Speculative Bubble Detection in Australian Housing Markets

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Statement of Originality

This work has not previously been submitted for a degree or diploma in any university. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

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Md. Arafat Rahman

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Dedication

I dedicate this thesis

To the memory of my beloved

Late Father

Asst/Prof Md. Ataur Rahman (1948-2014)

Abstract

Housing prices have risen significantly in all Australian capital cities over the past 30 years. Strong house price growth has led to the widespread belief that speculative bubbles exist in Australian housing markets. Whilst the issue of bubbles has been discussed in Australian housing market studies for some time, a robust investigation into the existence of speculative bubbles has not been given the same level of consideration. This paper investigates whether there is any evidence of speculative bubbles in the Australian national and the eight capital city housing markets during the period 1999 to 2017. We apply the bubble detection method proposed by Shi (2017), which controls for the impact of a large set of macroeconomic factors. The results are compared with those from the bubble detection method of Phillips et al. (2015*a*,*b*, PSY). The PSY real-time detection method controls for the impact of rent. Both approaches identify a significant speculative bubble during period 2003:Q2-2005:Q4 in most of the Australia's capital cities. While the method of PSY reveals significant evidences of speculation over the 2014-2017 period, the new method finds no evidence of speculation in all capital cities except Canberra since mid-2005. By taking into consideration the impact of macroeconomic factors (such as mortgage interest rate, disposable income, employment, population, and housing supply growth) on house prices, this study provides a better control for housing market fundamentals, which leads to a more precise detection of speculative bubbles. The outcomes of the study have important policy implications by aiding the control of speculative bubbles in house prices through smoother adjustments using housing market fundamentals.

Keywords: Speculative bubbles, Market fundamentals, Log price-rent ratio, Macroeconomic variables, PSY, Australia

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1 Introduction

"When you look at the housing bubble evidence, it is unequivocally the case in Sydney." (John Fraser, Secretary to the Australian Treasury, 2015)

"Sydney and Melbourne real estate markets are showing every sign of being in a dangerous price bubble." (Smith Vernon, Nobel Prize-winning economist, 2015)

"There is no bubble...If housing was unaffordable in Sydney, nobody would be buying it." (Joe Hockey, the former Treasurer of Australia, 2015)

Housing is strongly related to the economic growth of Australia and the welfare of Australians (Rahman, 2010). Housing is considered the most valuable and single largest asset class in Australia, and Australian residential housing was estimated to be worth \$7.3 trillion in September 2017, which is significantly higher than the value of listed equities/stocks (\$1.8 trillion) and the total value of Australian superannuation (\$2.3 trillion) (Corelogic, 2017). Figure 1 shows the distribution of housing worth for capital cities, with around 80 per cent of Australian national housing value centred within the capital cities.

Housing prices have risen significantly in all Australian capital cities over the past 30 years. According to statistics from the Switzerland-based Bank for International Settlement (2017), real house prices in Australia rose by 32 per cent from 2012 to 2017, which is the third highest increase among advanced economies, following a 47 per cent increase in New Zealand and a 38 per cent increase in Canada over the same period. The increase in Australia's real house prices was higher than that experienced in both the United Kingdom (UK) and the United States (US), which saw increases of 22 per cent and 28 per cent, respectively.

Australian house prices have increased significantly faster than average rents and average household incomes (Richards, 2008). In the Australian housing mar-

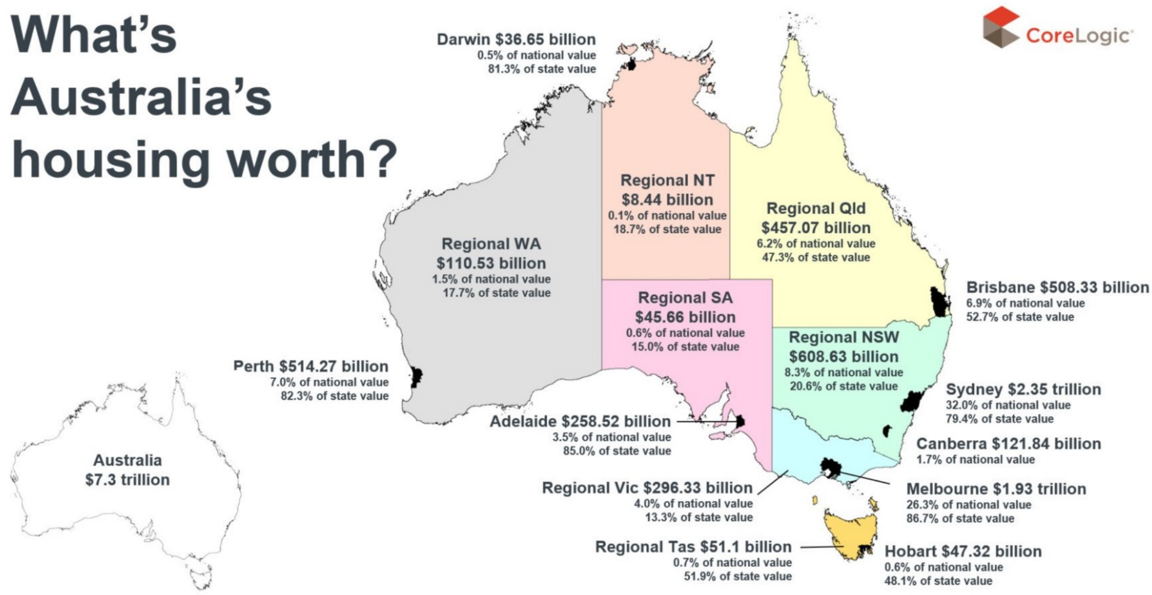


Figure 1: Concentration of Australia's housing worth within the capital cities. Source: (Corelogic, 2017)

ket there is some evidence that while the price-to-rent ratio has subsequently declined, housing prices remain well above the historical average (Hatzvi and Otto, 2008). What caused this rise in housing prices is still not evident, and such strong house price growth in Australia has led to the widespread belief that a speculative bubble exists in the Australian housing market (Buiter, 2017; Economist, 2003; Tharenou, 2015).

A speculative bubble is part of an asset price variation that is not explained by market fundamentals (Stiglitz, 1990). Brunnermeier (2008) adds that asset prices exceed their fundamental value because of buyer expectations of future price increases. A burst housing bubble would have a significant impact on the aggregate economy, leading to a severe decline in house prices and consequently a loss of household wealth and a reduction in household consumption (Case et al., 2005; Skinner, 1996). According to statistics from the Australian Prudential Regulation Authority (APRA), 63.7 per cent of all bank lending relates to housing (APRA, 2014). Therefore, a severe decline in house prices may also result in unanticipated losses for lenders (Case et al., 2000). Moreover, a sharp drop in house prices is likely to discourage investment and new building construction, which would in turn lead to lower economic growth (Tejvan, 2017). Hence, it is very important from an aggregate economic perspective to investigate whether house price increases due to speculative bubbles.

The issue of a housing bubble has been discussed frequently in Australian housing market studies and this stream of research has recently gained momentum (Baur and Heaney, 2017; Bourassa et al., 2001; Engsted et al., 2016; Hatzvi and Otto, 2008; Ji and Otto, 2015; Shi et al., 2016; Vogiazas and Alexiou, 2017; Wang et al., 2018). Most of the recent studies on house price bubble identification (see, for example, Engsted et al., 2016; Ji and Otto, 2015; Shi et al., 2016; Vogiazas and Alexiou, 2017) consider only housing market factors such as house price-to-rent ratio (a measure of a potential deviation between house prices and their fundamental value) or only house prices. These studies investigate the presence of speculative bubbles based on a price-to-rent ratio using a novel approach (PSY test) proposed in Phillips et al. (2015*a*,*b*). The PSY test is one of the most popular and thoroughly researched approaches for real-time bubble detection. It identifies the possibility of a bubble for period where a stochastic process exhibits explosive behaviour rather than unit root behaviour. The PSY bubble detection test has been extensively applied in different financial markets. A few recent applications of the PSY procedure for detecting bubbles include housing/real estate markets (see, for instance, Anundsen et al., 2016; Deng et al., 2017; Gomez-Gonzalez et al., 2017; Hu and Oxley, 2018*a*; Shi et al., 2016; Vogiazas and Alexiou, 2017), stock markets (see, for example, Escobari et al., 2017; Hu and Oxley, 2018*b*), commodity markets (Alexakis et al., 2017; Li et al., 2017), energy markets (Narayan and Narayan, 2017; Sharma and Escobari, 2018), exchange rates (see, for instance, Hu and Oxley, 2017; Maldonado et al., 2018) and artworks markets (Assaf, 2018).

Some other researchers in Australia follow the cointegration approach of Diba and Grossman (1988) to investigate housing bubbles, whereby house prices that are not continuously balanced in a long-run equilibrium state suggest a high probability that a bubble exists (Diba and Grossman, 1988; Flood and Hodrick, 1986).

However, studies based on the cointegration approach provide ex-post analysis of a housing bubble rather than real-time monitoring. Moreover, the cointegration technique loses its power in detecting periodically collapsing bubbles. A different approach by Hatzvi and Otto (2008), points to the possible role of a speculative bubble when the variation of house prices cannot be explained by either expected rents or returns.

Existing real-time bubble monitoring studies in the Australian context (see, for example, Baur and Heaney, 2017; Engsted et al., 2016; Ji and Otto, 2015; Shi et al., 2016; Vogiazas and Alexiou, 2017) either consider price-to-rent ratios or house prices in the detection of a bubble. However, studies using only rent as a proxy for market fundamentals overlook the impact of the aggregate economy on house prices. For example, changes in interest rates influence home ownership affordability, economic and population growth reflect the demand for housing, and supply-side factors affect the responsiveness of new dwelling construction to changes in housing demand. Therefore, the inference that a housing bubble exists based only on the price-to-rent ratio or only on house price measures can be misleading. Consequently, studies applying the PSY test only to the price-to-rent ratio in the detection of bubbles may produce false speculations (Shi, 2017).

In general, house prices have changed because of changing housing market fundamentals or speculative bubbles (or both) (Engsted et al., 2016; Gilles and LeRoy, 1992), and speculative bubbles can lead house prices to diverge from market fundamentals (Ji and Otto, 2015). A challenging task is that of separating the effects on house prices of both housing market fundamentals and speculative bubbles. Consider a scenario where house prices change depending on their fundamental value and a speculative bubble, both of which are typically unobserved. So even if we notice strong increases in house prices, we cannot be certain whether these increases are caused by the speculation of a bubble or by market fundamentals. Therefore, proper specification of market fundamentals is very important in understanding the dynamics of house prices. Many studies (see, for example, Abelson et al., 2005; Baur and Heaney, 2017; Hatzvi and Otto, 2008; Wadud et al., 2012) have investigated the impact of various macroeconomic conditions on house prices. However, an under-researched area in the literature is the extent to which the behaviour of the house prices is consistent with underlying market fundamentals.

Much of the literature on the determinants of house price dynamics in Australian housing markets provides evidence that house price changes have a significant relationship with macroeconomic factors (Meidani et al., 2011). More specifically, studies have found that house prices have a positive relationship with population growth (Bodman et al., 2004; Bourassa et al., 2001; Ge and Williams, 2015; Otto, 2007) and household income (Abelson et al., 2005; Bourassa et al., 2001; Fox et al., 2012; Jiang et al., 2011; Otto, 2007; Richards, 2008). In addition, employment (unemployment) has also a positive (negative) relationship with house prices (Abelson et al., 2005; Bourassa et al., 2001; Otto, 2007). There is also evidence that interest rates (affecting the cost of financing and mortgages) have a strong influence on house prices (Abelson et al., 2005; Bourassa et al., 2001; Choudhury et al., 2004; Fry et al., 2010; Ge and Williams, 2015; Gomez-Gonzalez et al., 2017).

However, none of these studies control for the impact of macroeconomic conditions in their investigation of whether a housing bubble exists in Australia, and there seems a lack of uniformity in the existing literature in determining house price dynamics. Our study contributes to filling this gap by adopting a new framework for the investigation of house price bubbles in Australia. Instead of merely considering housing market information (i.e. house prices and rent), our approach predominantly accounts for the impacts of such macroeconomic conditions as mortgage interest rates, disposable income, employment, population and housing supply growth in identifying a speculative housing bubble.

Some studies focus explicitly on a determination of a speculative bubble in Australia at the national level. However, there are considerable differences in house price growth and macroeconomic conditions across the country's capital cities. For example, house prices in Adelaide increased rapidly after the beginning of the mining boom in 2000 and with the mining boom in Perth around mid-2006. Whereas, the annual growth rate of house prices in Sydney and Melbourne has increased by 8-10 per cent in the last 3-4 years (ABS, 2017). Economic growth and employment growth rates have been relatively strong in New South Wales and Victoria compared to other states (ABS, 2017).[1] These results imply that house prices and macroeconomic conditions vary across the capital cities/states of Australia. Our study takes into account these important perspectives. Therefore, we are mainly interested in investigating the possibility of speculative bubbles in Australia's eight capital cities.

Hence, our study's aim is to identify house price speculative bubble behaviours in the housing markets of Australia's eight capital cities and at the national level over the period 1999 to 2017. We adopt the real-time bubble detection framework of Shi (2017) to investigate the existence of speculative bubbles. Compared with other bubble detection methods, Shi's (2017) method explores information beyond housing markets and accounts for the impact of macroeconomic factors. This approach has been applied to US national and regional housing markets (Shi, 2017) and to housing markets in the Canadian provinces (Gomez-Gonzalez and Sanin-Restrepo, 2018). Macroeconomic factors are assumed to affect housing market fundamentals through rent and interest rates. Following Shi (2017) and Gomez-Gonzalez and Sanin-Restrepo (2018), we consider macroeconomic factors such as disposable income, employment, population and supply growth through a vector autoregressive (VAR) model to estimate the future stream of rent and interest rates. After the decomposition of house prices into fundamental and non-fundamental (residual) components, we apply the recursive PSY bubble detection test to the non-fundamental (residual) component estimates to find evidence of a

[1] Sydney, Melbourne, Brisbane, Adelaide, Perth, Hobart, Darwin and Canberra are the capital cities of the States of New South Wales, Victoria, Queensland, South Australia, Western Australia, Tasmania, Northern Territory and Australian Capital Territory respectively.

speculative bubble.

To our knowledge, this is the first study in Australia that considers all potential housing market fundamentals (demand-and supply-side factors) while detecting speculative bubbles at the national level and for the eight capital cities. Since the US sub-prime crisis, almost all advanced economies have focused their attention on fostering early-warning mechanisms to detect housing bubbles. Consequently, our results would contribute to the current investigation of housing speculation and help policy-makers prevent further development of speculative behaviour. Our results suggest that the Reserve Bank of Australia (RBA) should account for these fundamental factors when designing housing-related policies.

This thesis is structured as follows: Section 2 provides a brief literature review, Section 3 describes the data and Section 4 describes the methodology chosen. The empirical results are discussed in Section 5, and Section 6 draws a conclusion to the thesis.

2 Literature Review

Our literature review comprises three parts. The first section evaluates the relevant literature on various methods of bubbles detection, the second section provides evidence of housing bubbles in the Australian national and capital city housing markets. Finally, the last section examines the main determinants of house price dynamics in Australian housing markets.

2.1 Bubble identification methods

Several bubble detection techniques have been developed and employed over the last three decades. Most of the studies have used an ex-post identification approach rather than a real-time date-stamping technique. The ex-post test investigates for the existence of bubbles over an entire historical dataset, whereas a real-time monitoring approach can identify bubbles contemporaneously. The frequently used ex-post identification methods include: the variance bounds tests of Shiller (1981), West's two-step specification test (West, 1987), the cointegration-based test of Diba and Grossman (1988), regime switching bubble tests of Van Norden (1996) and Brooks and Katsaris (2005), and the Markov-switching test of Hall et al. (1999). On the other hand, the PWY test of Phillips et al. (2011); the approaches of Phillips and Yu (2011) and Pavlidis et al. (2017), the CUSUM test of Homm and Breitung (2012), the PSY test of Phillips et al. (2015*a*,*b*) are all widely used real-time bubble monitoring techniques.

There is considerable variation in the choice of bubble detection methods used in the literature for detecting an asset bubble. However, those most commonly employed are based on the present value model and the rational bubble assumption. In the absence of bubble conditions, a standard present value model infers that a house price equals the expected present discounted value of its future returns (Blanchard and Watson, 1982). In contrast, in the presence of a bubble, the house price is composed of a fundamental component and a bubble component.

Shiller (1981) uses a variance bounds test that is based on the present value model. Although this test is not initially designed for bubble detection, Shiller's (1981) idea has been subsequently used in bubble detection tests. It compares the variance of actual price volatility with the variance of the ex-post rational price. The variance bounds test is violated when actual price volatility exceeds the bound imposed by the variance of the ex-post rational price. Blanchard and Watson (1982) claim that this violation is due to rational bubbles. However, the variance bound test has some limitations. For example, it assumes a constant discount rate of return and uses the sample average of de-trended real prices as the ex-post rational price.

West (1987) developed the two-step method with which he first incorporated the bubble component in the alternative hypothesis. West's (1987) two-step test is based on the underlying equilibrium model of asset prices. The method compares the estimates from regressing the asset price with the lagged return (assuming no bubble), and the estimates of the impact of the fundamental value on price in an underlying equilibrium model. A Hausman specification test is then applied to check whether or not the linear model and underlying equilibrium model coincide. Ultimately, the difference between the two estimates suggests the presence of a bubble. For a successful application of the two-step method, proper specification of an underlying equilibrium model in West's (1987) approach is crucial; misspecifications of the underlying equilibrium model can also affect the power of the test. Moreover, Yiu et al. (2013) and Gürkaynak (2008) point out another limitation. Simply using past returns to forecast the future is not adequate and therefore, Gürkaynak (2008) recommends a consideration of additional information while predicting future returns.

To address the limitations of Shiller's (1981) variance bounds test and West's (1987) two-step test, Campbell and Shiller (1987) propose the cointegration based test, arguing that the difference between the asset price and its fundamental value will show explosive behaviour when in the presence of a bubble. This process also involves two steps: the first is to apply a unit root test to house prices and market fundamentals. The variance bounds test suggests that, among the possible outcomes of the unit root test, the existence of bubbles may be possible in two cases: either the asset price is non-stationary while the fundamental value is stationary; or both are non-stationary. Second, in the presence of a bubble, the fundamental value and house price may not be cointegrated and hence the second case is violated.

The milestone bubble identification test is that proposed by Diba and Grossman (1988). They point out that bubbles do have some theoretical properties that can be utilized in a bubble detection test. This idea motivated them to design a test based on the ground-breaking work of Engle and Granger (1987). Diba and Grossman (1988) use cointegration and unit root tests to identify explosive behaviour without precluding the possible effects of unobservable variables on market fundamentals. This test identifies bubbles by analysing the stationary properties of asset prices and their fundamentals based on the assumption that fundamental values and prices should follow a cointegrated stationary process. This technique has been widely applied in the identification of asset bubbles over the last two decades. However, Evans (1991), in response to the test (Diba and Grossman, 1988), posited that markets have self-feeding explosive components that are run by self-fulfilling expectations (markets impulsively pop up and collapse) and may not be estimated by standard unit root tests. Another limitation of Diba and Grossman (1988) seems to be that the cointegration technique loses its power in the presence of periodically collapsing bubbles. Furthermore, Gürkaynak (2008) criticises the technique for not ensuring accurate analysis of stationary properties.

Several alternative bubble detection techniques that can deal with the limitations of the Diba and Grossman (1988) test have been documented in the literature. For instance, the regime switching bubble test designed by Van Norden (1996) and the three-regime model of Brooks and Katsaris (2005), which identify bubbles by searching for time-varying patterns (regime switching patterns).

Hall et al. (1999) employ Markov-switching unit root tests, which assume Markov-switching under the null, and test only for an explosive root. Chow and CUSUM-type tests by Homm and Breitung (2012), which are also popular tests for structural breaks and bubble identification. The approach of Pavlidis et al. (2017) is based on the rolling Fama regressions and the recursive unit root tests of Phillips et al. (2015*a*), which exploit the fact that future and spot prices must converge in the absence of a bubble. This test approach doesn't demand pre-specifying a variable capturing the fundamental part of prices. However, it does require a lengthier dataset compared to what is used in presently available bubble tests. Furthermore, the intrinsic bubble test of Froot and Obstfeld (1991) focuses on the behaviour of the price-dividend ratios. Under the null hypothesis of no intrinsic bubbles, prices are a linear function of dividends and the price dividend ratio is a constant. Thus the test for bubbles just involves regressing price-to-dividend ratios on a constant and dividends. A non-linear relationship between prices and dividends suggests evidence of an intrinsic bubble.

Most of the bubble detection techniques designed in the 20th century can be used to detect (nonlinear) periodically collapsing bubbles. As an additional advantage over Diba and Grossman's (1988) conventional unit root and cointegration method, Phillips et al. (2011) (PWY hereafter) propose a forward recursive right-tail Augmented Dickey-Fuller (ADF) test (also known as Supremum ADF (SADF) test). This method executes a right-tailed ADF test repeatedly on a forward expanding sample sequence, making inferences based on the Sup value of the corresponding DF statistic sequence. The technique is used as an ex-ante early warning alert system that can identify and date stamp the period of the occurrence of bubbles. SADF tests perform significantly better than typical unit root and cointegration tests. However, in the presence of multiple collapsing bubble episodes, the SADF test does not consistently detect the origination and termination of a bubble.

To overcome this constraint in PWY, recently Phillips et al. (2015*a*,*b*) suggested an alternative approach (referred to as the PSY procedure) to detect periodically collapsing bubbles with a real-time date-stamping of the origination and termination of bubbles. Although this technique also depends on the repeated execution of right-tailed ADF tests like PWY, its advantage over the PWY is that it covers the sample sequence by changing the initial point of the sample over a feasible range of flexible windows rather than fixing the start point of each regression window. After a comparison between PSY and PWY procedures, Homm and Breitung (2012) confirm that PWY works better in the presence of periodically collapsing bubbles whereas the PSY test outperforms the PWY test in the presence of multiple bubble episodes.

However, the application of the PSY test only to house price-to-rent ratios or to house prices can produce misleading results. A new method, developed by Shi (2017), incorporates macroeconomic factors to obtain better control of housing market fundamentals in the process of bubble detection. The factors include per-capita income, employment, population growth and housing supply. They are incorporated into the VAR model to estimate the future streams of rent and interest rates. Then, rather than applying the PSY bubble detection test to the price-to-rent ratio, this new approach applies the test to the non-fundamental estimates (residual). Interestingly, using this approach Shi (2017) has found a significant reduction in the number of bubble episodes and their duration. This approach helps to estimate speculative bubbles with a lower probability of false identification.

2.2 Bubbles in the Australian national and capital city housing markets

The existence of Australian housing price bubbles has received much attention and discussion in the academic literature after the era of the global financial crisis (GFC) 2007-2009 (see, for instance, Baur and Heaney, 2017; Bourassa et al., 2001; Engsted et al., 2016; Hatzvi and Otto, 2008; Ji and Otto, 2015; Shi et al., 2016; Vogiazas and Alexiou, 2017; Wang et al., 2018). A significant number of studies have applied the PSY test to price-to-rent or to house prices to investigate the existence of a speculative bubble (see, for example, Baur and Heaney, 2017; Engsted et al., 2016; Ji and Otto, 2015; Shi et al., 2016; Vogiazas and Alexiou, 2017).

For instance, the seminal up-to-date study by Shi et al. (2016) investigates the existence of house price bubbles in all eight capital cities of Australia from 1995 to 2016 based on the price-to-rent ratio. They identify house price bubbles with different durations and find a bubble that has progressed in the house market of Sydney since 2014.

Similarly, Ji and Otto (2015) test for the existence of a house price bubble in six Australian capital cities (except Hobart and Darwin) from 1975 to 2015. Their results are consistent with Shi et al.'s (2016) findings; particularly the result that suggests a progressive bubble in Sydney since the earlier part of 2015. On the other hand, Baur and Heaney (2017) test for evidence of a bubble for all eight Australian capital cities between 1995 and 2015 using house prices instead of the price-to-rent ratio. They identify a bubble around the year 2003 in all capital cities except Darwin. Moreover, they find a recent bubble episode around 2014 in all capital cities with the exceptions of Perth, Hobart and Canberra.

Rather than focusing on Australian capital city-level housing markets, Vogiazas and Alexiou (2017) and Engsted et al. (2016) both investigate for house price bubbles in Australia at the national level as a member country of the OECD. Using house prices between 2003 and 2015, Vogiazas and Alexiou (2017) find two speculative bubble episodes; one from 2007:Q2 to 2008:Q4 and one from 2013:Q1 to 2015:Q1. Whereas, based on the price-to-rent ratio series between 1971 and 2013, Engsted et al. (2016) find a total of four speculative episodes. Two longer episodes: one starting 2000:Q2 and terminating in 2003:Q4; and another commencing 2006:Q2 and collapsing in 2007:Q3. Two shorter episodes from 2004:Q2 to 2004:Q3 and 2005:Q4 to 2006:Q1. These results are partially consistant with that of Vogiazas and Alexiou (2017). A summary of the results for identified bubble episodes in the Australian national and capital city housing markets is given in Table B1 of Appendix B.

Some other empirical studies have used Diba and Grossman's (1988) cointegration framework to test for the existence of house price bubbles. For example, a recent paper by Wang et al. (2018) investigates the cointegrating relationship between house prices and economic fundamentals at the Australian national level between 1995 and 2015. Another study by Jiang et al. (2011) uses a similar approach (though the economic fundamentals are not identical to those in Wang et al. (2018)) and tests the existence of house price bubbles in all eight Australian capital cities' housing markets between 1995 and 2008. Both studies rely on the same assumption: that the existence of house price equilibrium over the long term suggests that a bubble does not exist (Diba and Grossman, 1988; Flood and Hodrick, 1986). Hence, we can simply say that cointegration between house prices and fundamentals rules out a bubble. However, these studies each produce different results: Wang et al. (2018) find no evidence of a bubble in the Australian national housing market, while Jiang et al. (2011) identify the presence of bubbles in two capital cities (Perth from December 2000 to June 2008, and Sydney from March 2002 to December 2004).

A study on the Sydney housing market by Hatzvi and Otto (2008) tests for speculative bubbles in the local government area of Sydney from 1991 to 2006. The authors follow Cochrane's (1992) idea that in the absence of a bubble, the variation in house prices can be fully explained by market fundamentals. Their findings show that a significant proportion of the variation that exists in house prices in western regions of Sydney cannot be explained by either rents or discount factors. Hence, a possible speculative bubble exists, influencing Sydney's house prices.

2.3 Market fundamental factors considered

This section reviews the literature on the determinants of house price dynamics in the Australian housing market. A change in house prices is driven both by the demand for housing and by the supply of housing (Rahman, 2010). Housing demand is strongly related to macroeconomic variables such as household income, population growth and migration patterns (Megbolugbe and Cho, 1993).

Australia's population growth is relatively high among developed countries (ABS, 2017), and the net migration rate is higher compared to some other advanced economies, which contributes to higher population growth. To facilitate the economy of regional areas of Australia, the Australian government grants privilege (in terms of residency) to immigrants who want to live in regional centres. However, despite this, people still prefer to live in a capital city area such as Sydney or Melbourne, where housing has already condensed. Capital cities are preferred as there are more employment opportunities. According to recent figures from the Australian Bureau of Statistics (ABS), in 2017 net overseas migration increased by 31 per cent in NSW and 23 per cent in Victoria compared to 2016 (ABS, 2017). Previous studies suggest that population growth and net overseas migration both have had a significant effect on house prices (Bodman et al., 2004; Bourassa et al., 2001; Otto, 2007). However, there are opposing findings; for example, those of Ge and Williams (2015) who find that population growth and net overseas migration do not significantly impact house price change.

The demand for housing is also amplified by increases in household income. Higher income allows people to attain a larger mortgage loan for a house, increasing the overall housing demand and consequently causing house prices to rise (Rahman, 2010). A series of papers on capital cities' housing markets suggest that in some cities of Australia, household income has a positive relationship with house prices (Bourassa et al., 2001; Jiang et al., 2011; Otto, 2007; Richards, 2008). For example, Jiang et al. (2011) find that household income has a positive impact on house prices in Sydney, Brisbane and Canberra. Likewise, Otto (2007) finds similar evidence for Sydney and Canberra.

Similarly, more empirical studies (see, for instance, Abelson et al., 2005; Bourassa et al., 2001; Richards, 2008) at the Australian national level find that income has a significantly positive effect on house prices. Furthermore, Abelson et al. (2005) go further to argue that long-run real house prices are determined significantly and positively by real disposable income. Interestingly, the selection of a proxy variable for household income differs across the studies. For example, Bourassa et al. (2001) consider real wage income, whereas state final demand is selected by Otto (2007), and Costello et al. (2011) and Richards (2008) use average household income.

In addition to income and population growth, employment is another potential driver of house price change. Several studies (see, for instance, Abelson et al., 2005; Bourassa et al., 2001; Ji and Otto, 2015; Otto, 2007) have shown with empirical evidence that employment (unemployment) has a positive (negative) relationship with house prices. In contrast, Wang et al. (2018) find that unemployment has a positive but insignificant effect on house price increases. They show that a rise in the unemployment rate may lead to the central bank cutting the cash rate to stimulate economic growth, which consequently increases house prices.

There is an enormous amount of literature investigating the effect of interest rates on house prices (see, for example, Abelson et al., 2005; Berry and Dalton, 2004; Bodman et al., 2004; Bourassa et al., 2001; Fry et al., 2010; Hatzvi and Otto, 2008; Otto, 2007; Tu, 2000). Interest rates play a significant role in fixing the cost of mortgage interest repayments. Mortgage lenders usually decrease the cost of the variable mortgage payments when the interest rate falls. Hence, a lower interest rate encourages people to buy a house. Since the greater proportion of Australian home-owners have variable mortgages, a slight change in the interest rate may have an impact on the affordability of home ownership.

Mortgage interest rates have considerable effects on house prices (Berry and Dalton, 2004; Tu, 2000). For example, Otto (2007) posits that mortgages influence house prices in all capital city housing markets except Darwin, while Hatzvi and Otto (2008) observe that about a quarter of the variation in Sydney prices are caused by consumers' speculation of variations in real interest rates. The findings from Choudhury et al. (2004), Ge and Williams (2015) and Abelson et al. (2005) suggest a negative relationship between house prices and mortgage rates in Australia. In addition, Wadud et al. (2012) investigates the effect of monetary policy (e.g. interest rates) on the Australian housing market . Their findings suggest that the Reserve Bank of Australia (RBA) should take into account housing prices when setting monetary policies.

Previous studies have put more emphasis on demand-side drivers in establishing the asset price model, with the supply of housing assumed to be fixed. There is little doubt that housing supply has a significant influence on the future rent and leads to a change in house prices (Hatzvi and Otto, 2008). Some studies have taken into account housing supply as an important factor that impacts on house prices (see, for instance, Abelson et al., 2005; Bodman et al., 2004; Bourassa et al., 2001; Fry et al., 2010; Otto, 2007; Peng and Chen, 2016; Richards, 2008). According to Abelson et al. (2005) and Peng and Chen (2016), housing supply has a significant impact on the increase in house prices.

On the other hand, Fry et al. (2010) and Otto (2007) argue that a supply shock has little impact on real house prices. This might be one reason for researchers to select more demand-side variables rather than supply factors. Like income, the proxy for the supply variable also varies across studies. Most existing literature considers construction costs as a supply factor (see, for example, Bodman et al., 2004; Bourassa et al., 2001; Fry et al., 2010; Richards, 2008). Ge and Williams (2015) consider the total number of dwelling unit building approvals, whereas Abelson et al. (2005) and Peng and Chen (2016) choose housing stock and new residential dwelling respectively. A summary of the literature about the relationship between the macroeconomic variables and house prices is given in Appendix B: Table B.2.

The existing literature on the Australian housing market shows various drivers of house price dynamics. This thesis only accounts for the impact of potentially the most significant drivers impacting house prices to identify the existence of speculative bubbles in the housing market in Australia. The drivers examined in our paper are: disposable income, employment, population, mortgage interest rates, and housing supply.

3 Descriptions of the Data

To estimate the market fundamentals, we need three sets of data series: 1) house price, rent, Consumer Price Index (CPI) (excluding shelter); 2) real mortgage interest rate; and 3) macroeconomic variables such as employment, population, disposable income and housing supply. All data series are either collected or converted to a quarterly frequency for eight capital cities and for Australia as a nation for the longest available period from 1999:Q3 to 2017:Q4. We convert all monthly frequency data series to a quarterly frequency by an average of the observations in the corresponding quarter data.

3.1 House prices and rent

Monthly house prices have been sourced from SIRCA's (2018) CoreLogic RP online database. House prices are estimated by CoreLogic using a hedonic regression methodology across both time and space (Goh et al., 2012), which addresses the issue of compositional bias related to median price and other housing characteristics (such as the number of bedrooms and bathrooms, land area and geographical context of the dwelling). The accuracy and robust characteristics of CoreLogic house price data make them preferable to other available data series. Indices rather than monetary values of house prices are available from the Australian Bureau of Statistics (ABS). The ABS published established house price indices for all capital cities in Australia from June 1986 to June 2005. However, the Bureau adopted a different methodology after June 2005, publishing and backdating established house price indices only from March 2002. House price indices after the new methodology was adopted are available from March 2002, which would give us a limited number of data points. This is another reason to choose the CoreLogic house price data.

In the CoreLogic RP database, house price series are available from 1995:Q2 at the national level and for all capital cities except Darwin (Darwin starts from

1999:Q3). As we focus on house price dynamics in each of the eight capital cities of Australia including Darwin, our house prices data for the country and eight capital cities are collected from 1999:Q3 to 2017:Q4.[2] To align the frequency of the house price series to other series, we convert monthly frequency data to a quarterly frequency by an average of the observations in the corresponding quarter data.

Monthly rent (return) series are also available from CoreLogic RP data, but only from 2009:Q2, and so would give us a limited number of data points. Hence, we use rent indices from the Australian Bureau of Statistics (ABS) to obtain a longer data series. The ABS publishes rent indices for the eight capital cities and the national level for Australia, which are available at quarterly frequencies and are presented as one of the subgroups of the CPI (non-seasonally adjusted, reference period 2011-2012=100).[3] To keep consistent with the period from which house prices were collected (see above), we consider rent indices for the period 1999:Q3 to 2017:Q4.

We then decompose house prices to fundamental and non-fundamental (residual) components. The non-fundamental component is computed as the deviation of the estimated fundamental component from the price-to-rent ratio. To calculate the predicted fundamental component, we need monetary values for rent and house prices instead of indices. Actual house prices and rent need to be incorporated in a VAR system, not the price-to-rent ratio. Like Campbell et al. (2009), Davis et al. (2008), Gomez-Gonzalez and Sanin-Restrepo (2018) and Shi (2017), we convert the rent indices to actual rental cost. The ABS publishes the rent indices, rather than the actual rental cost; hence, we collected weekly rental values for 2014:Q4 from CoreLogic's rental review report for Australia at the national level and for eight capital cities (presented in Table 1). Rental review reports

[2]Australia's eight capital cities are Sydney, Melbourne, Brisbane, Adelaide, Perth, Hobart, Darwin and Canberra.

[3]For the national house price and rent, we consider the figure of a weighted average of eight capital cities as the Australian national figure. A detailed explanation is given in the latter part of this section. All the other Australian national variables are representing Australia as a whole.

provide the median rent per week during the quarter, however, not all quarterly rental review reports are publicly available. By using median rent per week, we extrapolate actual rents from the corresponding ABS rent index.

Table 1 displays the actual rental values for Australia and eight capital cities in 2014:Q4 (October-December 2014). The median weekly rental cost for Australia was \$400. Based on weekly house rent data, Darwin was the most expensive city with a median weekly rent of \$645, followed by Sydney, Canberra, and Perth (with median weekly house rent of \$525, \$475 and \$450 respectively).

Table 1: Weekly rental cost for Australia and eight capital cities.

	Median House Rent
Australia	\$400.0
Sydney	\$525.0
Melbourne	\$385.0
Brisbane	\$410.0
Adelaide	\$350.0
Perth	\$450.0
Hobart	\$343.0
Darwin	\$645.0
Canberra	\$475.0

We collected Australian national and eight capital cities CPI excluding shelter from the ABS. The CPI less shelter series is disaggregated to remove influence from accommodation expenses. To calculate real house prices and real rents for the country and eight capital cities, we deflate the nominal house prices and real rents using their corresponding CPI excluding shelter.

Figure 2 shows the log price-to-rent ratios in eight capital cities of Australia for the period 1999:Q3 to 2017:Q4. At the end of our sample period, the log price-to-rent ratio for Melbourne was the highest, followed by Sydney. We can see that the log price-to-rent ratio ranges from 6.24 for Hobart in 1999 to 7.84 in Melbourne in 2017. During the whole sample period, Sydney shows the highest mean of the log price-to-rent ratio (7.35), followed by Melbourne (7.34), Perth (7.19) and Canberra (7.12). Considering the standard deviation, Hobart (0.27) had more volatile log price-to-rent ratio, followed by Perth (0.26) and Melbourne (0.25), whereas Sydney

(0.15) and Canberra (0.18) experienced the lowest volatility levels.[4] In Darwin and Hobart, the log price-to-rent ratios have always been lower than those of the other capital cities. These ratios for the eight capital cities show some fluctuation during the sample period particularly due to the mining boom around mid-2006, where the log price-to-rent ratio for Perth exceeded all other city ratios. Two different periods of fluctuating movements are evident.

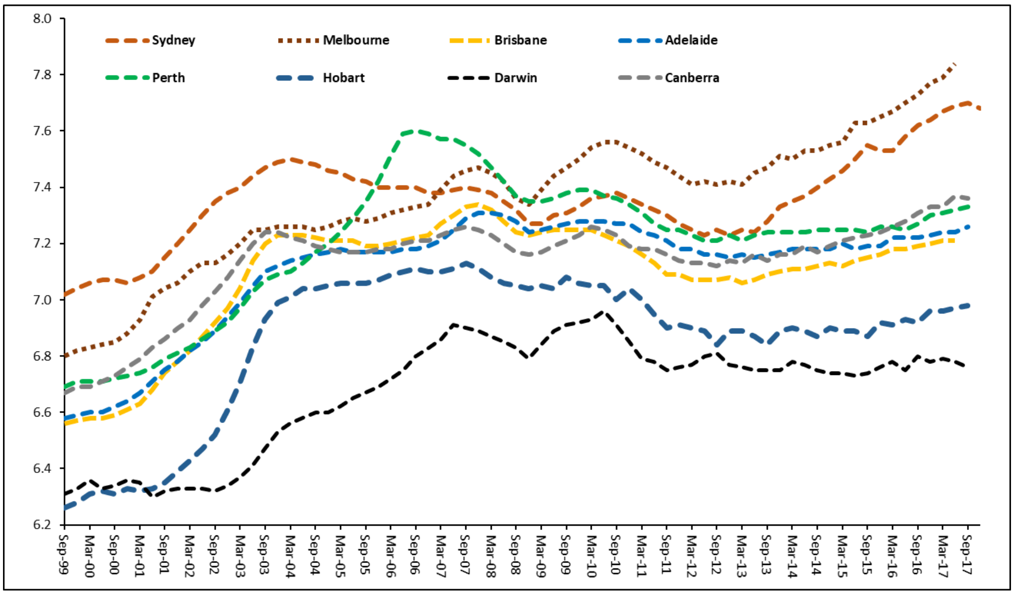


Figure 2: The log price-to-rent ratio for eight capital cities.

The first occurs around 2003-2004, when house prices in almost all capital cities rose sharply. Then the second period was around the middle of 2008, when the ratios for all capital cities showed a similar pattern; they fell sharply and then stabilized at higher levels. Overall, all series display an upward trend in this sample. We are interested to see whether these increases are due to the effects of changes in market fundamentals or to speculative bubbles.

3.2 Real mortgage interest rate

The real mortgage rate variable is estimated by adjusting the standard variable mortgage rate for inflation. The nominal mortgage rate series is obtained from the

[4]Descriptive statistics of the log price-to-rent ratios for national and eight capital cities are mentioned in Table C.2 of Appendix C. Moreover, house prices and rent in Australia's national and eight capital cities are shown in Figure E.1 of Appendix E.

Federal Reserve Bank of Australia (RBA), which is available as averaged monthly data (non-seasonally adjusted). It is measured by the standard variable home loan rate offered by banks to owner-occupiers.

The RBA also publishes inflation expectations data at a quarterly frequency. As inflation expectations and nominal mortgage rates are available at different frequencies, we converted the monthly nominal mortgage rate observations to quarterly observations.[5] The real mortgage rate is calculated as the nominal mortgage rate less the inflation expectations. In Figure 6, panel (b) shows the dynamics of the real mortgage interest rate including the log price-to-rent ratio for the nation.

3.3 Macroeconomic variables

The macroeconomic variables such as disposable income, employment, population and housing supply are collected from ABS data. However, there is a spatial mismatch between housing market variables (i.e. house prices and rent) and macroeconomic variables. House prices and rental series are available for the capital cities, whereas the macroeconomic variables are available only at the state level. In addition, Australian national house prices and rent data are available as the weighted average of the eight capital cities' house price and rent data respectively, while the national level macroeconomic variables represent the whole country.

This problem is unavoidable due to the availability of data. In the case of Australia, working with two different levels data (the capital city versus the state level) is not a major problem due to the strong concentration of population in the capital cities (Costello et al., 2011). Based on the recent statistics from the ABS (2017), the percentage of the state population living in capital cities is 100 per cent for Canberra, 64.82 per cent for Sydney, 76.47 per cent for Melbourne, 48.68 per cent for Brisbane, 64.82 per cent for Perth, 77.31 per cent for Adelaide, 43.37 per cent for Hobart and 59.38 per cent for Darwin. Figure 3 shows the percentage

[5] We choose both average observations and last observation methods for high to low frequency conversion. We plot them on the same graph, which shows two series as similar.

of the state population living in capital cities.[6] Overall, on average about 70 per cent of the Australian population lives in capital cities. Moreover, about 80 per cent of Australia's national housing value is concentrated in capital cities.

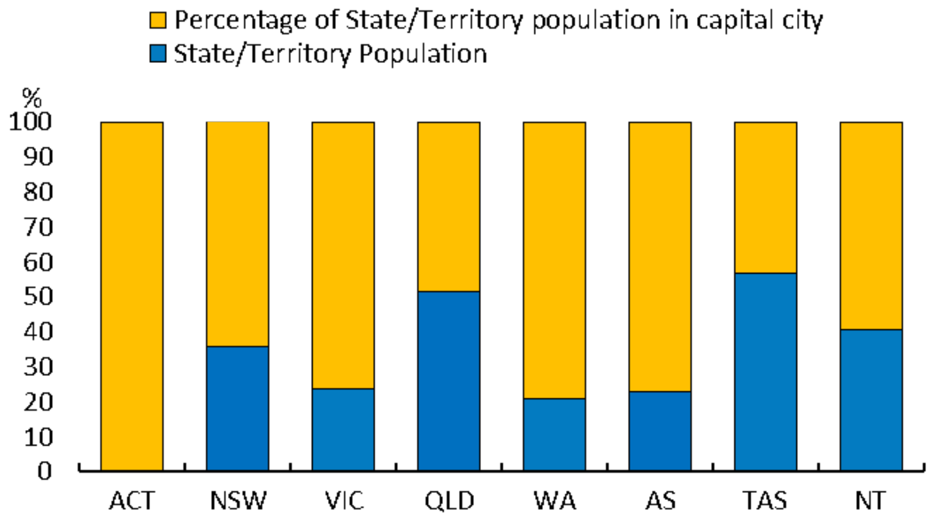


Figure 3: The percentage of the state population in the capital city.

All macroeconomic variables were obtained as follows: the population data (non-seasonally adjusted) was obtained from the ABS, available as part of the Australian Demographic Statistics, which considers the Australian resident population and is estimated by adding net overseas migration and natural increase (the excess of births over deaths) to the population at the beginning of each period. The population data is available at a quarterly frequency for Australia's eight states and Territories and at the national level. Australia is divided into six states: New South Wales (NSW), Victoria (VIC), Queensland (QLD), Western Australia (WA), South Australia (SA), and Tasmania (TAS) and two Territories: Australian Capital Territory (ACT) and the Northern Territory (NT). Hereafter the term "states" will be used to refer to both states and territories.

Employment data for this study were collected from the Australian Labour Force Survey, which is available from the ABS. Employed persons are defined as those aged 15 and over who reported that they were employed (either in full-

[6]Population statistics are detailed in the Table C.1 of Appendix C.

time or part-time work) during the reference week.[7] The employment data of the country and all eight states are available on monthly frequency (seasonally adjusted).

We consider the number of new housing completions as a proxy for housing supply.[8] Consisting of both private-and public-sector housing completions, the housing supply data are available from the ABS on quarterly frequency (seasonally adjusted and the reference year 2015-16) for Australia and all eight states.

To estimate the fundamental component, this study requires suitable income data for the whole country and eight states. Based on the available secondary data across Australia, there are potentially three variables that could be used as the proxy for income (e.g. gross state product, average weekly earnings, and state final demand (SFD)). All these variables are available for the whole country and eight states; however, gross state product is published at an annual frequency. As most other variables considered are available at a quarterly frequency and assume a constant gross state product throughout the year (for four quarters), which may not reflect the actual impact of income on house prices. Another possible variable is average weekly earnings, which is based on wages and salaries, but does not account for the impact of wealth. For the reasons explained further below, we chose SFD (seasonally adjusted) as the proxy for income.

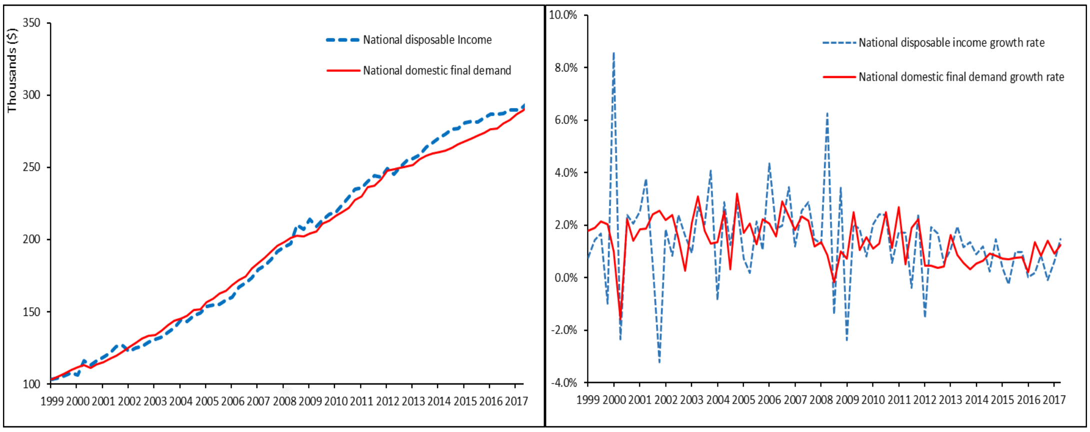
SFD is an estimate of the level of spending in the local economy by the private and public sectors. Spending is reported on the basis of consumption of goods and services and capital investment (ABS, 2017). At the national level, domestic final demand is equivalent to state final demand, and gross disposable income (seasonally adjusted) can be used for national disposable income. However, disposable income data are not available at the Australian state level. Therefore, following Costello et al. (2011), we assume that state-level final demand values can be a

[7] The ABS uses internationally agreed standards in defining employment and unemployment. See Tables A.1, A.2 and A.3 in Appendix A for data source details and definitions of house markets and all macroeconomic variables considered in this study.

[8] A building is considered completed when building activities are at a stage where the building can be functionalized.

robust proxy for state-level disposable income.

In Figure 4 panel (a), we compare national domestic final demand and national disposable income in levels, while panel (b) depicts the growth rates of national domestic final demand and national disposable income.



(a) Figures in levels (b) Growth rates

Figure 4: Pattern of national domestic final demand and national disposable income.

We observe from panel (a) that the lines for national disposable income and national domestic final demand show a very similar trend. For growth rates, we see a moderate positive association (correlation r= 0.30) between these variables. Therefore, based on the relevant statistics, we are confident that at the state level, SFD is a suitable proxy indicator for disposable income.

4 Methodology

4.1 Specification of the fundamental value component

To compute the fundamental value, we start with the single period return (V_{t+1}) to housing as

$$V_{t+1} = \frac{P_{t+1} + R_{t+1}}{P_t}, \tag{1}$$

where P is the real house price, and R is the real housing rent. Applying a first order Taylor series expansion, the log house price is expressed as

$$p_t = k + \rho p_{t+1} + (1 - \rho) r_{t+1} - v_{t+1}, \tag{2}$$

where lower case variables refer to the natural logarithm of the real variables, $v_{t+1} = logV_{t+1}$, $p_{t+1} = logP_{t+1}$, $r_{t+1} = logR_{t+1}$, $\rho = \frac{e^{\bar{p}}}{e^{\bar{p}} + e^{\bar{r}}}$, and $k = -log(p) + (1 - \rho)(\bar{p} - \bar{r})$, with $\bar{p}$ and $\bar{r}$ being sample means of p_t and r_t, respectively.

Iterating equation (2) forward, we obtain log house prices as the sum of a long-term component ($\frac{k}{1-\rho}$), the discounted future cash-flows ($(1 - \rho) \sum_{j=0}^{\infty} \rho^j r_{t+1+j} - \sum_{j=0}^{\infty} \rho^j v_{t+1+j}$) and the bubble component (B_t). Hence, log house prices can be written as,

$$p_t = \frac{k}{1 - \rho} + (1 - \rho) \sum_{j=0}^{\infty} \rho^j r_{t+1+j} - \sum_{j=0}^{\infty} \rho^j v_{t+1+j} + B_t. \tag{3}$$

The bubble component B_t

$$B_t \equiv \lim_{j \to \infty} \rho^j p_{t+j} = \frac{1}{\rho} B_{t-1}. \tag{4}$$

B_t satisfies the sub-martingale property (Diba and Grossman, 1988)

$$E_t(B_{t+1}) = \frac{1}{\rho} B_t \quad \text{with} \frac{1}{\rho} > 1. \tag{5}$$

Using equation (3), we get the following expression,

$$p_t - r_t = F_t + B_t \text{ with } F_t = \frac{k}{1-\rho} + \sum_{k=0}^{\infty} \rho^k (\Delta r_{t+1+k} - v_{t+1+k}). \quad (6)$$

We define bubbles in house prices as departures from the fundamental value of housing. In the absence of speculative bubbles (B_t=0), house price-to-rent ratio is equal to the market fundamental. If bubbles exist ($B_t \neq 0$), the house price-to-rent ratio is the sum of the market fundamental and bubble components that induce explosive behaviour caused by the sub-martingale property of the bubble component.

Following a common approach in the literature (see, for instance, Campbell et al., 2009; Gomez-Gonzalez and Sanin-Restrepo, 2018; Shi, 2017; Sun and Tsang, 2013), this study assumes that the log gross return (v_{t+j}) to housing is the sum of the real risk-free rate (i_{t+1}) and a time-varying risk premium (φ_{t+1}). This premium is derived by $\varphi_{t+1} = \varphi + \varepsilon_{t+1}$, where φ is the expected long-term risk premium and ε_{t+1} is a zero mean disturbance. Hence, we formulate the log gross return $v_{t+1} = \varphi + i_{t+1} + \varepsilon_{t+1}$ and future log gross return to housing $\{\hat{v}_{t+j}\}_{j=1}^{\infty}$ can be determined as

$\hat{v}_{t+j} = \hat{\varphi} + \hat{i}_{t+j}$,

where $\hat{\varphi}$ is the ordinary least square (OLS) estimate of φ and $\hat{i}_{t+j}$ is the expected future interest rate at time t. Using equation (6), the market fundamental component F_t is then computed as

$$\hat{F}_t = \frac{\tilde{k} - \hat{\varphi}}{1-\tilde{\rho}} + \left[\sum_{k=0}^{\infty} \tilde{\rho}^k \Delta \hat{r}_{t+1+k} - \sum_{k=0}^{\infty} \tilde{\rho}^k \Delta \hat{i}_{t+1+k} \right] \quad (7)$$

where $\tilde{k}$ and $\tilde{\rho}$ are calibrated model parameters based on historical data, and $\{\hat{r}_{t+j}\}_{j=1}^{\infty}$ are the expected future rent growth rates. According to equation (7), the market fundamental mainly consists of rent growths and the present value of the future real risk-free interest rates.

In this study, we first decompose the log price-to-rent ratio into a fundamental component and non-fundamental (residual) component. The framework for decomposition and bubble detection is presented in Figure 5. Following Shi (2017), we assume macroeconomic variables only have an indirect impact on housing markets, i.e. through rent and interest rate. We forecast future streams of real interest rate and rent growth with macroeconomic conditions such as population, employment, disposable income and housing supply using VAR models.

The fundamental component is estimated recursively (this is explained in more detail later in Section 5.1) using only information in the past periods. The non-fundamental component is computed as the fundamental component from the log price-to-rent ratio. Finally, we apply the PSY bubble detection test on the non-fundamental component of the log price-to-rent ratio. This process is different from the conventional procedure where the PSY technique is directly applied to the price-to-rent or price-to-income ratio.

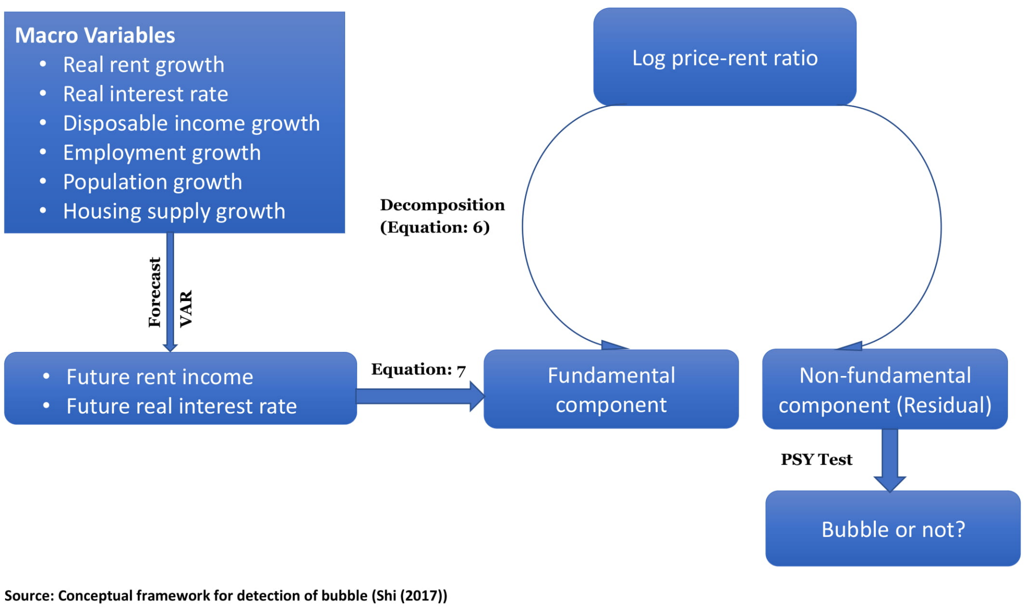


Figure 5: Bubble detection framework for housing markets.

4.2 The VAR systems for forecasting the fundamental component

Forecasting for the growth rate of real rent (Δr_t) and real interest rate (i_t) is based on VAR models. We construct a separate VAR model for each of the eight capital cities and the country level using housing market variables and macroeconomic conditions. Let ΔY, ΔL, ΔN and ΔS be disposable income growth, employment growth, population growth and housing supply growth, respectively.

Country-level variables are labelled with a superscript AUS. In the case of the Australian national housing market, the VAR system has six variables, i.e. (Δr_t^{AUS}, i_t, ΔY_t^{AUS}, ΔL_t^{AUS}, ΔN_t^{AUS}, ΔS_t^{AUS}). For the capital cities, the VAR system contains eleven variables; the six national-level variables (Δr_t^{AUS}, i_t, ΔY_t^{AUS}, ΔL_t^{AUS}, ΔN_t^{AUS}, ΔS_t^{AUS}) and five capital city-level variables (Δr_t, ΔY_t, ΔL_t, ΔN_t, ΔS_t).

The Australian national-level variables only depend on the lags of national variables, whereas the capital city-level variables depend on the lags of capital city-level variables plus lags of the national real interest rate. The forecasting equation for the real interest rate, which only includes national level variables, can be expressed as,

$$\begin{aligned} i_t = \delta_0 \;+\; \delta_j \sum_{j=1}^{p} \Delta r_{t-j}^{AUS} \;+\; \gamma_j \sum_{j=1}^{p} i_{t-j} \;+\; \eta_{1j} \sum_{j=1}^{p} \Delta Y_{t-j}^{AUS} \;+\; \eta_{2j} \sum_{j=1}^{p} \Delta L_{t-j}^{AUS} \\ +\; \eta_{3j} \sum_{j=1}^{p} \Delta N_{t-j}^{AUS} \;+\; \eta_{4j} \sum_{j=1}^{p} \Delta S_{t-j}^{AUS} \;+\; \varepsilon_{1t}, \end{aligned} \tag{8}$$

The dynamics of capital city-level rent growth is specified as

$$\begin{aligned} \Delta r_t = \alpha_0 + \alpha_j \sum_{j=1}^{p} \Delta r_{t-j} + \beta_j \sum_{j=1}^{p} i_{t-j} + \phi_{1j} \sum_{j=1}^{p} \Delta Y_{t-j} + \phi_{2j} \sum_{j=1}^{p} \Delta L_{t-2j} \\ + \phi_{3j} \sum_{j=1}^{p} \Delta N_{t-j} + \phi_{4j} \sum_{j=1}^{p} \Delta S_{t-j} + \varepsilon_{2t} \end{aligned} \tag{9}$$

where p is the lag order. The right-hand side variables for the equations of (Δr_t^{AUS},

ΔY_t^{AUS}, ΔL_t^{AUS}, ΔN_t^{AUS}, ΔS_t^{AUS}) are the same as those for equation (8). All variables used in forecasting rent growth are measured at the capital city market level, except the real interest rate. The equations for (ΔY_t, ΔL_t, ΔN_t, ΔS_t) have the same right-hand side variables as equation (9).

4.3 Calculating expected components

The maximum likelihood approach is employed to estimate the parameters of the VAR models. The VAR in companion form can be specified in the following way:

$$Z_t = A_0 + A_1 Z_{t-1} + \varepsilon_t, \tag{10}$$

where A_1 is the companion matrix. The conditional forecasting of Z_t given limited information set H_t containing current and lagged values of real interest rate (i_t), real rent growth (Δr_t) and the macroeconomic variables (ΔY_t, ΔL_t, ΔN_t, ΔS_t), is given as,

$$E(Z_{t+s}|H_t) = (I - A_1^s)(I - A_1)^{-1} A_0 + A_1^s Z_t. \tag{11}$$

At period t+s, the optimal forecasts of the future real interest rate and rent growth are the rows in $(I - A_1^s)(I - A_1)^{-1} A_0$ and $A_1^s Z_t$ corresponding to the dependent variable real interest rate (i_t) and real rent growth (Δr_t). Based on equations (7) and (11), the optimal forecast of the market fundamental component F_t can be expressed as

$$E(F_t|H_t) = \frac{\kappa - \varphi}{1 - \rho} + (\mathbf{h}_1' - \mathbf{h}_2')(1-\rho)^{-1}(I - \rho A_1)^{-1} A_0 + (\mathbf{h}_1' - \mathbf{h}_2') A_1 (I - \rho A_1)^{-1} Z_t, \tag{12}$$

where $\mathbf{h}_1'$ and $\mathbf{h}_2'$ are column vectors with all their elements being zeros, except for the element corresponding to rent growth (Δr_t) in $\mathbf{h}_1'$ and the element corresponding to real interest rate (i_t) in $\mathbf{h}_2'$.

In equation (12), φ, κ and ρ values can calibrated from the current and the historical data. The coefficients of the matrices A_0 and A_1 are calculated from the VAR models using information for past periods. Based on equations (12) and (6), an estimated non-fundamental component $\hat{NF_t}$ can expressed as a deviation of the estimated fundamental $\hat{F_t}$ from the price-to-rent ratio, such that

$$\hat{NF_t} = (p_t - r_t) - \hat{F_t}. \tag{13}$$

4.4 The PSY procedure for testing bubbles

The PSY bubble-testing algorithm examines whether a particular observation has been generated by an explosive process (H_A) or by a martingale process (H_0). The testing algorithm is based on repeatedly implementing a right-tailed DF test. The martingale null hypothesis can be written as

$H_0 : y_t = kT^{-\eta} + y_{t-1} + \epsilon_t$, with constant k and $\eta > 0.5$,

where y_t can be either the log price-to-rent ratio or the non-fundamental (residual) component at period t, ϵ_t is the error term, and T is the sample size. A mildly-explosive alternative hypothesis could therefore be,

$H_A : y_t = \delta_T y_{t-1} + \epsilon_t$ with $\delta_T = 1 + cT^{-\alpha}$, $c > 0$ and $\alpha \epsilon [0, 1)$.

The fitted regression is an estimated Augmented Dickey-Fuller (ADF) equation with lag order K and an intercept but no time trend:

$$\Delta y_t = \alpha + \beta y_{t-1} + \sum_{i=1}^{K} \gamma_i \Delta y_{t-i} + \varepsilon_t \tag{14}$$

The PSY test is based on a recursive estimation of the ADF regression. In the implementation, r_0 is the minimum (proportion) of the sample size (T) and $\lfloor r_0 T \rfloor$ is the minimum requirement of the window size to initiate a regression, where $\lfloor . \rfloor$ denotes the integer part of the argument.

Based on the PSY dating algorithm, we draw an inference of explosiveness for each observation between $\lfloor r_0 T \rfloor$ and the last observation of the sample T. If we consider $\lfloor rT \rfloor$ as the observation of interest, the PSY dating algorithm estimates the ADF statistic repeatedly on a sequence of backward expanding samples. The ending points of all samples $\lfloor r_2T \rfloor$ are fixed on $\lfloor rT \rfloor$, whereas the starting point of the samples $\lfloor r_1T \rfloor$ varies from the first observation (0) to $\lfloor (r - r_0)T \rfloor$. The corresponding ADF test statistic sequence is symbolized by $\{ADF\}_{r_2=rT}^{r_1 \epsilon [0,(r-r_0)T]}$. Inference of explosiveness for observation $\lfloor rT \rfloor$ is based on the backward supremum ADF statistic ($BSADF_r$) and is defined as

$$BSADF_r(r_0) = sup \left\{ ADF_{r_2}^{r_1} : r_2 = r \quad \text{and} \quad r_1 \epsilon [0, r - r_0] \right\}.$$

The lag order K is selected by the Bayesian information criterion (BIC) with a maximum lag order of six. The minimum window size is considered according to the rule of thumb suggested by PSY, i.e. r_0=0.01 + 1.8/$\sqrt{T}$. The finite sample critical value sequences for the BSADF's are obtained by Monte Carlo simulation with 5000 replications.

To determine the origination and termination of each bubble, Phillips et al. (2015*b*) derive the asymptotic distribution (critical values) of the BSADF test statistic under the null hypothesis. The bubble origination (collapse) date is the first chronological observation whose BSADF statistic is greater than (falls below) its corresponding critical value of BSADFs. In this paper, we use a BSADF pseudo-real-time test rather than the generalised supremum ADF(GSADF).[9]

[9]We also present the GSADF test statistic and results of the GSADF in Table C.1 and Figures C.1 and C.2 of Appendix C.

5 Empirical Results and Discussions

We calculate the fundamental component of the price-to-rent ratio following equation (12). The non-fundamental component is computed as the deviation of the estimated fundamental component from the log price-to-rent ratio.

5.1 The decomposition of the price-to-rent ratio

We assume that disposable income, employment, population and housing supply growth affect house market fundamentals indirectly through rent and mortgage interest rates. Hence, macroeconomic variables are incorporated in the VAR system to forecast the real mortgage interest rate and rent growth. One important task is to select the lag order of the VAR model. We use the out-of-sample forecasting criteria (i.e root mean square forecast error (RMSFE) of the one-step-ahead forecast) for model selection.

The in-sample period starts in 1999:Q3 and extends to 2010:Q4 and the out-of-sample period from 2011:Q1 to 2017:Q3. The one-step-ahead forecasting function based on the forward expanding regressions is deployed to evaluate forecasting performance. The sample period 1999:Q3-2010:Q4 is used to initiate the regression. Then from 2011:Q1 onwards, the regression window expands forward, providing updated coefficient estimates for each sample observation. Specifically, we obtain $\hat{Z}_t$ for all $t\epsilon \{2011 : Q1\ to\ 2017 : Q3\}$ using the following equations:

$$\hat{Z}_t = \hat{A}_{0,t-1} + \hat{A}_{1,t-1} Z_{t-1}. \tag{15}$$

$\hat{A}_{0,t-1}$ and $\hat{A}_{1,t-1}$ are the VAR estimate companion matrices. With

$$\hat{A}_{0,t-1} = \begin{cases} \hat{A}_0 & t\epsilon \{1999 : Q3\ to\ 2010 : Q4\} \\ \tilde{A}_{0,t-1} & t\epsilon \{2011 : Q1\ to\ 2017 : Q4\} \end{cases}$$

and

$$\hat{A}_{1,t-1} = \begin{cases} \hat{A}_1 & t\epsilon \{1999 : Q3\ to\ 2010 : Q4\} \\ \tilde{A}_{1,t-1} & t\epsilon \{2011 : Q1\ to\ 2017 : Q4\}, \end{cases}$$

where $\hat{A}_0$ and $\hat{A}_1$ are the ordinary least square estimates (OLS) of A_0 and A_1 from the sample period 1999:Q3 to 2010:Q4 and $\tilde{A}_{0,t-1}$ and $\tilde{A}_{1,t-1}$ are obtained from the sample period from the first observation to $(t-1)^{th}$ observation. The estimations are based on the final models reported in Table 2.

We consider the two lag order specifications for our VAR model, namely p=1 and p=2.[10] Some relevant studies, for example, Shi (2017) estimate VAR models with a maximum lag order of 2 for the US national and 21 regional housing markets. Campbell et al. (2009) uses a first order VAR model with macroeconomic variables, whereas Sun and Tsang (2013) consider a VAR(2) model without macroeconomic variables for all US housing markets. VAR(1) and VAR(2) models are used in a related study (Costello et al., 2011) for calculating the non-fundamental component of house prices for Australia's eight states and nationally.

Table 2: The out-of-sample forecasting performance based on the VAR models.

		Root Mean Square Forecast Errors	
	Variable	lag=1	lag=2
Australia	i_t	**0.0191**	0.0212
Australia	Δr_t^{AUS}	**0.0038**	0.0044
Sydney	Δr_t^{SYD}	**0.0222**	0.0325
Melbourne	Δr_t^{MEL}	**0.0216**	0.0268
Brisbane	Δr_t^{BRI}	**0.0201**	0.0244
Adelaide	Δr_t^{ALD}	**0.0215**	0.0611
Perth	Δr_t^{PER}	**0.0293**	0.0862
Hobart	Δr_t^{HOB}	**0.0232**	0.0362
Darwin	Δr_t^{DAR}	**0.0336**	0.1007
Canberra	Δr_t^{CAN}	**0.0292**	0.0631

Table 2 illustrates the out-of-sample forecasting results for two different lag orders. Bold RMSFEs indicate the minimum RMSFEs between p=1 and p=2. We observe that the VAR model with lag order 1 provides the best forecast for the interest rate, national rent growth rate, and capital city-level rent growth rates. Therefore, we prefer VAR(1) over VAR(2).

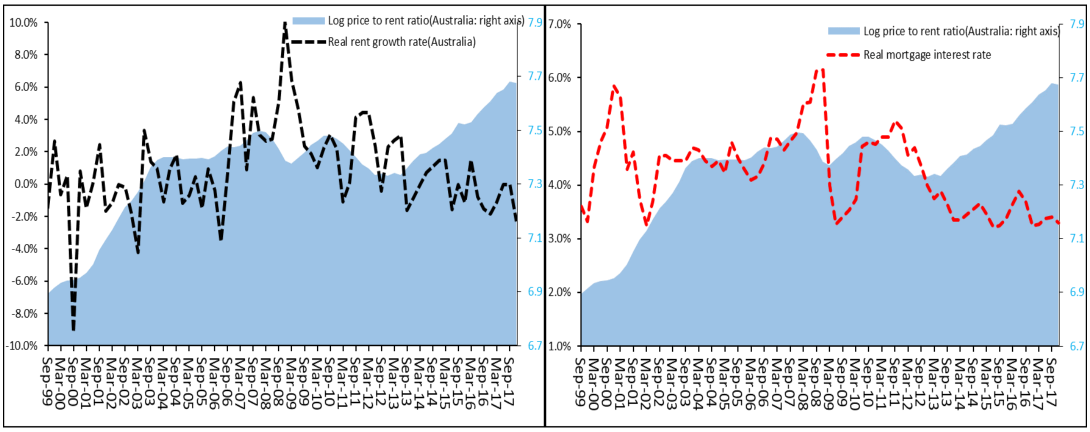
The calibrated long-term parameters ($\hat{\rho}$, $\hat{\kappa}$, and $\hat{\varphi}$) are shown in Table 3, with the calibration based on the full sample. The calibrated parameters across all units of analysis are expressed as mean (standard deviation): 0.959 (0.010) for $\hat{\rho}$,

[10] We perform Lagrange Multiplier (LM) tests for residual serial correlation. The LM statistics for autocorrelation of order up to two fail to reject the null hypothesis of no serial correlation.

0.171 (0.030) for $\hat{\kappa}$, and 0.021 (0.008) for $\hat{\varphi}$.

Table 3: The calibrated historical coefficients ($\hat{\rho}$, $\hat{\kappa}$, and $\hat{\varphi}$).

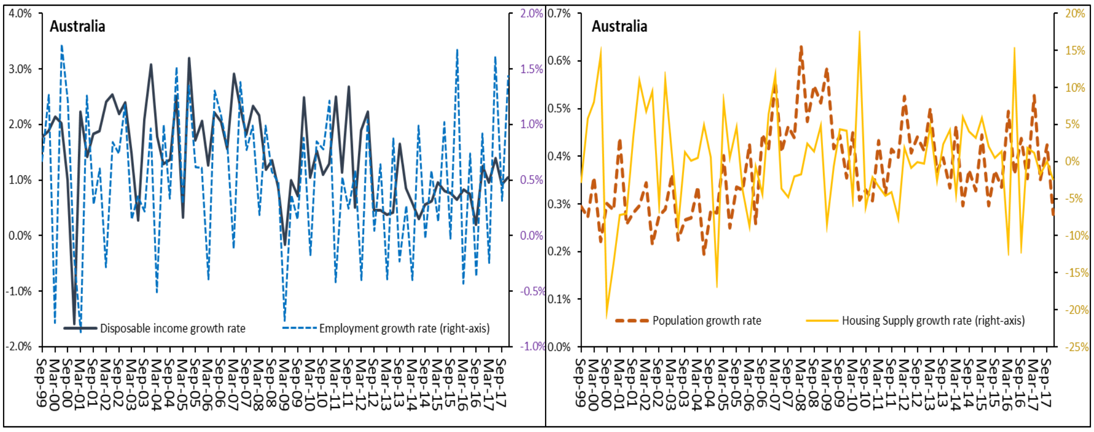
	$\hat{\rho}$	$\hat{\kappa}$	$\hat{\varphi}$
Australia	0.968	0.142	0.022
Sydney	0.968	0.142	0.019
Melbourne	0.968	0.143	0.035
Brisbane	0.958	0.174	0.019
Adelaide	0.959	0.172	0.016
Perth	0.962	0.161	0.014
Hobart	0.948	0.205	0.026
Darwin	0.938	0.233	0.008
Canberra	0.960	0.169	0.027



(a) Dynamics of the rent growth rate. (b) Dynamics of the real interest rate.

Figure 6: The log price-to-rent ratio, real rent growth, real interest rate for the national housing market.

In Figure 6, panel (a) plots the rent growth rate and log price-to-rent ratio and panel (b) displays the real mortgage interest rate and log of the price-to-rent ratio for Australia. The log price-to-rent ratio is included in both panels for comparison purposes. Australian real mortgage interest rates increased gradually with some fluctuations from 2002 until September 2008 as Australia's economy boomed and anchoring inflation was the RBA's main concern. In September 2008, the real mortgage interest rates peaked but substantially dropped during the GFC. Meanwhile, real rent growth lifted by around 7 per cent in one year since September 2008. However, there is no obvious pattern in the changes in the rent growth rate over whole sample period. The price-to-rent ratio displays upward trends over the sample. It is particularly obvious that this ratio has been rising sharply since March 2013 until the end of sample period, while the real mortgage interest rate has been gradually decreasing since September 2011 (declined from 5.20 per cent in September 2011 to 3.40 per cent in September 2017).

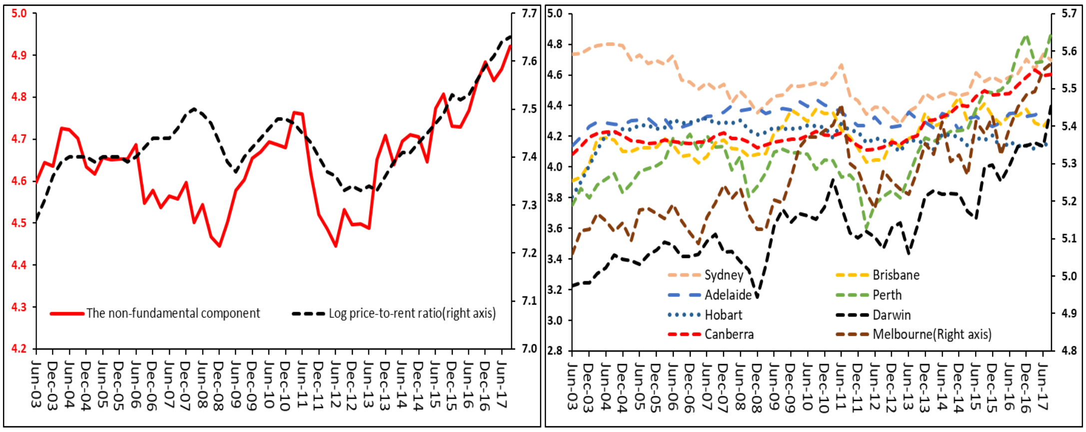


(a) Employment and disposable income (b) Population and housing supply

Figure 7: Growth rates of macroeconomic variables for Australia.

Figure 7 displays the growth rates in the macroeconomic variables for the nation: panel (a) employment and disposable income, and panel (b) population and housing supply. The population growth rate indicates a gradual increase with some fluctuations over the whole sample period with an average of 0.37 per cent, while both the disposable income and employment growth series move more closely together. In contrast, there is no pattern of changes in the housing supply growth rate, but it has been more volatile than population growth rates. Figure 7 shows a dramatic decrease in disposable income, employment, and housing supply growth around the end of the GFC in early 2009. Meanwhile, during the same period as shown in Figure 6, we notice a significant drop in the log price-to-rent ratio and real mortgage interest rate. However, the population growth rate was higher in that period.

We use equation (13) to estimate the non-fundamental component, and present the dynamics of the component and the log price-to-rent ratio of Australia as a whole in Figure 8 panel (a). It is evident that the dynamics of the non-fundamental component closely follow the log price-to-rent ratio and both experience a sharp



(a) Nation (b) Eight capital cities

Figure 8: The non-fundamental components for the nation and eight capital cities.

increase from mid-2003 to mid-2004. In contrast, while the non-fundamental component experienced a sharp decrease prior to the GFC from early 2006 to mid-2008, the log price-to-rent ratio rapidly increased. It can be observed that the non-fundamental component is more volatile than the log price-to-rent ratio at the national level.

Figure 8 panel (b) shows the dynamics of the non-fundamental component in the eight Australian capital cities. The series for eight cities exhibit obvious upward and downward fluctuations. At the beginning of our sample period around 2003-2004, the non-fundamental component experiences a moderate increase in all eight capital cities. During the GFC of 2008-09, a market downturn is seen in all cities, but afterwards an upward surge has continued until mid-2011. At the end of our sample period, between mid-2013 and onwards, another upward trend is apparent in all cities. It is obvious that all upward or downward surges in the log price-to-rent ratios remained visible in the non-fundamental component. However, the durations of expansions are shorter than the log price-to-rent ratio. Similar to that found for the national housing market, the dynamics of the non-fundamental components for the capital cities are more volatile compared with the log price-to-rent ratios shown in Figure 2.

The PSY method is then applied to both the estimated non-fundamental components and to the log price-to-rent ratios for each of the eight capital cities and to the Australian national data. We conclude that there is speculative bubble behaviour if explosive behaviour is identified.

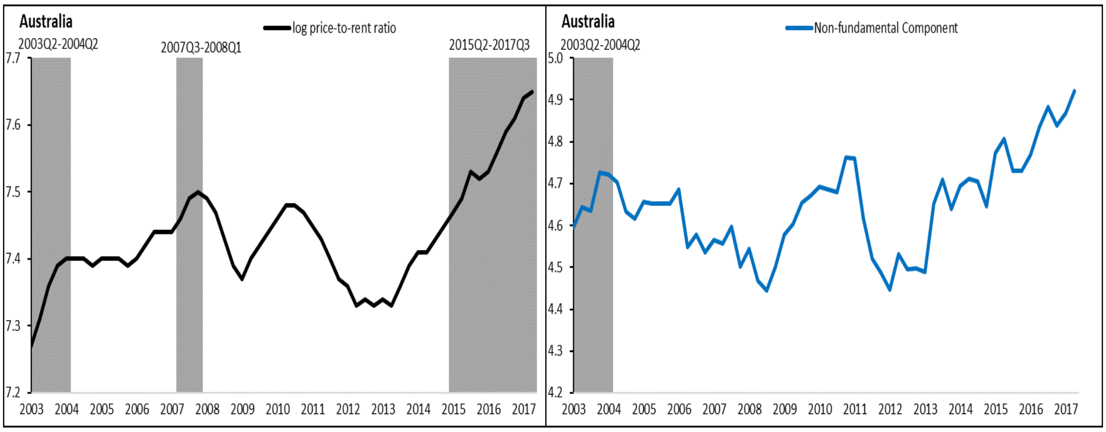
To calculate the BSADF test statistics, the minimum window size of 15 is obtained using the rule of thumb suggested by PSY.[11] The BSADF test statistics for the log price-to-rent ratios start in 2003:Q1, while for the non-fundamental components, they start from 2003:Q2. Figures from D.1 to D.9 in Appendix D illustrate the BSADF statistics and corresponding critical values for the log price-to-rent ratio in panel (a) and the non-fundamental component in panel (b) at the 90 per cent, 95 per cent and 99 per cent levels.

We conducted a Monte Carlo simulation with 5000 replications to generate the BSADF critical values. We shaded the bubble episodes when the BSDAF statistics exceeded the 90 per cent critical value sequence for the eight capital cities and national figures.

[11] A minimum window size equal to 15 quarters indicates that BSADF test statistic commences after the 16th observation.

5.2 Speculative bubbles in the national housing market

While both methods control for the impact of rent growth, the method based on the non-fundamental components additionally controls for the impact from macroeconomic conditions (such as real mortgage interest rates, disposable income, population, employment and housing supply). Figure 9 compares the identified bubble episodes for the Australian national housing market for the log price-to-rent ratio in panel (a) and the non-fundamental component in panel (b).



(a) The log price-to-rent ratio (b) The non-fundamental component

Figure 9: Dating speculative bubbles for the Australian national housing market.

The PSY test based on the log price-to-rent ratio suggests the presence of three bubble episodes. The first one shows as commencing in 2003:Q2 and lasting until 2004:Q2. There was one episode before the GFC (2008-2009) running from 2007:Q3 to 2008:Q1. The final episode started in 2015:Q2 and lasted until the end of the sample. By applying the PSY test to the non-fundamental component of the log price-to-rent ratio, the number of identified speculative bubbles is apparently reduced. We observe an episode commencing in 2003:Q2 that lasts until 2004:Q2 as in panel (a). The last two episodes identified by the PSY using the log price-to-rent ratio (2007:Q3-2008:Q1 and 2015:Q2-2017:Q3) disappear.

The identified 2003:Q2-2004:Q2 bubble episode coincides with the housing boom in Australia which started in late 2000 and continued until 2004. In September 1999, the Federal Government made changes to the tax policy on capital gains. According to the new policy, those who bought an investment property and held it for at least one year could receive a discount on the tax on their capital gain of 50 per cent for individual taxpayers or 33.3 per cent for superannuation funds. Therefore, the sharp increase in house prices over this period was mainly triggered by this tax policy change. The number of rental property investors also increased due to negative gearing around the year 2000 or 2001 (ACOSS, 2015). Moreover, according to Bloxham et al. (2011), 45 per cent of new loans in 2003 were taken out for housing investment purposes, while this figure was around 25 per cent in the 1990s.

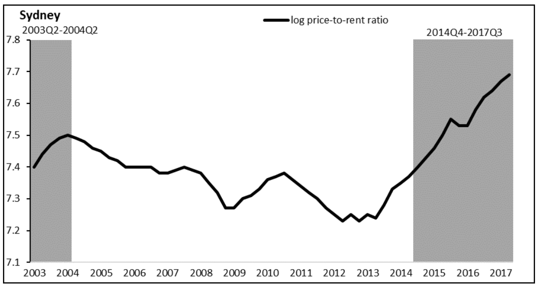
After controlling for the impact of macroeconomic variables, we do not find any speculation from 2004:Q2 to the end of the sample in Australia at the national level. This is consistent with the results of Wang et al. (2018), where a different strategy was taken to investigate the presence of a bubble.

5.3 Speculative bubble in capital city housing markets

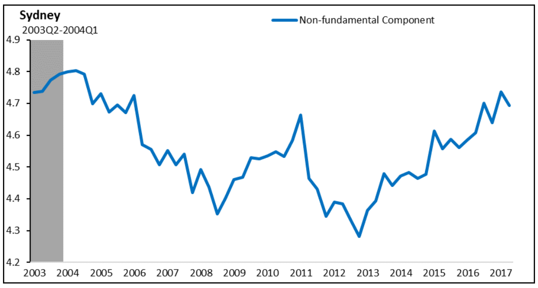
The identified speculative bubble episodes for the eight capital cities based on the log price-to-rent ratio and the non-fundamental component are listed in Table 4. Moreover, Figure 10 and Figure 11 compare the speculative bubble episodes experienced in each capital city between two approaches. Looking at the results for the log price-to-rent ratio, a speculative bubble episode is identified in all capital cities except Darwin in 2003:Q2. In Darwin, the speculative bubble commenced two quarters later in 2003:Q4. This episode collapsed between 2003:Q4 and 2008:Q3.

Based on the non-fundamental components, seven capital cities (except Darwin) are found to have had a speculative bubble during the period 2003:Q2 to 2005:Q4. Six of them (except Perth) commenced in 2003:Q2. These bubble episodes lasted until 2004:Q1 for both Sydney and Melbourne, 2004:Q3 for Brisbane and Canberra, 2004:Q4 for Adelaide and 2005:Q4 for Hobart. In Perth, the bubble episode started one quarter later in 2003:Q3 and it was a very short-lived bubble lasting only one quarter.

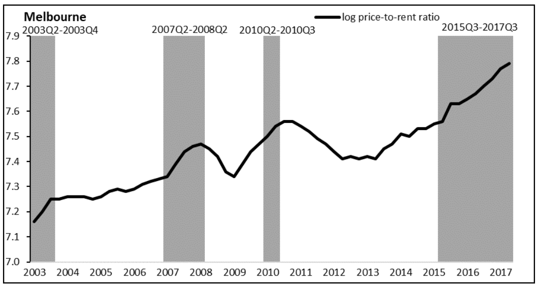
The test based on the log price-to-rent ratio suggests a speculative episode prior to the GFC in some capital cities such as Melbourne, Brisbane and Adelaide from 2007:Q2 to 2008:Q2. In addition, in the immediate post-GFC, Melbourne experienced another shorter speculative episode from 2010:Q2 to 2010:Q3. Interestingly, according to the new approach, all of these episodes no longer exist.



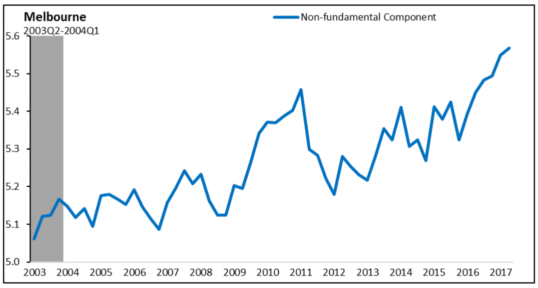
(a) Log price-to-rent ratio (Sydney)



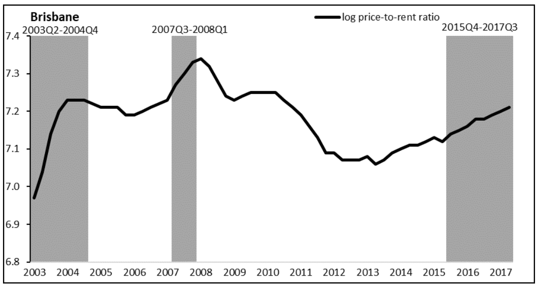
(b) Non-fundamental component (Sydney)



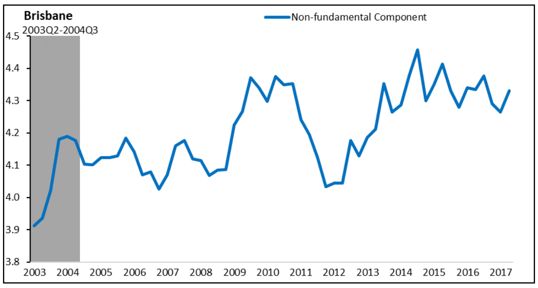
(c) Log price-to-rent ratio (Melbourne)



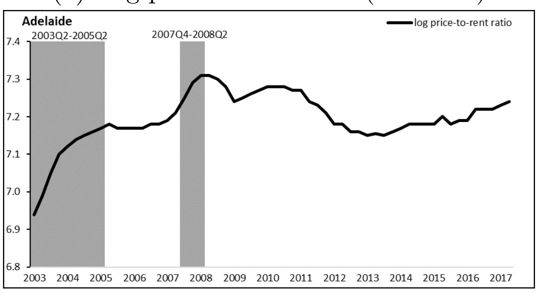
(d) Non-fundamental component (Melbourne)



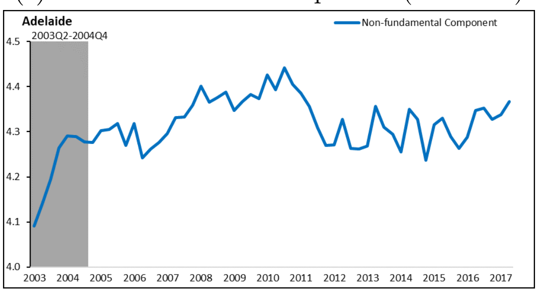
(e) Log price-to-rent ratio (Brisbane)



(f) Non-fundamental component (Brisbane)

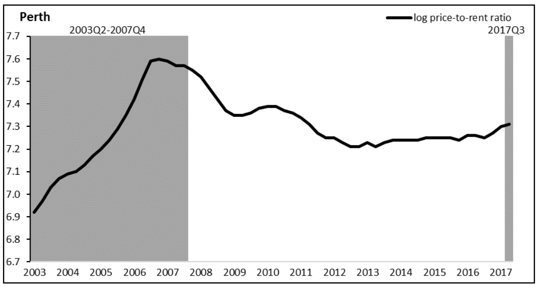


(g) Log price-to-rent ratio (Adelaide)

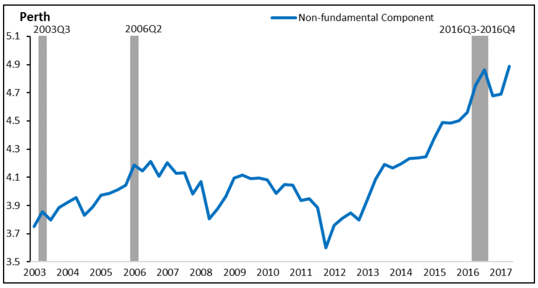


(h) Non-fundamental component (Adelaide)

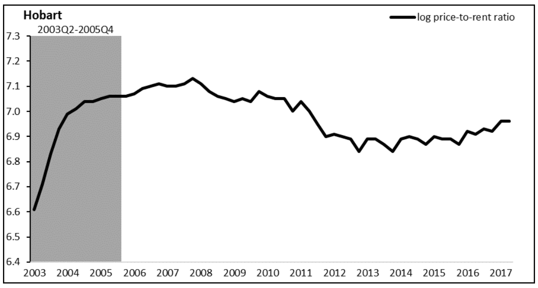
Figure 10: Dating speculative bubbles for capital cities.



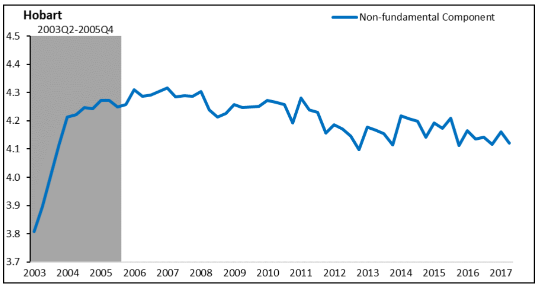
(a) Log price-to-rent ratio (Perth)



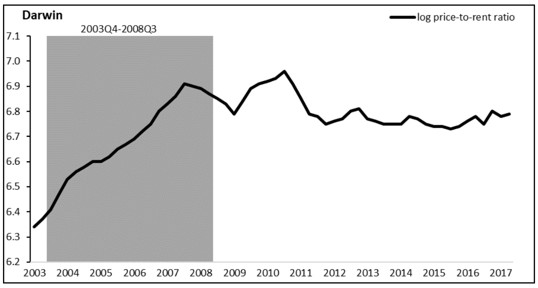
(b) Non-fundamental component (Perth)



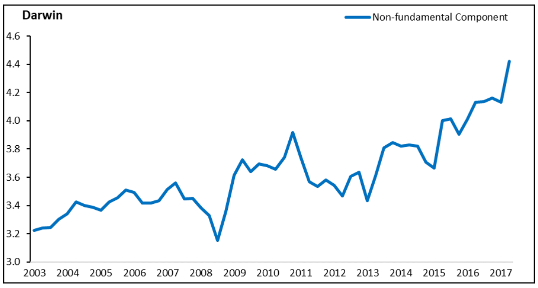
(c) Log price-to-rent ratio (Hobart)



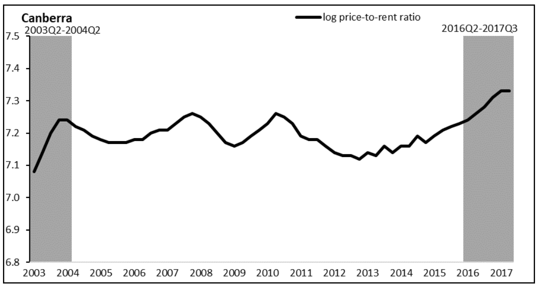
(d) Non-fundamental component (Hobart)



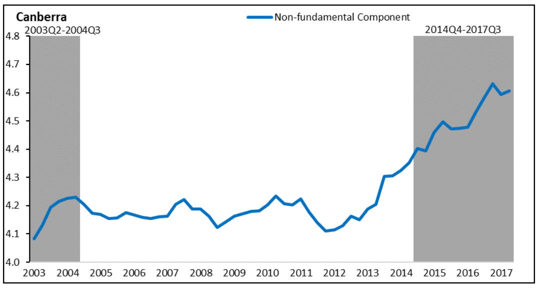
(e) Log price-to-rent ratio (Darwin)



(f) Non-fundamental component (Darwin)



(g) Log price-to-rent ratio (Canberra)



(h) Non-fundamental component (Canberra)

Figure 11: Dating speculative bubbles for capital cities (continued).

Based on the log price-to-rent ratio, several periods are identified around the period of the GFC (2008-2009). Some of these episodes are associated with market downturns. As illustrated in Phillips and Shi (2018), the PSY test also has the capacity to identify crises. The focus of this thesis is on periods associated with upward trends. Therefore, we do not list the downward episodes.

Results from the log price-to-rent ratio show Sydney, Melbourne, Brisbane, Perth and Canberra all experiencing a speculative episode until the end of the sample period starting in 2014:Q4 for Sydney, 2015:Q3 for Melbourne, 2015:Q4 for Brisbane, 2017:Q3 for Perth, and lastly in 2016:Q2 for Canberra.[12] However, after controlling for impact of the real mortgage interest rate and macroeconomic variables, the results indicate that only Canberra out of the eight capital cities experienced a bubble at the end of the sample period .

Table 4: Date-stamping for the log price-to-rent ratio and the non-fundamental component.

Areas	**Log price-to-rent ratio**	**Non-fundamental component**
Australia	2003Q2-2004Q2 2007Q3-2008Q1 2015Q2-2017Q3	2003Q2-2004Q2
Sydney	2003Q2-2004Q2 2014Q4-2017Q3	2003Q2-2004Q1
Melbourne	2003Q2-2003Q4 2007Q2-2008Q2 2010Q2-2010Q3 2015Q3-2017Q3	2003Q2-2004Q1
Brisbane	2003Q2-2004Q4 2007Q3-2008Q1 2015Q4-2017Q3	2003Q2-2004Q3
Adelaide	2003Q2-2005Q2 2007Q4-2008Q2	2003Q2-2004Q4
Perth	2003Q2-2007Q4 2017Q3-2017Q3	2003Q3 2006Q2 2016Q3-2016Q4
Hobart	2003Q2-2005Q4	2003Q2-2005Q4
Darwin	2003Q4-2008Q3	
Canberra	2003Q2-2004Q2 2016Q2-2017Q3	2003Q2-2004Q3 2014Q4-2017Q3

Market downturns are not accounted here. Series used to identify bubbles based on 90% critical values derived from 5,000 simulations.

We compare the number of speculative capital city housing markets between two approaches in Figure 12. First, as expected, for all periods identified based on the non-fundamental component that controls for the broader market fundamental, we find a significantly smaller number of speculative markets compared to the log price-to-rent ratio. For example, while the PSY test based on the non-

[12] These findings are similar to those in Shi et al. (2016), Baur and Heaney (2017) and Ji and Otto (2015), where either only rent or no information about market fundamental is used.

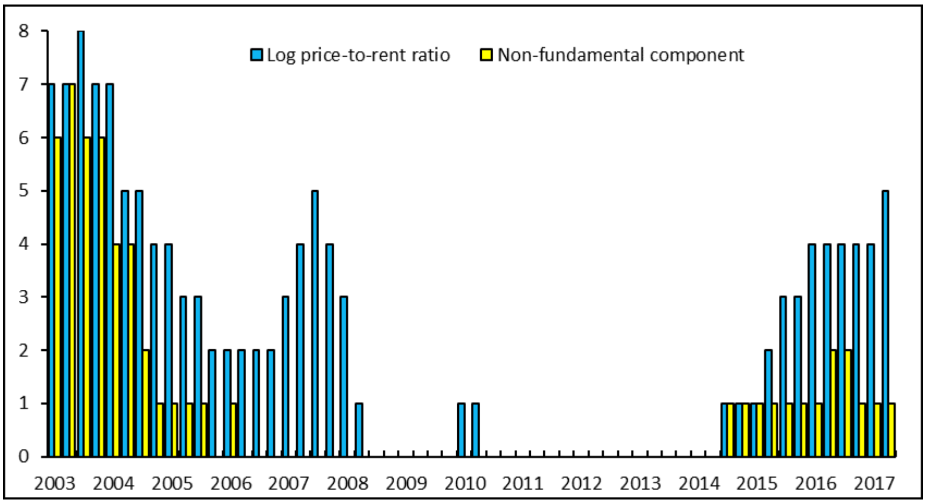


Figure 12: Number of speculative capital city housing markets.

fundamental component identifies four speculative housing markets in 2004:Q2, the test based on the log price-to-rent ratio identifies as many as seven speculative housing markets. During the period 2006:Q3 to 2008:Q3, while a test based on the log price-to-rent ratios identified speculation in many of the eight capital city housing markets (ranging from two to five), results from the non-fundamental component indicate that no speculative bubbles exist in any of the eight capital city housing markets. Both approaches find the presence of speculation between mid-2003 and late 2005, although in terms of markets involved, the number found from the non-fundamental component is lower than that from the log price-to-rent ratio.

Overall, Figures 10 and 11 clearly reflect the significance of controlling for the impact of macroeconomic conditions in bubble detection, particularly to avoid false positive housing bubble conclusions. The dynamics of the macroeconomic conditions of each market are presented in Figure E.2 and Figure E.3 of Appendix E.

Figure 13 compares the total duration (quarter) of speculation between two approaches.[13] For example, the test based on the log price-to-rent ratio identifies as many as 17 quarters of bubbles in Sydney, while results based on the non-fundamental component suggest only 4 quarters. Moreover, there is also a dra-

[13] Market downturns are not included here.

matic reduction in the duration of speculative bubbles in Melbourne, Brisbane, Adelaide, Perth and Darwin when we control for macroeconomic variables.

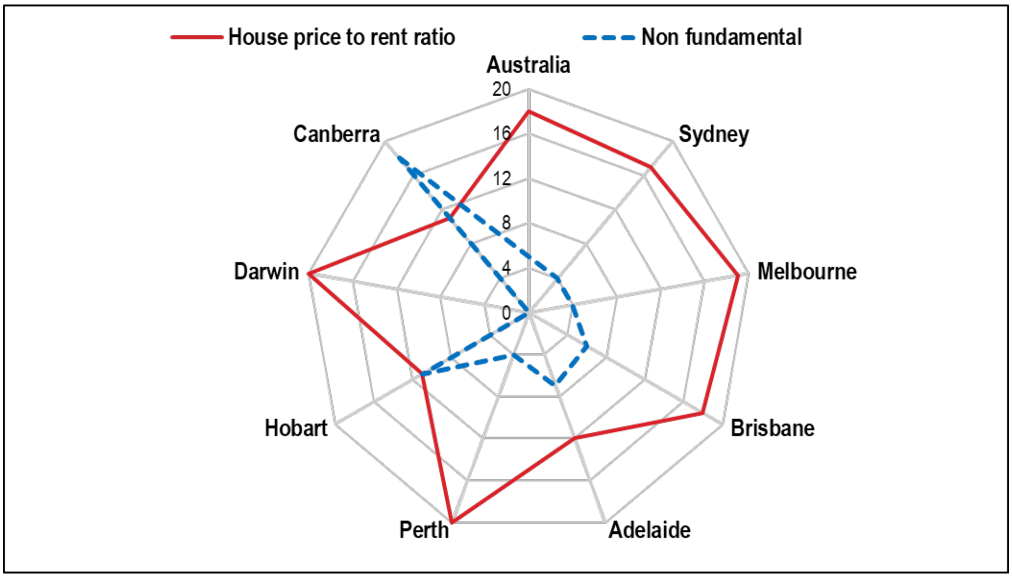


Figure 13: The total duration (quarters) of speculation based on the log price-to-rent ratios and the non-fundamental components.

Overall, the total number of speculative bubbles identified and the estimated bubble durations for most of the capital cities based on the non-fundamental components is significantly less than identified bubbles and their durations based on the log price-to-rent ratios. This indicates that the speculative bubble lasts for a shorter period when we control for the impact of real mortgage interest rates, the real rent growth rate and macroeconomic conditions. In total, this new approach finds around half less speculative bubble episodes than estimations based upon a traditionally used the log price-to-rent ratio.

These test results clearly show that it is meaningful to take consideration of changes in macroeconomic conditions when detecting speculative bubble behaviours in the housing market. In terms of a reduction in the number of speculative bubbles and in their duration, our findings align with Shi (2017) and Gomez-Gonzalez and Sanin-Restrepo (2018).

Furthermore, we consider the Sydney house market as an example to reveal the importance of controlling for the impacts of macroeconomic variables in bubble detection. When applying the PSY test to price-to-rent ratio, two episodes are identified: one from 2003:Q2 to 2004:Q2, and one from 2014:Q4 to 2017:Q3. After taking changes in the macroeconomic conditions into account, we see only one speculative bubble from 2003:Q2 to 2004:Q1. This result suggests that the bubble episode identified in the period 2014:Q4 to 2017:Q3 in the log price-to-rent is due to changes in macroeconomic factors rather bubble behaviour.

Looking at the dynamics of macroeconomic variables for Sydney in panel (a) and panel (b) of Appendix Figure E.2, we notice a moderate increase in the employment growth rate and population growth rate from 2014:Q4 to 2017:Q3 (the end of the sample period). In addition, the real mortgage interest rate in panel (b) of Figure 6 depicts that since 2011 the rate has been gradually decreasing until the end of the sample period.[14] Therefore, the testing results for Sydney indicate that it is very important to consider those changes when investigating speculative bubbles in housing markets.

While most capital cities experienced significant reduction in speculative bubbles, in Hobart speculation duration is equal when comparing both approaches. The new method finds that the speculative bubble in Canberra endured for a significantly longer duration when using the PSY method to the non-fundamental component.

It is noticeable from our results that Canberra is the city in which we find two speculative bubble episodes using both calculation approaches. Episodes of speculative bubbles reported in Canberra find quite similar period as first bubble using both approaches, but second episode is longer based on the non-fundamental component.[15] This is an interesting finding as most of the other capital cities have experienced no speculation since mid-2005 but Canberra continues to experience

[14] While average growth rates for the population and employment over the whole sample period were 0.42 per cent and 0.29 per cent respectively, from 2014:Q4 to 2017:Q3, the average growth rates were 0.62 per cent and 0.38 per cent respectively. Moreover, during this period the real mortgage interest rate decreased from 3.65 per cent in 2004:Q4 to 3.36 per cent in 2017:Q3.

[15] To check the significance of the macroeconomic variables for Canberra, we estimated a bivariate VAR(1) model without macroeconomic variables. This new VAR(1) model incorporated only the real rent growth rate and the real mortgage interest rate and produced similar results to the VAR(1) with all macroeconomic variables. This result corresponds to the fact that macroeconomic conditions do not contribute to dynamics for the Canberra housing market.

exuberance after controlling for the impact of the macroeconomic conditions.

One possible reason for this finding is that rent is not a good proxy for the Canberra housing market fundamental. Canberra is an isolated city in terms of its demographics and a significant proportion of the population either work in the public service (including defence and politicians) or are students. According to Australian Public Service Commission, the public service accounts for 42 per cent of Canberra's total workforce (APSC, 2017), which is significantly higher than for other capital cities. House market participants are separated into two groups i.e. buyer and renter. A high proportion of Canberra's workforce is transient, so more market participants rent rather than buy, which seems to support the notion that the two markets are segmented due to its demographic. To explain Canberra's house price dynamics more rigorously, we need to segregate these two groups of market participants. Given the limited time for this present study, it was not possible to obtain such data. However, there is scope for us to work on this interesting feature in future research.

6 Conclusion

We have conducted a careful investigation into the existence of house price bubbles in Australia as a whole, and in the eight capital city housing markets for the period 1999 to 2017. We follow a recently proposed method (Shi, 2017) for real-time monitoring of speculative bubbles.

Unlike existing bubble detection methods, the new method explores information beyond the housing market and considers the aggregate economic conditions. Macroeconomic factors such as the real mortgage interest rate, disposable income, employment, population and supply growth are included in forecasting the future real rent growth rate and real interest rates, which are subsequently used in the calculation of housing market fundamentals. Using quarterly data spanning more than one decade, we apply the PSY test to a recursively calculated non-fundamental component of house prices and to the log price-to-rent ratio (most commonly used in the relevant literature) for real-time monitoring for speculative bubbles in housing markets.

After controlling for the impact of macroeconomic conditions, we find evidence of speculative bubbles in most capital cities, but significant decline in the numbers and durations of bubbles identified than had been previously recorded from using only the log price-to-rent ratio. With both approaches, a significant bubble period (2003:Q2-2005:Q4) is identified for almost all capital cities, which coincided broadly with the housing boom in the first half of the 2000s. This followed changes to the tax policy on capital gains for investment properties that was implemented in September 1999. At the end of the sample period, we find no evidence of a speculative bubble in any capital city except Canberra. The bubble evidence in Canberra could potentially be due to the disconnection between rental and sale markets in Canberra. Given that our results find the presence of a speculative bubble in one city (Canberra) at the end of the sample period, the results are consistent with the position of the Reserve Bank of Australia that while prices will fall, the risks are manageable (RBA, 2015).

This is the first study in applying the bubble detection method of Shi (2017) to Australian housing markets. By taking the impact of macroeconomic factors on house prices into consideration, this study provides a better control for housing market fundamentals, which has led to a more precise detection of speculative bubbles. The outcomes of the study have important policy implications for governments aiming to control speculative bubbles in house prices through smoother adjustments towards housing market fundamentals. We could reduce the probability of false positive identification, which would help to avoid potential damaging consequences such as hampering economic growth. We consider that the approach we have applied has the potential to be a general early warning mechanism to detect speculative bubbles in Australia as well as in other countries/markets.

6.1 Limitations

The first limitation of the study could be in possibly overlooking the influence of various government taxes imposed on the housing market such as a discount on capital gains for housing investors, capital gains tax exemption for owner-occupied housing, land tax exemption for owner-occupied housing and negative gearing. It is important to consider these factors when analysing a housing boom. The study would have been stronger and more comprehensive if it had considered the impact of tax policies, particularly if had controlled for periods of significant tax policy reform. Further study could be done to explore this issue in greater detail.

The second limitation is the spatial mismatch between housing market variables (i.e. house prices and rent) and macroeconomic variables. House prices and rental series are available for the capital cities, whereas the macroeconomic variables such as employment, population, disposable income and housing supply are available at the state level. This problem is unavoidable due to the availability of the data. As previously described in Section 3.3 of the data description, this issue is likely to be less problematic in the Australian context due to the strong concentration of the population in capital cities. Some scholars encounter similar spatial mismatch issues and imply this has an insignificant impact on results (see, for example, Costello et al. (2011)).

7 Appendix

Appendix A: Data description and sources

Appendix B: Literature summary table

Appendix C: Distribution of population, descriptive statistics for log price-to-rent and GSADF test results

Appendix D: Speculative bubble detection and date stamping

Appendix E: Dynamics of the housing markets

Table A.1: Description of the variables.

Variable	**Description**	**Frequency**	**Geographical level(Capital city/State)**	**Source**
Real house prices	House price series are compiled based on the hedonic imputation methodology. It is considered robust at varying levels of disaggregation both across time and space. It also overcomes the issue of compositional bias associated with median price and repeats sales measures. We convert the nominal house price series to real house price series by deflating with Consumer Price Index (CPI) excluding shelter. –Statistical adjusted: Non-seasonally adjusted	Monthly	Nationwide and eight capital cities	CoreLogic RP indices.
Real rent	Rent index is part of the CPI. Rental value is the median rent per week during the quarter. We extrapolate actual rents from corresponding ABS rent index using CoreLogic actual rental figures for the 2014:Q4. Then deflate the nominal series using the CPI excluding shelter to get real house rent. –Statistical adjusted: Non-seasonally adjusted	Quarterly	Nationwide and eight capital cities	Authors calculation based on the ABS index and CoreLogic rent data.
CPI excluding housing	The ABS also provides a series of CPI excluding shelter. CPI measures quarterly changes in the price of a basket of goods and services, which account for a high proportion of expenditure by the CPI population group. The CPI less shelter removes the influence of accommodation expenses. –Statistical adjusted: Non-seasonally adjusted	Quarterly	Nationwide and eight capital cities	Australian Bureau of Statistics (ABS)
The real mortgage interest rate	The nominal mortgage data is measured by the standard variable home loan rate offered by banks to owner-occupiers. The real mortgage is calculated as the nominal rate less the inflations expectations. –Statistical adjusted: Non-seasonally adjusted	Monthly	Nationwide	Reserve Bank of Australia (RBA)

Table A.2: Description of the variables (continued).

Variable	**Description**	**Frequency**	**Geographical level(Capital city/State)**	**Source**
Employment	The number of employed persons. Based on the ABS definition, employed persons aged 15 and over who, during the reference week: worked for at least one hour for pay, profit, commission or worked for one hour or more without pay in a family business or employees who had a job but were not at work and were on paid leave. –Statistical adjusted: Non-seasonally adjusted	Monthly	Nationwide and eight states	Australian Bureau of Statistics (ABS)
Population	Estimates of the Australian resident population are generated on a quarterly basis by adding natural increase (the excess of births over deaths) and net overseas migration (NOM) occurring during the period to the population at the beginning of each period. Estimated resident population refers to all people, regardless of nationality, citizenship or legal status, who usually live in Australia, except for foreign diplomatic personnel and their families. It includes usual residents who are overseas for less than 12 months over a 16-month period. It excludes overseas visitors who are in Australia for less than 12 months over a 16-month period. –Statistical adjusted: Non-seasonally adjusted	Quarterly	Nationwide and eight states	Australian Bureau of Statistics (ABS)

Table A.3: Description of the variables (continued).

Variable	Description	Frequency	Geographical level(Capital city/State)	Source
State Final Demand	State final demand is an estimate of the level of spending in the local economy by the private and public sectors, spending is reported based on the consumption of goods and services, and capital investment. –Statistical adjusted: Seasonally adjusted	Quarterly	Nationwide and eight states	Australian Bureau of Statistics (ABS)
Housing Completions	A number of new residential housing completions in each month. It consists of both private and public-sector housing completions. A residential building is defined as a building consisting predominantly of one or more dwelling units, which can be either houses or other residential buildings. –Statistical adjusted: Non-Seasonally adjusted	Monthly	Nationwide and eight states	Australian Bureau of Statistics (ABS)

Table B.1: The empirical literature on the evidence of bubbles in Australian housing markets.

Study	**Data frequency & Time Frame**	**Study Area**	**Method**	**Relevant Findings**
Shi et al. (2016)	Monthly (December 1995 to January 2016)	Australia's eight capital cities	Apply PSY test to the log of price-to-rent ratio	→Find evidence of housing bubbles of differing duration in several capital cities. →A housing bubble in the Sydney housing market (since 2014 till the end of the sample period).
Ji and Otto (2015)	Quarterly (1975:Q3-2015:Q1)	Australia's six capital cities (Hobart & Darwin not considered)	Apply PWY and PSY tests to the log price-to-rent ratio	→All cities except Melbourne are found to exhibit such speculative episodes, which are primarily clustered in the early to mid-2000s. →There is an evidence of explosive growth at the start of 2015 in Sydney.
Baur and Heaney (2017)	Monthly (December 1995 to March 2015)	National level	Apply PSY test to house price (rent not considered)	→A bubble is identified around the year 2003 in all cities except Darwin. →Find a bubble in 2014 in all capital cities with the exceptions of Perth, Hobart, and Canberra.
Jiang et al. (2011)	Monthly (December 1995 to June 2008)	Australia's eight capital cities	Cointegration approach	→There is a house price bubble in Perth from December 2000 to June 2008. →A house price bubble occurred in Sydney from March 2002 to December 2004.
Wang et al. (2018)	Quarterly (1995:Q3-2015:Q3)	National level	Cointegration approach	There are no housing bubbles in Australia because the short-run disequilibrium always corrects over time (house prices are in equilibrium).
Vogiazas and Alexiou (2017)	Quarterly (2003:Q1-2015:Q3)	National level	Apply PSY to residential real property price index	Australia has experienced two bubbles: 2007:Q2-2008:Q4 and 2013:Q1-2015:Q1.
Engsted et al. (2016)	Quarterly (1973:Q3-2013:Q4)	National level	Apply PSY to the price-to-rent ratio	Australia has experienced four bubbles: 2000:Q2-2003:Q4, 2004:Q2-2004:Q3, 2005:Q4-2006:Q1, 2006:Q2-2007:Q3.
Hatzvi and Otto (2008)	Quarterly (1991:Q3-2006:Q3)	Local Government areas of Sydney	Not applied any formal bubble identification test	Variations in price-to-rent ratios are not explained by expected returns or expected rent, pointing to a possible role for a speculative bubble.

Table B.2: Macroeconomic variables considered in Australian housing markets literature.

List of Authors	**Findings of their research**
Bodman et al. (2004); Bourassa et al. (2001); Ge and Williams (2015); Otto (2007)	Population growth has a significant effect on house prices.
Abelson et al. (2005); Bourassa et al. (2001); Jiang et al. (2011); Otto (2007); Richards (2008)	Household income has a positive relationship with house prices.
Abelson et al. (2005); Bourassa et al. (2001); Ji and Otto (2015); Otto (2007)	Employment (unemployment) has a positive (negative) relationship with house prices.
Abelson et al. (2005); Bodman et al. (2004); Bourassa et al. (2001); Choudhury et al. (2004); Fry et al. (2010); Ge and Williams (2015)	Interest rates (affected through the cost of financing and mortgages) have a strong influence on house prices.
Abelson et al. (2005); Bodman et al. (2004); Bourassa et al. (2001); Fry et al. (2010); Ge and Williams (2015); Peng and Chen (2016); Richards (2008)	Housing supply (i.e. construction cost/total dwelling approvals/housing stock/new residential dwelling) has a significant impact on the rise of house prices.

Table C.1: Percentage of the populations living in the Australian states and capital cities.

Jurisdiction	**Capital**	**City Population**	**State Population**	**Percentage of State population in capital city**
Australian Capital Territory	Canberra	403,468	403,468	100.00%
New South Wales	Sydney	5,029,768	7,759,274	64.82%
Victoria	Melbourne	4,725,316	6,179,249	76.47%
Queensland	Brisbane	2,360,241	4,848,877	48.68%
Western Australia	Perth	2,022,0448	2,558,951	64.82%
South Australia	Adelaide	1,324,279	1,713,054	77.31%
Tasmania	Hobart	224,462	517,588	43.37%
Northern Territory	Darwin	145,916	245,740	59.38%

Source: ABS (2017)

Table C.2: Descriptive statistics of the log price-to-rent ratios.

	Mean	**Standard deviation**
Sydney	7.35	0.15
Melbourne	7.34	0.25
Brisbane	7.07	0.22
Adelaide	7.09	0.22
Perth	7.19	0.26
Hobart	6.85	0.27
Darwin	6.66	0.20
Canberra	7.12	0.18
Australia	7.35	0.19

The generalised supremum ADF test

The generalised supremum ADF (GSADF) test is proposed by Phillips et al. (2015*a*) and is designed for testing the existence of speculative bubbles with improved discriminatory power. The GSADF test is an ex-post bubble identification procedure, which does not provide information such as the origination and collapse dates of bubble episodes. The GSADF test statistic, which is a function of $GSADF = sup\{BSADF_r \quad \text{with} \quad r\epsilon[r_0, 1]\}$.

Table C.3: The GSADF test result.

	The price-to-rent ratio	**Non-fundamental component**
Australia	3.07***	0.86**
Sydney	2.73***	0.91**
Melbourne	5.03***	0.36*
Brisbane	7.28***	1.30**
Adelaide	7.03***	2.23***
Perth	6.94***	1.02**
Hobart	8.82***	4.25***
Darwin	2.74***	0.13
Canberra	7.20***	2.97***

Significance at 1%(***), 5%(**) and 10%(*) based on the critical values obtained from 5000 Monte Carlo simulation.

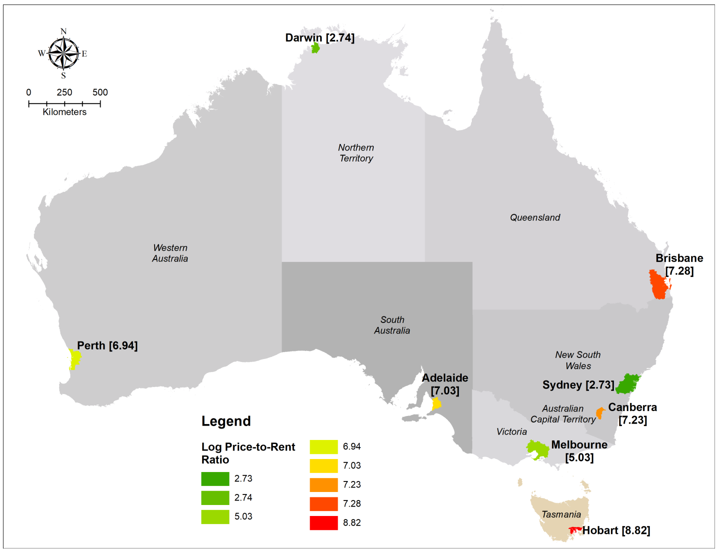


Figure C.1: GSADF test for the log price-to-rent ratio.

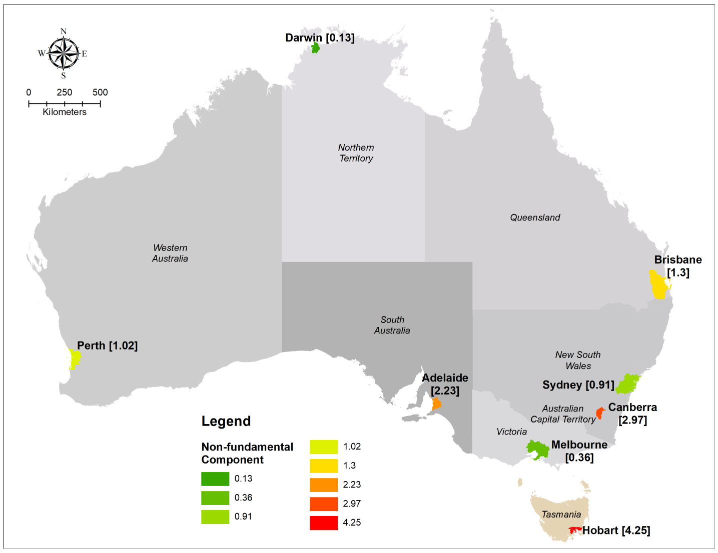
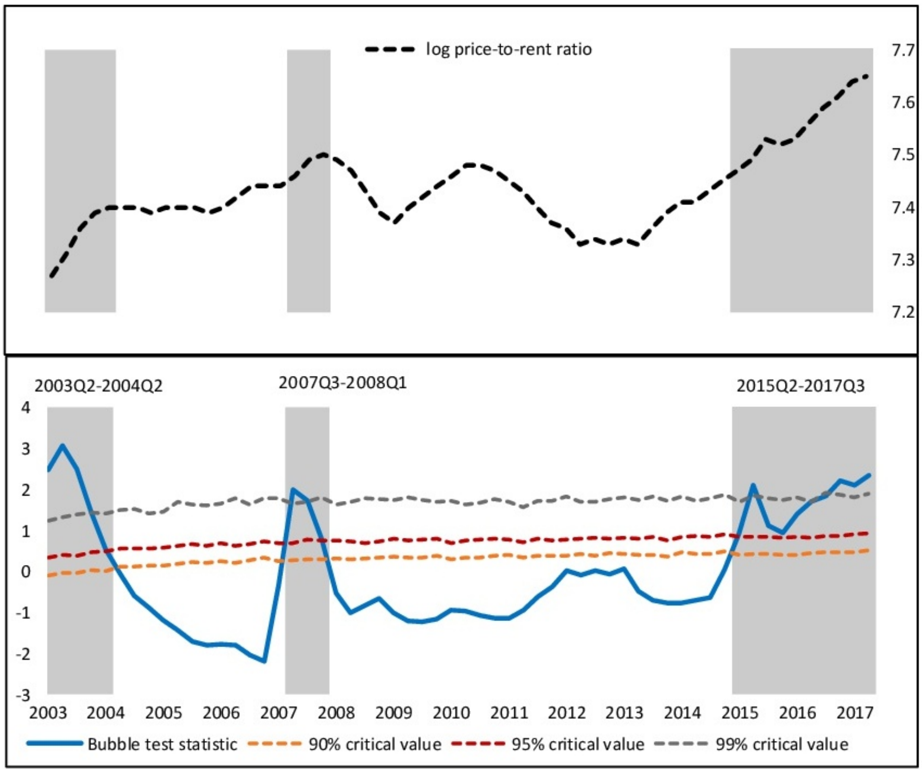
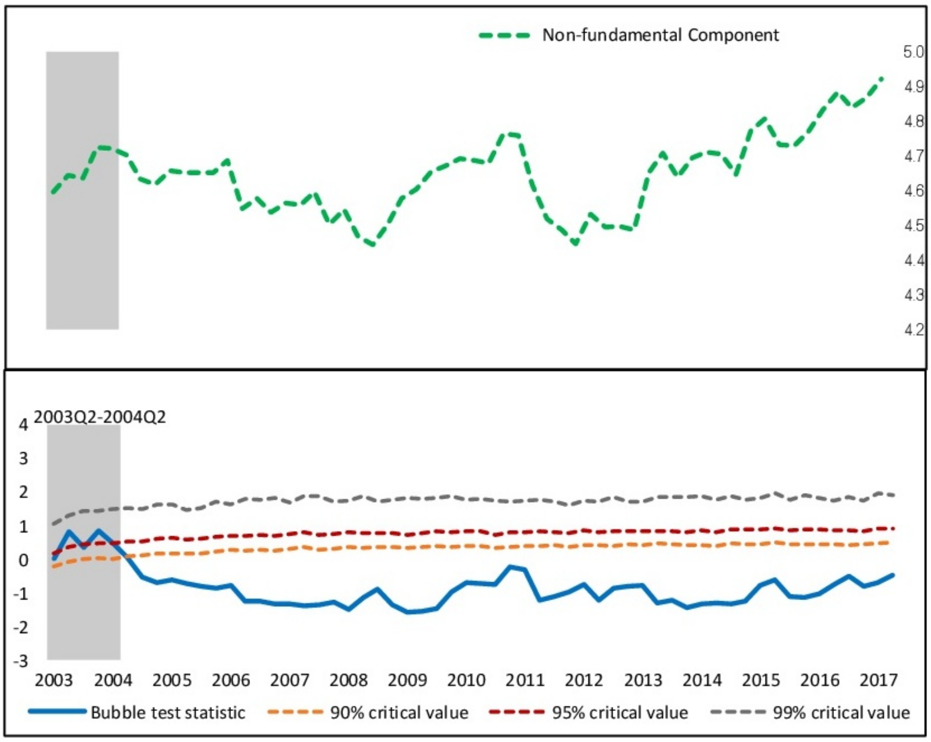


Figure C.2: GSADF test for the non-fundamental component.

The upper panel in each figure corresponds to the log price-to-rent ratio or the non-fundamental component, respectively. The lower part shows the BSADFs statistics with 99%, 95% and 90% critical values. Shaded areas are based on the speculative bubbles episodes at 90% of confidence.

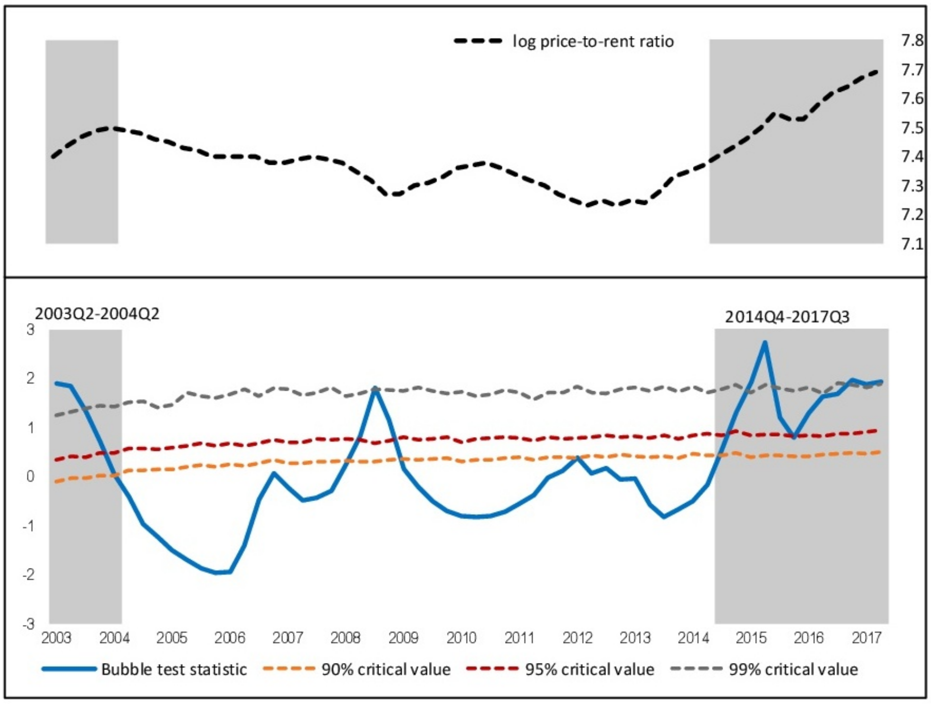


(a) Date stamping for price-to-rent ratio

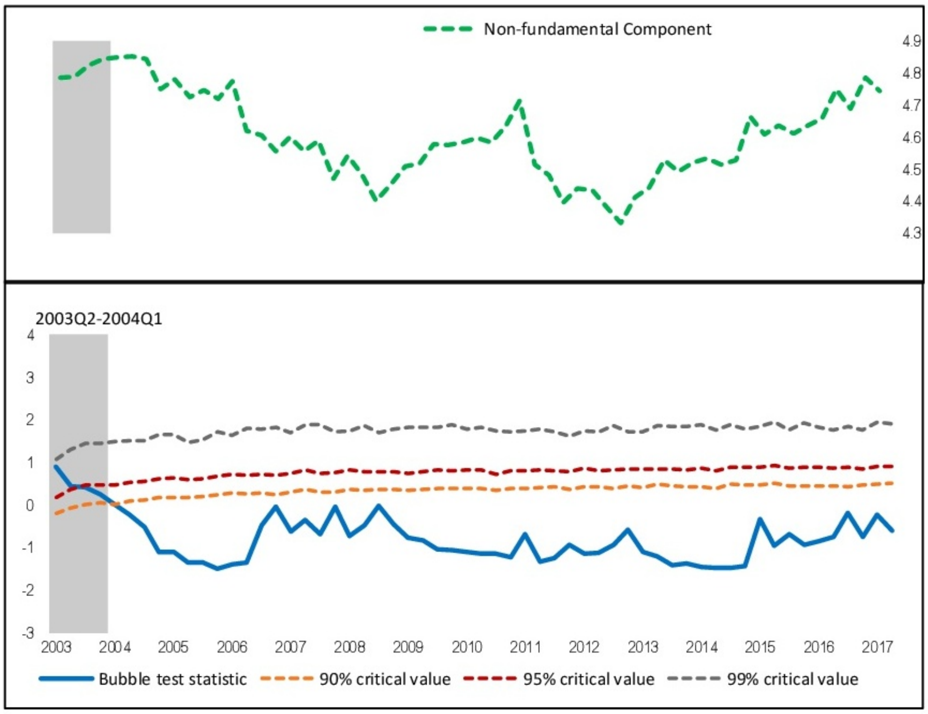


(b) Date stamping for non-fundamental component

Figure D.1: Date stamping for Australian housing market

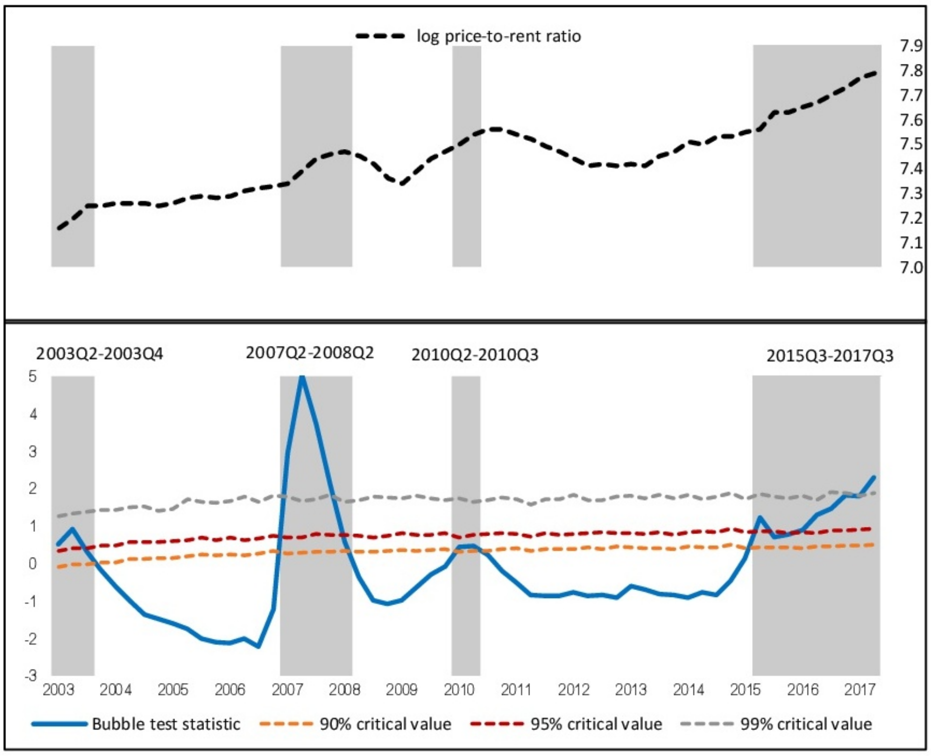


(a) Date stamping for price-to-rent ratio

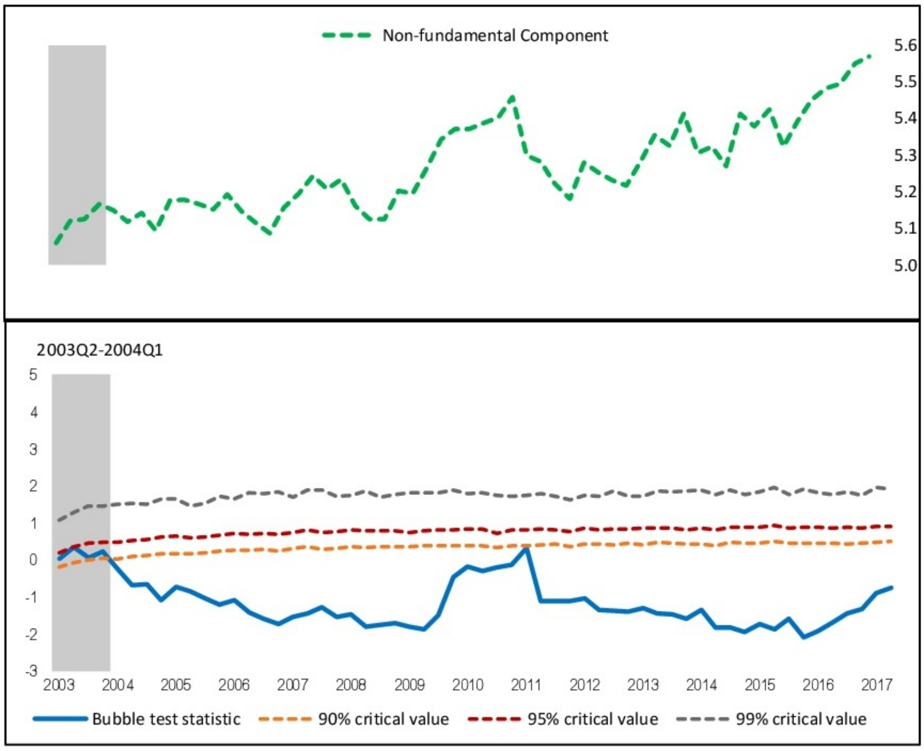


(b) Date stamping for non-fundamental component

Figure D.2: Date stamping for Sydney housing market

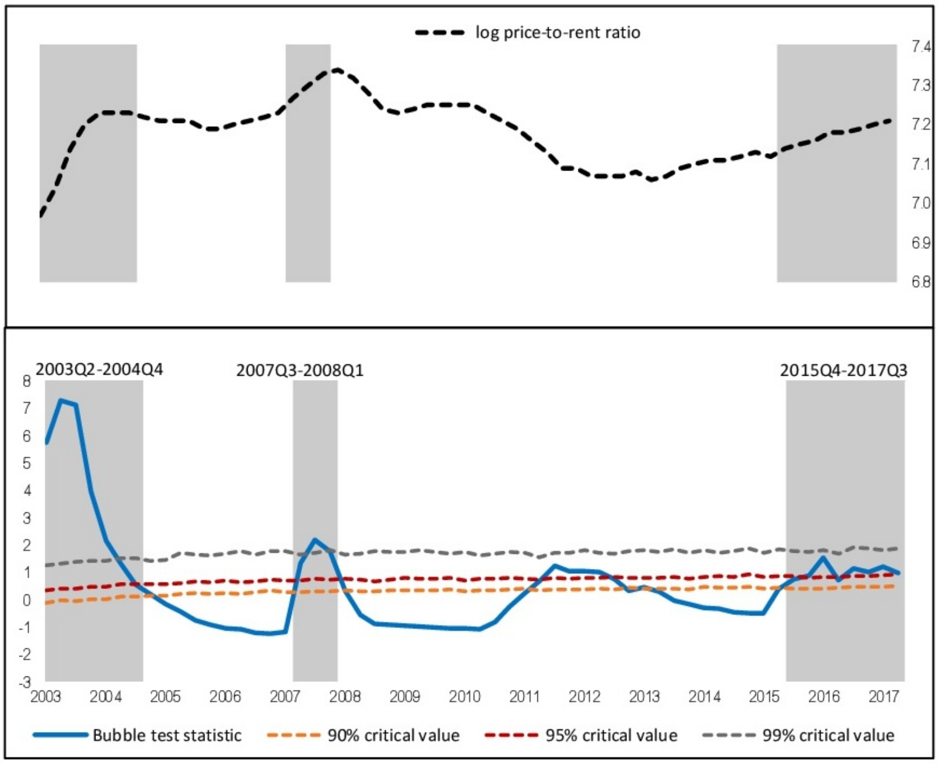


(a) Date stamping for price-to-rent ratio

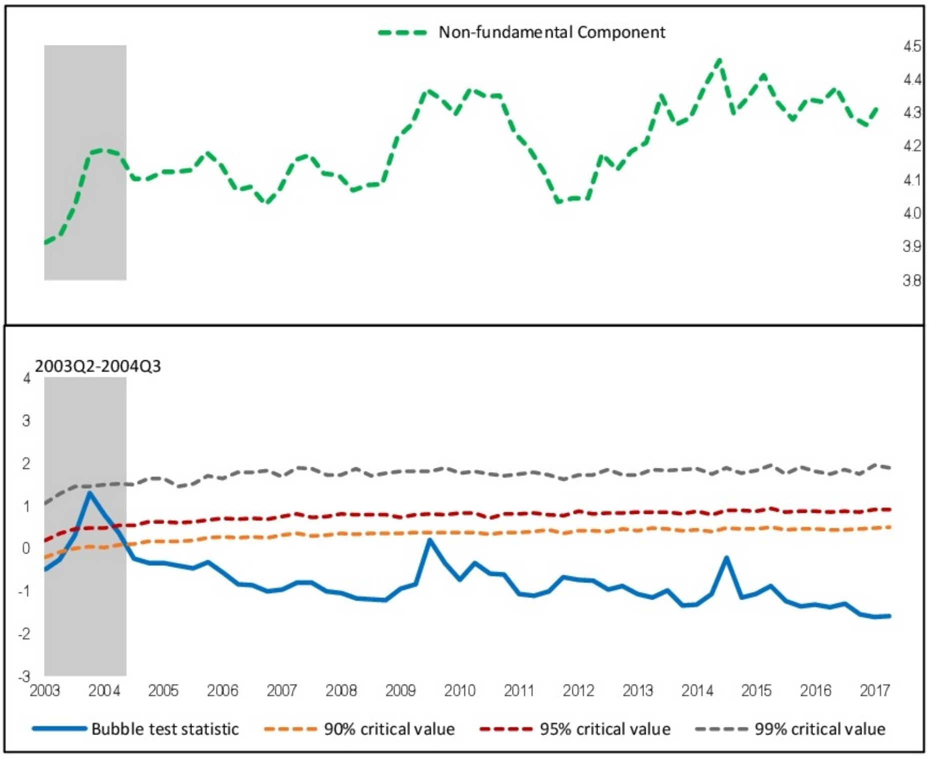


(b) Date stamping for non-fundamental component

Figure D.3: Date stamping for Melbourne housing market

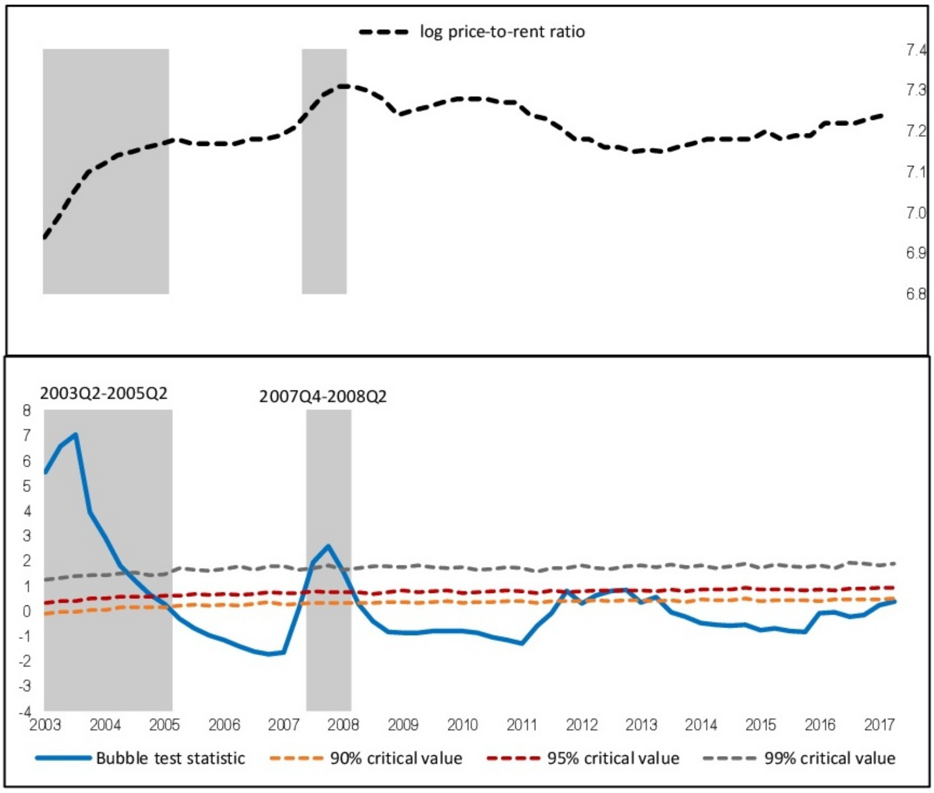


(a) Date stamping for price-to-rent ratio



(b) Date stamping for non-fundamental component

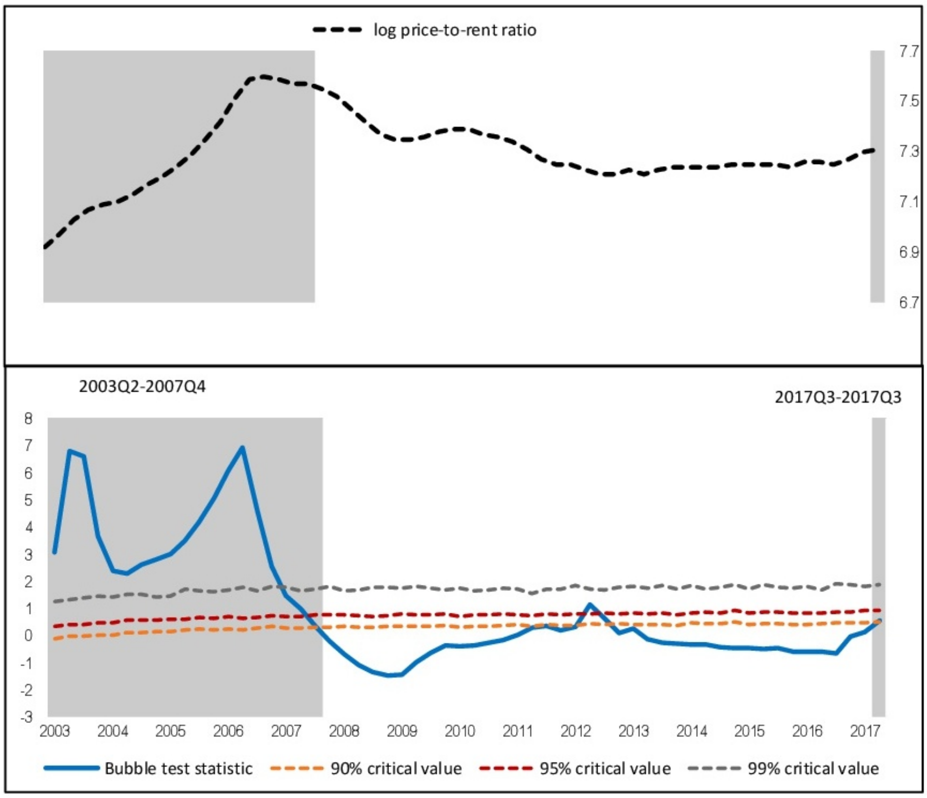
Figure D.4: Date stamping for Brisbane housing market



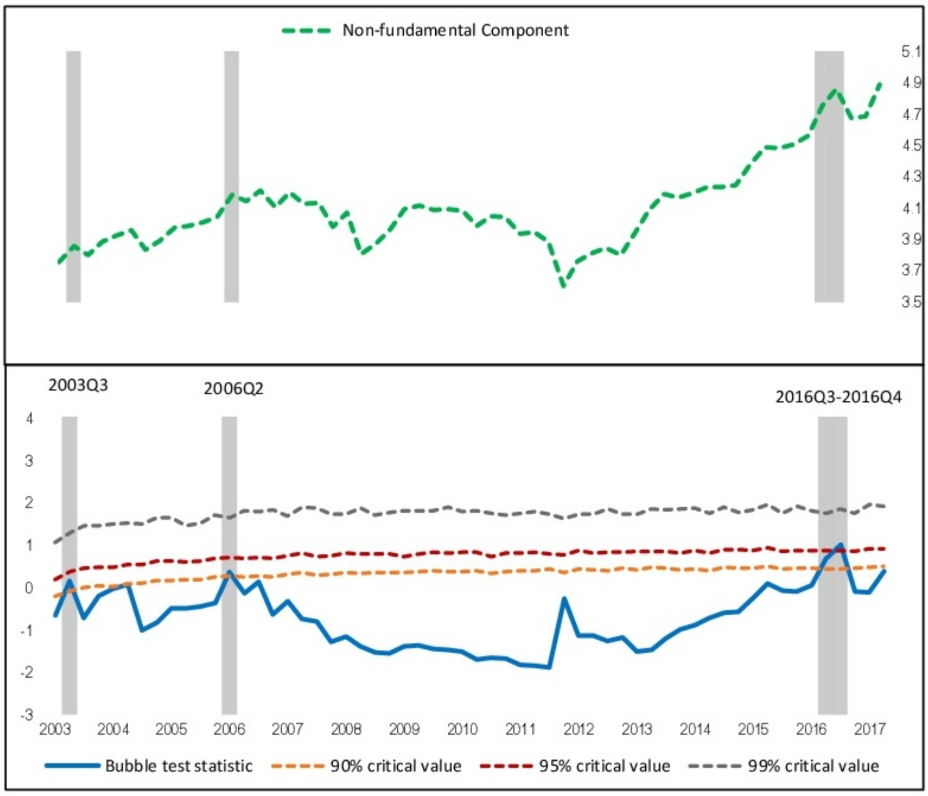
(a) Date stamping for price-to-rent ratio

(b) Date stamping for non-fundamental component

Figure D.5: Date stamping for Adelaide housing market

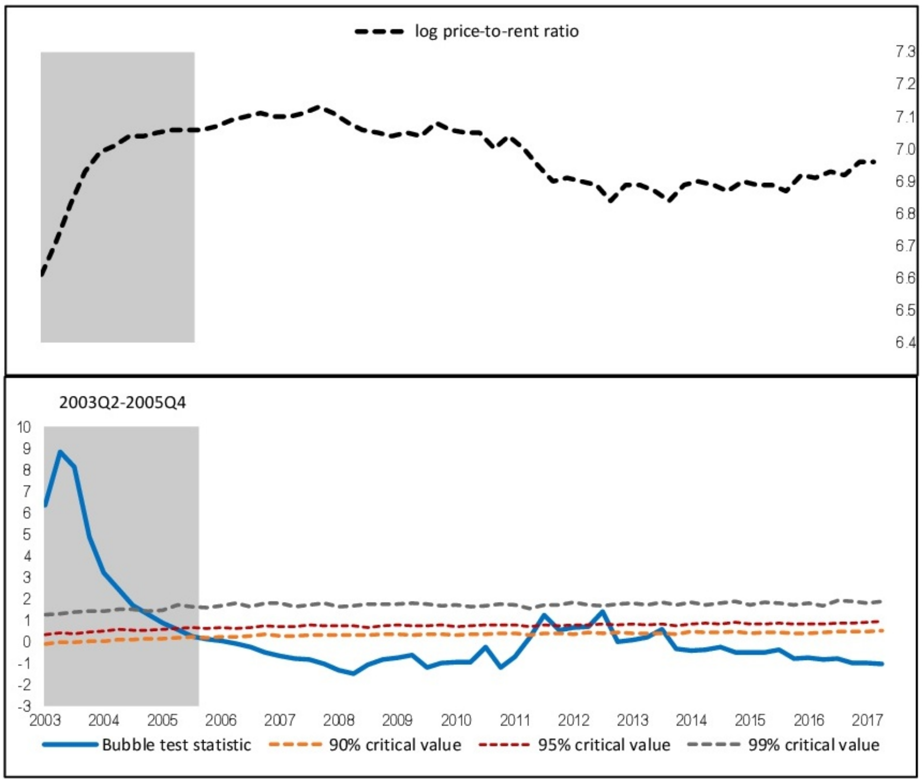


(a) Date stamping for price-to-rent ratio

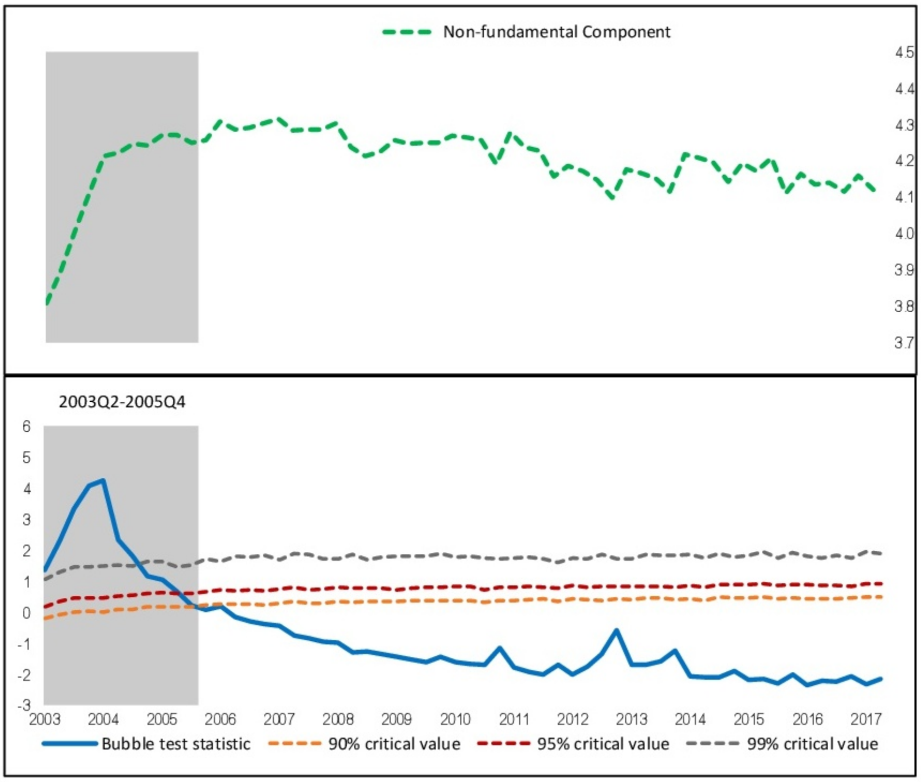


(b) Date stamping for non-fundamental component

Figure D.6: Date stamping for Perth housing market

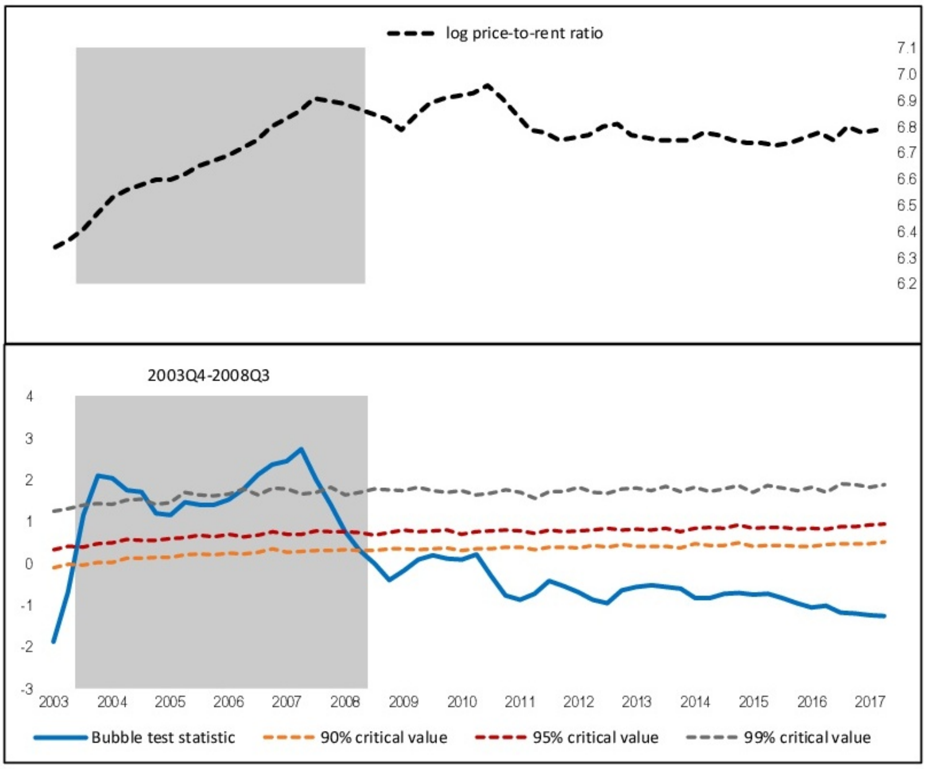


(a) Date stamping for price-to-rent ratio

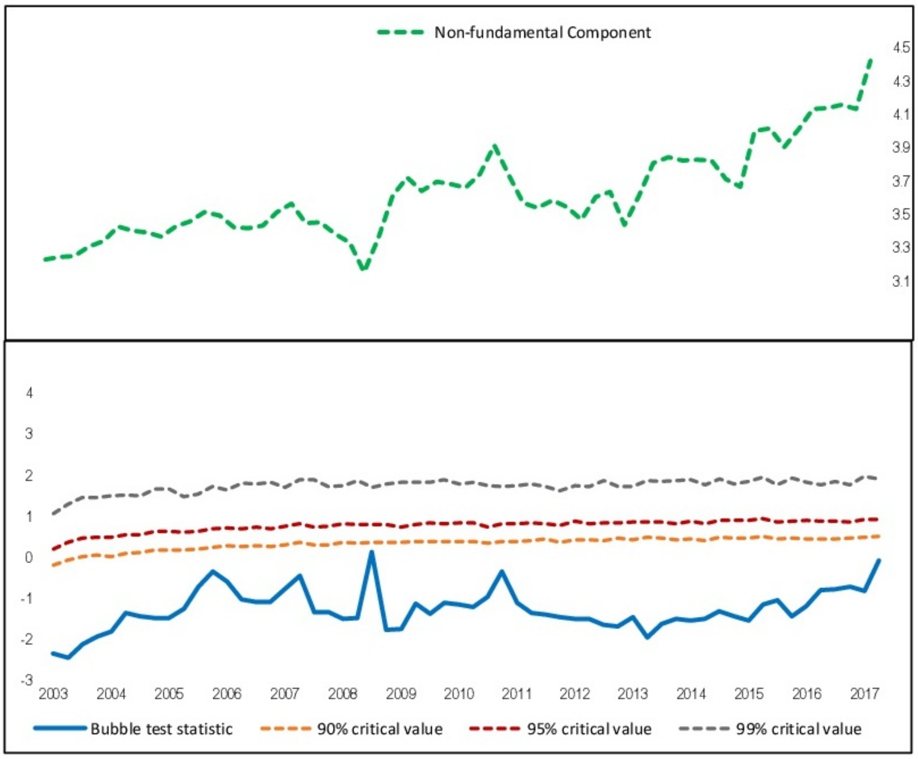


(b) Date stamping for non-fundamental component

Figure D.7: Date stamping for Hobart housing market

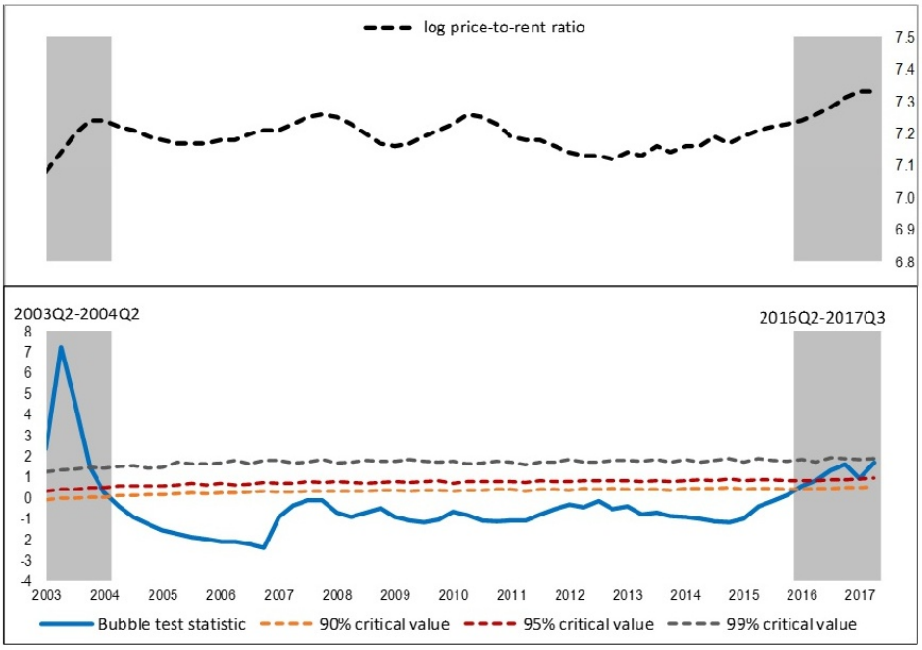


(a) Date stamping for price-to-rent ratio

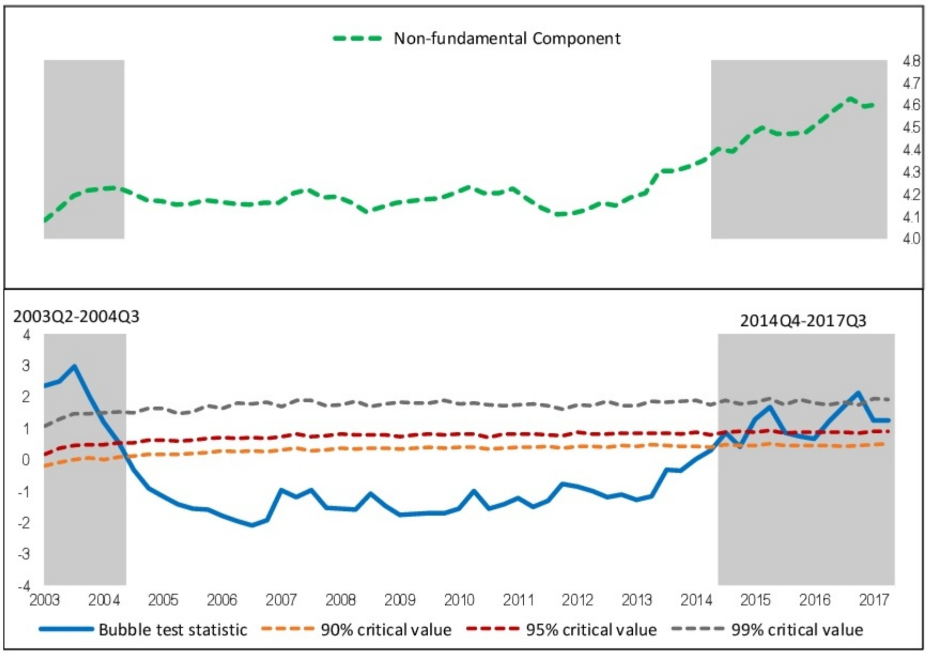


(b) Date stamping for non-fundamental component

Figure D.8: Date stamping for Darwin housing market

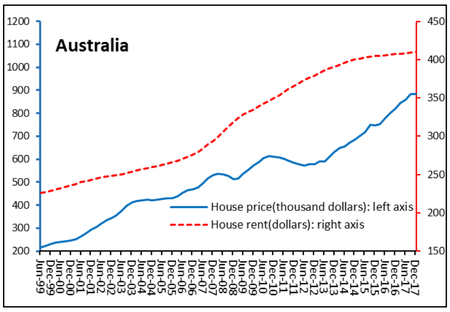


(a) Date stamping for price-to-rent ratio

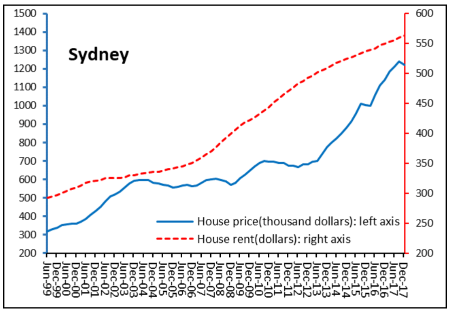


(b) Date stamping for non-fundamental component

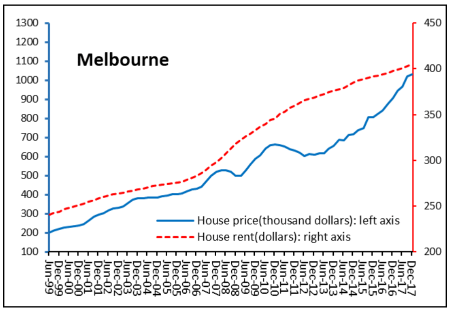
Figure D.9: Date stamping for Canberra housing market



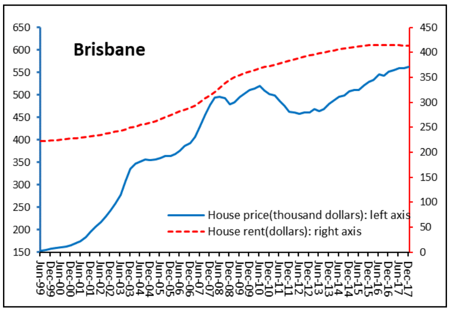
(a) House prices and rent (Australia)



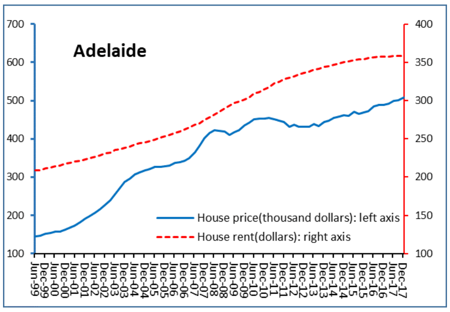
(b) House prices and rent (Sydney)



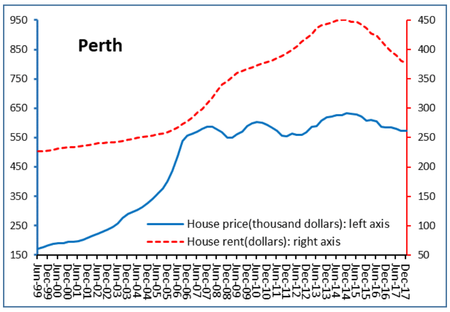
(c) House prices and rent (Melbourne)



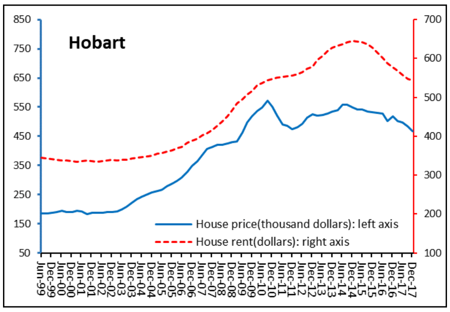
(d) House prices and rent (Brisbane)



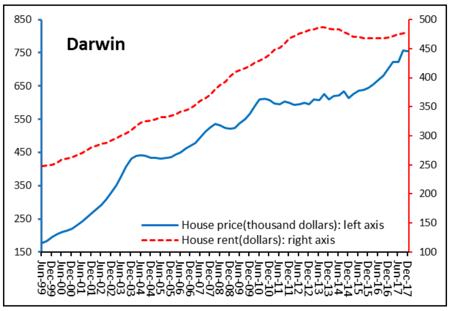
(e) House prices and rent (Adelaide)



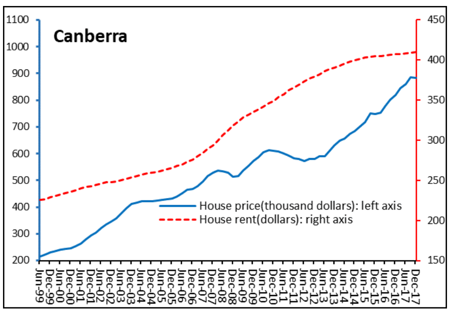
(f) House prices and rent (Perth)



(g) House prices and rent (Hobart)

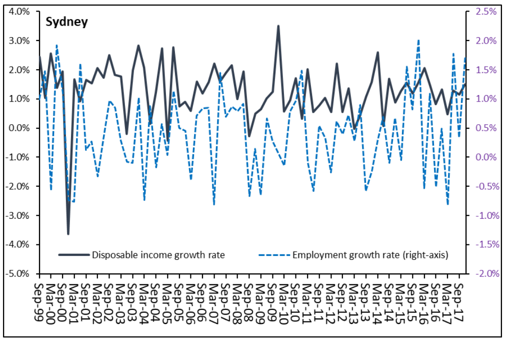


(h) House prices and rent (Darwin)

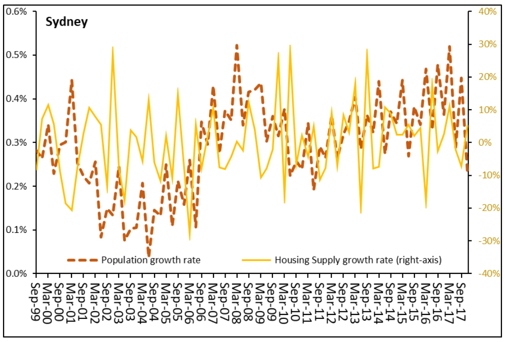


(i) House prices and rent (Canberra)

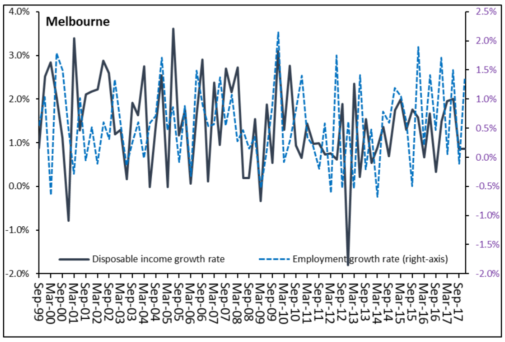
Figure E.1: House prices and rental costs for Australian national and eight capital cities.



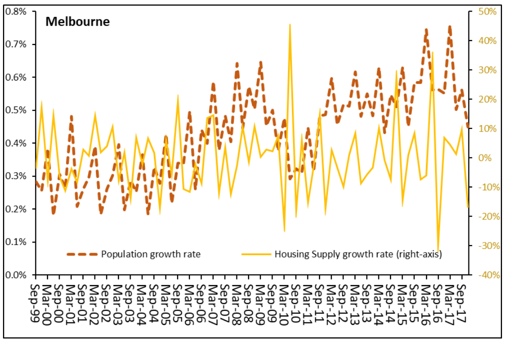
(a) Employment and disposable income



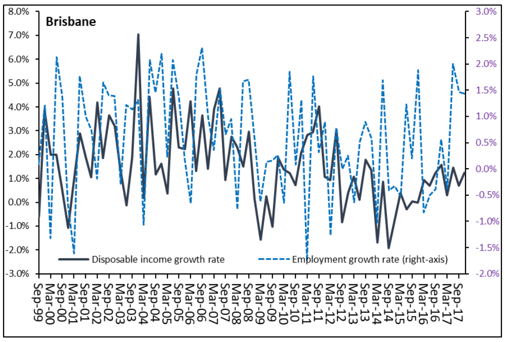
(b) Population and housing supply



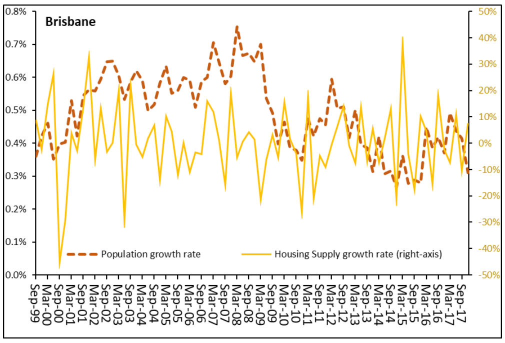
(c) Employment and disposable income



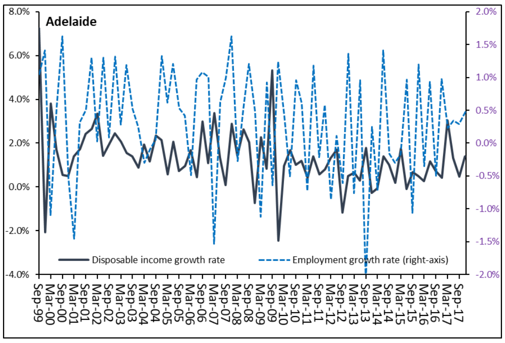
(d) Population and housing supply



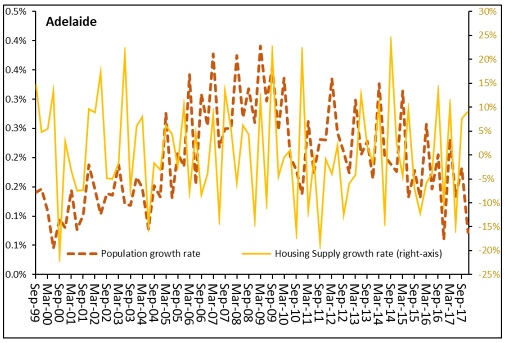
(e) Employment and disposable income



(f) Population and housing supply

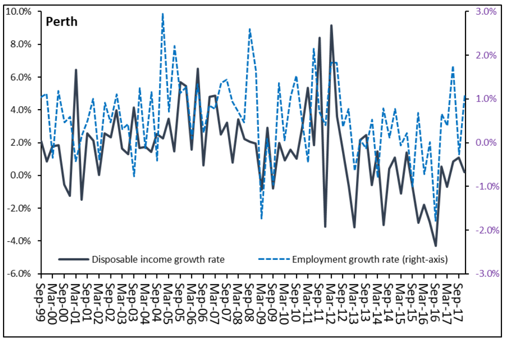


(g) Employment and disposable income

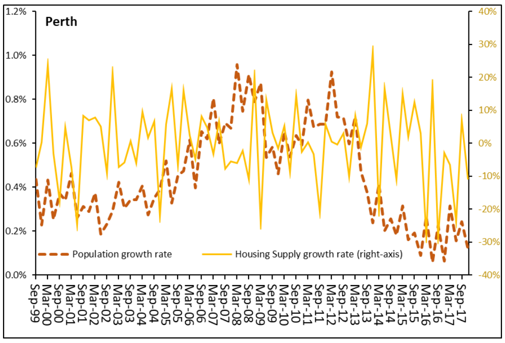


(h) Population and housing supply

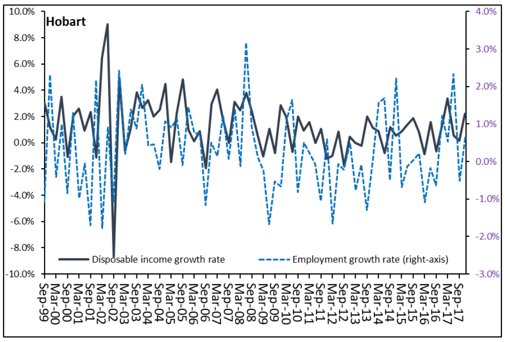
Figure E.2: The employment, population, disposable income and housing supply growth rate.



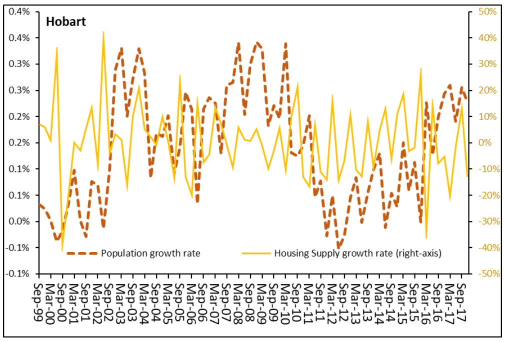
(a) Employment and disposable income



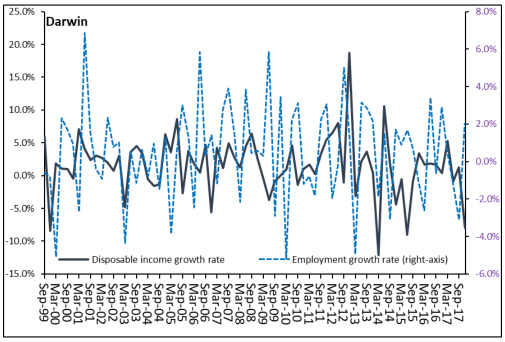
(b) Population and housing supply



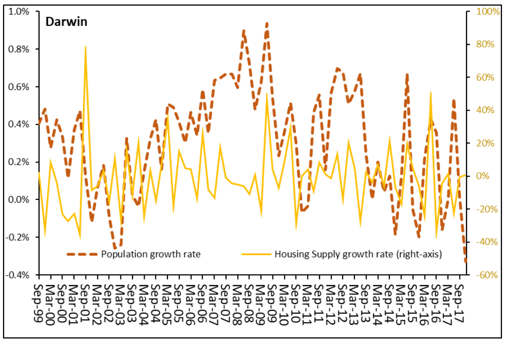
(c) Employment and disposable income



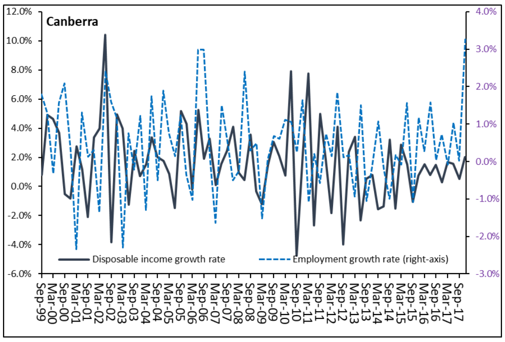
(d) Population and housing supply



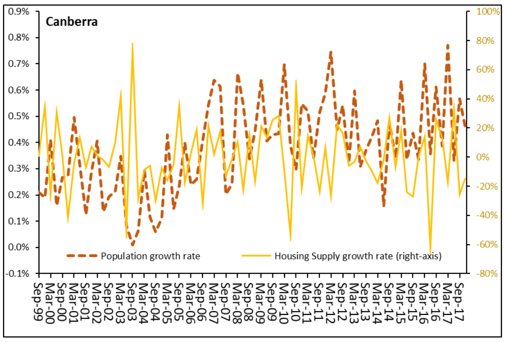
(e) Employment and disposable income



(f) Population and housing supply



(g) Employment and disposable income



(h) Population and housing supply

Figure E.3: The employment, population, disposable income and housing supply growth rate (continued).

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