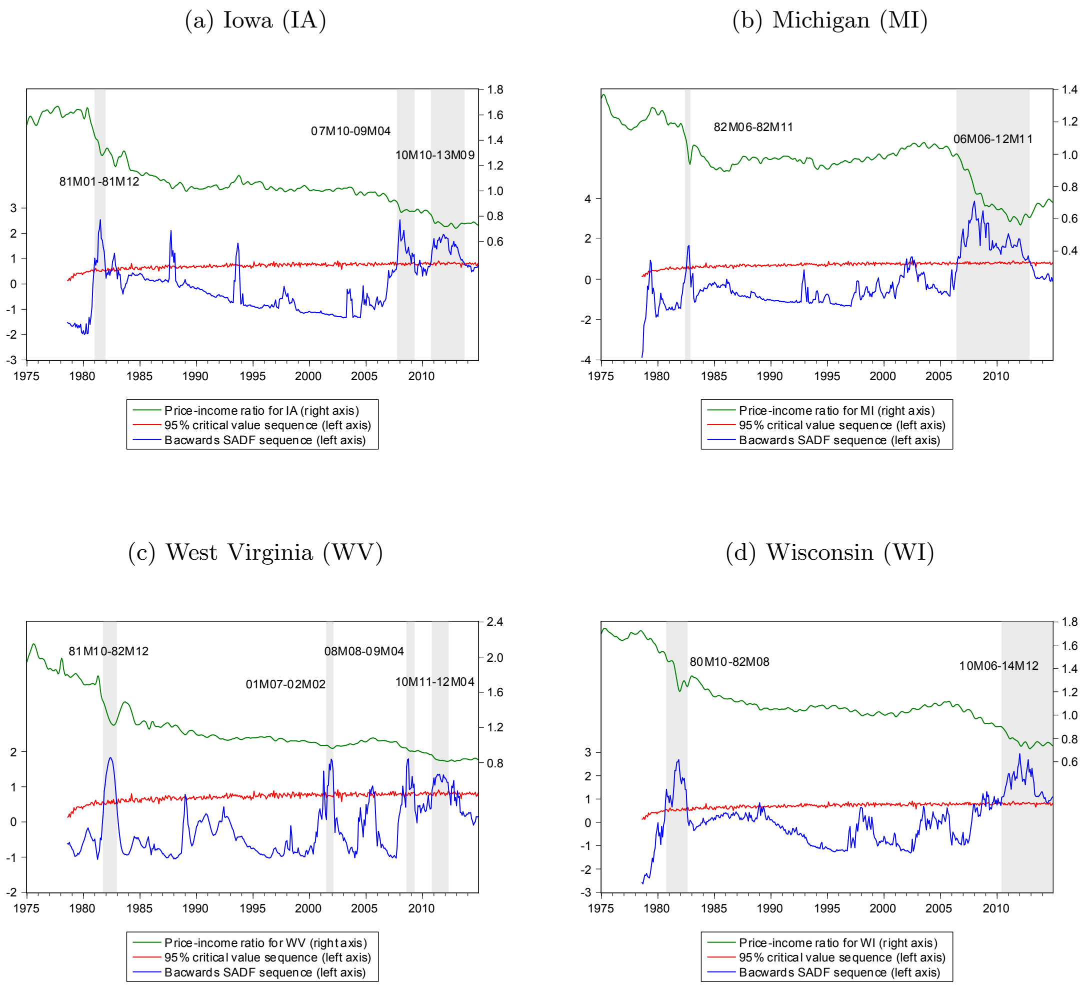


Figure 8: Date-stamping strategy of price-income ratio for farm and the "Rust Belt" States based on the model formulation under the null hypothesis with an intercept.

Based on the model without an intercept, the null hypothesis of no explosive periods can be rejected for Alaska, Montana and Wyoming at the 5%, 5% and 10% significance level whereas the null hypothesis cannot be rejected for Louisiana and Texas. Perhaps more importantly, we find insufficient evidence to support that house price busts associated with the sharp decline in energy prices during the early-mid 1980s are bubbles in Figure 11.

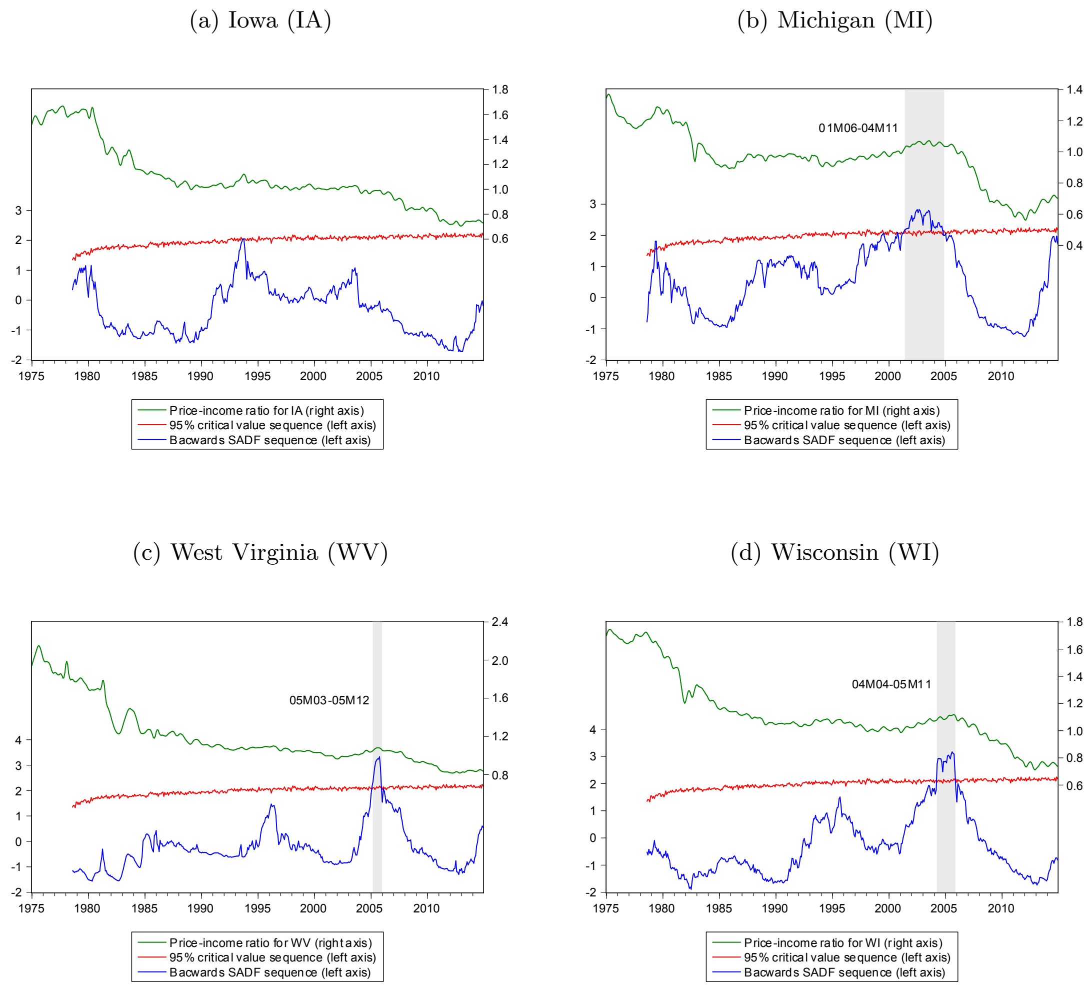
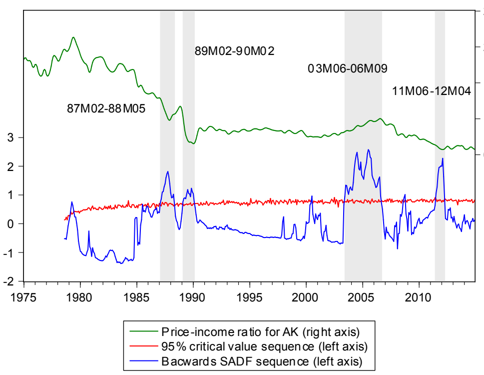


Figure 9: Date-stamping strategy of price-income ratio for farm and the "Rust Belt" States based on the model formulation under the null hypothesis without an intercept.

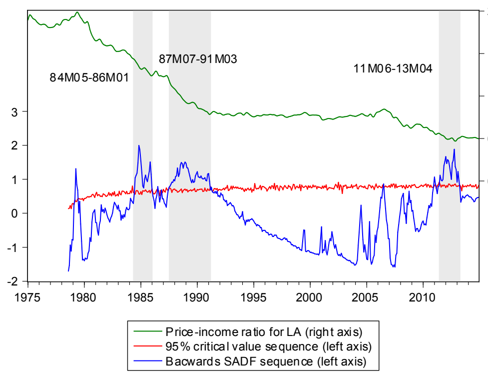
6. Conclusion

In this paper, we investigate the presence of bubbles in the US housing market at the State level based on price-income ratio data, Jan 1975 - Dec 2014. The recently developed right-tailed unit root test of Phillips, Shi & Yu (2015, PSY) is adopted in our study. Our results are summarised as follows. Firstly, we find the presence of a bubble in several States in the 1980s (i.e., California, Hawaii, Massachusetts and New York), which is consistent with some existing studies that investigate housing bubbles or housing booms and busts (i.e., Case (1986), Case & Shiller (1988), Case & Shiller (1994), Riddel (1999), Case & Shiller (2003) and Zhou & Sornette (2003)). Our paper completes analysis in this area by formally testing for bubbles (rather than simply analyzing graphs or house

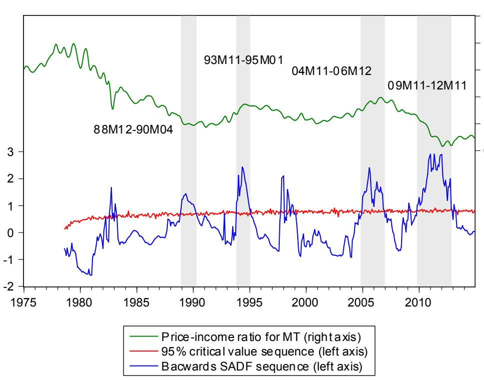
(a) Alaska (AK)



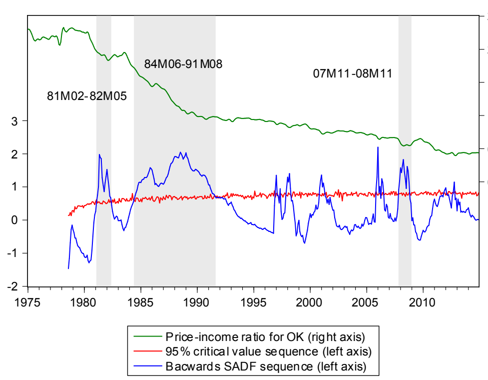
(b) Louisiana (LA)



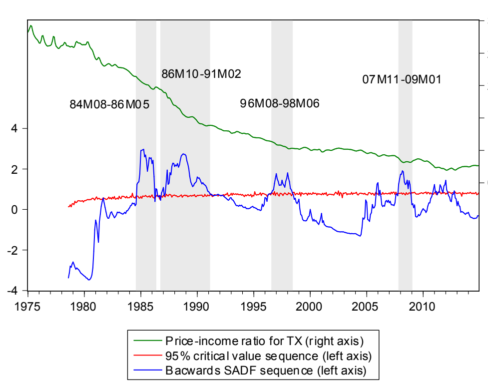
(c) Montana (MT)



(d) Oklahoma (OK)



(e) Texas (TX)



(f) Wyoming (WY)

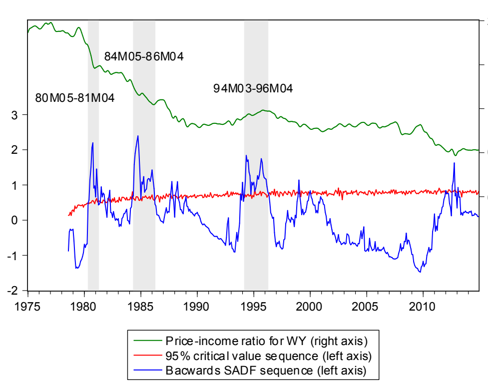
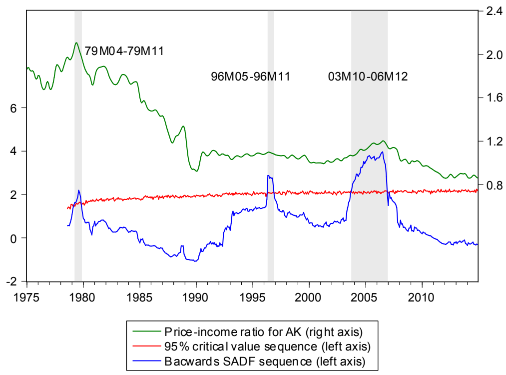
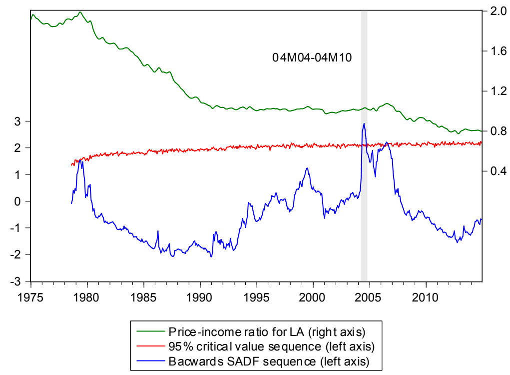


Figure 10: Date-stamping strategy of price-income ratio for energy-producing States based on the model formulation under the null hypothesis with an intercept.

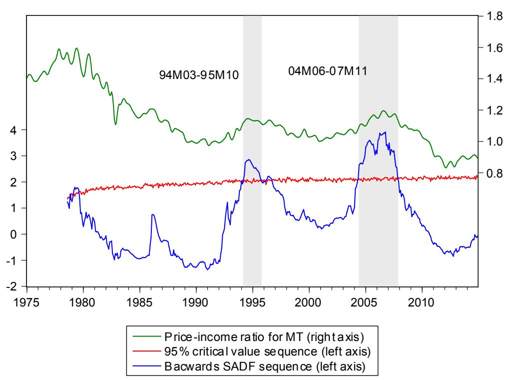
(a) Alaska (AK)



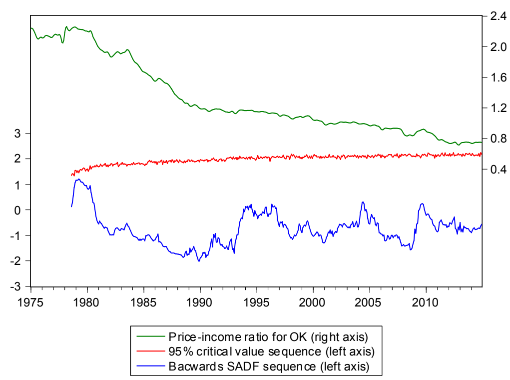
(b) Louisiana (LA)



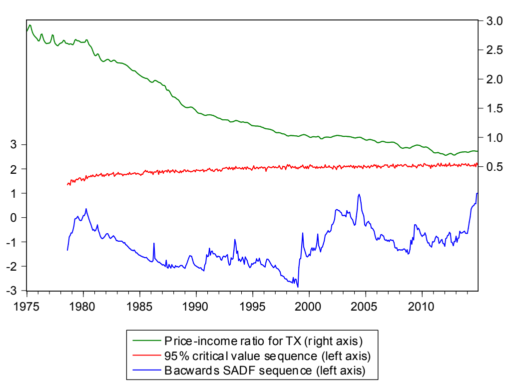
(c) Montana (MT)



(d) Oklahoma (OK)



(e) Texas (TX)



(f) Wyoming (WY)

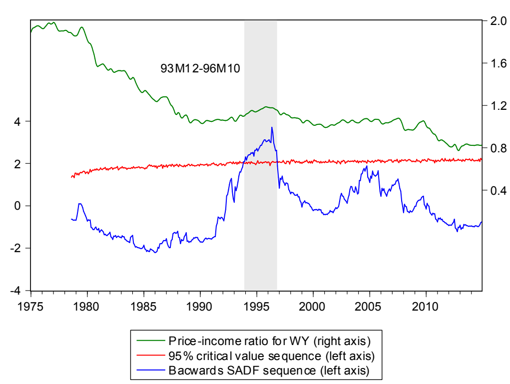


Figure 11: Date-stamping strategy of price-income ratio for energy-producing States based on the model formulation under the null hypothesis without an intercept.

price indicators) in all US States (and DC) during the 1980s, providing empirical evidence of housing bubbles in several States. Secondly, we identify the existence of a housing bubble that originates in the early 2000s and collapses in the mid-2000s in more than 20 States and the District of Columbia. Our results also suggest that the rapid rise in house values during the early 2000s is not a nationwide bubble which is in agreement with the talk given by Alan Greenspan in 2005. However, the housing bubble in the early 2000s is more widespread than the 1980s. Lastly, the exclusion of an intercept in the null hypothesis has shown to affect the asymptotic theory and date-stamping outcomes for the PSY approach. When the intercept is removed from the model specification in the null hypothesis, we no longer detect the collapse or recovery episode only the potential bubble. We do not try to suggest a particular model specification, which always provides the best date-stamping outcomes. One of the take home messages from our study is there is a need to consider different model specifications for assessing evidence of bubbles in the right tailed unit root tests. This represents an important example of how care is required when using the PSY approach.

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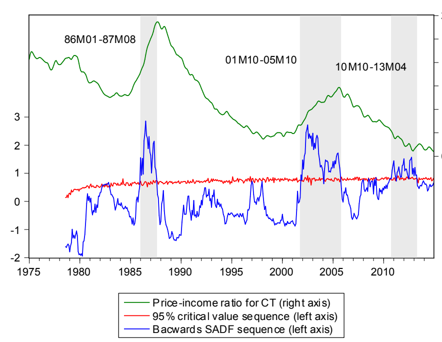
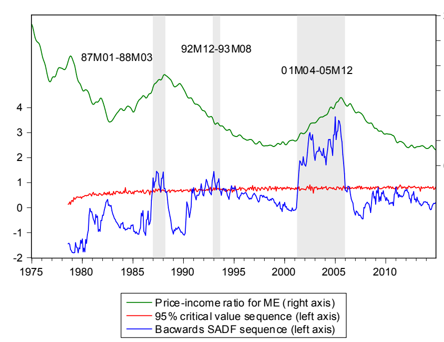
Appendix

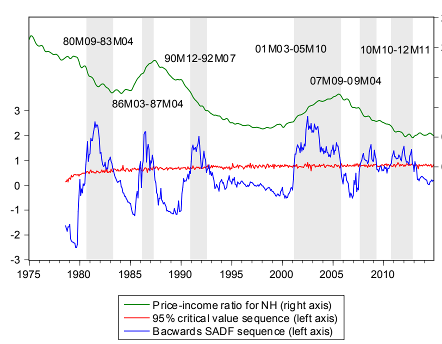
(a) Connecticut (CT)



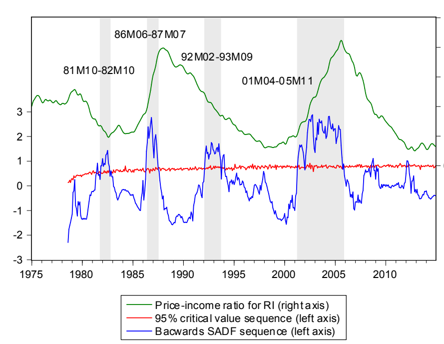
(b) Maine (ME)



(c) New Hampshire (NH)



(d) Rhode Island (RI)



(e) Vermont (VT)

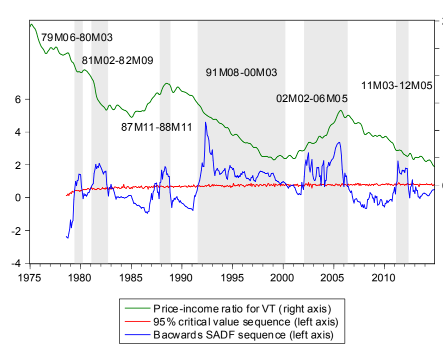
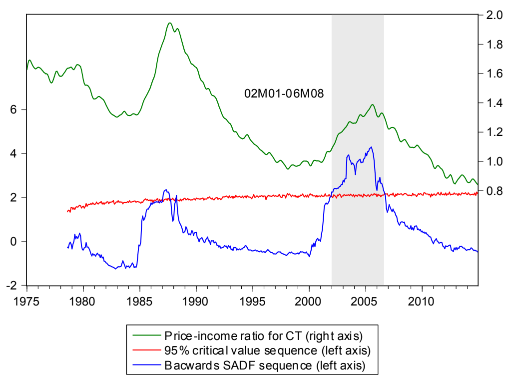
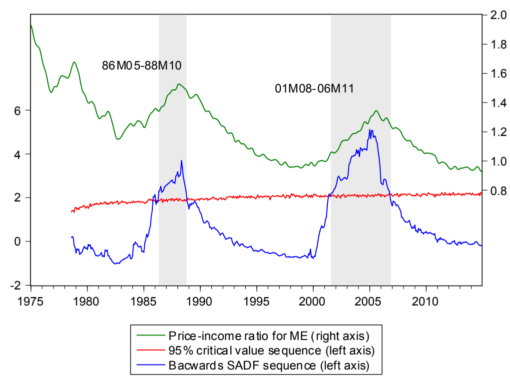


Figure A.12: Date-stamping strategy of price-income ratio for Northeast-New England States based on the model formulation under the null hypothesis with an intercept.

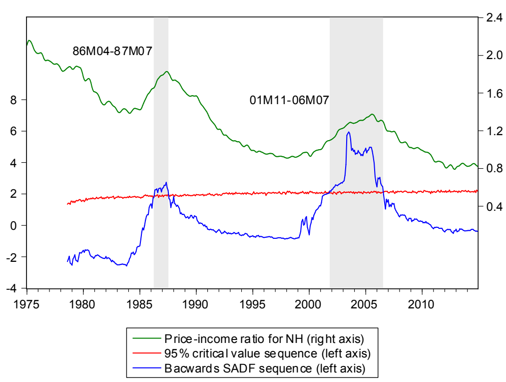
(a) Connecticut (CT)



(b) Maine (ME)



(c) New Hampshire (NH)



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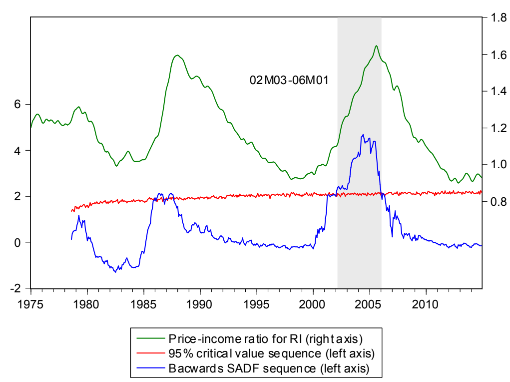


(e) Vermont (VT)

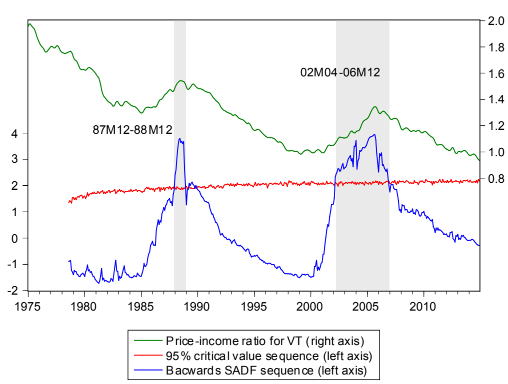


Figure A.13: Date-stamping strategy of price-income ratio for Northeast-New England States based on the model formulation under the null hypothesis without an intercept.

(a) New Jersey (NJ)

(b) Pennsylvania (PA)

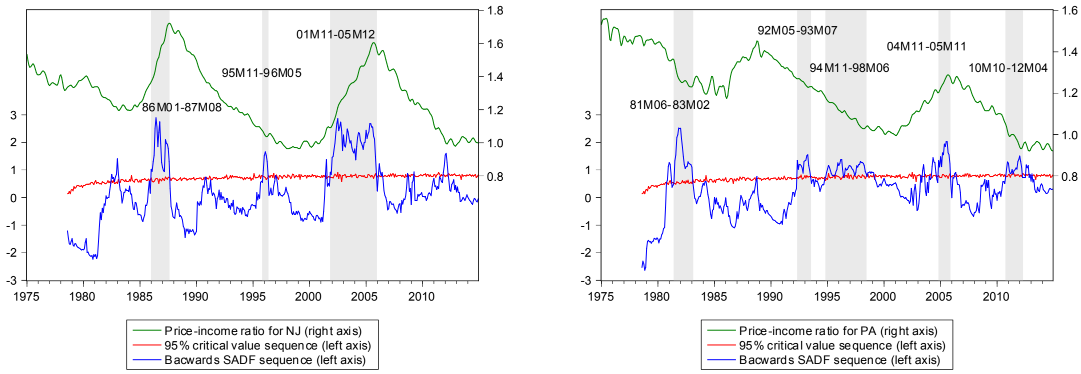


Figure A.14: Date-stamping strategy of price-income ratio for Northeast-Mid-Atlantic States based on the model formulation under the null hypothesis with an intercept.

(a) New Jersey (NJ)

(b) Pennsylvania (PA)

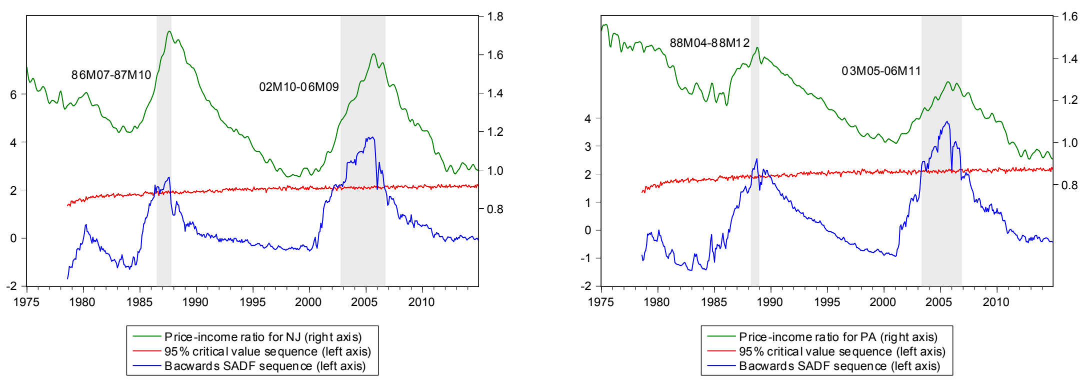
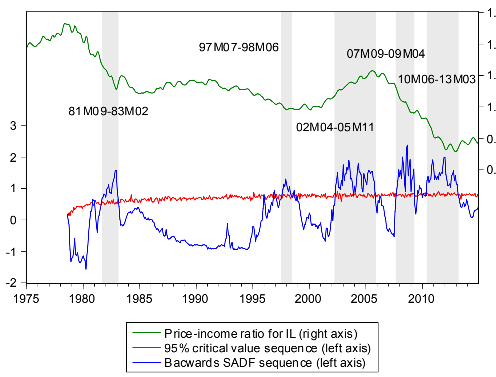
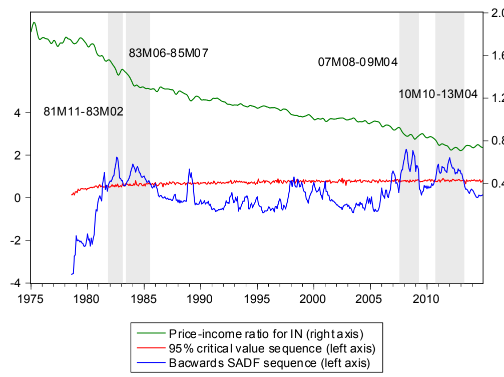


Figure A.15: Date-stamping strategy of price-income ratio for Northeast-Mid-Atlantic States based on the model formulation under the null hypothesis without an intercept.

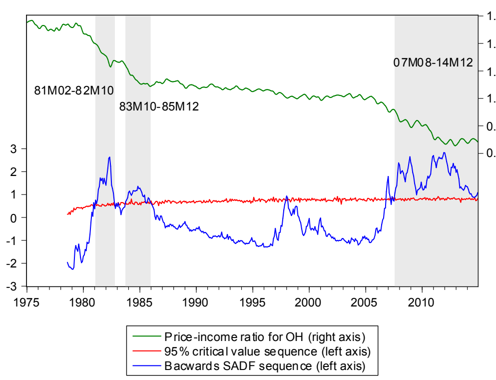
(a) Illinois (IL)



(b) Indiana (IN)



(c) Ohio (OH)



(d) Minnesota (MN)

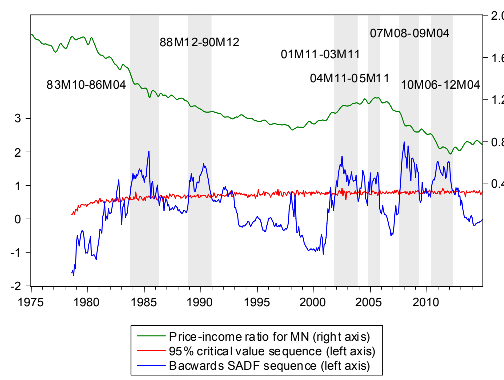
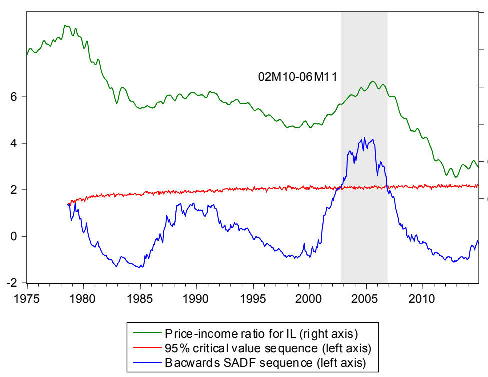
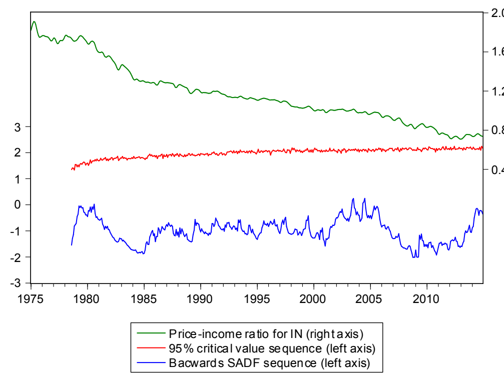


Figure A.16: Date-stamping strategy of price-income ratio for Midwest-East/West North Central States based on the model formulation under the null hypothesis with an intercept.

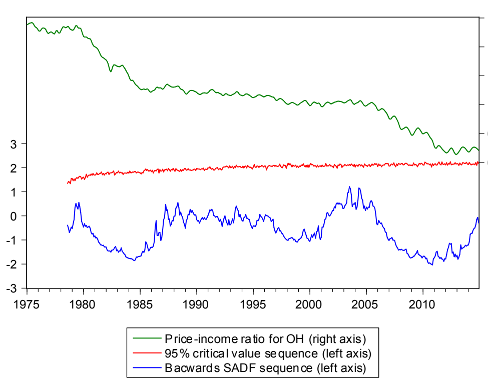
(a) Illinois (IL)



(b) Indiana (IN)



(c) Ohio (OH)



(d) Minnesota (MN)

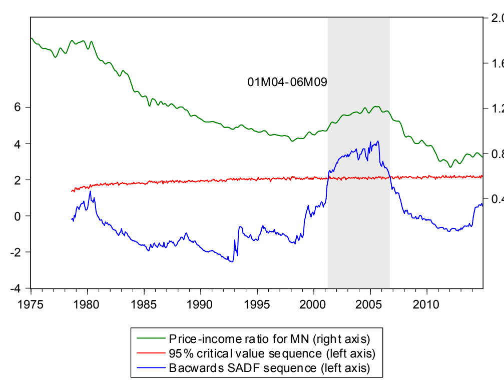
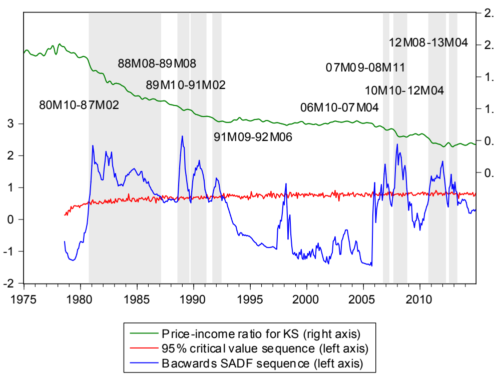
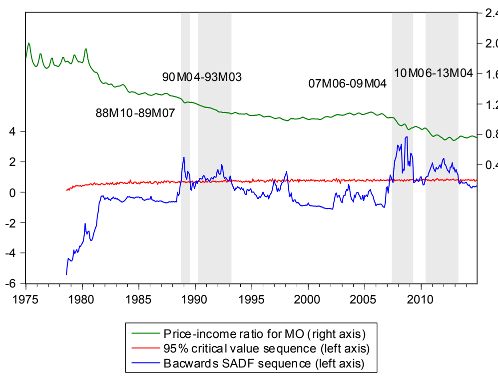


Figure A.17: Date-stamping strategy of price-income ratio for Midwest-East/West North Central States based on the model formulation under the null hypothesis without an intercept.

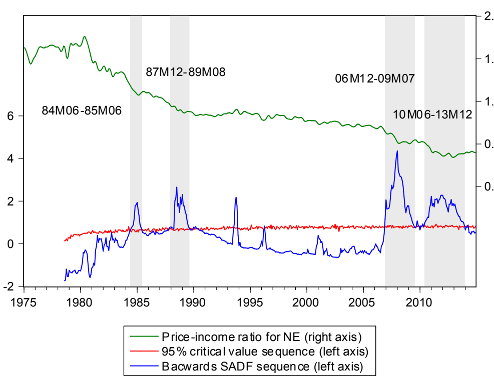
(a) Kansas (KS)



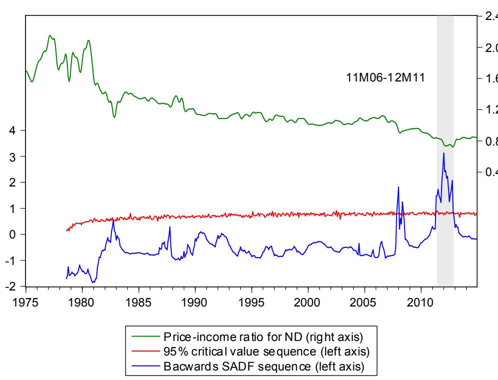
(b) Missouri (MO)



(c) Nebraska (NE)



(d) North Dakota (ND)



(e) South Dakota (SD)

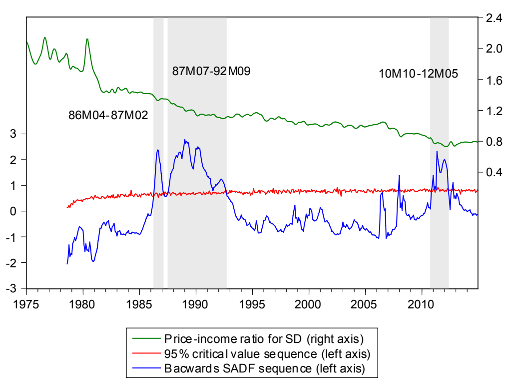
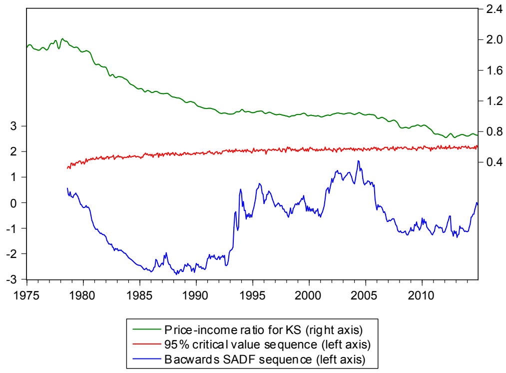
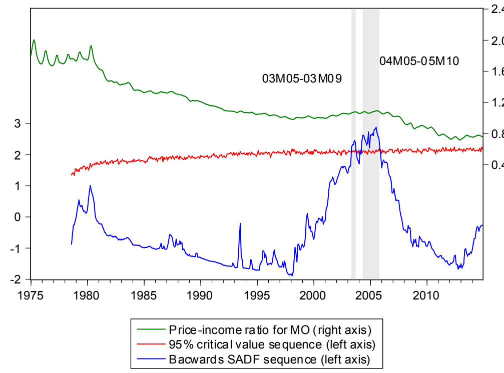


Figure A.18: Date-stamping strategy of price-income ratio for Midwest-West North Central States based on the model formulation under the null hypothesis with an intercept.

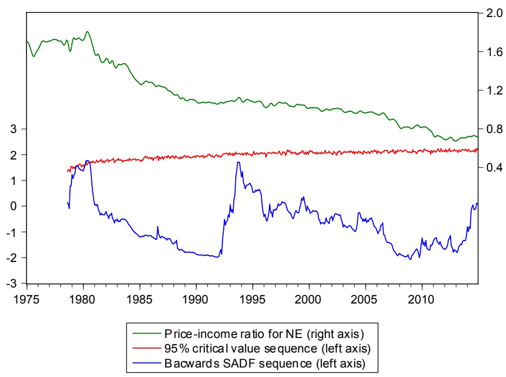
(a) Kansas (KS)



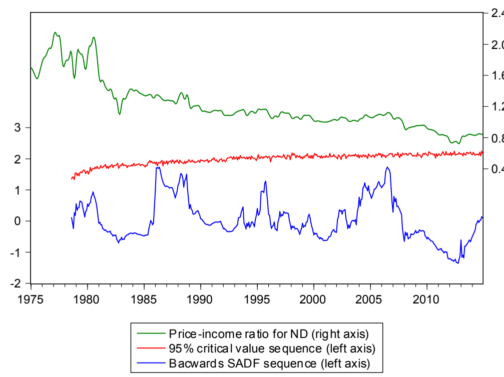
(b) Missouri (MO)



(c) Nebraska (NE)



(d) North Dakota (ND)



(e) South Dakota (SD)

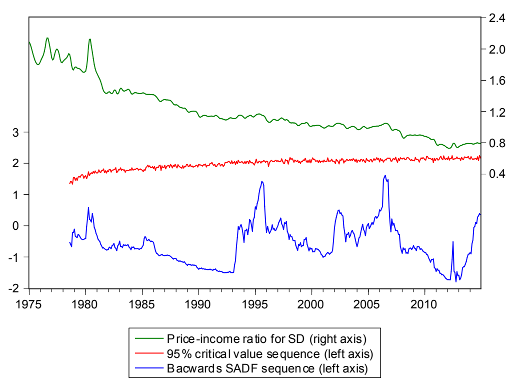
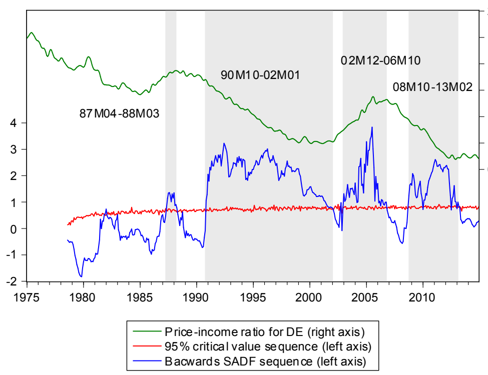
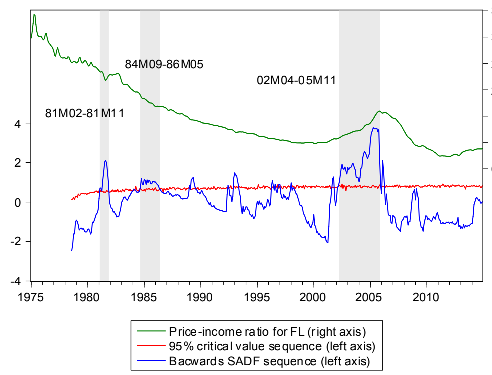


Figure A.19: Date-stamping strategy of price-income ratio for Midwest-West North Central States based on the model formulation under the null hypothesis without an intercept.

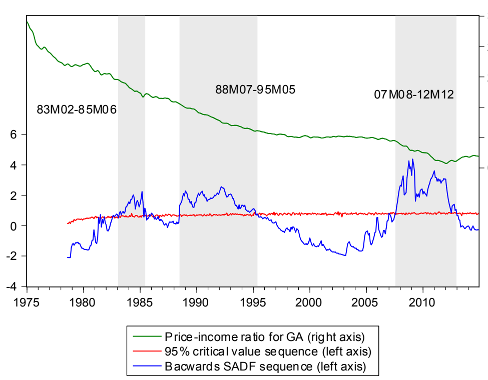
(a) Delaware (DE)



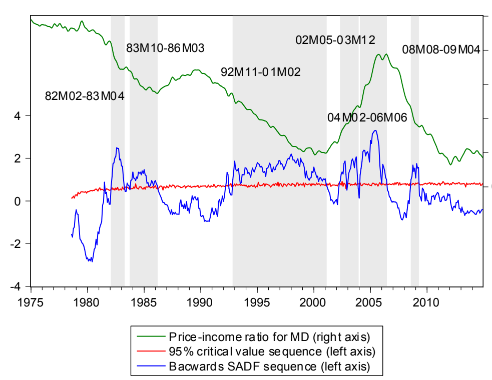
(b) Florida (FL)



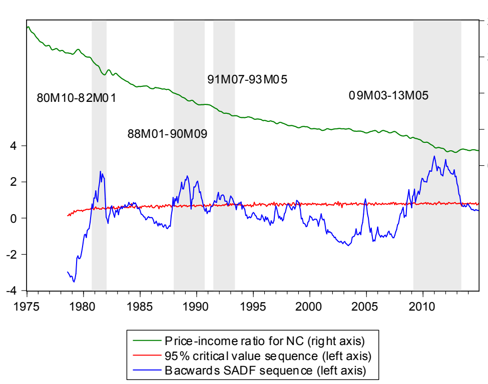
(c) Georgia (GA)



(d) Maryland (MD)



(e) North Carolina (NC)



(f) South Carolina (SC)

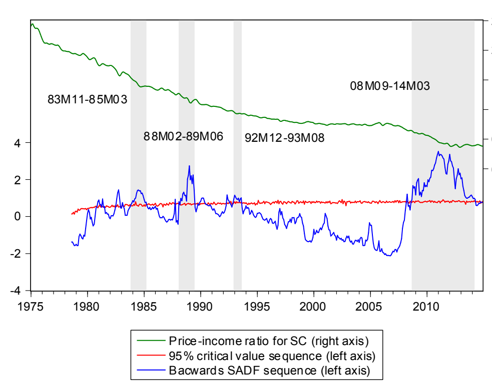
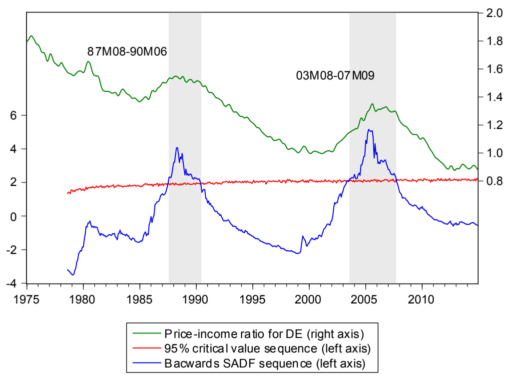
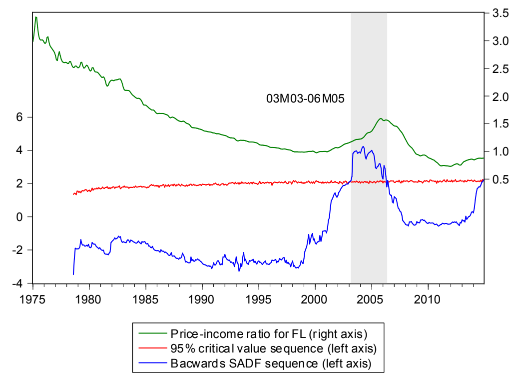


Figure A.20: Date-stamping strategy of price-income ratio for South Atlantic States based on the model formulation under the null hypothesis with an intercept.

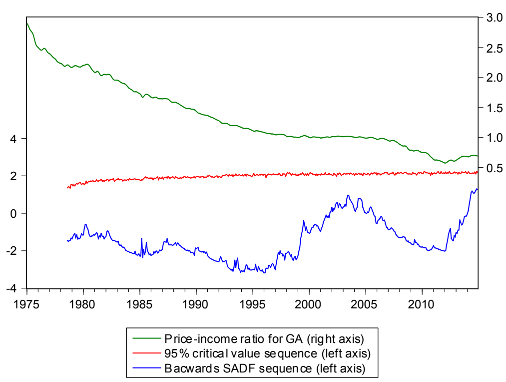
(a) Delaware (DE)



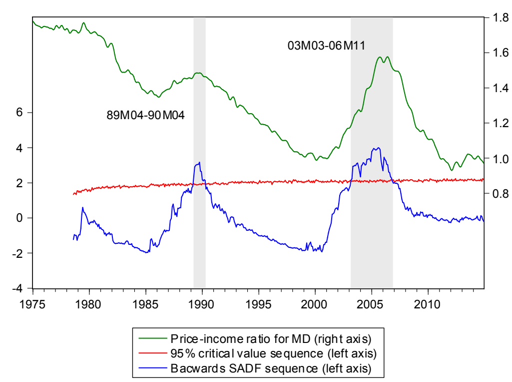
(b) Florida (FL)



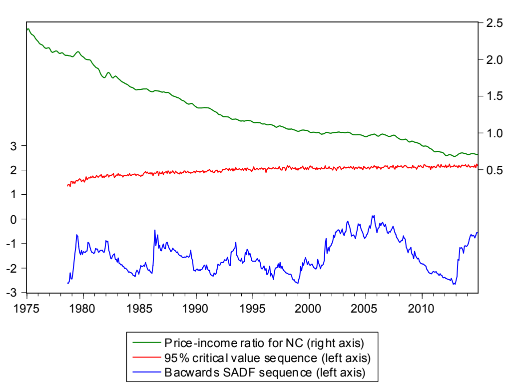
(c) Georgia (GA)



(d) Maryland (MD)



(e) North Carolina (NC)



(f) South Carolina (SC)

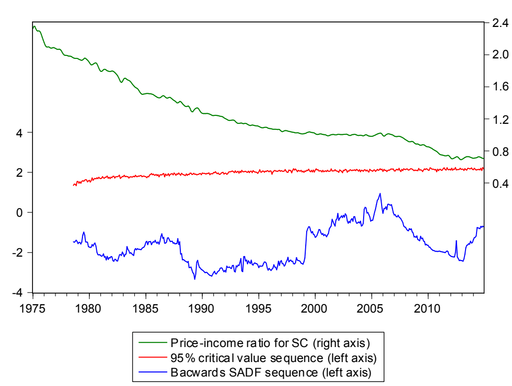
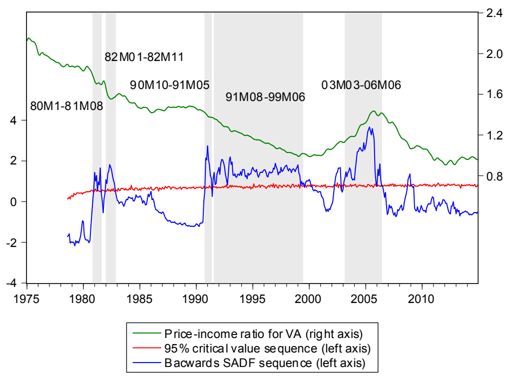
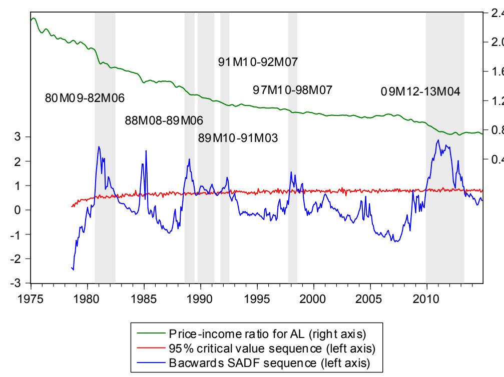


Figure A.21: Date-stamping strategy of price-income ratio for South Atlantic States based on the model formulation under the null hypothesis without an intercept.

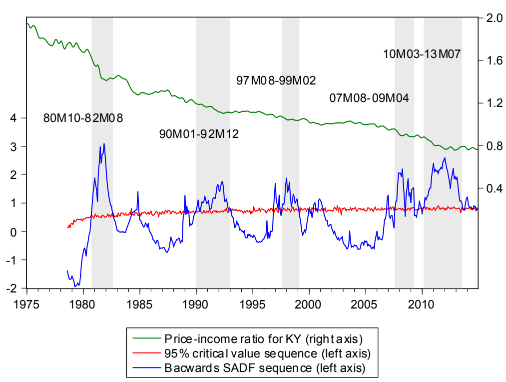
(a) Virginia (VA)



(b) Alabama (AL)



(c) Kentucky (KY)



(d) Mississippi (MS)

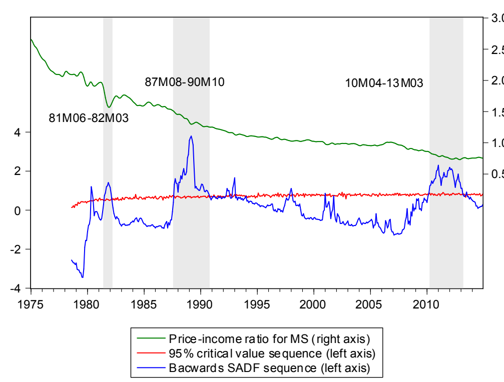
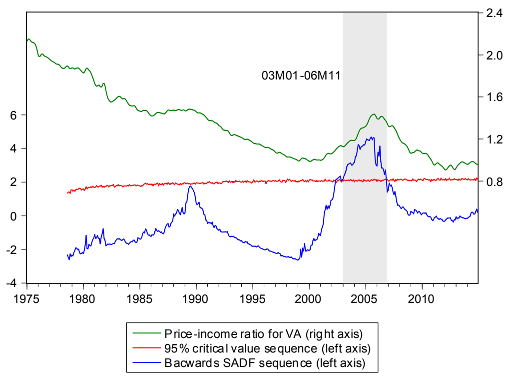
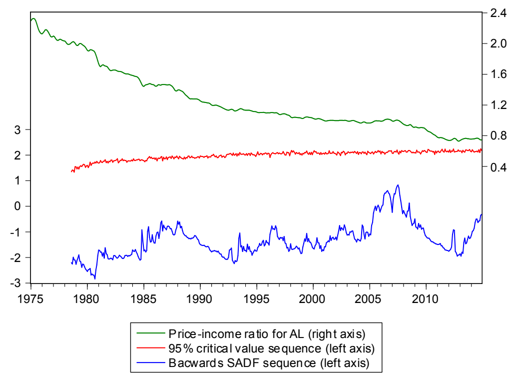


Figure A.22: Date-stamping strategy of price-income ratio for South Atlantic / East South Central States based on the model formulation under the null hypothesis with an intercept.

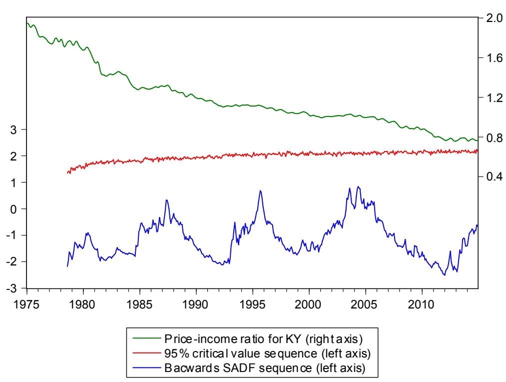
(a) Virginia (VA)



(b) Alabama (AL)



(c) Kentucky (KY)



(d) Mississippi (MS)

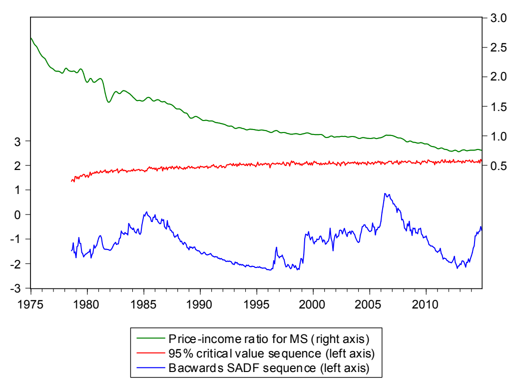
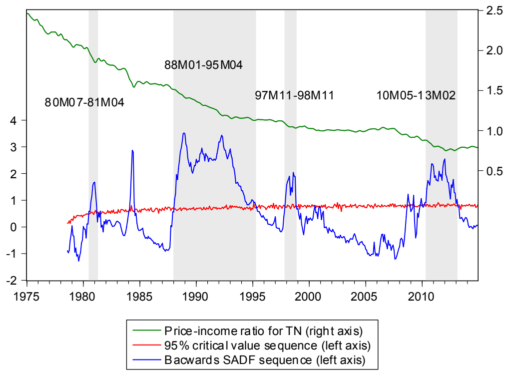


Figure A.23: Date-stamping strategy of price-income ratio for South Atlantic / East South Central States based on the model formulation under the null hypothesis without an intercept.

(a) Tennessee (TN)



(b) Arkansas (AR)

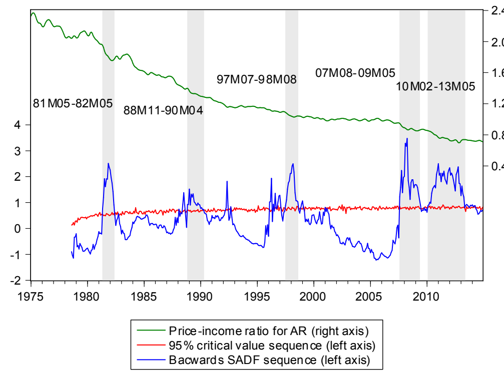
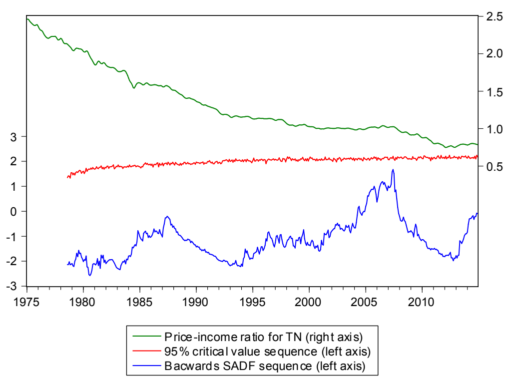


Figure A.24: Date-stamping strategy of price-income ratio for East / West South Central States based on the model formulation under the null hypothesis with an intercept.

(a) Tennessee (TN)



(b) Arkansas (AR)

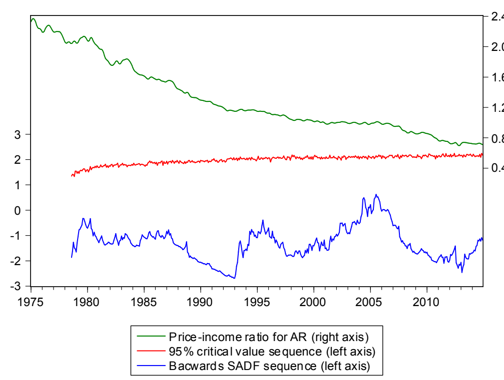
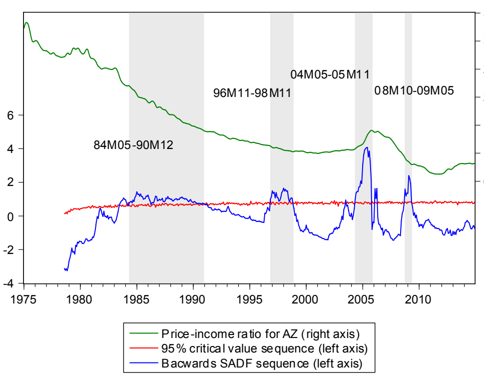
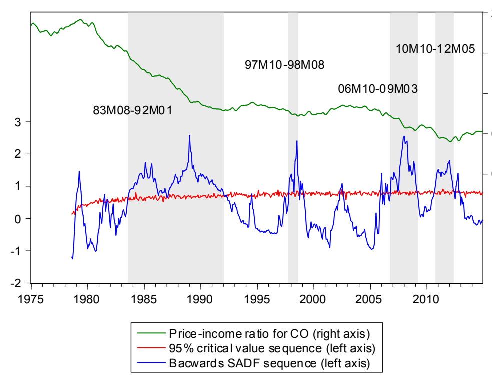


Figure A.25: Date-stamping strategy of price-income ratio for East / West South Central States based on the model formulation under the null hypothesis without an intercept.

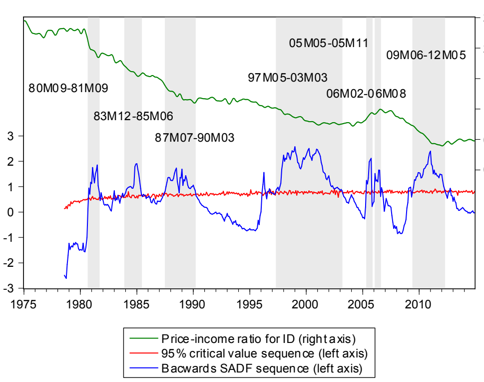
(a) Arizona (AZ)



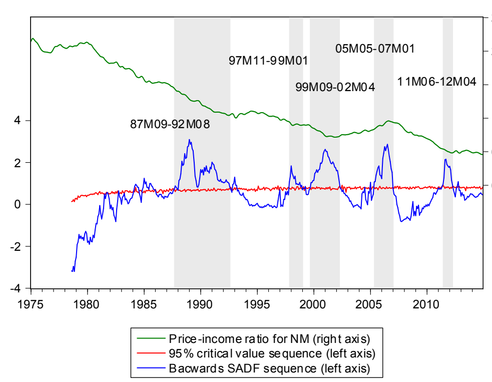
(b) Colorado (CO)



(c) Idaho (ID)



(d) New Mexico (NM)



(e) Utah (UT)

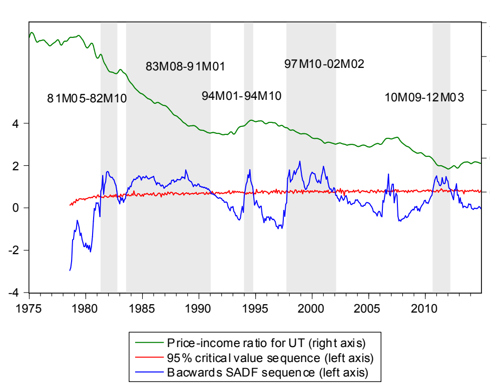
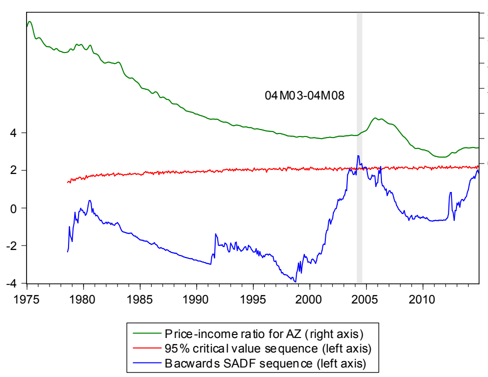
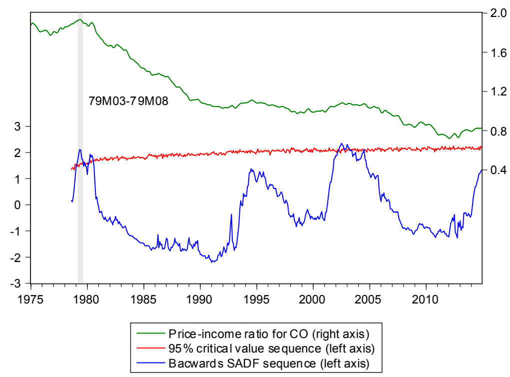


Figure A.26: Date-stamping strategy of price-income ratio for West-Mountain States based on the model formulation under the null hypothesis with an intercept.

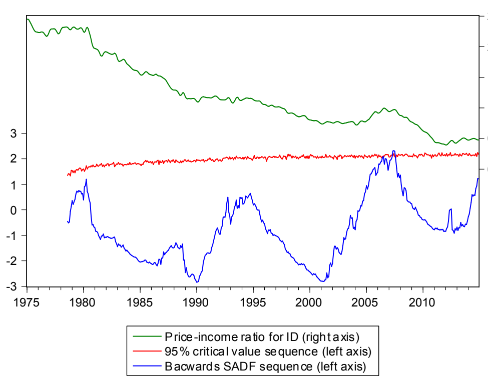
(a) Arizona (AZ)



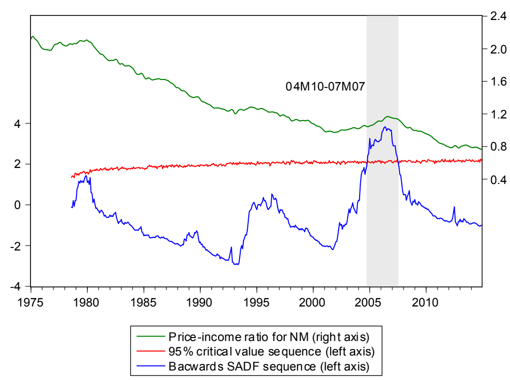
(b) Colorado (CO)



(c) Idaho (ID)



(d) New Mexico (NM)



(e) Utah (UT)

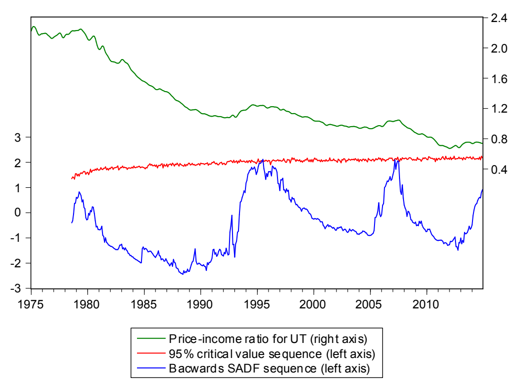
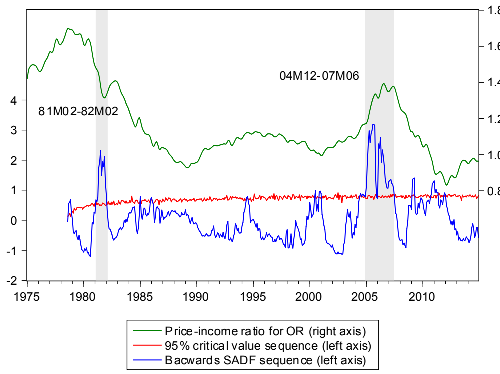


Figure A.27: Date-stamping strategy of price-income ratio for West-Mountain States based on the model formulation under the null hypothesis without an intercept.

(a) Oregon (OR)



(b) Washington (WA)

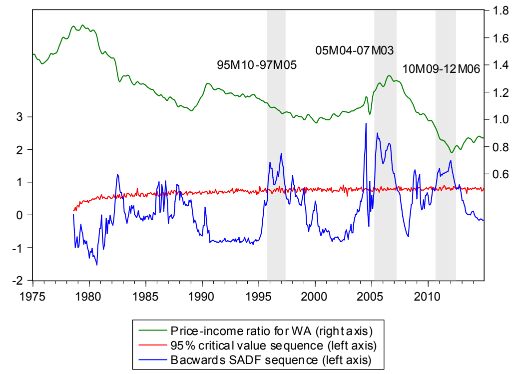
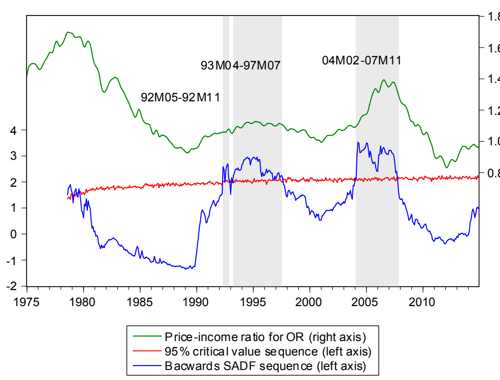


Figure A.28: Date-stamping strategy of price-income ratio for West-Pacific States based on the model formulation under the null hypothesis with an intercept.

(a) Oregon (OR)



(b) Washington (WA)

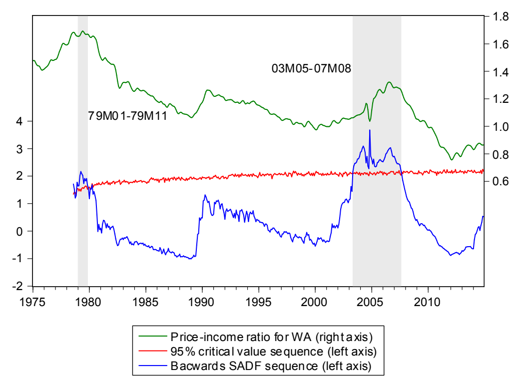


Figure A.29: Date-stamping strategy of price-income ratio for West-Pacific States based on the model formulation under the null hypothesis without an intercept.