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Structural breaks and explosive behavior in the long-run: the case of Australian real house prices, 1870-2020

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Abstract

In this article, we use tests of explosive behaviour in real house prices with annual data for the case of Australia for the period 1870–2020. The main contribution of this paper is the use of very long time series. It is important to use longer span data because it offers more powerful econometric results. In order to detect episodes of potential explosive behavior in house prices over this long period, we use the recursive unit root tests for explosiveness proposed by Phillips, Wu, and Yu (2011), and Phillips, Shi, and Yu (2015a,b).

Keywords: House price; Explosiveness; Recursive unit root test; Multiple Structural Breaks

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1 Introduction

In this article, we use tests of explosive behavior in real house prices with annual data for the case of Australia for the period 1870–2020. The Australian case can be of interest given that it has experienced strong growth since the mid-1990s, leading the ranking of OECD countries, as shown in Figure 1.[1]

Real housing prices in Australia have risen significantly over the past 33 years (total increase of 175.6% and on average of +3.7% per annum), and housing has become the most important type of asset in Australia. According to BIS statistics (2021), real housing prices in Australia increased by 31.6% between 2012 and 2017 (on average + 4.3% annually). This rapid growth in house prices not only generates a debate about the affordability of housing, but also increases unrest over the presence of speculative bubble behaviours and their impact on economic and financial stability.

Changes in house prices can negatively influence the behaviour of different macroeconomic variables. First, household consumption can be influenced through the housing wealth channel. Second, Tobin's Q relationship would explain movements in housing investment (where the investment occurs as long as the expected return is higher than the cost of the investment). Finally, investment by small businesses may be limited by restrictions on access to credit that affect many small firms [2]

In Australia, housing prices have experienced a significant growth that promoted an intense debate about the existence of a housing bubble. The related literature on testing the determinants of Australian house prices is abundant; see Costello et al. (2011), Fox and Tulip (2014), Fry et al. (2010), Kholer and van der Merwe (2015), Kulish et. al. (2012), Otto (2007), and Shi et al. (2016, 2020), among others.[3]

In our paper we try to analyze the behavior of real house prices by using a long span series data (151 years), which represents a contribution to the literature in this regard. The use of a longer than usual span of data should allow us to obtain some more robust results than in previous analyses. As far as we know, there are no empirical tests available in the literature regarding the existence of speculative

[1] Source of data: Federal Reserve Bank of Dallas (2021).

[2] For more details, see Dvornak and Kholer (2003) and Windsor et al. (2013) on the wealth channel; Corder and Roberts (2008) on Tobin's Q relationship; and Connolly et al. (2015) on the small business investment and collateral constraints to access credit.

[3] Most of these papers test explosive behaviour in housing markets apply the test on house price to rent ratio. In our case, it is not possible because there are not data disposable for such a long sample (1870-2020).

bubbles in the Australian housing market from a long-term perspective for such a long period.

In order to detect episodes of potential explosive in house prices dynamic we use the recursive unit root tests for explosiveness proposed by Phillips, Wu and Yu (2011), and Phillips, Shi, and Yu (2015a,b).

The scheme of the paper is as follows. In Section 2 we introduce the econometric methodology. Section 3 presents and discusses the main empirical results. Section 4 draws the main conclusions.

2 Econometric methodology

2.1 Structural break tests in the level or slope of the trend function of the time series

It is called a structural break when a time series abruptly changes at a point in time. Theses changes could involve a change in mean or a change in the other parameters of the process that produce the series, such as persistence or explosiveness. Both the statistic and econometric literature contain a vast amount of work on issues related to structural changes in macroeconomic time series with unknown break dates (for an extensive review, see Perron (2006) and Casini and Perron (2019)).

The issue of structural change is of considerable importance in the analysis of macroeconomic time series. Structural change occurs in many time series for any various reasons, including economic crises, changes in institutional arrangements, policy changes and regime shifts. Most importantly, if such structural changes are present in the data generating process, but are not allowed for in the specification of an econometric model, results may be biased towards.

It also implies that any shock – whether demand, supply, or policy-induced – on the variable will have effects on it in the long-run. It is therefore very important to test for the presence of multiple structural breaks in the data so as to more reliably conduct the tests of non-stationarity or tests of explosiveness.

The seminal works of Chow (1960) and Quandt (1992) and the CUSUM test focused on testing for structural change at a single known break date. Over time, the econometric literature has led to the development of methods that allow for estimation and testing of structural change at unknown break dates. These include the tests proposed by Andrews (1993) and Andrews and Ploberger (1994) for the case of a single structural change, and Andrews et al. (1996), Liu et al. (1997), and Bai and Perron (1998, 2003a, 2003b) for the case of multiple structural changes.

More recently, Perron and Yabu (2009a,b) proposed a test for structural changes in the deterministic components of a univariate time series when it is unknown a priori whether the series is trend-stationary or contains an autoregressive unit root. The Perron and Yabu test statistic, called $Exp - W_{FS}$, is based on a quasi-Feasible Generalized Least Squares (FGLS) approach that uses an autoregression for the noise component, with a truncation to 1 when the sum of the autoregressive coefficients is in some neighborhood of 1, along with a bias correction. For given break dates, Perron and Yabu (2009a,b) proposed an F-test for the null hypothesis of no structural change in the deterministic components using the Exp function developed in Andrews and Ploberger (1994). Perron and Yabu (2009a,b) specified three different models depending on whether the structural break only affects the level (Model I), the slope of the trend (Model II) or the level and the slope of the time trend (Model III).

2.2 Structural break tests in the variance of the time series

Recently, both statistic and econometric literature related to structural changes has focused to test changes in the variance of macroeconomic times series (for a review, see Perron et al. (2020)). These testing problems are important for practical applications in macroeconomics and finance to detect structural changes in the variability of shocks in time series.

In empirical applications based on linear regression models, structural changes often occur in both the error variance and the regression coefficients, possibly at different dates. McConnell and Perez-Quirós (2000) confirmed a break in the volatility of US production, occurring in the early mid-1980s. In the same line of research, and with a broader database of macroeconomic series for the United States, vanDijk and Sensier (2001) found that in the vast majority of real series a change in variance is observed in the early mid-1980s; see also Gadea et al. (2018), Perron and Yamamoto (2021), and Stock andWatson (2002, 2003a, 2003b).

We have used the test statistics to test jointly for structural changes in mean and variance proposed by Perron et al. (2020). More specifically, these authors presented a new methodology to address this problem in a single equation regression model that involves stationary regressors, allowing the break dates for the two components to be different or overlap.

Perron et al. (2020) consider several types of test statistics for testing structural changes in mean and/or variance: 1) the $\sup LR_T$ test statistic for m coefficient changes given no variance changes; 2) the $\sup LR_{1,T}$ test statistic for n variance changes given no coefficient changes; 3) the $\sup LR_{2,T}$ test statistic for n variance changes given m coefficient changes; 4) the $\sup LR_{3,T}$ test statistic for m coefficient changes given n variance changes; 5) the $\sup LR_{4,T}$ test statistic for m coefficient changes and n variance changes; 6) The $UD\max$ tests for each version can be computed by taking a maximum over a range of $1 \leq n \leq N$ for $\sup LR_{1,T}$ and $\sup LR_{2,T}$, over a range of $1 \leq n \leq M$ for $\sup LR_T$ and $\sup LR_{3,T}$, and over ranges of $1 \leq n \leq N$ and $1 \leq m \leq N$ for the $\sup LR_{4,T}$; 7) the $seqLR_{9,T}$ test statistic for m coefficient changes versus $m+1$ coefficient changes given n variance changes; 8) the $seqLR_{10,T}$ test statistic for n variance changes versus $n+1$ variance changes given m coefficient changes. M and N denotes the maximum number of breaks for the coefficients and the variance, respectively.

2.3 A model for recurrent explosive behavior in time series data

Evans (1991) argued that standard right-tailed unit root tests, when applied to the full sample, have little power to detect periodically collapsing bubbles (the explosive behavior is only temporary) and demonstrated this effect in simulations. The low power of standard unit root tests is due to the fact that periodically collapsing bubble processes behave rather like an $I(1)$ process or even a stationary linear autoregressive process when the probability of bubble collapse is non-negligible, thereby confounding empirical evidence.[4]

To overcome the problem identified in Evans (1991), Phillips, Wu and Yu (2011, PWY henceforth) and Phillips, Shi, and Yu (2015a, 2015b, PSY henceforth) developed a new recursive econometric methodology for real-time bubble detection that proved to have a good power against mildly explosive alternatives. The interest in

[4] An illustrative pedagogical introduction to the empirical analysis of searching for collapsing bubbles in nonstationary time series, and its theoretical foundations, can be found in Phillips (2012). Other relevant references are the seminal papers by Yu and Phillips (2009) and Phillips and Yu (2011).

testing algorithm is whether a particular set or group of consecutive observation comes from an explosive process (H_A) or from normal martingale behavior (H_0). The algorithm testing is based on a right-tailed unit root test proposed by Phillips, Shi and Yu (2014).

On the one hand, the martingale null is specified as,

$$H_0 : y_t = kT^{-\eta} + \delta y_{t-1} + \varepsilon_t \tag{1}$$

with constant k and $\eta > 1/2$, and where y_t is data series of interest (in our case the house prices) at period t, ε_t is the error term, and T is the total sample size.

The hypothesis that the parameter $\delta = 1$ implies that y_t is integrated of order one, i.e., $y_t \sim I(1)$.

On the other hand, the alternative is a midly explosive process, namely,

$$H_A : y_t = \delta_T y_{t-1} + \varepsilon_t \tag{2}$$

where $\delta_T = (1 + cT^{-\alpha})$ with $c > 0$ and $\alpha \in (0, 1)$, and it must be indicated that this type of mildly explosive and collapsing behaviour under the alternative hypothesis corresponds to, at least, one subperiod of the full sample, not to the whole sample. In this case, if $\delta_T > 1$, it implies the explosive behavior of y_t over sub-period $t \in [T_1, T_2]$.[5]

In addition to the classic reference of Evans (1991), Charemza and Deadman (1995) extends the above analysis to the case of multiplicative processes with a stochastic explosive root encompassing non-negative processes used in the analysis of exuberant time series. The formulation of equation(1), as a restrictive representation of the generating process under the null hypothesis, includes a particular, not standard, representation for the drift term. Given that the recursive representation can be written as,

$$\frac{1}{\sqrt{T}} y_t = kT^{1/2-\eta} \left(\frac{t}{T}\right) + \frac{1}{\sqrt{T}} y_0 + \frac{1}{\sqrt{T}} \sum_{j=1}^{t} \varepsilon_j \tag{3}$$

[5]For the formulation and development of asymptotics for this type of mildly integrated (when $c < 0$) and mildly explosive (when $c > 0$) behavior, see the basic references to the works of Phillips and Magdalinos (2007a, b).

where $T^{1/2-\eta} \longrightarrow 0$ as $T \longrightarrow \infty$, so that the drift term is asymptotically negligible and does not interfere with the standard asymptotics for a nonstationary process.

2.4 Recursive unit root test for explosiveness

The methodology developed in PWY and PSY can be applied to test the unit root hypothesis in the standard model described in (1) against an alternative of multiple sub-periods of explosive behavior $[T_1^{(i)}, T_2^{(i)}], i = 1, 2, ...k, k \geq 1]$, where of the house price dynamics is described in (2). The sustainable dynamics of house prices implies that y_t is a process integrated $I(1)$ that is interrupted by recurrent episodes of explosive house prices dynamics. That is, it represents the maintained hypothesis of the empirical analysis in order to obtain empirical evidence in favour of a sustainable house prices process in terms of a "global" nonstationary sequence eventually interrupted by, at least, one collapsing mildly explosive episode.

The testing procedure is developed from a regression model of the form,

$$\Delta y_t = \beta_0 + \beta_1 y_{t-1} + \sum_{i=1}^{K} \lambda_i \Delta y_{t-i} + \varepsilon_t \tag{4}$$

where β_0, β_1, and λ_i are model coefficients, K is the lag order, and ε_t is the error term. The key parameter of interest is β_1. We have $\beta_1 = 0$ under the null and $\beta_1 > 0$ under alternative. The model is estimated by Ordinary Least Squares (OLS) and the t-statistics associated with the estimated β_1 is referred to as ADF statistic.

First, PWY proposed a sup ADF ($SADF$) statistic to test for the presence of explosive behavior in a full sample. In particular, the test relies on repeated estimation of the ADF model on a forward expanding sample sequence, and the test is obtained as the sup value of the corresponding ADF statistic sequence. In this case, the window size (fraction) r_w expands from r_0 to 1, where r_0 is the smallest sample window width fraction (which initializes computation of the test statistic) and 1 is the largest window fraction (the total sample size) in the recursion. The starting point r_1 of the sample sequence is fixed at 0, so the endpoint 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 denoted by $ADF_0^{r_2}$.

The $SADF$ test is then a sup statistic based on the forward recursive regression and is simply defined as,[6]

$$SADF(r_0) = \sup_{r_2 \in [r_0, 1]} ADF_0^{r_2} \tag{5}$$

Second, PSY developed a double-recursive algorithms that enable bubble detection and consistent estimation of the origination (and termination) dates of bubble expansion and crisis episodes while allowing for the presence of multiple structural breaks within the sample period. They showed that when the sample includes multiple episodes of exuberance and collapse, the PWY procedures may suffer from reduced power and can be inconsistent, thereby failing to reveal the existence of bubbles. This weakness is a particular drawback in analyzing long time series or rapidly changing of data where more than one episode of explosive behavior is suspected.

To overcome this weakness and deal with multiple breaks of exuberance and collapse, PSY proposed the backward sup ADF ($BSADF$) statistic defined as the sup value of the ADF statistics sequence over interval $[0, r_2 - r_0]$. That is,

$$BSADF_{r_2}(r_0) = \sup_{r_1 \in [0, r_2 - r_0]} ADF_{r_1}^{r_2} \tag{6}$$

where the endpoint of each sub-sample is fixed at $T_2 = [r_2 T]$ where $r_2 \in [r_0, 1]$, and the start point of each sub-sample, $T_1 = [r_1 T]$ varies from 1 to $T_2 - T_0 + 1 (r_1 \in [0, r_2 - r_0])$. The corresponding ADF statistics sequence is $\left\{ADF_{r_1}^{r_2}\right\}_{r_1 \in [0, r_2 - r_0]}$.

PSY also proposed a generalized version of the sup ADF ($SADF$) test of PWY, based on the sup value of the $BSADF$. That is,

$$GSADF(r_0) = \sup_{r_2 \in [r_0, 1]} BSADF_{r_2}(r_0) \tag{7}$$

The statistic (7) is used to test the null of a unit root against the alternative of recurrent explosive behavior, as the statistic (5). It is important to note, and it must be clearly stated, that the fact that the two sequential versions of the ADF test indicated in equations (5) and (7) as the sup values in the sequences of the subsamples implies that all these tests are right-tailed, i.e., the rejection is obtained for large positive values. Moreover, it is relevant for these testing procedures the

[6] This notation highlights the dependence of $SADF$ of the initialization parameter r_0.

consistent estimation of the initialization and burst time periods of the explosive behavior when the null hypothesis is rejected.[7] [8]

The origination date $[T\hat{r}_e]$ of an episode of explosive behavior is defined as the first observation whose backward sup ADF exceeds the corresponding critical value,

$$\hat{r}_e = \inf_{r_2 \in [r_0,1]} \left\{ r_2 : BSADF_{r_2}(r_0) < scv_{r_2}^{\alpha_T} \right\} \tag{8}$$

where $scv_{r_2}^{\alpha_T}$ is the $100(1-\alpha_T)$ % critical value of sup ADF statistic based on $[Tr_2]$ observations and α_T the significance level which may depend on the sample size T.

The termination date $[T\hat{r}_f]$ of an episode of explosive behavior is computed as the first observation after $[T\hat{r}_e]$ $+\delta \log(T)$ whose sup ADF statistic falls below the corresponding critical value,

$$\hat{r}_f = \inf_{r_2 \in [\hat{r}_e + \delta \log(T)/T, 1]} \left\{ r_2 : BSADF_{r_2}(r_0) < scv_{r_2}^{\alpha_T} \right\} \tag{9}$$

where $\delta \log(T)$ is the minimal duration of an episode of explosive behavior.

3 Empirical results

3.1 Data

We consider a long historical time series in which many cycles in Australian real houses prices are known to have occurred. The length of this database makes it particularly suitable for the econometric approach adopted in this paper (1870-2020, 151 years).

The data and sources are: 1870-2017: a) nominal house prices, nhp_t, from Jordà et al. (2017); b) consumer price index, cpi_t, from Jordà et al. (2017); 2017-2020: a) nominal

[7]For more details of these recursive and sequential testing procedures can be found, for example and among some others, in Phillips and Shi (2020).

[8]The more recent and complete study on the properties of these estimates, both for the ADF-based detector and also for a CUSUM-type detector, and for different locations of the explosive sequence along the sample, can be found in Kurozumi (2021).

house prices index, nhp_t, from BIS. (2021); b) consumer price index, cpi_t, from BIS (2021); 1870-2020: real house prices index (linked series) $rhp_t = nhp_t/cpi_t$.

Figure 2 plots the data of the Australian real house price series, rhp_t, over the sample period (1870-2020) and shows quite clearly a stylized fact: the preeminence and persistence of the increase in real house prices from 1950, especially from 1997 onwards.[9]

The long-run history of data allows some observations on the two boom cycles in Australian real house prices. The first historical cycle in house prices took place between 1950-1974. Such boom occurred after the lifting of World War II price controls introduced in 1943 which, because they kept during a period of high inflation from 1943 to 1949, caused real house prices to be artificially reduced. These house prices controls, in conjunction with low construction activity and ceilings on house rents during the War-time, aggravated a post-World War II shortage of housing, which triggered the later increase in house prices. In this period, house prices in Australia increased on average by 7% per annum in real terms.

The second historical cycle in house prices spanned from 1997 to 2017. In this period, house prices in Australia increased on average by 5% per annum in real terms. There are several important determinants such as population and interest rates. Firstly, this boom cycle in houses prices is mainly due to the inflexibility of the supply side of the housing market in response to large shifts in population growth. Since the mid 2000s, Australia has experienced much higher net immigration, and thus population growth has increased at a significantly higher rate; see Kholer and van der Merwe (2015), among others. Secondly, Otto (2007) finds that the level of the mortgage interest rate was an important explanatory factor for the growth dwelling of prices in the Australian capital city during the period 1986:2-2005:2. Most recently, Kholer and van der Merwe (2015), suggested that the reduction in real mortgage rates since 2011 has been associated with stronger growth in both house prices and dwelling construction.

3.2 Structural changes of the time series

The first step in our analysis is to examine the structural changes in the level or slope of the trend function of the series of real house prices over the full sample. We have used the test statistics for structural changes in deterministic components

[9] More detail over the history of housing prices in Australia can be found in Stapledon (2010).

proposed by Perron and Yabu (2009a,b). The results of the $Exp - W_{FS}$ test for Model III (structural change in both intercept and slope) are presented in Table 1. The evidence in favor of a change in the trend function is very strong at the 1% level. Table 1 also shows an estimate of the break date obtained by minimizing the sum of squared residuals from a regression of the series on a constant, a time trend, a level shift dummy and a slope shift dummy. The break point is estimated at 1986. In addition, the pre and post-break annual growth rates are presented. The changes in the growth rates for the real houses price series are very large, from 1.8% to 3.5%.

The second step in our analysis is to examine the structural changes in the variance of the real house price series for the full sample. We have used the test statistics to test jointly for structural changes in mean and variance proposed by Perron et al. (2020). We investigate structural changes in the conditional mean and in the error variance. We use $M = 3$ and $N = 2$ and take into account any potential serial correlations in the error term via a HAC variance estimator following Bai and Perron (1998, 2003). Table 2(a) reports the $\sup LR_{4,T}$ and the $UD \max LR_{4,T}$ tests. The results do not suggest rejections of the null hypothesis of no breaks jointly in the conditional mean and in the error variance. Table 2(b) presents the results when testing for changes in the coefficients, allowing for changes in the variance. We obtain strong evidence of not change in the conditional mean coefficients. The sequential procedure, using the $\sup LR_{9,T}$ test, confirms these results. Table 2(c) presents the results of the $\sup LR_{2,T}$, the $UD \max LR_{2,T}$, and the sequential test $\sup LR_{10,T}$ tests. These results suggest the presence of breaks in the variance with a single break date estimated in 1949. The change is such that the variance went from 50.3 to 37.1 in 1951.[10] Hence, we obtain a structural change in the error variance and no change in the conditional mean.

3.3 Explosive dynamics of the time series

The third step in our analysis is to examine the explosive behavior in over the full sample. The methodology developed in PWY and PSY was originally proposed to test for recurrent explosive behavior for U.S. stock market. In this paper, we use this methodology to examine whether the Australian real house prices has speculative bubble behavior at any point time for the period 1870-2020. The method of Phillips

[10]To calculate the variance we have eliminated the value of 1950 due to the anomalous growth rate of the series after the lifting of World War II price controls introduced in 1943.

et al. (2015a,b) have also been applied in housing market for other countries; see Pan (2019), Shi (2017) and the references therein.

As far as we know, part of this methodology has only been used to test the explosive behavior of house prices for the case of Australian in two previous papers. First, Shi et al. (2016) applied the statistical test of asset bubbles, proposed by Phillips et al. (2015a,b), to detect, and time-stamp, bubbles to the house price to rent ratio in Australian capital cities using both monthly (December 1995January 2016) and quarterly (1986q32015q3) time series data. Their results pointed to a prolonged, although varying, degree of speculative behavior in all capital cities in the 2000s before the international financial crisis of 2008. Second, Shi et al. (2020) investigate the presence of housing bubbles for the house price to rent ratio in Australia at the national, capital city and local government area levels. They control for housing market demand and supply fundamentals using the approach of Shi (2017), and employ the recursive evolving method proposed by Phillips et al. (2015a,b) for the detection of explosive bubbles. While the national-level analysis suggests a short-lived bubble episode (2017Q3) throughout the sample period from 1999 to 2017, the results at the capital city level show notable differences between cities, with transitory and isolated bubbles in Sydney and Melbourne in the period of acceleration in house prices between 2013 and 2017.

For our empirical application, the lag order K is selected by Bayesian information criterion (BIC) with a maximum lag order of 5, as suggested by Campbell and Perron (1991). We set the smallest windows size according to the rule $r_0 = 0.01 + 1.8/\sqrt{T}$ recommended by PSY, giving the minimal length of a sub-sample at 22 years. The origination (termination) of an explosive episode is defined as the first chronological observation whose test statistic exceed (goes below) its corresponding critical value.

Table 3 reports the $SADF$ and $GSADF$ tests of the null hypothesis of a unit root against the alternative of an explosive root in real house prices variables. The various critical values for each of the two test are also reported. We conduct a Monte Carlo simulation with 2,000 replications to generate the $SADF$ and $GSADF$ statistics sequences and the corresponding critical values at the 10, 5 and 1 per cent levels.

As can be seen in Table 3, we reject the unit root null hypothesis in favour of the explosive alternative at the 1% significance level for the $SADF$ test and the 1% significance level for $GSADF$ test. Both tests exceed their respective 1% right-tail critical values, giving any evidence that the real house prices series had explosive subperiods. Consequently, we can conclude from both summary tests that there is some evidence of bubbles in this variable.

Next, we conduct a real-time bubble monitoring exorcise for the Australian real house prices using the PSY strategy. The PSY procedure also has the capability of identifying market downturns, in our case, potential house prices adjustments. To locate the origin and conclusion of the explosive real house prices behavior and the adjustments episodes, Figure 3 plots the profile of the $GSADF$ statistic for the Australian real house prices. We compared the $GSADF$ statistic with the 95% $GADF$ critical value for each observation of interest. The initial start-up sample for the recursive regression covers the period 1870-1891 (15% of the full sample). Figure 3 identifies of episodes of explosive real house prices behavior and it peermist to date-stamp its origination and termination, as well as the potential house prices adjustments.

Next, we also conduct a real-time bubble monitoring exercise for Australian real house prices using the PWY strategy. Figure 4 plots the $SADF$ test against the corresponding 95% critical value sequence. According to Figures 3 and 4, there is clear speculative bubble behavior in real house prices in 1997-2020.

Finally, Figure 2 shows the slight price adjustments in the 2018-2020 period. Since 2018, real prices have fallen just by 4.6 per cent (on average by -1.5% per annum). This decline of house prices in this recent period may be dued to for a combination of cyclical (or temporal factors): i) the higher rate of home building (supply factor); ii) the decline in residential investment for non-resident (demand factor); iii) the weaker demand from domestic investors in housing (demand factor), iv) the decrease in housing price-to-income ratios (demand factor); and v) the slowing in housing credit growth (demand factor).[11]

4 Conclusions remarks

In this article, we use tests of explosive behavior in real house prices for the case of Australian for the period 1870–2020. The main contribution of this paper is the use of long time series for testing the explosive behavior. It is important to use longer span data because it provides more powerful econometric results. In order to detect episodes of potential explosive in house prices over this long period, we use the recursive unit root tests for explosiveness proposed by Phillips, Wu, and Yu (2011), and Phillips, Shi, and Yu (2015a,b). According to the results, there is

[11] For more details, see Lowe (2019).

clear speculative bubble behavior in real house prices between 1997-2020, speculative process that has not yet been adjusted.

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Table 1

Tests for structural changes in the level or slope of the trend function from Perron an Yabu (2009a,b): Australian real house prices, rhp_t

			Annual Growth Rate	
Model	$Exp - W_{FS}$ test	Break dates	Pre-break	Post-break
III	18.12^3	1986	1.8%	3.5%

Note: Superscripts ^{1,2,3} indicate significance at the 10%, 5% and 1% levels, respectively. The critical values are taken Perron and Yabou (2009b), Table 2.c.

Table 2

Tests for structural changes in mean and variance

from Perron et al. (2020): Australian real house prices, rhp_t

(a) Tests for structural changes in mean and/or variance

	$\sup LR_{4,T}$			$UD\max LR_{4,T}$
	$m_a = 1$	$m_a = 2$	$m_a = 3$	$M = 3, N = 2$
$n_a = 1$	0.80	1.93	1.73	1.93
$n_a = 2$	0.93	1.38	1.50	

(b) Tests for structural changes in mean

	$\sup LR_{3,T}$			$UD\max LR_{3,T}$	$seqLR_{9,T}$			
	$m_a = 1$	$m_a = 2$	$m_a = 3$	$M = 3$	$m_a = 1$	$m_a = 2$	$m_a = 3$	Break dates
$n_a = 0$	4.94	4.98	3.88	4.98	4.22	4.22	4.22	–
$n_a = 1$	3.91	3.43	2.38	3.91	4.45	3.69	3.72	–
$n_a = 2$	1.88	0.50	2.53	2.53	3.69	3.69	3.72	–

(c) Tests for structural changes in variance

	$\sup LR_{2,T}$		$UD\max LR_{2,T}$	$seqLR_{10,T}$		
	$n_a = 1$	$n_a = 2$	$N = 2$	$n_a = 1$	$n_a = 2$	Break dates
$m_a = 0$	6.05	10.32^3	10.32^2	6.65	6.87	–
$m_a = 1$	24.44^3	16.61^3	24.44^3	4.66	5.40	1949
$m_a = 2$	15.96^3	8.70^2	15.96^3	7.08	7.08	1949
$m_a = 3$	14.06^3	8.00^1	13.07^3	6.53	6.58	1949

Note: Superscripts ^{1,2,3} indicate significance at the 10%, 5% and 1% levels, respectively. The critical values are taken from Bai and Perron (1998), Perron et al (2020), and Perron and Yamamoto (2021).

Table 3

Testing for explosive behavior from Phillips, Wu and Yu (2011)

and Phillips, Shi, and Yu (2015a,b): Australian real house prices, rhp_t

Unit root tests	Estimated Value	Finite Critical Value		
		1%	5%	10%
$SADF$	5.510^3	1.984	1.361	1.057
$GSADF$	5.510^3	2.686	2.023	1.770

Note: Superscripts ^{1,2,3} indicate significance at the 10%, 5% and 1% levels, respectively.

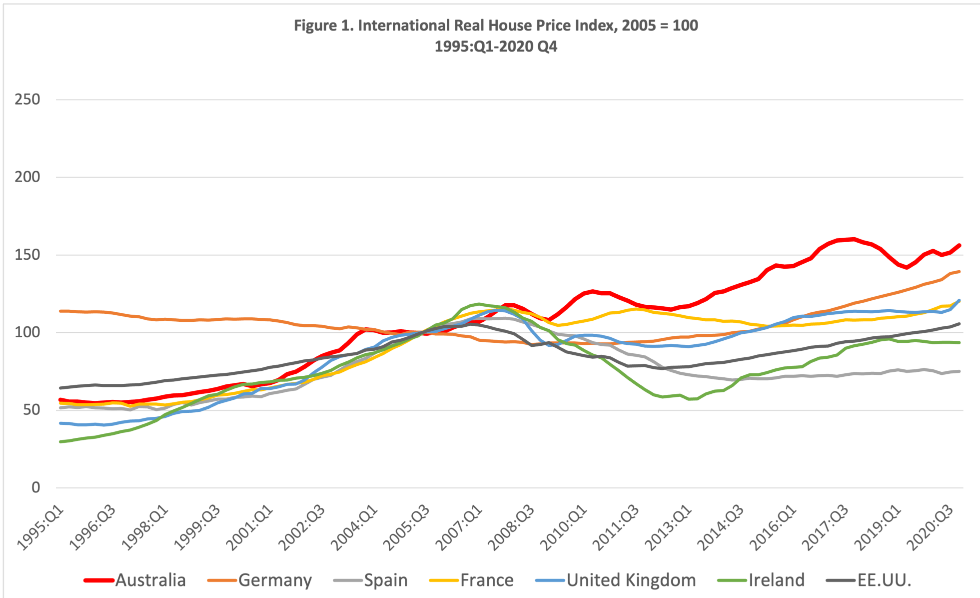
Figure 1. International Real House Price Index, 2005 = 100
1995:Q1-2020 Q4
250
200
150
100
50
0
1995:Q1
1996:Q3
1998:Q1
1999:Q3
2001:Q1
2002:Q3
2004:Q1
2005:Q3
2007:Q1
2008:Q3
2010:Q1
2011:Q3
2013:Q1
2014:Q3
2016:Q1
2017:Q3
2019:Q1
2020:Q3
Australia
Germany
Spain
France
United Kingdom
Ireland
EE.UU.

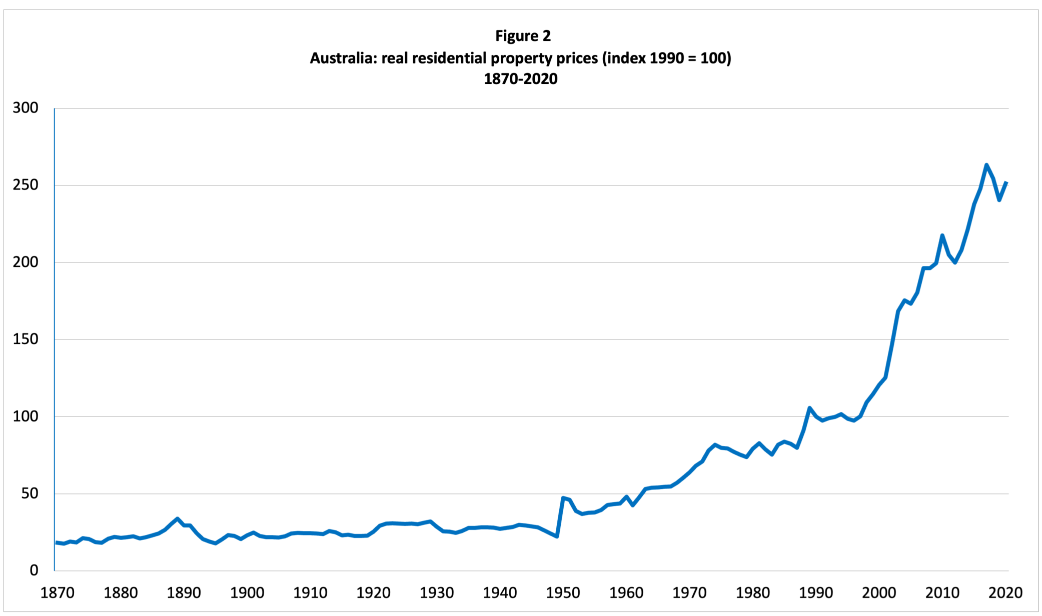
Figure 2
Australia: real residential property prices (index 1990 = 100)
1870-2020
300
250
200
150
100
50
0
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

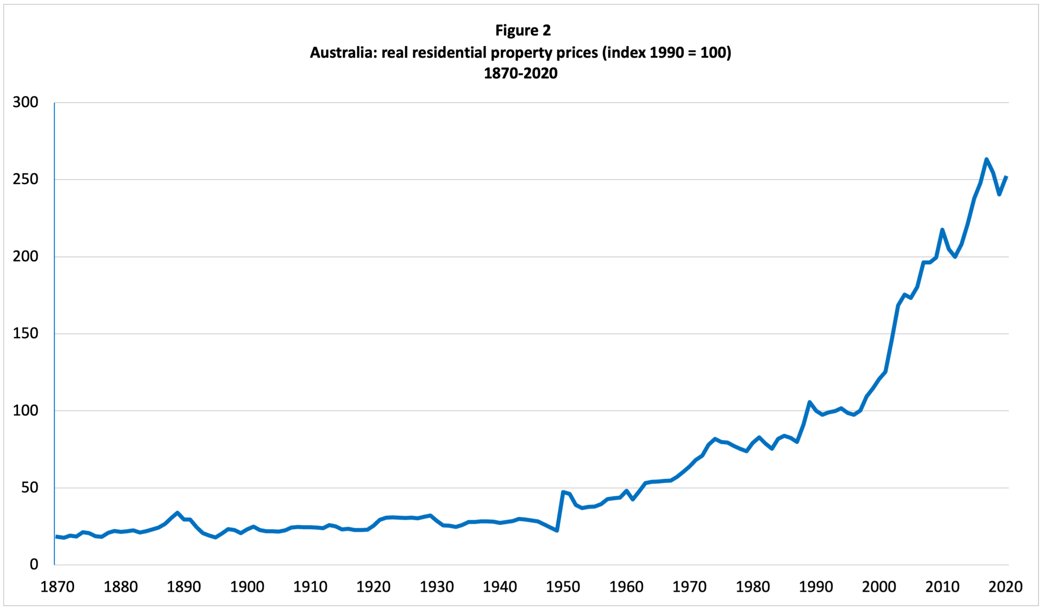
Figure 2
Australia: real residential property prices (index 1990 = 100)
1870-2020
300
250
200
150
100
50
0
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

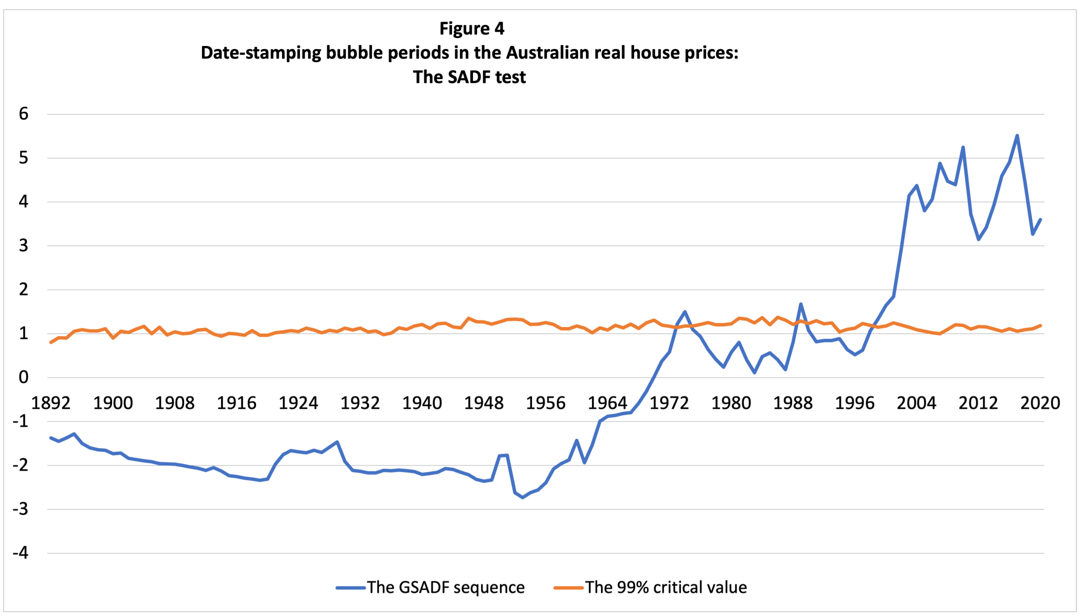
Figure 4
Date-stamping bubble periods in the Australian real house prices:
The SADF test
6
5
4
3
2
1
0
-1
-2
-3
-4
1892
1900
1908
1916
1924
1932
1940
1948
1956
1964
1972
1980
1988
1996
2004
2012
2020
The GSADF sequence
The 99% critical value