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Explosive Behaviour in Australian Housing Markets: Rational Bubbles or Not?

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Abstract
Using recently developed econometric procedures (Phillips, Wu and Yu, 2011; Phillips, Shi and Yu, 2015), we find evidence of temporary episodes of explosive behaviour in price-to-rent ratios for established houses, in five of Australia's largest cities. One interpretation of our results is that stochastic, rational bubbles were a feature of Australia's major housing markets; particularly during the early to mid-2000s. However, further analysis of each city's price-to-rent ratio indicates a very different pattern of behaviour in Sydney and Perth to that experienced in Brisbane, Adelaide and Canberra. For the latter three cities, we present evidence suggesting the explosive root tests are likely capturing the effects of a one-time structural break in their respective price-to-rent ratios. In any event, based on the estimated timing of the explosive episodes in Australia's housing markets, there is little evidence that what might be identified as house price bubbles had any important negative consequences for the wider economy. Despite the ability of the econometric procedures to provide a real-time signal of explosive behaviour, results from Australian housing markets, suggest policymakers need to be cautious in responding too aggressively to a positive signal from the tests.

JEL Classification Numbers: C22, G12, R30,
Key Words: Housing markets; Price-to-rent ratio; Rational Bubbles; Explosive roots

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1.0_Introduction

There has been a persistent debate over whether house prices in Australia are overvalued; in the sense that market prices are too high relative to some fundamental value for residential property. Advocates of the overvaluation hypothesis typically use indicators such as house price-to-income or house price-to-rent ratios as the basis for their claims (Demographia, 2015; The Economist, 2015). The case for overvaluation is often made by comparing the current value of these ratios to historical norms or by comparing the magnitude of the ratios in Australia to the values in other advanced countries. In fact standard measures of price-to-income and price-to-rent ratios for Australia have exhibited an upward trend over the last two decades and are typically at the high-end of international comparisons. However an inherent problem with this type of analysis – for drawing conclusions about overvaluation – is that price-to-rent and price-to-income ratios are themselves likely to be influenced by other economic factors and, in practice, tend to exhibit relatively persistent low-frequency fluctuations.

One potential source of overvaluation in Australian housing markets is the presence of speculative bubbles. Bubbles provide one mechanism which can lead house prices to (positively) diverge from economic fundamentals. In practice it is difficult to test for the existence of speculative bubbles (Gürkaynak, 2008). A key problem is distinguishing between the effects of economic fundamentals on an asset's price and the possible effects of a speculative bubble. Consider a situation where the price of an asset depends on its fundamental value and on a bubble. Fluctuations in the asset's price are driven by a combination of economic fundamentals and the bubble term, both of which are typically unobserved. So even if we observe sharp rises and falls in the asset price, how can one be really certain that these changes are caused by the bubble and are not due to changes in economic fundamentals? In principle it is possible to establish the absence of a bubble, if – subject to sampling uncertainty – 100 percent of the variation in an asset's price can be explained by some econometric model of economic fundamentals (Cochrane, 1992). In practice it is difficult to identify good specifications for asset prices; so it is generally unclear when economic fundamentals do not fully explain the observed variation in an asset's price, whether this is due to a speculative bubble or because the model for fundamentals is mis-specified?

In recent work Phillips and co-authors have developed econometric tests which have power to detect rational speculative bubbles (Phillips, Wu and Yu, (PWY) 2011; Phillips, Shi and Yu (PSY), 2015). Present value models of asset prices allow for the presence of a rational bubble term in an asset price, which grows at an explosive rate. If there is some probability attached to a bubble bursting in any period, this gives rise to stochastic bubbles that can grow explosively for a random period of time, before collapsing. The approach used in the PWY and PSY procedures is to search a univariate time-series on asset prices for temporary periods of explosive behaviour. Subject to some minimum length requirement, a bubble is identified with the periods during which the auto-regressive root for the time-series is (statistically) explosive (greater than unity). The distribution of the test statistic is non-standard but critical values can be calculated using simulations. A potentially attractive feature of these tests – compared to conventional tests for bubbles – is that identification of a bubble episode does not require a correct model for fundamentals.

In this paper we apply the PWY and PSY tests to measures of house price-to-rent ratios in Australia's six largest capital cities[1]. We find evidence of temporary periods of explosive behaviour in price-to-rent ratios in all cities except Melbourne. Taken at face-value, our results can be interpreted as providing support for the existence of speculative bubbles (or periods of overvaluation) in most of Australia's major housing markets in the early to mid-2000s and also in the Sydney market at the beginning of 2015. However closer inspection indicates that price-to-rent ratios display different behaviour in Sydney and Perth than in Brisbane, Adelaide and Canberra. In Sydney and Perth, price-to-rent ratios reached a maximum value – around the estimated time of their 2000 bubble episodes – and subsequently declined. In the other three cities, price-to-rent ratios grew rapidly in the early to mid-2000s, but have subsequently remained at a permanently higher level. This behaviour suggests that the explosive root tests may have power against alternative hypotheses – other than a rational bubble – such as abrupt structural breaks in fundamentals or nonlinear adjustment in the price-to-rent ratio to changed fundamentals (Pavlidis, Yusupova, Paya, Peel, Martinez-Garcia, Mack and Grossman, 2015).

To investigate these possible alternatives, we estimate a fundamental equilibrium model of a city's price-to-rent ratio for the period prior to the estimated start-date of their bubble

[1] Hobart and Darwin are not analysed due to their relatively shorter data samples.

episodes. This model is then used to forecast a path for the long-run (or steady-state) fundamental value of the price-to-rent ratio over the remainder of the sample. Since a rational bubble episode is expected to be transitory, we might expect to observe some convergence between the forecast fundamentals and the observed price-to-rent ratio after the bubble has burst. While we do find some evidence of convergence between estimated fundamentals and house price-to-rent ratios for Sydney and Perth, this is not the case for Brisbane, Adelaide and Canberra. To provide some further evidence we apply a test for parameter stability in co-integrating regressions due to Hansen (1992) to our fundamental models – estimated on the full sample – and find evidence of a break in the effect of the real interest rate on price-to-rent ratios in Brisbane and Adelaide just prior to the periods identified as bubbles by the PSY test. In the end we view our empirical results as being suggestive, rather than being strongly conclusive – with regard to bubbles – but in any event they may be sufficient to lead to some updating of prior beliefs.

In the final section of the paper we examine the possible policy implications of our findings. With the benefit of hindsight, it appears the explosive episodes that are identified in Australian housing markets in the 2000's, had relatively benign macroeconomic consequences. Whether this best reflects the outcome of actions taken by the Reserve Bank at that time, or represents a case where asset price bubbles did not have spill-over consequences for aggregate economic activity, is an open question (Bloxham, Kent and Robson, 2010).

The remainder of the paper has the following structure. Section 2 provides a review of the literature on Australian housing markets as it relates to evidence about bubbles. A description of the PWY and PSY tests for explosive roots is provided in Section 3. The data used in the study are described in Section 4, with the results of testing for explosive roots reported in Section 5. Section 6 presents additional evidence on whether it is reasonable to interpret the results from the explosive root tests as being indicative of a speculative bubble. Policy issues are examined in Section 7 and Section 8 concludes.

2.0_Related Literature

The relative importance of economic fundamentals verses overvaluation as drivers of Australian house prices is a common theme of many previous empirical studies. Bodman and Crosby (2004) report model-based estimates of the degree to which house prices in Australia's five biggest cities are over or undervalued relative to the predictions of a set of fundamentals. They find the Brisbane market to be overvalued by 25 percent and Sydney by 15 percent around mid-2003. To address the question of overvaluation Fry, Martin and Voukelatos (2010) use a structural vector auto-regression (VAR) model. Their results imply aggregate house prices in Australia displayed two periods of overvaluation during the period 2002-2008; in the first, the degree of overvaluation reached a peak of 15 percent towards the end of 2003 and in the second, it reached a peak of about 12 percent at the end of 2007.

Costello, Fraser and Groenewold (2011) analyse data on house price-to-income ratios for Australia's eight (State and Territory) capital cities.[2] They use the VAR methodology proposed by Campbell and Shiller (1987) to test the implications of a present value model for house prices with time-varying expected returns. The testing procedure is derived under the assumption of no rational bubbles, so provided the restrictions imposed on the VAR are not rejected, this can be viewed as evidence against a rational bubble as a source of overvaluation. In their analysis Costello, Fraser and Groenewold find – using standard Dickey-Fuller tests – log price-to-income ratios are non-stationary. However using the Johansen (1995) approach they do find evidence in all cities of a cointegrating relationship between log real house prices and log real income. Partly based on this result they undertake the Campbell-Shiller tests assuming stationary log price-to-income ratios. For all cities except Hobart, the formal restrictions implied by the present value model are rejected by the data and for the period after 2000 actual house prices in most capitals exhibit persistent deviations from the VAR-based estimates of fundamental price. It seems reasonable to conclude that the results from the study cannot strongly rule out rational bubbles in Australia's major property markets.

A present value framework is also used by Hatzvi and Otto (2008) to interpret the behaviour of residential property prices in local government areas of Sydney from 1991-2006. As part of the analysis the authors use a methodology due to Cochrane (1992) to estimate the contributions made by expected variations in real rent growth and real housing returns to fluctuations in the price-to-rent ratio. Their results suggest that a higher proportion of changes in price-to-rent ratios for apartments can be accounted for by fundamentals, than is the case for houses. In addition, for both apartments and houses in local government areas that are relatively distant from the CBD, there is considerable

[2] The data sample is for the period 1984 to 2008, expect for Hobart (begins in 1991) and Darwin (begins in 1994).

variation in price-to-rent ratios not accounted for by expected returns or expected rent growth. This leaves some role for rational bubbles to have influenced house prices in Sydney.

In a recent paper Fox and Tulip (2014) use matched price and rent data for Australian residential properties to compare the relative cost of renting to the (user-cost) of owning. The absence of arbitrage opportunities implies that these two alternative means of purchasing housing services should be equalised – at least over the longer term. Overvaluation is identified with a situation whereby the cost of owning is markedly higher than the cost of renting. One difficulty with this type of analysis is that an important influence on the user cost of housing is the expected future growth of real house prices. Since this variable cannot be directly observed, the issue of overvaluation will typically depend critically upon what is assumed about future appreciation of house prices. Fox and Tulip find that houses were fairly valued (in 2014) if real house prices were expected to grow at a rate similar to their long-run (post-1955) historical average of about 2.5 percent per annum.

Studies on the determinants of houses prices in Australia by Abelson, Joyeaux, Milunovich and Chung (2005) and Otto (2007) are only indirectly concerned with the issue of overvaluation and speculative bubbles. However to the extent that an econometric model based on economic fundamentals can provide a good description of the level or growth rate of house prices, it is more difficult to make a case for overvaluation. Abelson, et. al. find evidence for the period 1971 to 2003 that Australian house prices are co-integrated with the real mortgage interest rate; the real value of share prices; real per-capita household disposable income; the exchange rate; the unemployment rate, the consumer price index and the per-capita stock of housing. While a cointegrating relationship does allow for variations in house prices from economic fundamentals, the deviations need to be stationary and this would tend to rule out deviations due to rational bubbles. Otto develops empirical models of the growth rate of real house prices in Australia's eight capital cities for the period 1986 to 2005. One limitation of the study is that use of growth rates will not necessarily be an appropriate means of inducing a stationary series for house prices if there are periods during which rational bubbles generated explosive growth in prices.

While the results obtained by at least some of the previous studies on Australian house prices do not rule out the possibility of speculative bubbles, the validity of such findings depends on having a good fundamental model for house prices. Furthermore the main focus of much of the previous has not been concerned with formal tests of the presence and timing of bubble periods. It is to this issue that we now turn.

3.0_Testing for an Explosive Root

Phillips, Wu and Yu (2011) and Phillips, Shi and Yu (2015) develop econometric methods that can be used to test whether a time series exhibits temporary episodes of explosive behaviour. As outlined below such behaviour is consistent with the predictions of the present value model of an asset price that is subject to stochastic rational bubble episodes. Following this the PWY and PSY tests are briefly described. We also review some findings obtained from recent applications of these tests to residential property markets.

Present Value Model for the House Price-to-Rent Ratio

The following model links the logarithm of the house price-to-rent ratio to a constant, expected future growth in rents, expected future returns to housing and a stochastic rational bubble (Campbell and Shiller, 1988).[3]

$$p_t^h - v_t^h = \frac{k}{1-\rho} + E_t\left[\sum_{j=0}^{\infty} \rho^j \left(\Delta v_{t+1+j}^h - r_{t+1+j}^h\right)\right] + b_t \qquad (1)$$

The left-hand side of equation (1) shows the difference between the log of real house prices p^h and the log of real rents v^h. On the right-hand side there is a constant which depends on $\rho \equiv 1/[1 + \exp(\overline{v^h - p^h})]$, where $(\overline{v^h - p^h})$ is the average log rent-to-price ratio and on $k \equiv -\log(\rho) - (1-\rho)\log(\frac{1}{\rho} - 1)$. The other three right-hand side variables provide sources of variation in house price-to-rent ratios. These include expected changes in future real rent growth rates, expected changes in future real returns and a stochastic rational bubble b_t; which must satisfy the following condition,

$$E_t b_{t+1} = \frac{1}{\rho} b_t \qquad (2)$$

A periodically collapsing stochastic bubble is an example of a process that satisfies (2) and is given by the following:

$$b_{t+1} = \begin{cases} \frac{1}{\rho\pi} b_t + \varepsilon_{t+1} & prob = \pi \\ \varepsilon_{t+1} & prob = (1-\pi) \end{cases} \qquad (3)$$

[3] Use of expected returns to housing means the present value relationship is an (approximate) identity; but the model can capture various asset pricing theories if expected returns are replaced by a particular stochastic discount factor.

where $E_t \varepsilon_{t+1} = 0$. In equation (3) $(1 - \pi)$ is the probability that a bubble will burst in any period. If the bubble does not burst, it grows at an explosive rate since $\frac{1}{\rho\pi} > 1$. If the present value of future fundamentals is an I(1) series, the observed log price-rent ratio will generally be I(1), but due to (3) will exhibit temporary periods of explosive behaviour. Evidence on the existence of such behaviour can be provided using the tests of Phillips, Wu and Yu (2011) and Phillips, Shi and Yu (2015).

Phillips, Wu and Yu (2011)

PWY propose a forward recursive test for a temporary explosive root based on the following ADF test regression;

$$\Delta y_t = a_{0,r2} + \beta_{0,r2} y_{t-1} + \sum_{i=1}^{k} \theta_{0,r2}^{i} \Delta y_{t-i} + v_t \qquad (1)$$

where y_t is the series under test and v_t is assumed to be independently and identically distributed with zero mean and variance $\sigma_{0,r2}^2$. The index $r2$ corresponds to the fraction of the sample size over which a test regression is estimated (i.e. the end point of a subsample). In the PWY approach the starting point of each subsample is held fixed at some initial observation denoted by 0. The recursive estimation begins with some minimum sample size (or window) and expands forward until the final observation ($r2 = 1$). Each recursion produces an ADF test statistic

$$ADF_{0,r2} = \frac{\hat{\beta}_{0,r2}}{se(\hat{\beta}_{0,r2})} \qquad (2)$$

To test the null hypothesis of a unit root ($\beta_{0,r2} = 0$) against the alternative of an explosive root ($\beta_{0,r2} > 0$), PWY propose using the sup ADF (SADF) test statistic given by:

$$SADF(r0) = \sup_{r2 \in (r0,1)} ADF_0^{r2} \qquad (3)$$

PWY derive the limiting distribution of the SADF statistic along with appropriate critical values. If the value of $SADF(r0)$ exceeds the critical value (for a particular level of significance) the null of a unit root is rejected in favour of the alternative that the series exhibits an explosive root in some particular subsample.

The beginning and the end dates of the subsample of explosive behaviour can be estimated by comparing the ADF test sequence to a sequence of critical values, which increase with T. The date when the ADF test sequence initially exceeds critical value sequence, is identified as the start-date of the explosive root and when the ADF sequence next falls below the critical value sequence that indicates the end-date of the explosive root.

While the PWY test is relatively easy to implement, it is derived under the assumption that the population series contains only a single episode of explosive behaviour, and Phillips, Shi and Yu (2015) argue that the test may have low power if there are multiple episodes of explosive roots.

Phillips, Shi and Yu (2015)

PSY develop a test procedure that has good properties when a series exhibits multiple explosive episodes. The PSY test procedure generalises the SADF test by allowing the starting date for the sequence of ADF tests to vary. Thus equation (1) becomes

$$\Delta y_t = a_{r1,r2} + \beta_{r1,r2} y_{t-1} + \sum_{i=1}^{k} \theta_{r1,r2}^{i} \Delta y_{t-i} + v_t \quad (4)$$

where both the starting point $r1$ and ending point $r2$ of a subsample is allowed to vary. PSY refer the resulting test statistic to as Generalised Supremum ADF (GSADF) statistic and it is defined by:

$$GSADF(r0) = \sup_{r2 \in [r0,1]} \sup_{r1 \in [0,r2-r0]} ADF_{r1}^{r2} \quad (5)$$

PSY derive the limiting distribution of the GSADF statistic along with appropriate critical values. If the value of $GSADF(r0)$ exceeds the critical value (for a particular level of significance) the null of a unit root is rejected in favour of the alternative that the series exhibits at least one subsample with an explosive root.

As with the SADF test , if the GSADF test leads to the rejection of the unit root null, PSY suggest a procedure to identify the timing (beginning and end) of the explosive episodes. PSY recommend using an approach to date explosive periods based on the following backward sup ADF statistic;

$$BSADF_{r2}(r0) = \sup_{r1 \in [0,r2-r1]} BADF_{r1}^{r2} \quad (6)$$

In (6) $BSADF_{r2}(r0)$ is a sequence of test statistics that are compared to a sequence of critical values obtained by simulation. Subject a minimum length requirement (to eliminate incredibly short explosive episodes) the beginning of an explosive episode occurs if the *BSADF* sequence is greater than the relevant critical value and ends when the *BSADF* sequence falls below the relevant critical value. In this paper we use the approach based on the *BSADF* sequence to date the timing of periods of temporary explosive behaviour.

Applications

The PWY and PSY tests for explosive roots have been applied to a number of different asset markets, including residential property. We review four studies that are of relevance to our analysis.

Phillips and Yu (2010) apply the SADF test to a number of asset markets, including a measure of real house prices in the United States (US). They use the seasonally adjusted S&P Case-Shiller Composite 10 Index for monthly US house prices from Jan 1987 to Jan 2009. The house price index is deflated by the US CPI. The sample size is 265 observations. The size of the SADF test statistic implies the null hypothesis of a unit root is strongly rejected in favour of the explosive alternative. Using the dating procedures proposed by PWY, suggests an explosive period commenced in the early 2000s and ended either just prior to the start of GFC or a few months after the start of the GFC (dated as August 2007), depending on the choice of test.

Pavlidis, Yusupova, Paya, Peel, Martinez-Garcia, Mack and Grossman (2015) apply the GSADF test and associated bubble-dating procedures to real house prices and house price-to-income ratios for 22 countries, including Australia. In the case of Australia the authors use a quarterly measure of aggregate house prices that begins in 1960:3 and report SADF and GSADF tests.[4] Both tests indicate rejection of a unit root in favour of the explosive alternative. The Pavlidis et. al. analysis is updated quarterly as part of Federal Reserve Bank of Dallas's International House Price Project.[5] Figure 1 shows their sequence of BSADF test statistics and 95% critical values for the Australian data as of 2015:1.

The results in Figure 1 correspond to a data sample of 1975:3 to 2015:1, a minimum window for the test regression of 36 observations and one lag of the dependent variable being included in the regression. Using aggregate real house prices the results suggest three explosive periods; two relatively short episodes, in the late 1980s and in 2007 and then a much more persistent episode beginning in 1999:2 (or possibly 2000:4) and ending in 2004:1. Applying the test to the house price-to-income ratio yields one less period of explosive behaviour and the episode in the early 2000s is estimated to be shorter; beginning in 2002:1 and ending in to 2003:4.

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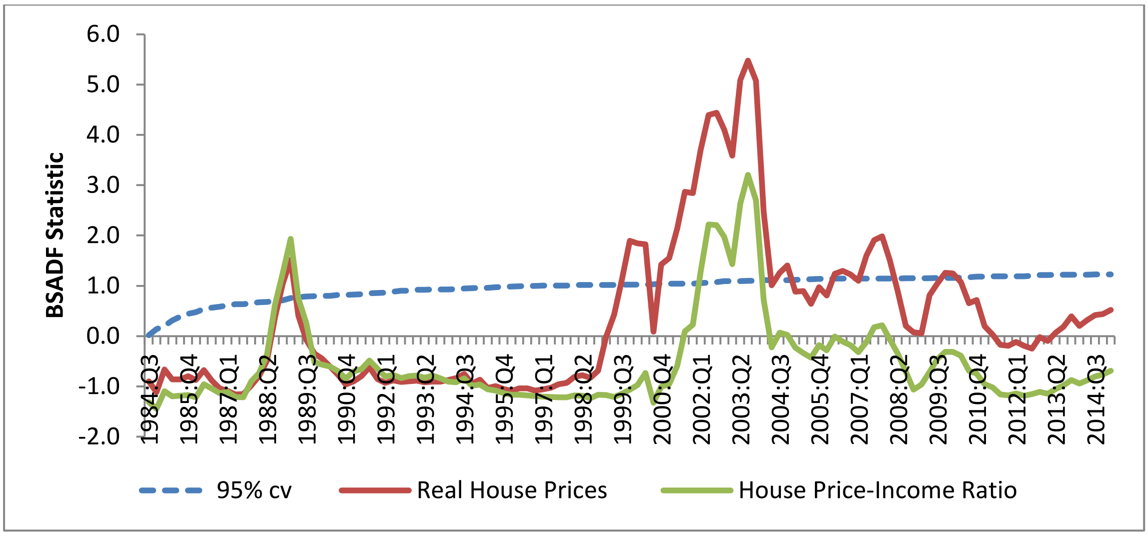
[4] Data since 1986:3 are from the Australian Bureau of Statistics (ABS) and prior from 1960:3 are a Federal Treasury series.

[5] http://www.dallasfed.org/institute/houseprice/

Figure 1: BSADF Test Sequence for Australian House Prices



Both of the above studies test for explosive behaviour using measures of house prices for the aggregate economy. In this paper we examine city-level data on Australian house prices and this allows us to identify differences across cities in terms of both effects and timing. We also focus on testing for explosive behaviour in house price-rent ratios. This variable is consistent with a standard present value model of asset prices. When this model is augmented with a stochastic rational bubble, and economic fundamentals are I(1) or approximately so, it can generate a process for the price-rent ratio that is I(1) but exhibits temporary periods of explosive behaviour.

Two recent studies by Greenaway-McGervy and Phillips (2015) and Shi, Valadkhani, Smyth and Vahid (2015) have also used the PSY approach to test for bubbles in sub-national housing markets in New Zealand and Australia, respectively. Greenaway-McGrevy and Phillips (2015) apply the GSADF tests to house price-to-rent ratios in 72 metropolitan and regional areas in New Zealand for the period 1993:1 to 2014:4. In about two-thirds of the cases there is evidence of explosive episodes in price-to-rent ratios, which Greenaway-McGrevy and Phillips interpret as "exuberance" in housing these housing markets. The BSADF test sequence dates one New Zealand wide explosive episode from 2003 to 2005 and a more recent episode beginning in 2013 which to date seems to be confined to the Auckland metropolitan area.

Shi, Valadkhani, Smyth and Vahid use the BSADF statistic to identify explosive episodes for all of Australia's capital cities (except Darwin). Using a monthly index of the price-to-rent for the period 1995:12 to 2015:8, they find temporary episodes of explosive behaviour in all capital cities. While some cities show evidence of multiple bubbles, a common result for all cities is strong evidence of bubble episodes beginning around the late 1990s or early 2000s. For Melbourne and Sydney the estimated length of their bubbles is around three years while the other capitals have bubbles of around twice this duration. For more recent data, the authors find evidence of an incomplete bubble episode for Sydney beginning in November 2014.

Our analysis in this paper differs from Shi, Valadkhani, Smyth and Vahid in a couple of ways. First we use quarterly data for house prices and rents, which allows us to have a longer sample period, beginning in 1982. Second we investigate whether the results from the bubbles tests for some Australian cities might be driven by a one-time structural change in the relationship between price-to-rent ratios and the real interest rate.

4.0_Price and Rent Data

The data on house prices and rents for our six Australian capital cities are produced by the *Real Estate Institute of Australia*. House prices are measured by the median price for an established house, while rents are measured as the median weekly rent on a three bedroom house. The data are available on a quarterly frequency from 1982:2 to 2015:2. The price-rent ratio is calculated as the median house price divided by the annual rent. Real house prices and real rents are obtained by dividing the series for a capital city by the consumer price index (CPI) for the relevant State.

Figures 2a and 2b show the price-rent ratios for the six cities. The cities are separated into two groups to emphasise differences in behaviour during the 2000s – with data for Melbourne included on both figures as a point of reference. The price-rent ratio series for Sydney and Perth exhibit obvious peaks and subsequent declines. The peak for Sydney is around 2003-04, while for Perth the peak is in 2006-07. Price-rent ratios for Brisbane, Adelaide and Canberra display a similar pattern; rising sharply in the first-half of the 2000s and then (apparently) stabilising at the permanently higher levels.

Figure 2a: Price-Rent Ratios in Sydney, Melbourne and Perth

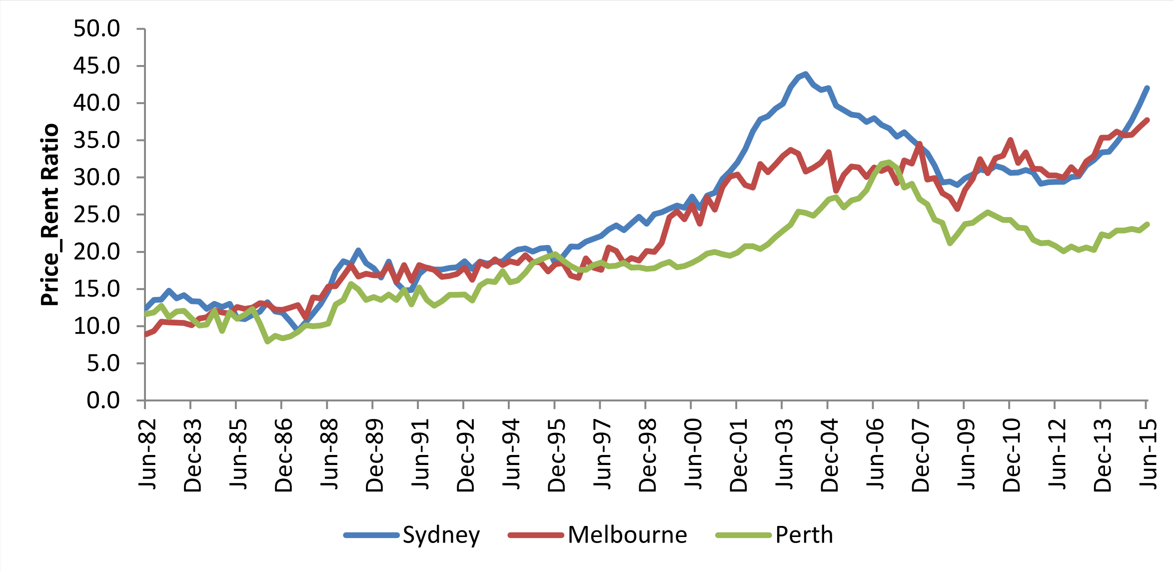
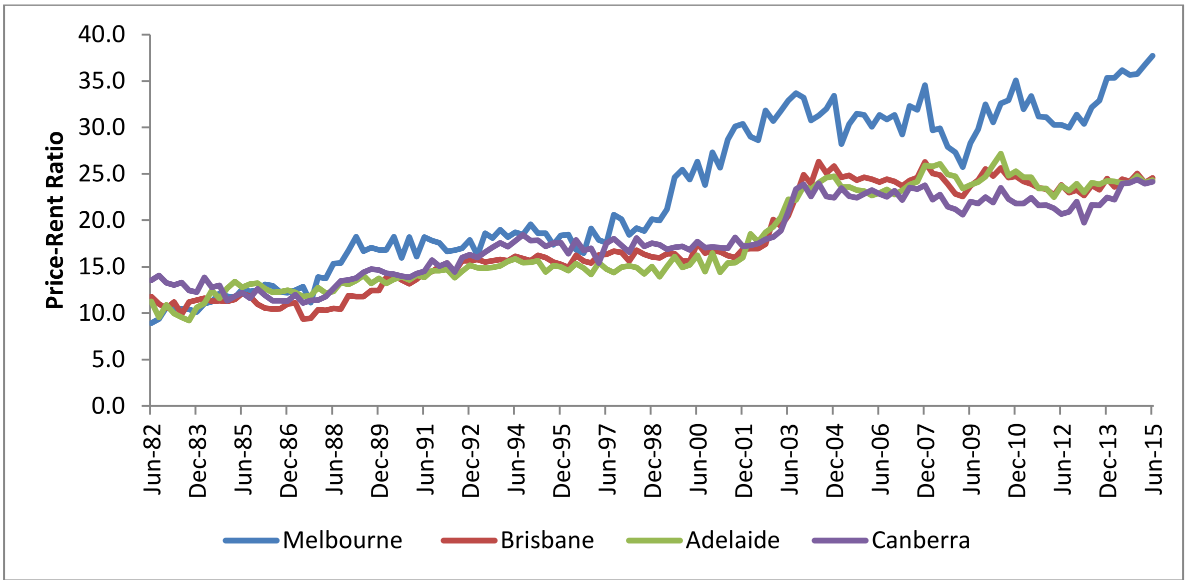


Figure 2b: Price-Rent Ratios in Melbourne, Brisbane, Adelaide and Canberra



All series display upward trends over the sample and visual inspection of the price-to-rent ratios in Figures 2a and 2b suggests that the series are non-stationary. Formal evidence of the non-stationary of the price-to-rent ratios is provided in Table 1 using an augmented Dickey-Fuller (ADF) test and the DF-GLS test (Elliott, Rothenberg and Stock, 1996) for unit roots. Table 1 reports the results for the logarithm of the price-to-rent ratio; although similar conclusions are obtained for each of the series in levels.[6] The magnitudes of the ADF test statistics imply the null of a unit root cannot be rejected against the stationary alternative.

[6] Results are available on request.

Table 1: Unit Root Tests on Logarithm of Price-to-Rent Ratio

	AR coefficient	ADF t-statistic	DF-GLS t-statistic
Sydney	0.94	-2.39 (2)	-2.40 (2)
Melbourne	0.88	-2.53 (1)	-1.59 (1)
Brisbane	0.92	-2.01 (1)	-1.87 (1)
Adelaide	0.90	-2.41 (3)	-2.54 (3)
Perth	0.93	-1.87 (1)	-1.91 (1)
Canberra	0.88	-2.59 (1)	-2.09 (1)

Notes: Results from use of ADF test regression including a constant and linear time trend; based on full sample 1982:2-2015:2. Number of lags (indicated in brackets) is selected by testing-down from a maximum of four lags using a t-test for the significance of last lag (5 percent level). At a minimum, one lag is included in the ADF test regression. The 5% critical value for the ADF test (against the stationary alternative) is -3.44. The DF-GLS tests allow for both a constant and linear time trend. Number of lags (indicated in brackets) is selected by testing-down from a maximum of four lags using a t-test for the significance of last lag (5 percent level). The 5% critical value for the DF-GLS test is -2.89.

The negative values for the ADF test statistics also imply that it would not be possible to reject the null hypothesis of a unit root against the alternative of an explosive root, over the full sample of data. However this does not rule out the possibility of explosive behaviour during particular sub-periods of the sample. It is to this possibility to which we now turn.

5.0_Testing for Explosive Episodes

Table 2 reports the results obtained from applying the SADF and GSADF tests to the house price and rent data for the six capital cities. The tests for an explosive root (or bubble) are applied to the log price-to-rent ratio and separately to real house prices and real rents. The initial regression for the SADF tests uses 30 observations. Conditional on the form of our test regression, the SADF test provides no strong evidence of the presence of a bubble in the log price-to-rent ratios in any of the capital cities. The strongest evidence against the null hypothesis of a unit root in favour for the explosive alternative is found for Brisbane (with a p-value slightly above 0.10). If the SADF test is applied to the log of real house prices, there is evidence of a bubble for Perth and Brisbane. However application of the test to the log of real rents does not point to any evidence of explosive behaviour in this variable.

We can use the approach recommended by PWY to date the beginning and the end of the bubbles in log house prices in Perth and Brisbane. Both cities show evidence of a "double bubble." For Perth we have a bubble from 2004:3 to 2008:3, closely followed by 2009:1 to 2010:4, while for Brisbane we identify as bubble periods 2003:1 to 2008:3 and 2009:3 to

2010:2. The finding of more than one bubble in the data is a potential problem, as PSY (2013) argue that the SADF test can have low power when there are multiple bubble episodes in the series being tested. In response PSY develop the GSADF test, which is shown to have better properties when there are multiple bubbles in a series.

Table 2: SADF and GSADF Tests for Bubbles in Capital City Housing Markets

	SADF			GSADF		
	log(P/R)	lnP	lnR	log(P/R)	lnP	lnR
Sydney	0.11	-0.04	-1.34	**2.56**	**3.50**	**2.46**
Melbourne	-0.07	0.10	0.28	1.21	**2.51**	0.97
Brisbane	1.04	1.27	-0.19	**2.64**	**5.75**	0.56
Adelaide	0.57	0.63	0.08	**2.18**	**4.09**	0.77
Perth	0.16	**1.55**	0.08	**1.98**	**4.63**	**3.00**
Canberra	0.43	0.38	-0.47	**2.59**	**4.01**	0.85

Notes: Critical values for the *S*ADF tests are 1.88 (1%), 1.37 (5%) and 1.10 (10%). Two lags of the dependent variable are included in the regressions for the SADF test. The initial sub-sample for the SADF test is 1983:1-1990:2 (30 observations). Critical values for the GSADF tests are 2.37 (1%), 1.98 (5%) and 1.67 (10%). One lag of the dependent variable is included in the regressions for the GSADF test. The minimum window used for the GSADF test is 24 observations. Asymptotic critical values for the SADF and GSADF test are from PSY (2015, Table 1, $r_0 = 0.19$). Numbers in bold indicate significance at the 5% level (or lower).

The GSADF test statistics reported in Table 2 are based on a minimum window for the test regression of 24 observations and one lag of the dependent variable being included in the regression[7]. Application of the GSADF test to the log price-to-rent ratio points to the existence of explosive behaviour in all capitals except Melbourne. When we apply the test directly to the log real house price, evidence of bubbles is found for all cities. In the case of the log of real rents, the GSADF test indicates explosive behaviour in Sydney and Perth. It is apparent that accounting for the possibility of multiple bubble episodes in a city does result in greater support for the presence of bubbles.

Given the results from the GSADF test, we can use the approach of PSY to identify the bubble periods in the relevant cities. Figures 3 to 8 show the sequence of BSADF statistics for the log price-to-rent ratio along with the 95% critical values for each city. The figures also show the log price-to-rent ratio for the city (measured on the left-had axis). All cities, expect Melbourne, show statistically significant evidence of (transitory) periods of explosive behaviour in the first half of the 2000s. In the case of Melbourne, there is a one-quarter spike (above the 95% critical value) in sequence of BSADF statistics in 1989:1. However given its short duration and the results from the GSADF tests, we do not treat this as evidence of explosive behaviour in the price-to-rent ratio for Melbourne. While most cities

[7] The conclusions of the GSADF test are robust with respect to changing the minimum window to either 16 or 32 observations.

have more than one period where the value of the BSADF test statistic is positive, typically there is only one period where the test statistics are statistically significant; with Sydney and Perth being the exceptions.

Figure 3: BSADF Test Sequence for Sydney

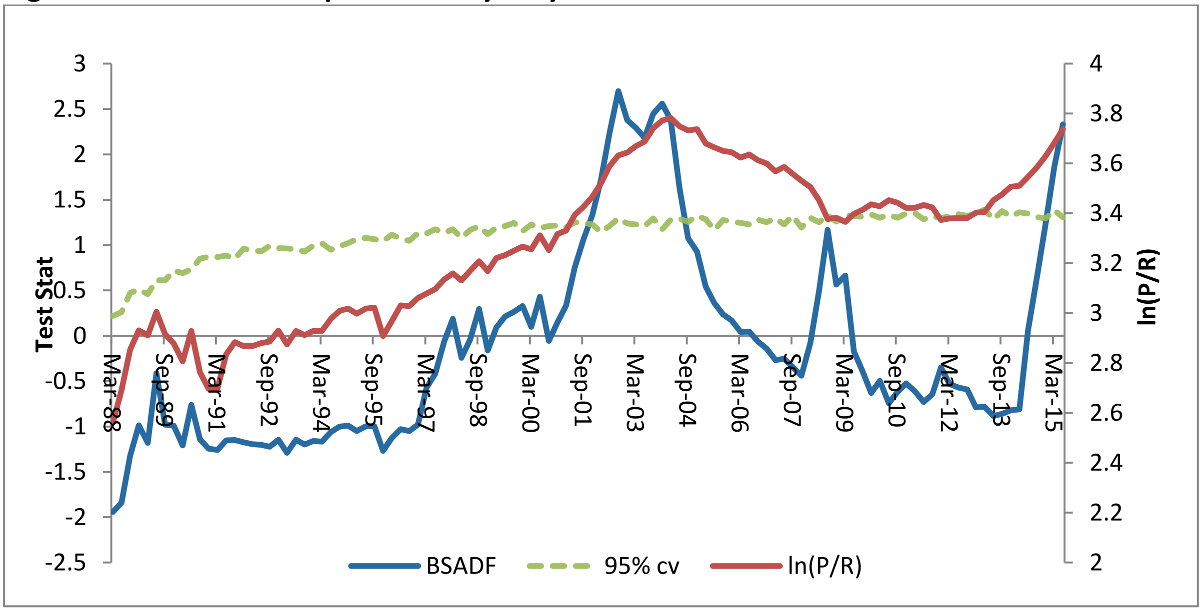


Figure 4: BSADF Test Sequence for Melbourne

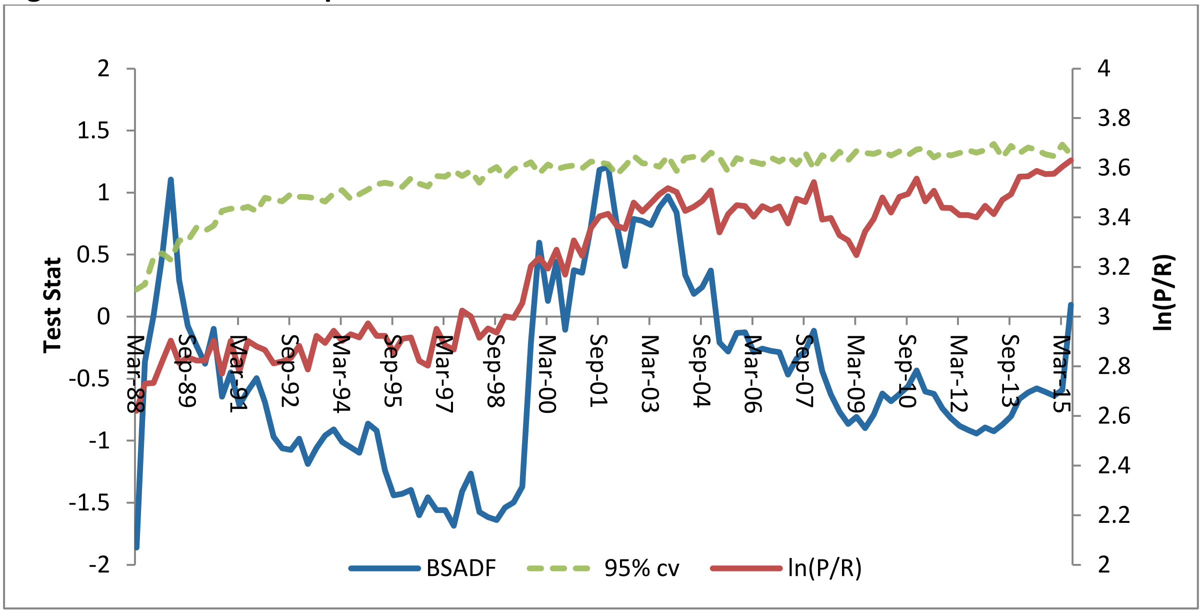


Figure 5: BSADF Test Sequence for Brisbane

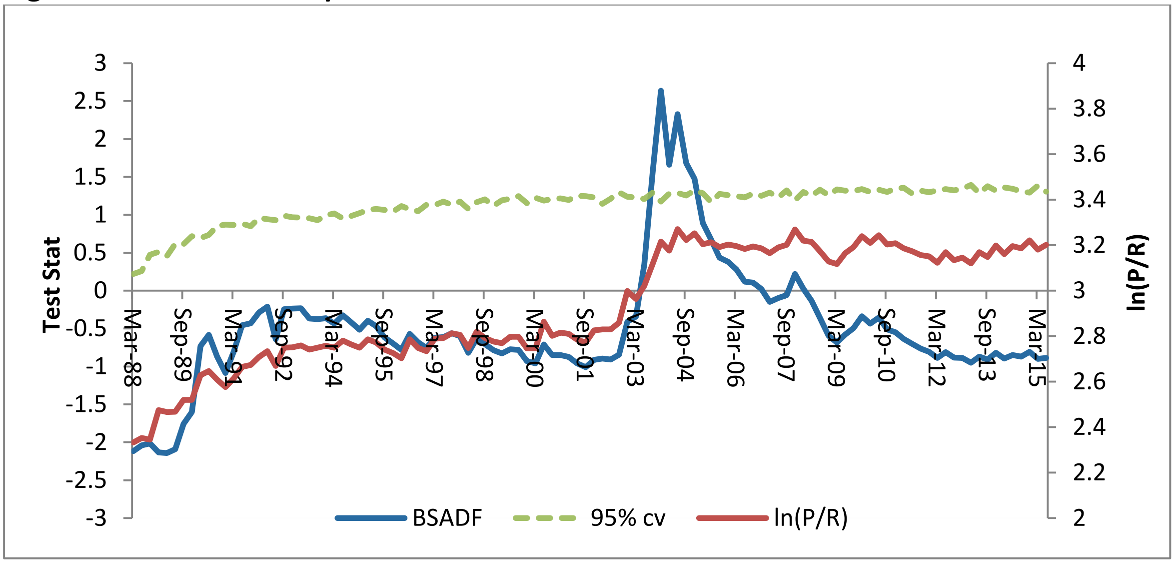


Figure 6: BSADF Test Sequence for Adelaide

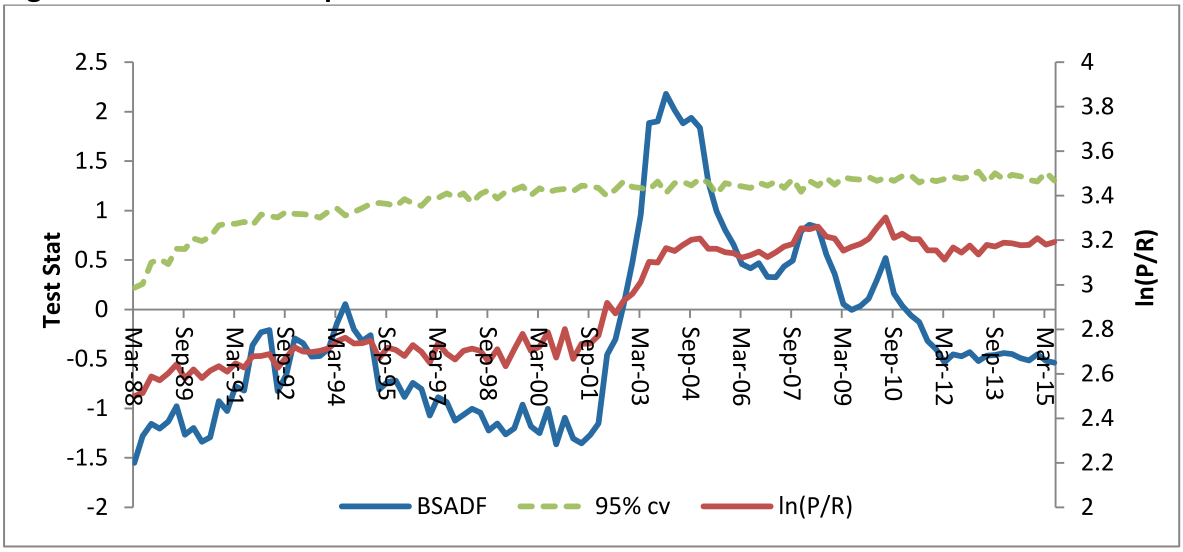


Figure 7: BSADF Test Sequence for Perth

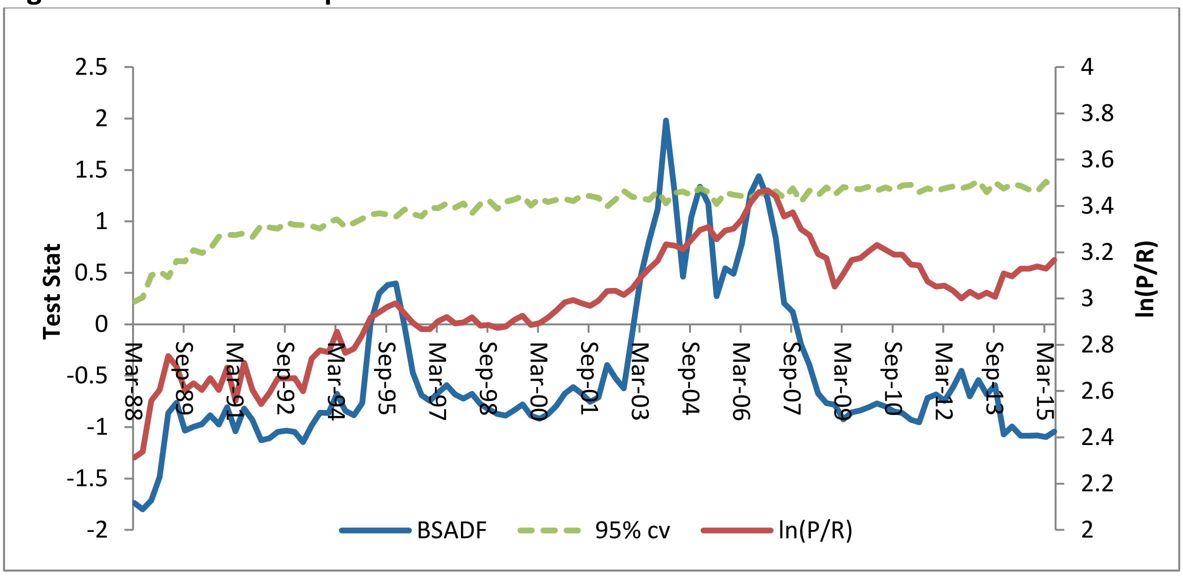


Figure 8: BSADF Test Sequence for Canberra

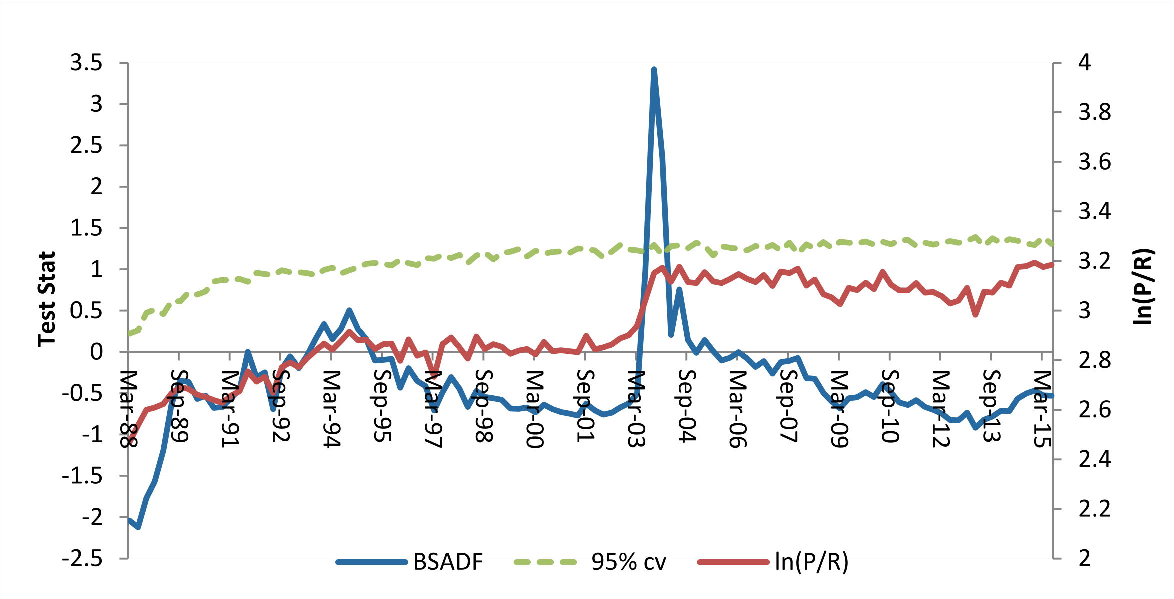


Table 3 reports the dates of the periods of statistically significant explosive behaviour. Of the five cities that exhibit bubbles in the 2000s, the episode for Sydney has the earliest start date and the longest duration. Brisbane, Adelaide, Perth and Canberra all have bubble episodes that begin around the same time in mid-2003. Perth has three separate bubble periods, each of which is of relatively short duration. The first of these episodes begins in December 2003. Sydney is only city to be currently experiencing an explosive episode and this was continuing as of 2015:2.

Table 3: Estimated Dates and Duration of Rational Bubble Episodes

	Start	End	Duration (quarters)
Sydney	Dec 2001	Jun 2004	11
	Mar 2015	continuing	≥2
Melbourne	Mar 1989	Mar 1989	1
Brisbane	Sep 2003	Dec 2004	6
Adelaide	Jun 2003	Mar 2005	8
Perth	Dec 2003	Mar 2004	2
	Dec 2004	Dec 2004	1
	Jun 2006	Sep 2006	2
Canberra	Sep 2003	Dec 2003	2

Notes: Series used to identify bubbles is log price-to-rent ratio and estimates are based on 95% critical values derived from 5,000 simulations.

6.0_Rational bubbles?

The results from the GSADF test indicate there were temporary periods of explosive behaviour in price-rent ratios in five out of Australia's six largest cities during the 2000s. Melbourne is the only city where the price-rent ratio does not exhibit statistically significant evidence of an explosive root during that period. The question that arises is how likely is it that the periods of explosive behaviour were due to the presence of a rational bubble in cities' housing markets. While the finding of an (temporary) explosive root is consistent some rational bubble models; there are other factors that might also produce such behaviour. Phillips and Yu (2010) and Pavlidis, Yusupova, Paya, Peel, Martinez-Garcia, Mack and Grossman (2015) present models in which time variation in the discount rate can produce explosive behaviour in the (fundamental) price of an asset. They indicate that the type of explosive behaviour that is detected by the GSADF tests may be the result of such time variation in the discount rate. Temporary periods of explosive behaviour in the price-rent ratio could arise due to explosive behaviour in fundamentals (Engsted and Nielsen, 2012).

The existence of stochastic rational bubbles generate periods when series changes from being I(1) to explosive, so bubbles create serious difficulties for modelling the full-sample behaviour of a series. However if we can use the GSADF test to identify periods of potential bubbles, we can also use the test to identify non-bubble periods, where a series might be modelled using economic fundamentals. For the Australian cities where the GSADF test identifies a possible bubble – the timing of the bubble is in the second-half of the sample – and this suggests trying to estimate a fundamental model of the price-rent ratio using data prior to the beginning of the bubble, and possibly after the end of the bubble.

In the following section we seek to develop models for the price-to-rent ratios in the subsample prior to the explosive period, for all cities expect for Melbourne. Since price-to-rent ratios are assumed to be I(1) outside of explosive episodes, we look for evidence of a cointegrating relationship between a city's price-to-rent ratio and a small set of economic fundamentals.

Cointegration Tests

We hypothesize that each city's price-to-rent ratio has a long-run relationship with three economic variables. The first of these variables is the (ex-post) real mortgage rate, defined as $log(1 + r_t^m)$, where r^m is the standard variable mortgage rate less the four-quarter-ended headline inflation rate. The second variable is the price-to-rent ratio for Melbourne, measured as $log(PR^{Mel})$. Based on the GSADF test the price-to-rent ratio for Melbourne does not exhibit any explosive episodes during the available sample; and we use it as a proxy for any unobserved common factors that might influence all of Australia's major housing markets. The final variable included in the model $\left(Un_t^i - Un_t^{Mel}\right)$, is the difference between the unemployment rate in the State for which the city is capital and the unemployment rate in Victoria (for which Melbourne is capital). This variable is designed to reflect demand for housing in a capital city relative to housing demand in Melbourne.

The long-run model is represented by the following equation;

$$log(PR_t^i) = \beta_0^i + \beta_1^i\, log(1 + r_t^m) + \beta_2^i log(PR_t^{Mel}) + \beta_3^i\left(Un_t^i - Un_t^{Mel}\right) + u_t^i \qquad (7)$$

where the index *i* references Sydney, Brisbane, Adelaide, Perth and Canberra and the sample *t* corresponds to the data prior to the estimated start-date for an explosive episode in a specific city. Equation (7) is estimated using least squares, dynamic ordinary least squares (DOLS) (Stock and Watson, 1993) and maximum likelihood (Johansen, 1995). The results along with some tests for cointegration are reported in Table 4.

Results from applying the Engle-Granger (EG) test for no-cointegration to the OLS residuals indicates there is reasonably strong evidence (at about 10% or less) against the hypothesis of no-cointegration for all cities expect Canberra. Furthermore the error correction mechanism – formed from the OLS estimates – is statistically significant in an error correction model for changes in the log price-to-rent ratio, for all cities. Support for cointegration from Johansen's trace test is not as strong, with only the trace statistics for Brisbane and Adelaide, being close to the 95% critical value of 47.7.

The estimates of the long-run coefficients obtained by DOLS are generally sensible. Price-to-rent ratios in all cities have a positive relationship with that for Melbourne and a rise in a State's relative unemployment rate has a negative effect on its price-to-rent ratio. Increases in the real mortgage rate typically have a negative effect on a city's price-to-rent ratio – except for Adelaide – but the long-run effects are quite imprecisely estimated. The estimates of β_2^i and β_3^i obtained from Johansen's maximum likelihood estimator are broadly similar to those obtained by DOLS, however except for Sydney the Johansen procedure produces a positive long-run estimate on the real mortgage rate.

Table 4: Estimates of Cointegration Model Prior to Explosive Episode

	Sydney	**Brisbane**	**Adelaide**	**Perth**	**Canberra**
			OLS		
β_1^i	-2.90	-0.40	1.01	-1.89	-0.64
β_2^i	0.81	0.47	0.40	0.60	0.40
β_3^i	-5.22	-5.36	-2.10	-6.49	-1.40
			Cointegration Test		
EG	-3.89 [0]	-4.68 [0]	-5.36 [0]	-3.79 [0]	-2.26 [1]
			ECM		
α^i	-0.19	-0.30	-0.52	-0.25	-0.14
	(0.07)	(0.07)	(0.10)	(0.08)	(0.06)
			DOLS		
β_1^i	-2.27	-0.83	1.10	-0.30	-0.17
	(1.47)	(0.53)	(0.67)	(1.21)	(1.02)
β_2^i	0.87	0.48	0.41	0.68	0.46
	(0.13)	(0.03)	(0.05)	(0.07)	(0.09)
β_3^i	-6.58	-5.81	-1.69	-7.24	-2.64
	(2.93)	(0.89)	(0.81)	(1.96)	(1.30)
			Johansen		
β_1^i	-5.18	0.97	1.23	1.08	-0.71
β_2^i	0.83	0.58	0.44	0.73	0.55
β_3^i	-7.57	-4.58	-1.58	-6.86	-9.89
			Cointegration Test		
Trace	38.40 [1]	45.10 [1]	47.34 [1]	31.65 [1]	33.14 [1]
Smpl	82:2-01:3	82:2-03:2	82:2-03:1	82:2-03:3	82:2-03:1

Notes: Models are estimated using data prior to the start-date of the explosive episode. EG is the Engle-Granger test for cointegration and the relevant critical values are -4.64 (1%), -4.10 (5%) and -3.81 (10%), source MacKinnon (2010). ECM only includes a constant and lagged error-correction term. The DOLS estimates are based on a model with 2 leads and lags and Newey-West robust standard errors (m= 8 lags). The 95% critical value for the Trace statistic is 47.7. Numbers in [ ] brackets indicate number of lags in a model, while those in ( ) are standard errors.

While the results reported in Table 4 are somewhat mixed; the findings are sufficiently supportive of cointegration for us to use the DOLS coefficient estimates for equation (7) to construct a long-run implied value for the log price-rent ratio over the entire sample. If we then subtract the estimate of the long-run price-to-rent ratio from the observed log price-rent ratio, this yields a series that is a mixture of stationary fundamentals (the error correction term) and a temporary explosive sequence. Figures 9 to 13 show plots for the various cities. It is evident that there are two distinctly different patterns of behaviour across the five cities. For Sydney and Perth, the series show a persistent run of positive values around the period that is identified as an explosive bubble.[8] Eventually, however, the series for both cities return to zero. Since a rational bubble episode is expected to be transitory, we might expect to observe some convergence between the forecast fundamentals and the observed price-rent ratio after the bubble has past.

In contrast, for Brisbane, Adelaide and Canberra there appears to be a highly persistent upward shift in the series, which is more indicative of a structural break on the cointegrating relationship. We investigate the question of a structural break in the following section.

Figure 9: Stationary Fundamentals and Identified Explosive Period for Sydney

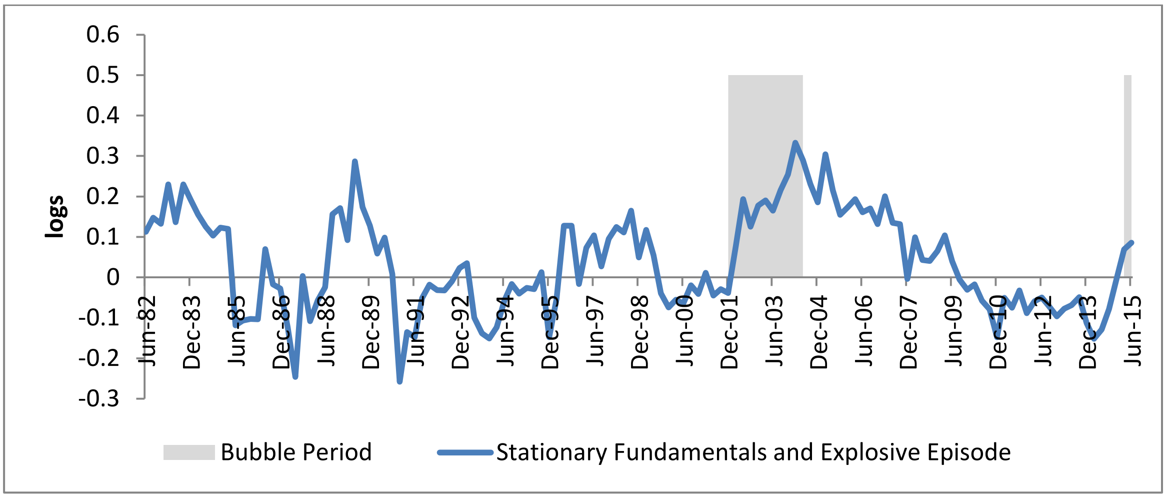
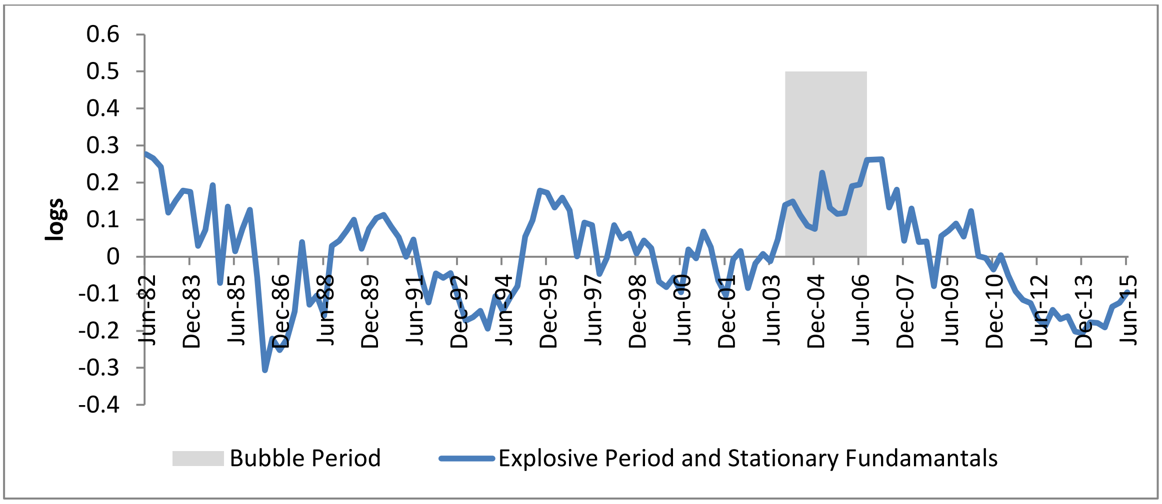


Figure 10: Stationary Fundamentals and Identified Explosive Period for Perth



[8] In the case of Perth the three separate bubble episodes are combined into a single period, 2003:2 to 2006:3.

Figure 11: Stationary Fundamentals and Identified Explosive Period for Brisbane

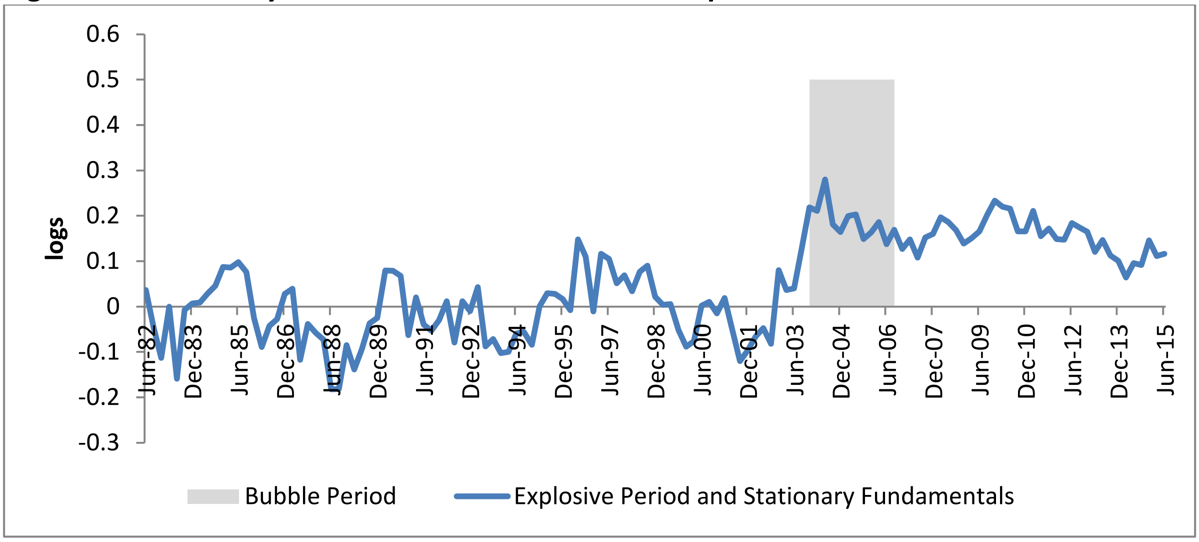


Figure 12: Stationary Fundamentals and Identified Explosive Period for Adelaide

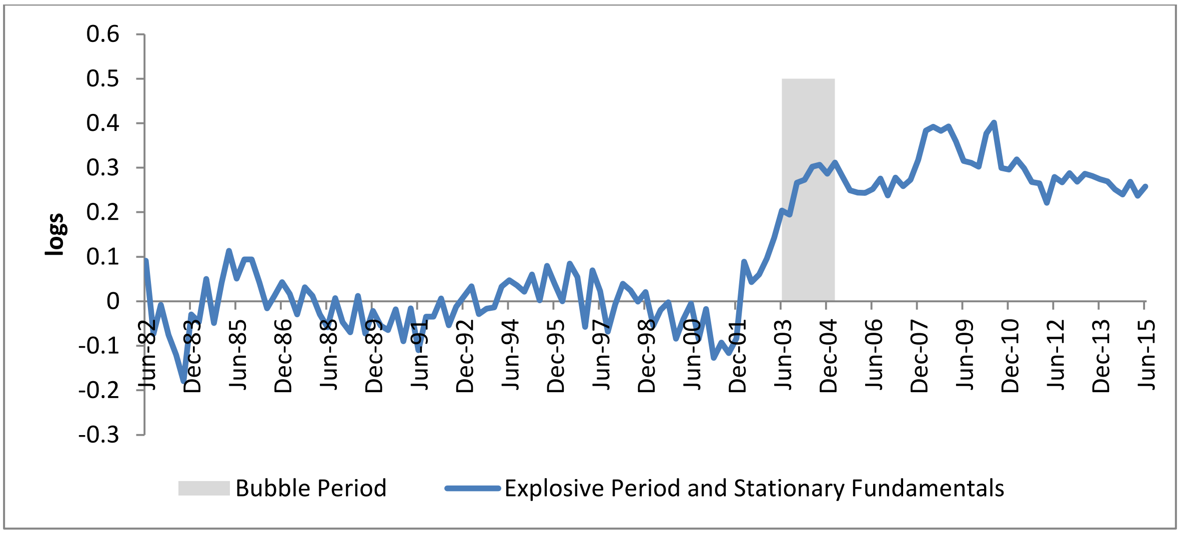
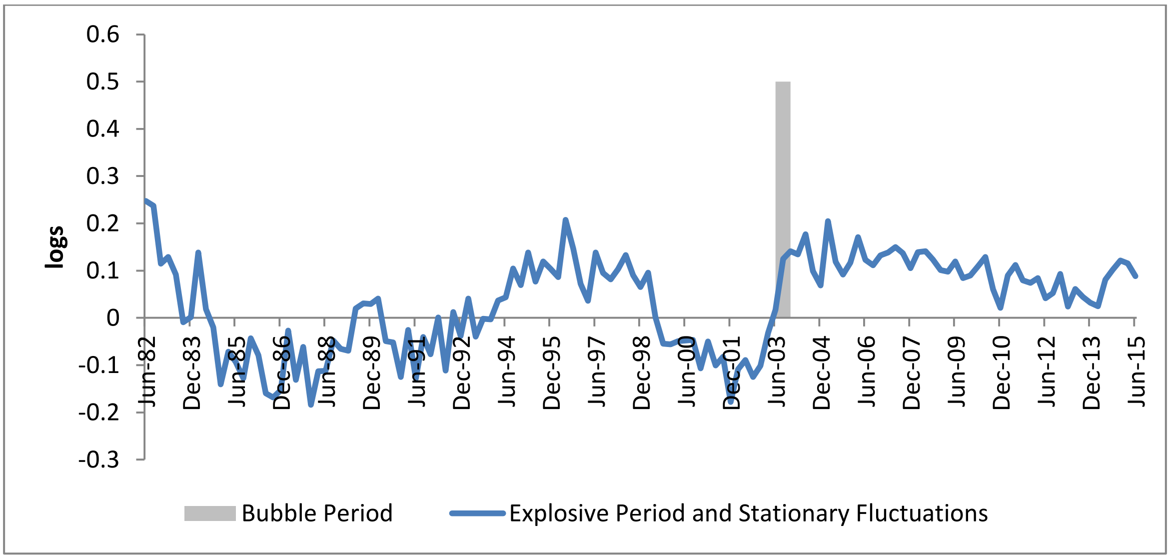


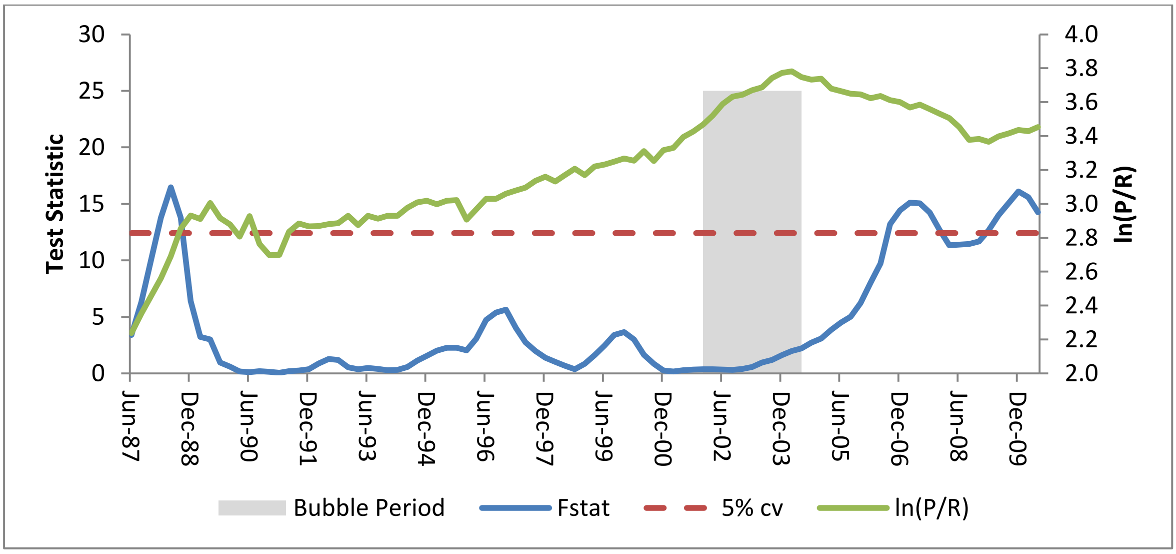
Figure 13: Stationary Fundamentals and Identified Explosive Period for Canberra



Stability Tests

In this section we present some evidence on whether the behaviour of the price-to-rent ratio in Brisbane, Adelaide and Canberra is best viewed as reflecting a one-time structural break in a cointegrating relationship. To do this we estimate model (7) over our full data sample, 1982:2 to 2015:2. We then use Hansen's (1992) sup-F statistic to test for evidence of a structural break in the hypothesised cointegrating model. In applying the stability test we focus on a structural break on the coefficient on the real mortgage rate (and also the intercept). This seems to best capture the possibility that the price-to-rent ratio may respond in a non-linear fashion to changes in the discount rate. Figures 14 to 18 report the sequence of F-statistics and the 5% critical value for each city, along with log of the price-to-rent ratio and a shaded region indicating the explosive episode.

Figure 14: Stability Test for Sydney CI Relationship: Constant and Real Rate Coefficient



Figures 14 and 15 present the results for Sydney and Perth. These two cities seem to be the most plausible candidates for a rational bubble. We view the results from the stability tests as being indicative rather than a formal test. If there is a bubble episode for house prices in these two cities, we would not expect to see a cointegrating relationship. What is evident from the two figures is the lack of any evidence of a structural break in the relationship between the price-rent ratio and real interest rates around the bubble period.

It is interesting to compare the results for Sydney and Perth with those for Brisbane, Adelaide and Canberra, see Figures 16, 17 and 18. We have argued that behaviour of price-rent ratios in these three cities is not really consistent with a classic bubble and that the persistent rise in the price-rent ratio may be indicative of some changed relationship with the real interest rate. The results for Brisbane and Adelaide in Figures 16 and 17 are consistent with evidence of a structural break in the intercept and real interest rate parameter, just prior to the period identified as a bubble. The evidence for Canberra suggests it differs from the other four cities, with the sup-F test indicating a structural break as likely in the early 1990s.

Figure 15: Stability Test for Perth CI Relationship: Constant and Real Rate Coefficient

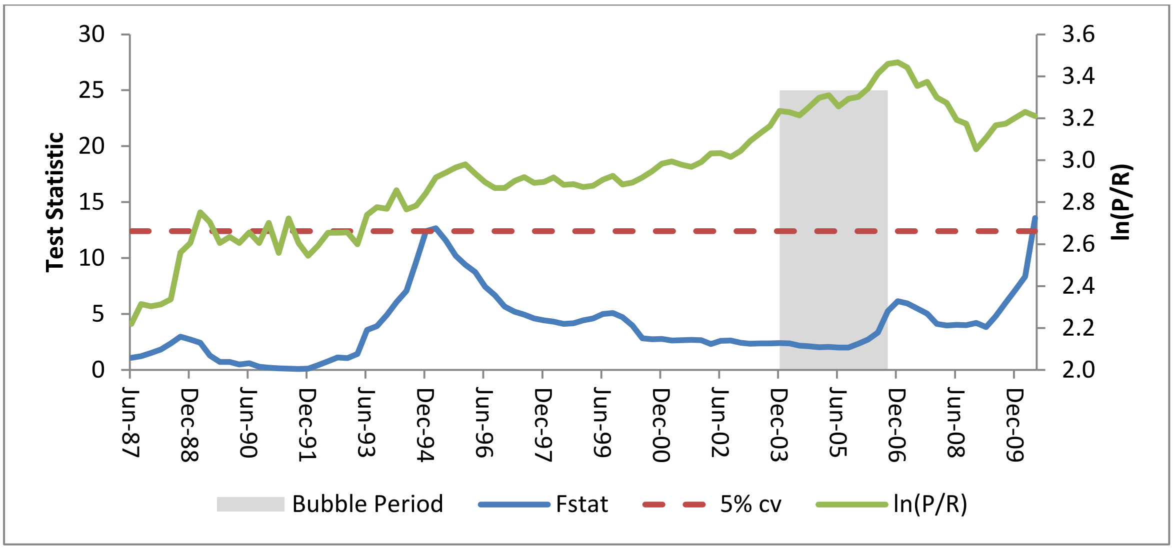


Figure 16: Stability Test for Brisbane CI Relationship: Constant and Real Rate Coefficient

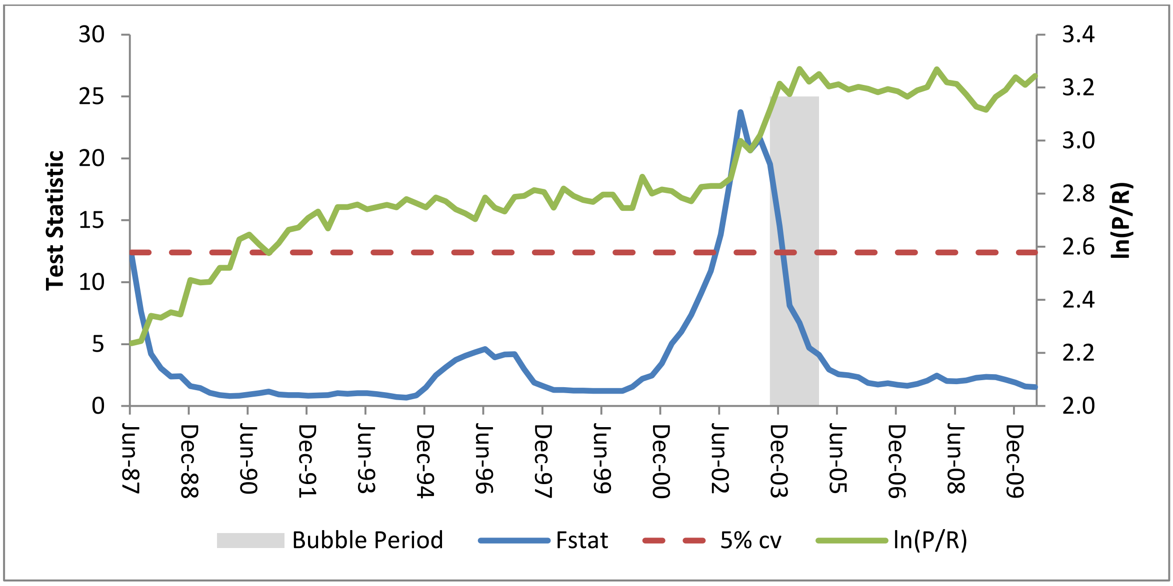


Figure 17: Stability Test for Adelaide CI Relationship: Constant and Real Rate Coefficient

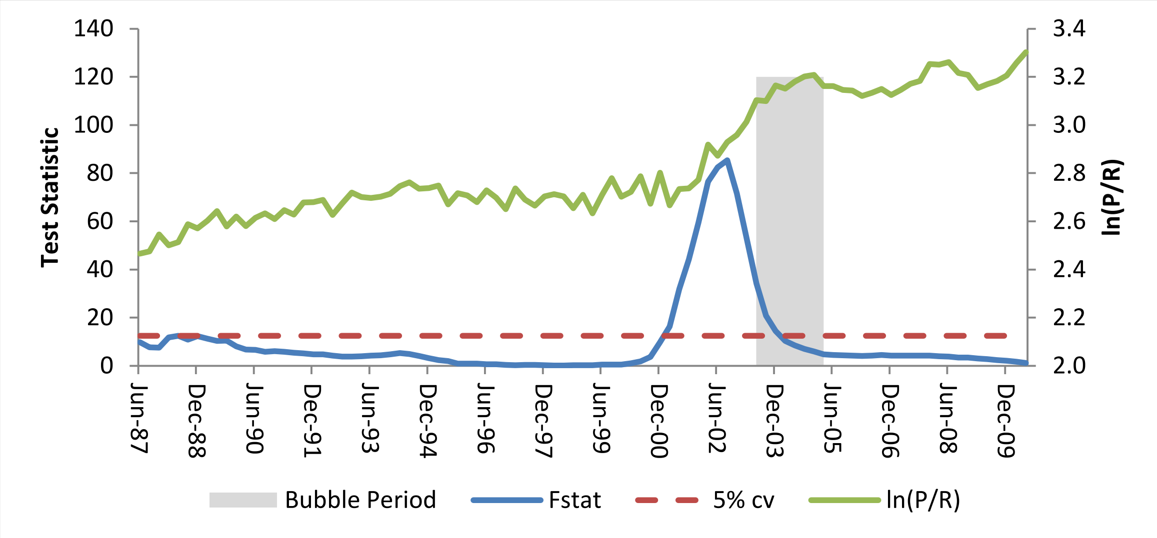
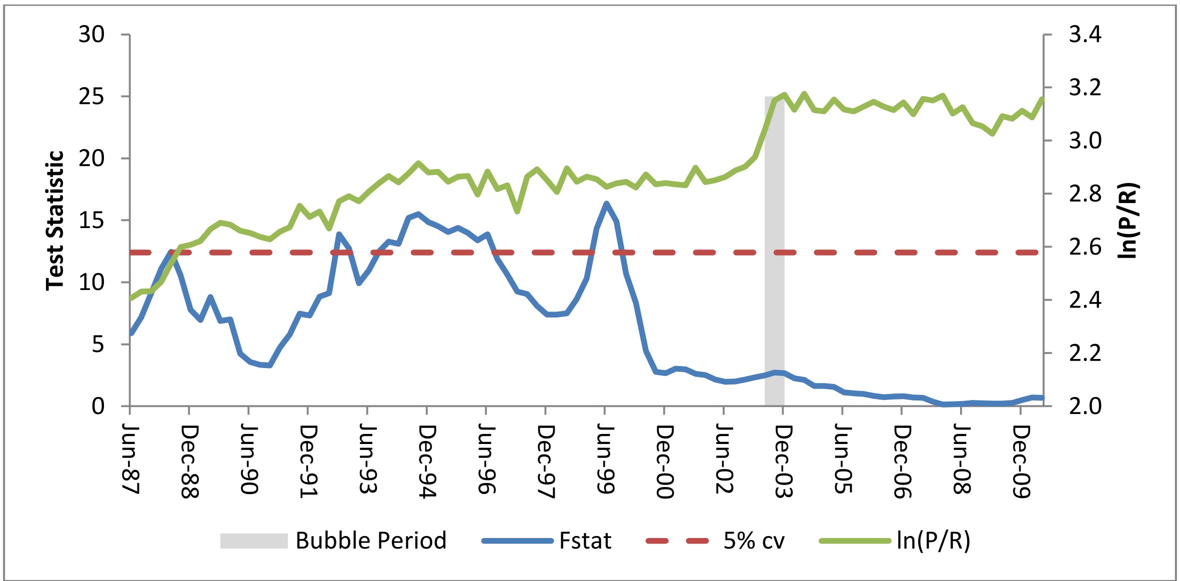


Figure 18: Stability Test for Canberra CI Relationship: Constant and Real Rate Coefficient

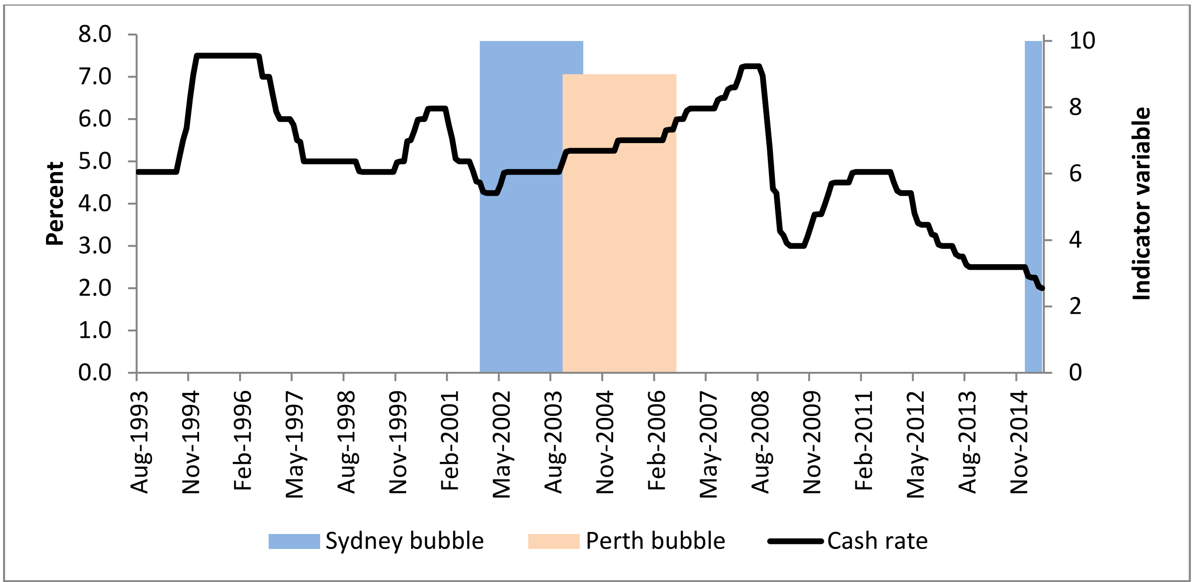


6.0_Implications for Policy

This section considers the implications of our econometric results for policymakers. There is an unresolved debate about how monetary policy should respond to perceived asset price bubbles. Prior to the Global Financial Crisis (GFC) the dominant view – typically associated with Alan Greenspan – was that monetary policy should not directly respond to asset price bubbles. Instead central banks would allow bubbles to run their course, but be prepared to provide necessary liquidity to ensure the stability of the financial system in the event that a financial crisis occurred with the collapse of the bubble. Following the GFC, there has been renewed support for the argument that policymakers should seek to mitigate emerging asset price bubbles (or misalignments); with a focus on using macro-prudential instruments to achieve their objectives.

In their review of asset price bubbles, Brunnermeier and Schnabel (2015) examine 23 episodes; one of which is the "real estate bubble in Australia 2002-04". Of the 23 bubbles examined, the authors classify the Australian bubble as one of only three whose ending was not associated with an economic crisis and recession. Drawing on the detailed analysis of Bloxham, Kent and Robson (2010); Brunnermeier and Schnabel argue that absence of a serious crisis is in considerable part due to the policies pursued by the Reserve Bank of Australia (RBA). These policies included a combination of communication of the risks associated with the rapidly rising house prices and the associated increase in borrowing; modest, but relatively early increases in the policy interest rate and some strengthening of macro-prudential requirements. According to Brunnermeier and Schnabel the RBA's response to the house price bubble provides an example of successful "leaning against the wind" policy.

Figure 19: Cash Rate and Estimated Bubble Dates for Sydney and Perth



We can use the estimated bubble dates and the behaviour of the cash rate to provide some evidences about Brunnermeier and Schnabel's claim. Figure 19 shows the estimated periods of bubbles in Sydney and Perth. The explosive episodes for the other three capital cities are contained within the union of the Sydney and Perth dates. The figure also shows the beginning of the recent bubble episode that has been identified for Sydney. The monthly level of the RBA cash rate is also displayed in the figure. It is evident that prior to the beginning of the bubble episode for the Sydney housing market in the 2000s, the cash rate had been reduced by about 2 percentage points. Consistent with the arguments of Bloxham, Kent and Robson (2010) and Brunnermeier and Schnabel (2015) the RBA did slowly increase the level of the cash rate over the periods in which explosive behaviour is identified in most of Australia's major housing markets. However as these authors note, it difficult to ascertain whether or not the RBA were simply responding to their forecasts for future inflation and activity or were actively using the cash rate to lean against episodes of rapid growth in house prices. In any event it is clear in retrospect that the end of the bubble or explosive episodes – while likely to have had negative consequences for some home-buyers – did not have notable consequences for the aggregate economy.

Finally Figure 19 indicates that the recent episode of high growth in Sydney house prices – which the BSADF statistic identifies as a bubble – has not prevented the RBA from reducing the cash rate by 50 basis points.

7.0_Conclusion

In this paper we have applied explosive root tests by Phillips, Wu and Yu (2011) and Phillips, Shi and Yu (2015) to identify episodes of abnormal price growth in house prices in Australia's major capital cities. All cities except Melbourne are found to exhibit such episodes, which are primarily clustered in the early to mid-2000s. Of the six cities analysed, only for Sydney, is there any evidence of explosive growth in the current (2015) period.

While our findings are consistent with the existence of a rational bubble in the housing markets of most of Australia's major cities in the 2000s, results from a simple long-run model suggest that a structural break or non-linear effect may be a more plausible explanation for the behaviour of the price-to-rent ratio in Brisbane, Adelaide and Canberra. For Sydney and Perth the evidence all points to both cities experiencing rational bubble episodes in the 2000s.

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Data Appendix

The definitions and sources of the variables used in the empirical analysis are indicated below.

House Prices

Data on house prices for Australian capital cities is obtained from the Real Estate Institute of Australia (REIA). The series is median house price, available quarterly from 1980:3 to 2015:2.

Rents

Data on house rents for Australian capital cities is obtained from the Real Estate Institute of Australia (REIA). The series is median weekly rent on a three bedroom house, available quarterly from 1982:3 to 2015:2

Consumer Prices

Quarterly data for capital cities consumer price indexes (all groups) are obtained from ABS Catalogue 6401.0 (Tables 1 and 2).

Mortgage Rate

The nominal mortgage rate is measured by the standard variable lending rate offered by banks to owner-occupiers (Source: RBA Indicator Lending Rates – F5). The monthly series is converted to quarterly observations by averaging the relevant monthly observations. The (ex-post) real mortgage rate is calculated as the nominal rate less the 4-quarter-ended percentage change in the consumer price index for Australia. (Source: ABS Catalogue 6401.0, Tables 1 and 2).

Unemployment Rate

Unemployment rates (seasonally adjusted) are measured by State and Territory and are obtained from ABS Catalogue 6402.0 (Tables 1 and 2). The monthly series is converted to quarterly observations by averaging the relevant monthly observations.