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DOI: https://doi.org/10.1080/00779954.2015.1065903

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HOT PROPERTY IN NEW ZEALAND: EMPIRICAL EVIDENCE OF HOUSING BUBBLES IN THE METROPOLITAN CENTRES

By

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June 2015

COWLES FOUNDATION DISCUSSION PAPER NO. 2004

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Hot Property in New Zealand: Empirical Evidence of Housing Bubbles in the Metropolitan Centres

Ryan Greenaway-McGrevy* Peter C.B. Phillips†

June 22, 2015

Abstract

Using recently developed statistical methods for testing and dating exhuberant behavior in asset prices we document evidence of episodic bubbles in the New Zealand property market over the past two decades. The results show clear evidence of a broad-based New Zealand housing bubble that began in 2003 and collapsed over mid 2007 to early 2008 with the onset of the worldwide recession and the financial crisis. New methods of analyzing market contagion are also developed and are used to examine spillovers from the Auckland property market to the other metropolitan centres. Evidence from the latest data reveals that the greater Auckland metropolitan area is currently experiencing a new property bubble that began in 2013. But there is no evidence yet of any contagion effect of this bubble on the other centres, in contrast to the earlier bubble over 2003-2008 for which there is evidence of transmission of the housing bubble from Auckland to the other centres. One of our primary conclusions is that the expensive nature of New Zealand real estate relative to potential earnings in rents is partly due to the sustained market exuberance that produced the broad based bubble in house prices during the last decade and that has continued through the most recent bubble experienced in the Auckland region since 2013.

Keywords: Bubble, Exuberance, Collapse, Contagion, Dating methods, House prices, Property market, Sup test.

JEL classification codes: J61, R23, R30, C33

1 Introduction

Housing has become prohibitively expensive in many regions of New Zealand, putting home ownership beyond the reach of a growing number of New Zealand

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households, particularly those without wider sources of family financial support. House prices in a number of the main centres, including Auckland and Christchurch, now sit at historic highs. For example, in February 2015 the median house price across the broader Auckland metropolitan area was $675,000 and the median household income was $85,865, giving a price-to-income ratio of 7.86[1]. Relative to economic fundamentals such as household income or rent, current house prices in New Zealand are only surpassed in the latest Organization of Economic Cooperation and Development (OECD) statistics[2] by Australia, Canada and Belgium. The ratio of the median property price to median income across New Zealand was 5.2 in 2014, exceeding the corresponding ratio in the U.S., Canada, the U.K., Ireland, Japan and Singapore[3].

Policy-makers, as well as the public, should be concerned about these developments for many reasons. First, the rising cost of housing has major intergenerational wealth effects, reducing the relative wealth and welfare of younger generations, renters, and first-time home buyers in relation to extant property owners. To buy a house in Auckland at the median price of $675,000 with a 20% deposit, a household with median income would need a deposit of $135,000 supplemented by an 80% mortgage, making the deposit greater than 1.5 times the household's annual gross income. Without further financial resources, substantial and persistent long term saving, or equity in existing property, these costs of entry are prohibitive to most younger households. Escalating house prices also exacerbate inequality by increasing the wealth gap between home owners and renters, raising social tensions. Recent feature articles in New Zealand popular magazines, such as North and South[4], have drawn attention to these tensions by focussing on the many perceived excesses of the New Zealand property market relative to overseas markets, drawing harsh hedonic comparisons in terms of the poor 'value for money' of run-down slum-level New Zealand housing in select areas in Auckland relative to the up-market gentrified housing that is available at comparable prices overseas in both Australia and the USA.

A second reason for concern is that large mortgages and high rates of leverage put financial and macroeconomic stability at risk to housing market downturns, as the financial crisis and Great Recession have illustrated in dramatic recent ways in the US (Mian and Sufi, 2014). Financial stability is a particular concern of the Reserve Bank of New Zealand (RBNZ), which has recently announced a new regulatory separation of property investors from owner occupiers to assist in lowering mortgage default risk implications for the wider economy in the event of a New Zealand property market collapse.

A third concern for households and policy makers involves the labour market. High housing costs in metropolitan areas can be an impediment to growth. These costs typically inhibit labor mobility and prevent labor from moving from

[1] http://www.interest.co.nz/property/house-price-income-multiples

[2] The Economist, August 29 2014.

[3] Demographia, 2015

[4] North and South (April, 2015): "House Price Insanity: Why Auckland's Mad Property Market affects All New Zealanders", 34-43; "Running on empty", 44-49; "Generation Rent", 50-53.

depressed outlying regions to booming city centres to fill job openings (Saks, 2008; Zabel, 2012).

Against this background we ask the following questions. Is the present high cost of housing in New Zealand sustainable? Is there an ongoing property bubble in New Zealand and, if so, what regions are being or have been affected? We seek to explore some of these questions by examining empirical evidence on house prices in New Zealand relative to rent and income fundamentals. Using recently developed econometric methodology designed to test for the existence of asset bubbles and to date-stamp bubble episodes, we assess the status of housing markets in various regions of New Zealand. Our findings suggest that the Auckland metropolitan area is currently experiencing a property bubble in terms of the house price-to-rent ratio that began in 2013. We also document evidence of an earlier and much broader-based bubble in New Zealand property markets that emerged in the mid 2000s and subsequently collapsed upon the onset of the Great Recession. The evidence indicates that this bubble likely originated in the Auckland region before spreading to the other main centres. If that recent history were to repeat itself, the ongoing property market bubble in Auckland would be expected to affect property prices in other regions. But, as yet, there is no empirical evidence of this contagion to the other centres from the current Auckland real estate bubble. So far, therefore, the ongoing Auckland housing bubble is a phenomenon distinct from the other centres.

Our empirical methods draw on the bubble detection and dating methods developed originally in Phillips, Wu and Yu (2011) and more recently in Phillips, Shi and Yu (2015a, 2015b; PSY). These methods associate the emergence of asset price bubbles with mildly explosive growth in a time series of suitably normalized asset prices. Because explosive behavior in the normalized price violates the typical transversality condition required for closed form stable solutions for asset prices, the statistical tests have a direct economic interpretation in terms of a rational bubble or herd behavior market exuberance.

Our base dataset consists of nominal house prices for the 72 territorial authorities (TAs) of New Zealand and spans 1993:Q1 to 2014:Q4. We find evidence for real estate bubbles in 46 of the 72 TAs. But since this paper focuses on the main metropolitan centres we use only 14 of these regions in the analysis that we report in the present study. To calibrate the price data against housing market fundamentals, we normalize house prices by rents in each region. So the empirical tests relate to distinguishing normal martingale from explosive behavior in the price-to-rent ratios. Rents are often used as an economic fundamental for housing prices, in a similar manner to the way dividends provide fundamentals for stock prices in much empirical work on the stock market. Regional incomes are also used as a secondary fundamental.

Our empirical findings show that a broad-based housing bubble emerged in the main centres of New Zealand (Auckland, Wellington, Christchurch and Hamilton) in 2003 and that the bubble collapsed in 2007. Bubble contagion regressions demonstrate how the emergence of a housing bubble in Auckland City was followed by successive bubbles in Christchurch, Hamilton, and the other territorial authorities that comprise the Auckland metro area. In addition, we find evidence of a second bubble that emerged in the Auckland metropolitan area property market in late 2013. At the time of writing, this bubble is ongoing and has not migrated to the other main centres. Our findings on the dates and geographic incidence of these real estate bubbles are largely invariant to changing the normalization of property prices by economic fundamentals from rents to income. The additional results are reported in the Appendix.

We conclude the paper with a short discussion of possible scenarios through which the Auckland property bubble could burst or more slowly deflate. The price-to-rent ratio can fall by house prices falling, by an increase in rents, or by some combination of these two channels. Household incomes ultimately place an upper bound on the amount of income that can be spent on housing costs (assuming that household incomes are exogenous to housing prices and rents). We show that rental expenditures as a proportion of income have remained remarkably constant over the past decade in the main centres of Auckland, Wellington and Canterbury. For example, in the Auckland region rents have remained consistently around 25% of expenditure since 2003. Thus, if a market correction were to come through an increase in rents, this would involve an unprecedented increase in rental expenditure shares. In our view, therefore, any correction is more likely to come through an adjustment in prices driven by a demand or supply side shock or combination of the two.

This paper joins a broader literature that has centered on identifying asset price bubbles using formal statistical methods. Phillips, Wu and Yu (2011) used similar methods to date the origination and termination of the NASDAQ stock market bubble during the 1990s in the US. Phillips and Yu (2011) identified a sequence of successive bubbles in various financial assets and commodities over the past two decades that included the GFC and its aftermath effects on the real economy. Their focus was on the concatenating effects of bubbles across different markets. In other recent work PSY (2015b) examined long historical data in stock prices over some 150 years, dating the onset and collapse of multiple bubbles in the S&P 500 over this time period. The present paper contributes also to a recent literature that has focussed on the housing market and the determination of house prices in New Zealand, including Grimes, Holmes and Tarrant (2010), Grimes and Hyland (2013) and Grimes and Mitchell (2015).

The remainder of the paper is organized as follows. The following section begins by briefly outlining the econometric methodology to be employed in the empirical work of testing and dating real estate bubbles in New Zealand. It then applies these methods to the data and discusses the empirical findings that relate to the existence and dating of bubbles as well as possible contagion effects over time. We conclude with a discussion of possible scenarios of collapse in the New Zealand property market.

2 Empirics

We applied the econometric methods discussed above to data on regional real estate prices, rents and incomes in various metropolitan centres of New Zealand.

The application reveals how prices have evolved relative to rent (as well as income) fundamentals over the last two decades, considers evidence relating to the existence of house price bubbles, and explores contagion diaspora effects from the Auckland metropolitan region as the core centre to the other metropolitan regions.

2.1 Modelling Asset Bubbles

The bubble tests proposed by Phillips, Shi and Yu (2015a) are based on establishing explosiveness in normalized asset prices using a reduced form technique. This method identifies an asset bubble through the estimation of autoregressive effects and right sided unit root tests to assess the significance of any departures that exceed unity in the autoregressive response. The empirical models used here are based on a simple first order autoregression or AR(1) of the form

$$\Delta y_t = \alpha + \beta y_{t-1} + e_t,\ t = 1, \ldots, T, \tag{1}$$

where y_t denotes the log normalized house price at time t. (In what follows regional house prices are normalized by dividing by regional rents before taking logarithms: see the discussion below for more details.) Asset bubbles in the expansionary phase are associated with the centered AR(1) coefficient in (1) satisfying $\beta > 0$: This corresponds to explosive autoregressive behavior in a time series with autoregressive coefficient $1 + \beta > 1$. Statistical tests of exuberance in asset prices therefore reduce to establishing whether the centered AR(1) coefficient β is positive and statistically significant over a subsample of the time period considered. The null hypothesis for this test is therefore $\beta \leq 0$. The bubble tests are consistent against such mildly explosive alternatives, and given the major differences in the shape of the null and alternative distributions, these tests typically have much strong discriminatory power in the explosive direction than unit root tests do against stationary alternatives.

In order to permit episodic bubbles we follow Phillips, Shi and Yu (2015a & 2015b; PSY) and permit structural breaks in the autoregressive coefficient β that accommodate shifts between normal ($\beta = 0$) and bubble periods ($\beta > 0$) in the process. This is achieved by recursively estimating (1) over subsamples of varying size. Tests of the null are then based on conventional unit root (Dickey-Fuller) test statistics for each subsample. The procedure yields a global supremum augmented Dicker-Fuller (GSADF) statistic, which is used to detect the presence of a bubble within the entire sample, and a time series of backwards supremum augmented Dickey-Fuller (BSADF) statistics, which are used to date the onset and the collapse of any bubbles. Details of the construction of these statistics and the precise dating methods are given in the Technical Appendix.

Explosiveness in the asset price is consistent with the concept of a rational bubble, which will manifest itself as accelerating growth in the asset price over time. Following the discussion in Campbell, Lo and Mackinlay (1997), we express an asset price at time t as

$$P_t = E_t \left(\sum_{j=1}^{\infty} (1 + R)^{-j} D_{t+j} \right) + B_t, \tag{2}$$

where D_t denotes the income stream from the asset between time $t-1$ and t, R denotes the constant discount rate on the asset, and B_t is a rational bubble that satisfies $B_t = E_t\left[B_{t+1}(1+R)^{-1}\right]$, thereby manifesting itself as accelerating growth in the asset price over time. (See the discussion in Phillips, Wu and Yu, 2011, for the case where the discount rate is permitted to vary over time, and Phillips and Lee, 2015, for the validity of a log linear approximation). Although (2) embodies predictions about how a bubble manifests in asset prices, it says nothing about what events originate or fuel such a bubble. Tirole (1985) considered conditions under which rational bubbles can survive in general equilibrium.

The bubble detection tests are inherently reduced-form, since they are based on the observed behaviour of the asset price over a prolonged time period. A primary benefit of the reduced-form approach is that it captures the main (submartingale) characteristics of rational and irrational bubbles, therefore embodying many different structural model alternatives that can lead to an explosive asset price. This strength should not be underestimated, given that there is presently no unifying theoretical framework or consensus in financial economics that enables a workable structural model of asset bubbles. The main drawback of the reduced-form approach is that observed explosiveness in the asset price could be rationalized in terms of explosiveness in either the realized or the expected income stream from the asset. The former problem is easily dealt with by standardizing the asset price by the dividend: in empirical applications bubble detection tests are often applied to log price-to-dividend ratios, and in our empirical application we use price-to-rent ratios. This leaves explosiveness in expected future dividends as a possible driver of explosiveness in normalized asset prices. In this regard, narratives that can generate explosive growth in expected dividends over a sustained period of time often lack credibility: these require not only that the expected present value of future dividends grows in each time period, but that the growth is exponential. In other words, not only do we require good news about future dividend growth in each successive time period, but we need successive items of news to be incrementally better than past news. In the context of real estate markets, it is important to note that commonly given explanations for high house prices - such as low interest rates or high migration rates - do not in themselves provide an explanation for a sustained acceleration in price growth.

We also normalize house prices by household incomes (although the available data is more limited). By doing so we address concerns regarding explosiveness in expected future rents as the driving force behind accelerating price growth, since household incomes place an ultimate upper bound on rents. This argument requires household incomes to be exogenous to house prices. Over the short term, measured regional incomes may increase with house prices by self selection demographic effects as low income households are forced out of the region. Such selection effects of price appreciation are however limited: Auckland cannot be expected to turn into Silicon Valley simply because of spiraling house prices.

The asset bubble tests are conservative in a well defined sense. Whereas a high asset price level (relative to some fundamental) often draws concern from economists and media commentators (e.g., The Economist, 2005), a high asset price level will not in itself lead to rejection of the null hypothesis that $\beta > 0$ in (1). In fact, due to the presence of the intercept in (1), asset prices may well drift upwards over time under the null $\beta = 0$. As shown below, price-to-rent ratios across the main centres of New Zealand have experienced sustained increases over the past two decades - particularly in Auckland - but this feature of the data is not in itself interpreted as evidence of a bubble under our approach. It is only when asset prices exhibit accelerating growth over a sustained period (i.e. when the data supports the alternative hypothesis that $\beta > 0$ up to some level of statistical precision) that a bubble is detected.

2.2 Data

Our complete dataset consists of quarterly nominal house prices ($P_{i,t}$) and nominal rents ($R_{i,t}$) at time t for each territorial authority (city or region) i. The data span Q1 1993 to Q4 2014 and cover 72 territorial authorities. In the present application, we focus attention exclusively on the most populous metropolitan centres. Rents are adjusted for seasonality and outliers. Additional details about the data and filters used to finalize the data are given in the Appendix.

The series we use for real estate bubble testing are the log price-to-rent ratios for each region, viz.,

$$y_{i,t} = \log(P_{i,t}) - \log(R_{i,t}) \tag{3}$$

These ratios anchor real estate asset prices to asset income as a fundamental, using a normalization that also helps to remove broader inflationary effects from the price series. Under the econometric methodology described above, periods in which explosive growth in asset prices is found without commensurate explosive growth in asset incomes are associated with real estate asset bubbles.

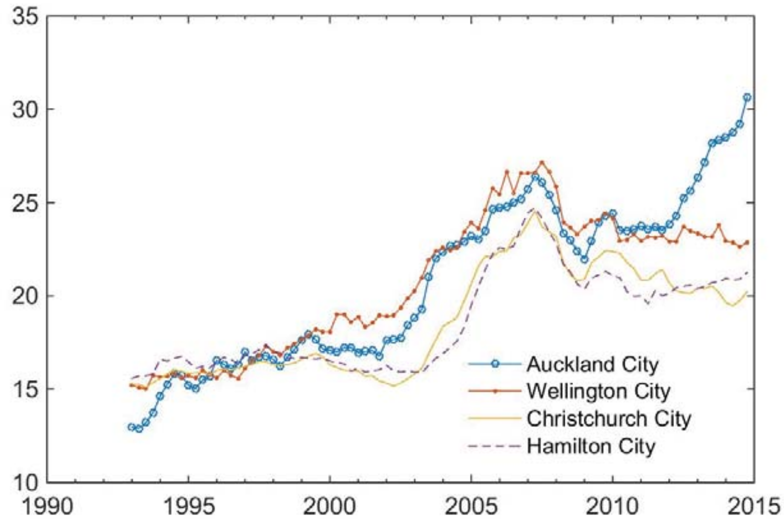

Figure 1: Price to Rent Ratios in the Main Centres

Figure 1 exhibits quarterly price-to-rent ratios over 1993 to 2014 for the central territorial authority in the four most populous metropolitan areas: Auckland. Wellington, Christchurch and Hamilton. All four ratios exhibit a large increase over the 2003 to 2008 period, after which there is a small decline. Price ratios in Wellington, Christchurch and Hamilton remain relatively constant over the subsequent period 2008 to 2014. Prices fluctuate between 20 and 25 times annual rents over this period. In contrast, the price-to-rent ratio for Auckland City begins to increase again in late 2013. Currently the ratio sits at about 35, which corresponds to a rental return of about 2.8% before depreciation.

Figure 2 shows price-to-rent ratios for the four main territorial authorities within the broader Auckland metropolitan area: Auckland City (corresponding to central Auckland), North Shore, Manukau and Waitakere. All four series exhibit very similar movements over time. Interestingly, the price-to-rent ratios in Auckland and North Shore are larger by a clear margin than those of Manukau and Waitakere. All four series move together over time in a very similar pattern that includes two significant growth periods in the asset-price ratios, so that the 2014Q4 observation is an all time high for each series.

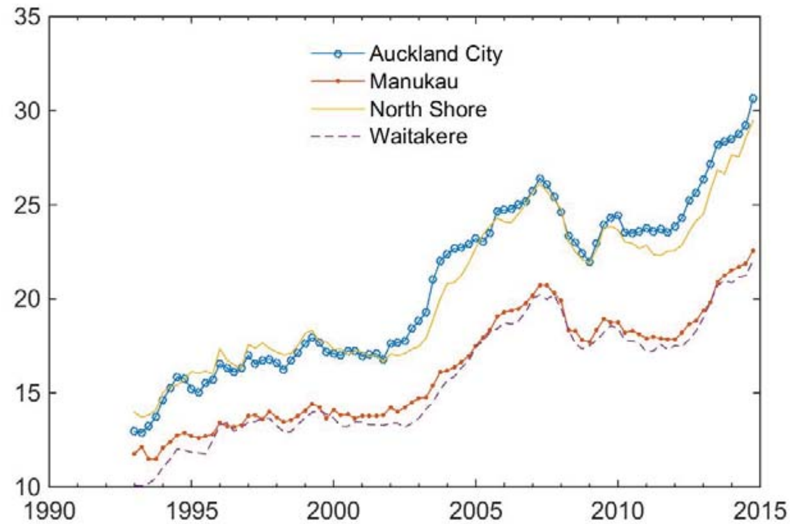

Figure 2: Price to Rent Ratios of Territorial Authorities in the Auckland Metro Area.

2.3 Testing for Exuberance

Figures 1 and 2 show that there has been a general upward, but by no means monotonic, movement in the price-to-rent ratios of housing for the four most populous cities of New Zealand over the sample period. Within the time frame 1993 to 2014 there are periods of substantial growth in each of the series, with some evident similarities and differences over certain subperiods. Our primary interest is to assess empirical evidence for periods of exuberance in the real estate markets for these regions and determine episodes of bubble activity. Accordingly, we implemented the formal tests for explosive market behavior in the normalized prices for each of the city centres and territorial authorities.

The table below exhibits calculated values of the GSADF statistic for the fourteen most populous territorial authorities in New Zealand.

Territorial Authority	Global supADF statistic
Auckland City	2.9735*
Manukau	2.8874*
North Shore	2.6974*
Waitakere	3.3056*
Christchurch City	4.5288*
Dunedin City	1.8475**
Hamilton City	5.4954*
Lower Hutt City	2.9861*
Napier City	7.6811*
Palmerston North City	3.2206*
Porirua City	2.1751*
Tauranga	5.9339*
Upper Hutt City	3.2139*
Wellington City	2.0230*

* and ** denote statistical significance at the 1% and 5% levels, respectively

The results from this test are unequivocal: evidently exuberance in house prices is broad-based throughout New Zealand, occurring in all regions considered at the 1% level with the sole exception of Dunedin city, which is significant at the 5% level.

In 26 of the 72 TAs there is little evidence of real estate bubbles. These regions are mainly rural (or with large rural areas). In particular, the null hypothesis cannot be rejected at the 5% level for the following TAs: Ashburton, Franklin, Papakura, Buller, Carterton, Central Otago, Greymouth, Hurunui, Kaikoura, Kaipara, Kawerau, MacKenzie, Opotiki, Otorohanga, Queenstown Lakes, Rangitikei, Selwyn, South Wairarapa, Southland, Waikato, Waimate, Wairoa, Waitomo, Western Bay of Plenty, Westland, and Whakatane.

2.4 Episodic Bubbles

Figure 3 shows recursive calculations of the BSADF statistics for territorial authorities representing the four most populous regions (Auckland, Wellington, Christchurch and Hamilton). The figure also graphs recursively the corresponding critical value for this recursion which is used for the crossing time dating algorithm. The critical value increases monotonically in the sample size, reflecting the dependence of the asymptotic distribution of the statistic on the date fraction and test size control that enables consistent date stamping and reduces the false positive detection probability under the null to zero asymptotically (Phillips and Yu, 2011, and see the Technical Appendix for details). We use Auckland city and Wellington city to represent the broader Auckland and Wellington metro areas, respectively. We date the origination of the asset bubble by noting the first crossing time of the critical value curve when the recursive test statistic sequence crosses the 5% significance threshold.

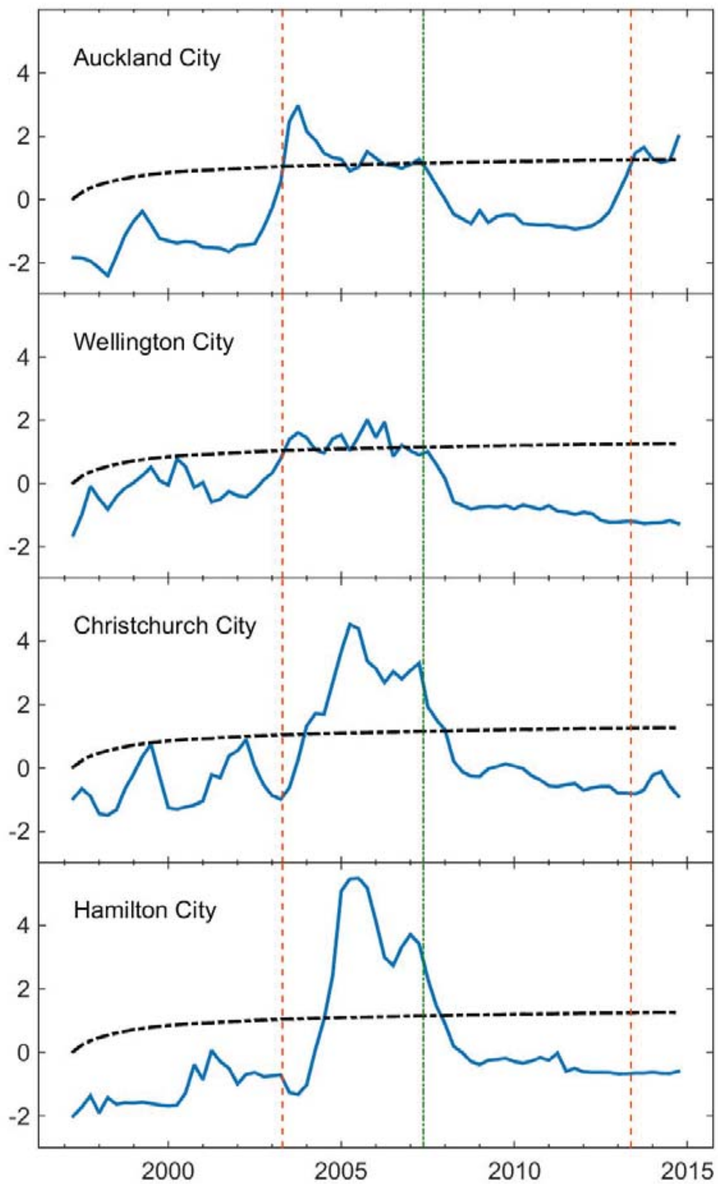

Figure 3: Backwards supremum ADF statistics for the main centres shown against the 5% critical value of the test. Vertical dashed lines (−−) indicate the onset of bubbles in Auckland City; vertical dot-dashed lines (− · −) indicate the bursting of the bubble.

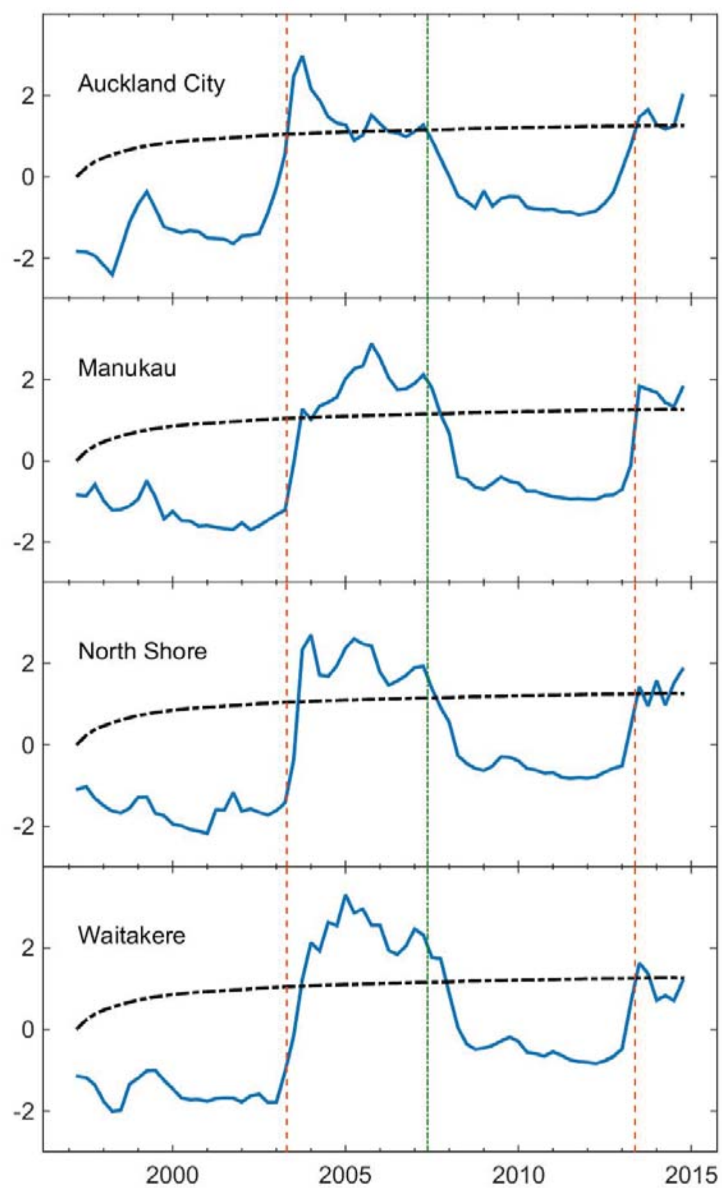

Figure 4: Backwards supremum ADF statistics for the Auckland Metro Area shown against the 5% critical value of the test. Vertical dashed lines (−−) indicate the onset of bubbles in Auckland City; vertical dot-dashed lines (− · −) indicate the bursting of the bubble.

There is evidence of a New Zealand-wide real estate bubble over the 2003-2008 period. Both Auckland and Wellington statistics cross the 5% threshold in Q2 2003. Christchurch follows in Q3 2003, and Hamilton follows in Q4 2004. Note that although Wellington and Auckland first cross the 5% threshold at the same time, the Auckland test statistic climbs much higher, indicating far stronger significance in the bubble test statistic. Indeed, at a one percent level of statistical significance for the recursive statistic we would only reject the null hypothesis of no bubble for Auckland. The bubble collapses around the time of the onset of the worldwide recession in late 2007 and early 2008. The Christchurch test statistic permanently falls below the critical value in Q4 2007, while the corresponding date for Hamilton is Q1 2008. Auckland and Wellington exit from the bubble earlier, in Q2 2007 and Q4 2006, respectively. (On these dates the statistic falls below the critical value permanently for Wellington, and for a prolonged period in the case of Auckland.)

Figure A1 in the Appendix depicts house prices (and rents) for the four main centres. It is evident that the collapse of the bubble was associated with a fall in house prices (rather than only an increase in rents). The collapse in house prices is on the order of magnitude of about 10% from peak to trough for each of the main centres. House prices fell by 11% in Auckland City, 8% in Wellington City, 10% in Christchurch and 12% in Hamilton. Our findings regarding bubble collapse mirror those typically found in asset markets: termination of a bubble is associated with a fall in the nominal price of the asset, rather than a rise in the fundamental – see Phillips and Yu (2011) and PSY (2015b). The magnitude of the price correction is however smaller, and more drawn out, than those found in more liquid asset markets (such as equity markets).

In the more recent period following 2008 there appears to be an Auckland-specific bubble, with the Auckland test statistic crossing the 5% threshold level in Q3 of 2013. This bubble in the real estate market is confined to the Auckland region, as the recursive statistics for all other centres show no evidence of an approach to the critical value since 2008, although there is some notable volatility in the case of the statistic for Christchurch which perhaps reflects market uncertainties in the aftermath of the earthquake and over the rebuilding of the city.

Figure 4 graphs the recursive backwards supremum ADF statistics for territorial authorities within the Auckland metro area. Note that Auckland city leads the other three regions into the mid 2000s bubble by one quarter, with Manukau, Waitakere and the North Shore crossing the threshold in Q3 2003. At the end of the bubble, Manukau and North Shore then cross back over the threshold in Q3 2007, with Waitakere crossing in Q4 2007. The collapse of the mid-2000s bubble was associated with a fall in prices right across the Auckland Metropolitan Area, as shown in Figure A2 in the Appendix. From peak to trough, house prices fell by 10% in Waitakere and North Shore, and by 9% in Manukau.

The more recent bubble that has emerged in late 2013 appears across the four main territorial authorities in the Auckland metro area, showing that the origination of the new bubble is quite broadly based in the Auckland region.

(All four statistics cross the 5% threshold in Q3 2013.) However, this bubble appears not to be uniformly sustained across the Auckland regions. The statistic for North Shore, for instance, clearly drops below the critical value in Q4 2013 before crossing it again in Q1 2014. Waitakere drops below the critical value permanently in Q4 2013. Only the statistic for Manukau remains above the threshold for the entire six quarters from Q3 2013 to Q4 2014. Nonetheless, the statistic for Auckland City, Manukau and North Shore are above the threshold for the final two quarters of 2014, and the statistic for Waitakere appears to be quickly approaching the threshold, all of which suggests that the ongoing bubble in the Auckland region is pervasive.

2.5 Testing for Bubbles in Price to Income Ratios

Household incomes are also often used as an economic fundamental for real estate prices. In this section we demonstrate that our main empirical findings regarding the timing and geographic incidence of New Zealand real estate bubbles remain broadly the same when average incomes are used as the relevant fundamental for house prices. In particular, we find that Auckland leads the rest of the country both into and out of the mid-2000s real estate bubble, and that Auckland is currently experiencing a new real estate bubble. The onset of these bubbles are dated slightly earlier in the price-to-income data, as documented below.

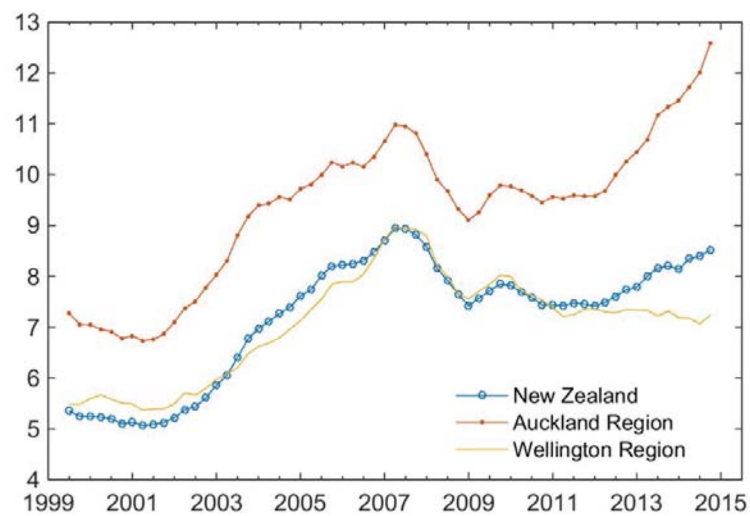

Figure 5: Price to Income Ratios

We use average annual earnings per full time equivalent worker as the measure of income. The available data are relatively limited, and so our analysis is constrained to the Auckland and Wellington metropolitan areas from Q3 1999 onwards. Earnings are obtained for the Auckland and Wellington area Regional

Councils. We use the Auckland and Wellington Area residential Quotable Value New Zealand (QVNZ) price indices for the corresponding house prices. We also include the whole of New Zealand in the analysis in order to provide a rudimentary understanding of bubble contagion.

Figure 5 exhibits the price-to-income ratio for Auckland, Wellington and New Zealand. Similar trend trajectories are evident in the price-to-income and price-to-rent ratios for the Auckland and Wellington regions, although there is some disparity in the trajectories towards the end of the period following 2012.

The table below exhibits calculated values of the global backwards supremum ADF statistics.

Region	Global supADF statistic
Auckland Region	3.9152*
Wellington Region	3.0878*
New Zealand	5.9823*

* and denotes statistical significance at the 1% level

Figure 6 exhibits recursive calculations of the backwards supremum ADF statistics together with the right-tailed 5% critical value. As before, we date the origination of the asset bubble by noting the first crossing time of the critical value curve when the recursive test statistic sequence crosses the 5% significance threshold. We include vertical lines to indicate the origination (dashed lines $--$) and collapse (dot-dashed lines $- \cdot -$) of bubbles in the Auckland market. Interestingly the onset of the episodic real estate bubbles is dated to occur slightly earlier when incomes are used as the fundamental rather than rents. The Auckland test-statistic crosses the 5% critical value threshold in Q3 2002, leading that of the rest of New Zealand and Wellington, which cross in Q4 2002 and Q3 2003, respectively. The bubble in Auckland collapses much earlier (Q1 2006) than in New Zealand (Q4 2007) or Wellington (Q1 2008), although the test-statistic for Auckland remains high until mid 2007. The recent Auckland bubble emerges in Q3 2012, leading New Zealand as a whole over the threshold by one year (the NZ test-statistic crosses in Q2 2013). This is not inconsistent with the second bubble being characterized as an Auckland-specific bubble since approximately one third of the population resides in Auckland and Auckland price statistics dominate the New Zealand data.

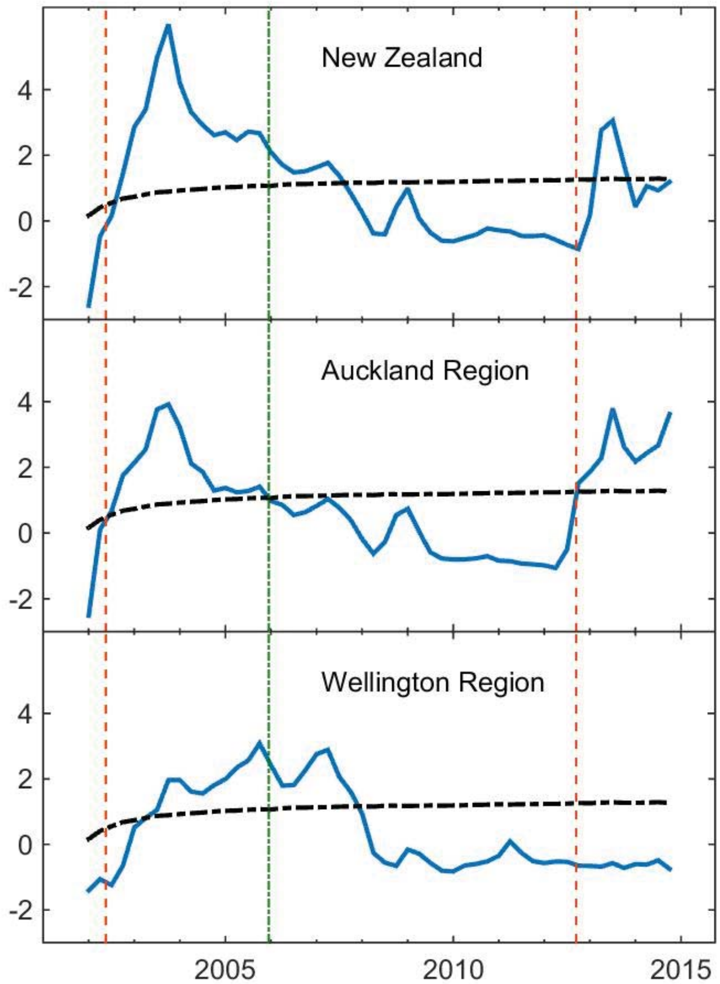

Figure 6: Backwards supremum ADF statistics shown against the 5% critical value of the test. Vertical dashed lines (−−) indicate the onset of bubbles in the Auckland region; vertical dot-dashed lines (− · −) indicate the bursting of the bubble.

2.6 Bubble Contagion

The evidence reported above suggests that the mid 2000s bubble originated in certain regions of the country first before spreading to the outlying regions. To model this diaspora of real estate market exuberance we estimate a series of contagion regressions as follows. We proceed by estimating autoregressions of the form (1) for each region recursively over the sample period, leading to the slope coefficient estimates $\hat{\beta}_{i,s}$, where i indexes the geographic region and

s indexes the ending date of the subsample ($s = S, ..., T$). With these data in hand, we fit the following empirical functional regression

$$\hat{\beta}_{j,s} = \delta_{1j} + \delta_{2j} \left(\frac{s}{T-S+1} \right) \hat{\beta}_{core,s-d} + error_s, \quad s = S, ..., T, \tag{4}$$

from some initialization date S for $j \neq core$, where *core* denotes a candidate core region where the asset bubble is hypothesized to originate. The quantity d that appears in the subscript of $\hat{\beta}_{core,s-d}$ is a non-negative delay parameter that captures the lag in market contagion from the core center on other regions. In our empirics, we allow for integer settings of d that range from a lag of zero to 12 months, so that $d \in \{0, 1, 2, \ldots, 12\}$. We therefore require initial data of at least $S - d \geq 2$ observations to be sufficient to calculate the estimate $\hat{\beta}_{core,s-d}$. In practice we select the lag order d by nonlinear least squares regression, which amounts in the present case to choosing the regression (4) with the largest R^2. See (8) in the Technical Appendix for more details.

We considered two methods for selecting the subsample sequence of recursively estimated centered autoregressive coefficients $\hat{\beta}_{i,s}$. These methods involve the use of either an expanding subsample or a fixed window width subsample. According to the expanding subsample scheme, the coefficients $\left\{ \hat{\beta}_{i,s} \right\}_{s=S}^{T}$ are recursively estimated (as the sample size increases) by least squares regression on (1) with the expanding subsample $\{t = 1, \ldots, s\}$ for $s = S, S+1, \ldots, T$. According to the fixed window width subsample scheme, the coefficients $\left\{ \hat{\beta}_{i,s} \right\}_{s=S}^{T}$ are obtained by regression on a moving window of data of length S. In this case, $\hat{\beta}_{i,s}$ is the least squares slope coefficient from a fitted least squares regression of (1) using the data window $\{t = s - S + 1, \ldots, s\}$ for $s = S, S+1, \ldots, T$. By virtue of its construction, the fixed window approach provides estimates $\hat{\beta}_{i,s}$ that depend on data over a window of time of fixed length S in the vicinity of the latest observation s. These estimates therefore have a sharper focus on the immediate data point than the expanding sample scheme estimates which use data from the origination date to the latest observation. In what follows we report results obtained with the fixed window subsample method. For implementation with the New Zealand real estate data, we set the fixed window sample size as $S = \lfloor 0.33 \times T \rfloor = 29$.

We select Auckland City as the core for two reasons. First, the wider Auckland region (Auckland City, Manukau, North Shore and Waitakere) accounts for a larger share of economic output than any other territorial authority or metropolitan area in the country. Second, as shown in Figures 3 and 4 above, the Auckland City real estate market exhibits exuberance before all other depicted regions except Wellington. As mentioned above, although Auckland and Wellington cross the 5% threshold at the same time, only Auckland city crosses the 1% threshold (this is not depicted in the figures), which is indicative of the strength of the market exuberance experienced in Auckland. In addition, when incomes are used as the relevant fundamental, the Auckland region crosses the 5% threshold before the Wellington region.

The regression equation (4) is a functional regression in which the primary coefficient $\delta_{2j}(r)$ is time-varying. This formulation permits the contagion effect from the core to a particular region to evolve smoothly over time. The variable responses over time accommodate possibly stronger (weaker) responses to the core bubble behaviour at various points during the pre-, post- and bubble episodes. For example, the effect of the core on a certain region j may take the time form of a $\cap$ shape, in which the contagion effect grows over some interval of time (following the emergence of a bubble in the core) before reaching a maximum and then declining. The time varying coefficient function $\delta_{2j}(r)$ may be estimated by local level kernel regression. Details are given in the Technical Appendix.

We explored an alternate approach in which the response function to the core market, $\delta_2(r)$, was held constant and did not vary with time. Fixed responses seem more compatible a priori with homogeneous markets rather than markets for real estate where location specific effects are prevalent. As demonstrated above, regional heterogeneity in New Zealand house prices is sufficiently large to merit a flexible approach to modelling contagion effects over time and the diaspora of market exuberance stemming from a core market. A prominent example of the need for flexibility in the present case is that the 2003-2008 real estate bubble was broad-based and experienced across many different regions in New Zealand, whereas the ongoing real estate bubble is, as yet, location specific to the Auckland region. Use of a fixed coefficient regression specification is too restrictive to capture such evolving inter-regional dynamics. Empirical evidence for the misspecification in the present case was manifest in the regression residuals exhibiting unit root behaviour, making the fixed coefficient response regression equation a spurious regression.

Figure 7 exhibits estimates for the main centres (Wellington, Christchurch, Hamilton) outside of Auckland, which is treated as the core centre. The sensitivity of these three centres to the Auckland market is clearly evident in the figure and shows some commonality of movement over the sample period following an inverted U shape. The sensitivity apparently rises to a peak in all cases during the 2003 to 2008 housing bubble and the subsequent collapse but then declines. In particular, over the course of the recent Auckland-specific real estate bubble beginning in 2013, the response function of these centres to the Auckland market declines. In fact, the response becomes negative in all these cases over the last year 2014, indicative of an adverse reaction in the regional centres relative to Auckland's exuberance. This effect is particularly noticeable for Wellington, whose response function to the Auckland market becomes strongly negative towards the end of 2014.

The estimated delay parameter d varies across the main centres. For Wellington, the estimated parameter is zero, indicating that the is no delay in contagion from Auckland to Wellington. As shown in Figure 3, the mid 2000s bubble began in Auckland and Wellington in the same quarter. The delay parameter for Christchurch is 2, corresponding to a two quarter lag. As we saw in Figure 3 above, the mid-2000s bubble emerges in Christchurch one quarter after Auckland. The delay parameter for Hamilton is much larger, corresponding to 5 quarters. Hamilton enters the mid-2000s bubble six quarters after Auckland.

Figure 8 exhibits similarly calculated response function estimates for territorial authorities within the Auckland metropolitan area to the Auckland city market. Interestingly, the sensitivity of all of these Auckland regions to central Auckland has also shown evidence of decline, most particularly following the collapse of the mid 2000s real estate bubble in 2008, but is still clearly positive. Interestingly too, there is evidence of a recent increase in responsiveness to the Auckland market during the recent Auckland-specific bubble. This is particularly evident for the North Shore region of Auckland. These findings indicate more cohesiveness in the Auckland real estate market during periods of exuberance and collapse than across New Zealand as a whole.

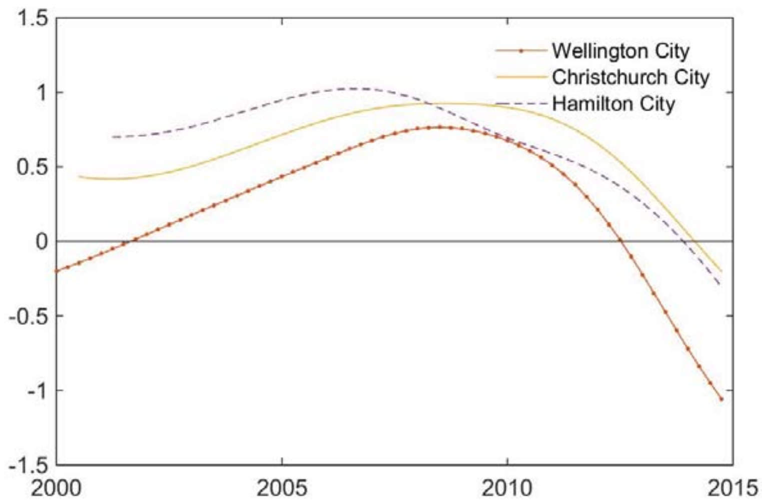

Figure 7: Time-varying Contagion Coefficients from the Auckland City Real Estate Market for the Main Centres.

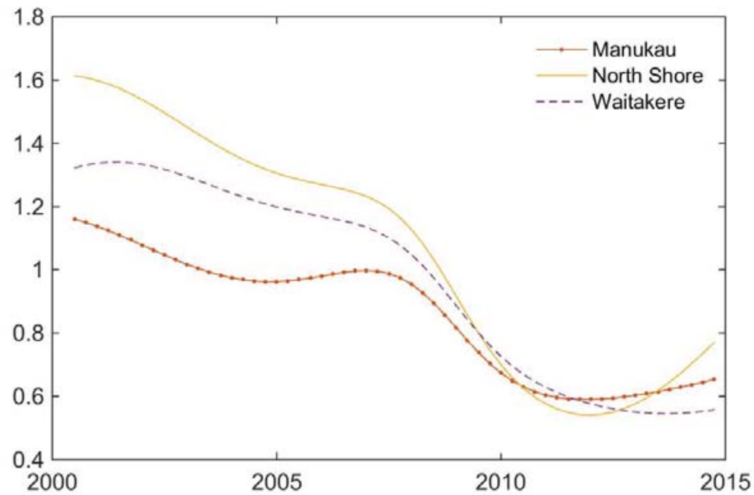

Figure 8: Time-varying Contagion Coefficients from the Auckland City Real Estate Market for Other Territorial Authorities in the Auckland Metropolitan Area.

The results exhibited in Figures 7 and 8 are largely descriptive in nature, showing how the time varying responses in the regional coefficients relate to those of Auckland through the kernel regression specification (4). The more fundamental question of identifying the driver variables that may underlie bubble contagion requires a more sophisticated modeling apparatus. We briefly describe here how such a model might be constructed to capture the mechanism of contagion as this may be useful in future work.

Suppose X_s is a collection of driver variables that have the potential to initiate a bubble and precipitate a collapse. Assuming A is the originating region for the bubble, we might functionalize this region's autoregressive coefficients in a varying coefficient form as $\beta_A = \beta_A(X_{t-1})$ so that the real estate price/rent ratio $y_{A,t}$ in A has generating mechanism

$$\Delta y_{A,t} = \alpha_A(X_{t-1}) + \beta_A(X_{t-1})\, y_{A,t-1} + e_{A,t},\ t = 1, \ldots, T, \tag{5}$$

in which the intercept and slope coefficients depend on the driver variables. Such a model has the form of a nonlinear predictive regression. Further, if the slope coefficient β_A has the localized (mildly explosive) form $\beta_A = \frac{c_A}{k_T}$ where $\frac{1}{k_T} + \frac{k_T}{T} \to 0$, the coefficient c_A may be functionalized on driver variables at each time period so that $c_A = c_A(X_{t-1})$. Then $c_A(X_{t-1}) > 0$ would produce mildly explosive behaviour consonant with the expansionary phase of a bubble and $c_A(X_{t-1}) < 0$ would produce mildly integrated behaviour consonant with reversion to normal market behavior in which $\beta_A = 0$. Phillips and Yu (2011) suggested some related ideas to explain bubble spillover effects and implemented the ideas to help explain market abnormality spillovers associated with the general financial crisis.

To make a model such as (5) operational, observable driver variables X_s need to be listed and functional forms for the intercept and slope parameter dependencies $\{\alpha_A(X_{t-1}), \beta_A(X_{t-1})\}$ need to be specified, unless nonparametric methods are employed. The roots of a property market bubble, like those of any market abnormality, typically reside in supply and demand distortions, some elements of which may be embodied in observable variables as components of X_s. In the New Zealand market, for instance, supply constraints include the country's physical geography, local zoning regulations, a variety of resource consent or building consent obstacles, as well as shortages of skilled trade labour and construction workers. Demographic changes from a growing population, returning ex patriates, and immigration provide additional demand pressures by injecting new-money into the housing market especially for desirable real estate in Auckland city, waterfront, rural, and island locations. These pressures overspill with relocations, retirements, vacation home, and multiple rental home purchases in a diaspora of new demand in regional markets.

This short and incomplete summary indicates some of the multifarious influences at work in driving real estate markets beyond the immediate return from rental income and the effect of policy measures that include interest rates and lending practices in the financial industry. Just as the combined effects of these many variables may lead to market exuberance, unexpected shocks to them may equally well lead to market correction.

3 Will the Auckland Real Estate Bubble Burst?

Our empirical findings show that a new housing bubble emerged in the Auckland region during 2013. The Auckland bubble has, as yet, not been accompanied by a broader real estate bubble in other New Zealand centres, unlike the bubble that began in 2003. Natural questions to ask now are whether this bubble will continue and is there a market correction on the horizon? Answering such questions using econometric methods is beyond the scope of the present apparatus. To do so requires a generative mechanism for the bubble with driver variables that can serve as predictors. Instead, in this section we explore the extent to which rents and incomes would have to rise in order to bring Auckland price-to-rent and price-to-income ratios back into line with the rest of the country.

Our empirical analysis uses data on house prices normalized by either rents or incomes. The finding of exuberance in a real estate market such as Auckland does not necessarily imply a house price correction is on the horizon. The findings show only that relative to either rent or income fundamentals, growth in housing prices has been irrational. A return to market normality in the price-to-rent or price-to-income ratio does not necessarily imply a future correction in house prices, because there is also the possibility that rents and incomes in Auckland will catch up to prices, thereby bringing the ratios back to normalcy.

How feasible is a market correction based on only a rent increase in Auckland? Currently the price-to-rent ratio in Auckland City and the North Shore is around 35 (see figure 1), while the price-to-rent ratios in Wellington, Christchurch and Hamilton are between 22 and 24 (see figure 1). If prices in all regions were held constant, rents in Auckland City and North Shore would have to increase by more than a third ($\frac{35-23}{35} \simeq 0.34$) in order to bring the Auckland City and North Shore price-rent ratios in line with the levels of the other centres. The corresponding rental increase needed to bring the price-to-rent ratio in Manukau and Waitakere in line with the other main centres is about 12% ($\frac{26-23}{26} \simeq 0.12$), given that the price-to-rent ratios in these regions is currently around 26.

Any real estate market correction based on an increase in rents entails a commensurate increase in the share of household incomes devoted to rent (if incomes are held constant). We therefore consider the current proportion of household income devoted to housing costs, and whether there has been any such steep rise in rents in the past. Mean annual household income in the broader Auckland region (including Auckland City, Manukau, Waitakere, North Shore, Franklin, Rodney, and Papakura) in 2014 was \$95,784 (= \$1,842 × 52). (Source: Statistics New Zealand).[5] The population-weighted annualized rents in the Auckland region were approximately \$25,115 in Q4 2014, which corresponds to just over a quarter of the household budget.[6] The mean annualized rent in Q4 2000 was \$14,008, and the mean household income was \$57,304 (= \$1,102 × 52), so that mean rent was about 25% of income. The mean annualized rent in Q4 2010 was \$21,252, and the mean household income was \$81,588, so that mean rent was again about 25% of mean income. These results show broad stability in the ratio of rents to incomes over a 15 year period.

Of course there is vast heterogeneity underlying these aggregate sample statistics, but the average household rental expenditure has stayed relatively constant in the broader Auckland region at around 25% of income. Rents are therefore by no means low relative to incomes. But it is certainly feasible that rents could increase substantially, thereby bringing house prices more in line with rent fundamentals. But such an increase in the budget share of rents would clearly be unprecedented, at least in the data currently available to us over the last two decades. We therefore conclude that to return the Auckland market to normalcy in terms of its price-to-rent ratio a more likely outcome is a housing price correction.

The percentage increase in incomes necessary to bring the price-to-income ratio of Auckland into line with that of Wellington is even more substantial. The Auckland region price-to-income ratio is almost twice that of Wellington (see figure 5), meaning that Auckland incomes would have to almost double to achieve alignment. A housing price correction is therefore far more likely than an increase in incomes if the price-to-income ratio in Auckland is to return to

[5] Retrieved from: http://nzdotstat.stats.govt.nz/wbos/Index.aspx?DataSetCode=TABLECODE7464# March 20 2015.

[6] The figure is inexact because we lack rents for the entire Auckland region. Instead, we obtain an approximate average rent by weighting TA rents with population weights, as calculated by the authors based on Statistics NZ subnational population data for 2014. The weights were as follows: Auckland City: 0.3; Franklin: 0.05; North Shore: 0.2; Manukau: 0.24; Papakura: 0.05; Rodney: 0.05; Waitakere: 0.14.

normalcy.

Such price corrections have occurred in many other countries that have experienced house price inflation in recent years. Yet the New Zealand real estate market has largely been spared such major corrections over the last two decades. International factors may now be playing a role in the New Zealand market, providing some degree of insulation from downturns as 'new money' drivers from foreigners, immigrants and ex patriates assist in sustaining demand side market pressure on prices and, in the process, bringing the prices of desirable real estate, particularly in Auckland, coastal and island locations, in line with prices of similar real estate overseas.

4 Extensions and Conclusion

The data available on the New Zealand real estate market are extensive and considerably larger in the spatial dimension than the data we have used in the analysis reported here. More specifically, the base dataset for the time period Q1 1993 to Q4 2014 that we have used here actually covers 72 different territorial authorities. There is, therefore, substantial scope for further empirical work to investigate linkages between rural and metropolitan regions and the effects of location-specific hedonics on housing market differentials. Response regressions of the type used in (1) may be extended to accommodate regional effects and to include potential driver variables to explain regional market differentials.

There is also scope for new econometric research on spatio-temporal panel econometric methods suited to the investigation of bubbles. In particular, the methodology of bubble testing and date-stamping algorithms may be extended to spatial panels to take advantage of the effects of cross section averaging. The limit theory for such models has yet to be studied. Associated extensions involve tests for homogeneity in the autoregressive slope coefficients across regional members of the panel and potential bubble classification methodology to determine commonality in behavior within certain groups of territorial authorities.

Notwithstanding all these potential extensions, the present study shows that much can be achieved with current methods. Our findings reveal the following distinctive features of the New Zealand real estate market over the last two decades. First, the expensive nature of New Zealand real estate relative to potential earnings in rents is partly explained by sustained market exuberance that produced a broad-based bubble in housing price-to-rent ratios during the mid 2000s that included all the major metropolitan centres. Second, empirical evidence confirms that the Auckland city real estate market led the emergence of bubbles in the other centres by up to two quarters in 2003, as well as other territorial authorities within the Auckland region by a single quarter. Third, estimation of the response function of the regional real estate markets to the core Auckland city region reveals a commonality of regional response over the sample period that follows an inverted U shape over time, rising to a peak during the 2003 to 2008 housing bubble and then subsequently declining. Finally, the data reveal that a new bubble in the Auckland real estate market emerged in 2013 and is ongoing but has yet to influence other regional centres.

5 Appendix

5.1 Technical Appendix

5.1.1 Asymptotic Theory for Bubble Detection Methods

The econometric theory of testing for exuberance allows for a triangular array formulation of (1) in which the intercept $\alpha = \alpha_T$ and slope coefficient $\beta = \beta_T$ may both depend on the sample size. Such a specification accommodates mildly explosive (rather than fixed explosive) processes for which $\beta_T = \frac{b}{k_T}$ is local to zero with fixed b and for some positive numerical sequence $k_T \to \infty$ satisfying $\frac{k_T}{T} \to 0$ as $T \to \infty$. This formulation implies that β_T gives rise to an AR(1) coefficient $\gamma_T = 1 + \frac{b}{k_T}$ in (1) that Phillips and Magdalinos (2007) characterize as mildly explosive, because the coefficient γ_T is further from unity as $T \to \infty$ than the usual $O\left(T^{-1}\right)$ interval around unity associated with local to unity roots (Phillips, 1987; Chan and Wei, 1987). Such mildly explosive autoregressive roots $\gamma_T = 1 + \frac{b}{k_T}$ penetrate more deeply into the explosive zone of the autoregressive parameter than local unit roots of the form $\gamma_T = 1 + \frac{b}{T}$.

The intercept α_T may also be sample size dependent, which allows for a localized drift in the time series under the null hypothesis. This specification offers some empirical advantage when dealing with time series whose normal behavior is well modeled in terms of a stochastic trend with a small deterministic linear drift. Such specifications often work well with time series of asset prices in normal market periods where no exuberance is present. The reader is referred to Phillips, Shi and Yu (2014) for further discussion of such localized parameter specifications and for the limit theory that applies in such cases.

Testing for Bubbles The test is based on global backwards supremum ADF statistics of the form

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

where

$$\begin{aligned} ADF_{r_1}^{r_2} &= \frac{\hat{\beta}_{r_1,r_2}}{\hat{s}_{r_1,r_2}}, \quad \hat{s}_{r_1,r_2} = \sqrt{\frac{1}{r_2 - r_1 + 1} \frac{\sum_{t=\lfloor r_1 T \rfloor}^{\lfloor r_2 T \rfloor} \left(\widetilde{\Delta y}_{t,r_1,r_2} - \hat{\beta}_{r_1,r_2} \tilde{y}_{t-1,r_1,r_2} \right)^2}{\sum_{t=\lfloor r_1 T \rfloor}^{\lfloor r_2 T \rfloor} \tilde{y}_{t-1,r_1,r_2}^2}}, \\ \widetilde{\Delta y}_{t,r_1,r_2} &= \Delta y_t - \sum_{t=\lfloor r_1 T \rfloor}^{\lfloor r_2 T \rfloor} \Delta y_{t,r_1,r_2}, \quad \tilde{y}_{t-1,r_1,r_2} = y_{t-1} - \sum_{t=\lfloor r_1 T \rfloor}^{\lfloor r_2 T \rfloor} y_{t-1,r_1,r_2}. \end{aligned}$$

The notations in these formulae correspond to those in PSY (2015).

In particular, the subscripted fractions (r_1, r_2) indicate the subsample window of data over which the statistics are computed and r_0 is the sample fraction corresponding to the minimum window width and, hence, the initialization of the recursive sequence of statistics. Thus, $\hat{\beta}_{r_1,r_2}$ denotes the OLS estimator of β in equation (1) based on the subsample $t = \lfloor r_1 T \rfloor, \ldots, \lfloor r_2 T \rfloor$ with end-fraction $r_2 \geq r_0 > 0$, begin-fraction r_1 satisfying $r_1 \geq 0$ and $r_1 \leq r_2 - r_0$, and window width $r_2 - r_1 \geq r_0$; the floor function $\lfloor \cdot \rfloor$ denotes the largest integer less than or equal to its argument; and r_0, r_1 and r_2 all denote fractions falling between 0 and 1.The asymptotic distribution of $GSADF\,(r_0)$ under the null is given in PSY (2015a). As the notation suggests, the distribution depends on the minimum sample size fraction r_0. Critical values for the test are obtained by simulation and are sample size T dependent in a manner that ensures that the size of the test tends to zero as $T \to \infty$, thereby eliminating false positives asymptotically under the null, and assuring consistency under the alternative, so that test power tends to unity as as $T \to \infty$. Readers are referred to PSY (2015a&b) for further details, limit theory, simulation performance and an illustration with long historical stock market series.

Following the simulation design rule given in PSY (2015b), we set the minimum subsample size to $r_0 = 0.01 + 1.8/\sqrt{T} \simeq 0.21$ for the price-to-rent sample (i.e, 21% of the sample which in the present case amounts to 18 quarters). For the price-to-income series we set the minimum subsample size to be smaller in order to capture the onset of the mid 2000s bubble: $r_0 = 0.18$.

Dating Episodic Bubbles To determine the origination date of a bubble we use the first crossing time dating algorithm of PSY, which we briefly describe here. The approach relies on recursive calculation over the full sample of the same backwards supremum ADF statistic on which the GSADF statistic is based, viz.,

$$BSADF_r\,(r_0) = \sup_{r_1 \in [0, r - r_0]} \left\{ ADF_{r_1}^{r} \right\}.$$

For each date fraction r, we compute the supremum of the ADF statistic based on subsamples beginning with $t = 1, 2, ..., \lfloor (r - r_0)\, T \rfloor$ and ending at $\lfloor rT \rfloor$. The asymptotic distribution of $BSADF_r\,(r_0)$ under the null of no bubbles is given in PSY (2015a), and, as the notation suggests, the distribution depends on the minimum sample size fraction r_0 as well as the fraction date r. Critical values for the test are obtained by simulation.

Following PSY, the bubble dating algorithm uses first crossing time methods to determine estimates of the origination and termination dates of a bubble in the data. In particular, we date the beginning of the bubble as the initial date fraction ($\hat{r}^e$, say) for which the $BSADF_r\,(r_0)$ statistic exceeds a pre-specified critical value (say, cv^{β_T}) that is based on the null distribution. The corresponding collapse date of the bubble is estimated as the first fraction ($\hat{r}^f$) for which the $BSADF_r\,(r_0)$ sequence falls below the critical value again after some amount of time L_T has elapsed from the origination of the bubble. The role of L_T is to eliminate from consideration as potential bubbles any short-lived blips in the recursive statistic whose fractional duration is less than $\frac{L_T}{T} \to 0$, where L_T is some slowly varying function such as $L_T = \mu \log T$ for some constant $\mu > 0$.

To fix ideas in a possible multiple bubble scenario, we have the following crossing time dating algorithm

$$\hat{r}^{ie} = \inf_{r \in [r^{i-1f},1]} \left\{ r : BSDF_r(r_0) > cv^{\beta_T} \right\},\ \hat{r}^{if} = \inf_{r \in [r^{ie}+\ell_T,1]} \left\{ r : BSDF_r(r_0) < cv^{\beta_T} \right\},$$

where $\hat{r}^{ie}$ ($\hat{r}^{if}$) denotes the origination (collapse) date fraction of the ith bubble, cv^{β_T} is the $100(1-\beta_T)\%$ critical value of the BSADF statistic, and ℓ_T is a regularly varying fractional delay function (such as $\ell_T = \frac{L_T}{T} = \frac{\mu \log(T)}{T}$ for some fixed $\mu > 0$) which places a minimum bound time (L_T) on the duration of the bubble. The parameter μ is time-unit sensitive and usefully allows for differences in the minimum delay time according to whether the units are in months, quarters or years.

5.1.2 Contagion Regressions

The time varying coefficient function $\delta_{2j}(r)$ may be estimated by local level kernel regression according to the formula

$$\hat{\delta}_{2j}(r; h, d) = \frac{\sum_{s=S}^{T} K_{hs}(r)\tilde{\beta}_{j,s}\tilde{\beta}_{core,s-d}}{\sum_{s=S}^{T} K_{hs}(r)\tilde{\beta}^2_{core,s-d}}, \quad \tilde{\beta}_{j,s} := \hat{\beta}_{j,s} - \frac{1}{T-S+1}\sum_{s=S}^{T}\hat{\beta}_{j,s}, \tag{6}$$

where $K_{hs}(r) = \frac{1}{h}K\left(\frac{s/T-r}{h}\right)$, $K(\cdot)$ is a smooth kernel function, and h is a bandwidth parameter. In our application we use the Gaussian kernel $K(\cdot) = (2\pi)^{-1/2} e^{-\frac{1}{2}(\cdot)^2}$ and set the bandwidth (BW) h according a simple cross validation approach. Our estimate of h is obtained by the cross validation criterion

$$\breve{h}_{jT}(d) = \arg\min_{h \in \mathcal{H}_T} \sum_{s=S}^{T} \left\{ \tilde{\beta}_{j,s} - \breve{\delta}_{2j}\left(\frac{s}{T-S+1}; h, d\right)\tilde{\beta}_{core,s-d} \right\}^2, \tag{7}$$

where $H_T = \left[(T-S+1)^{-1/2}, (T-S+1)^{-1/10}\right]$ and

$$\breve{\delta}_{2j}\left(\frac{s}{T-S+1}; h, d\right) = \frac{\sum_{p=S, p\neq s}^{T} K_{hp}\left(\frac{s}{T-S+1}\right)\tilde{\beta}_{j,p}\tilde{\beta}_{core,p-d}}{\sum_{s=S}^{T} K_{hs}\left(\frac{s}{T-S+1}\right)\tilde{\beta}^2_{core,p-d}}.$$

Note that this CV BW $\breve{h}_{jT}(d)$ depends on the lag d. We then choose d to minimise the equation j mean square error (MSE) as follows

$$\breve{d}_j = \arg\min_{d \in \{0,1,\ldots,12\}} \sum_{s=S}^{T} \left\{ \tilde{\beta}_{j,s} - \breve{\delta}_{2j}\left(\frac{s}{T-S+1}; \breve{h}_{jT}(d), d\right)\tilde{\beta}_{core,s-d} \right\}^2. \tag{8}$$

In this way we obtain a data dependent BW and lag parameter that jointly minimize the MSE for each equation. The resulting response function has the form $\breve{\delta}_{2j}\left(r;\breve{h}_{jT}\left(\breve{d}_j\right),\breve{d}_j\right)$.

5.2 Additional Figures

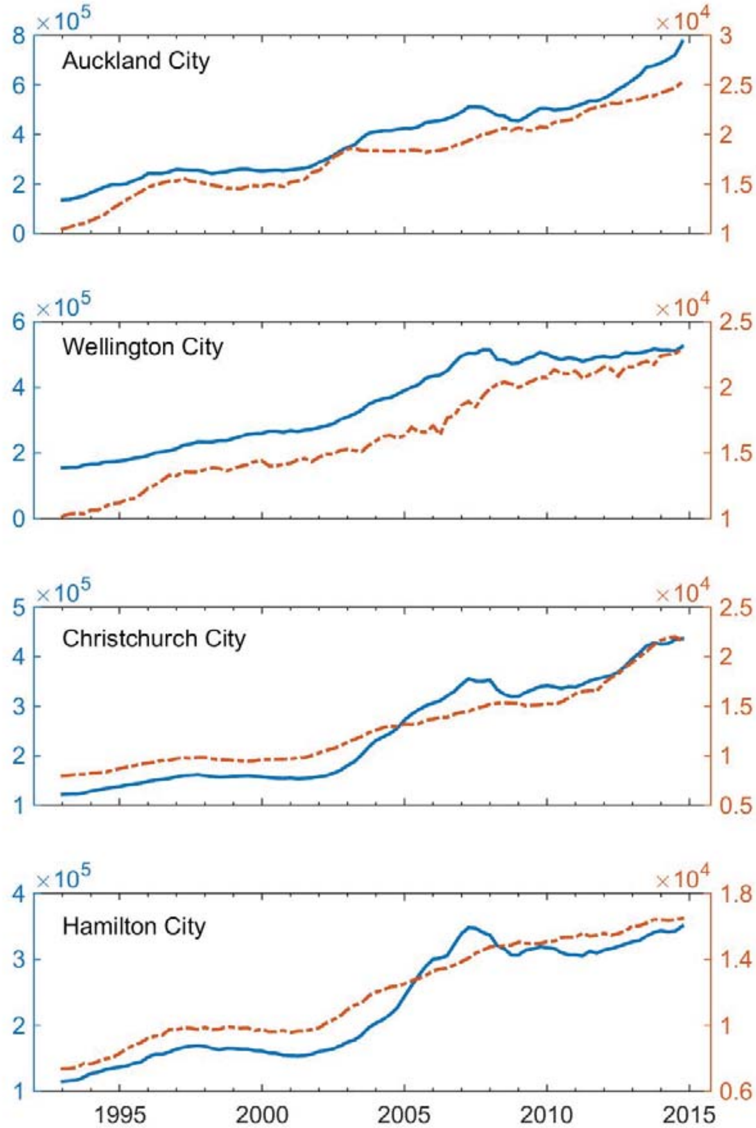

Figure A1: House Prices (solid line; left axis) and Rents (dashed line; right axis) in the Main Centres

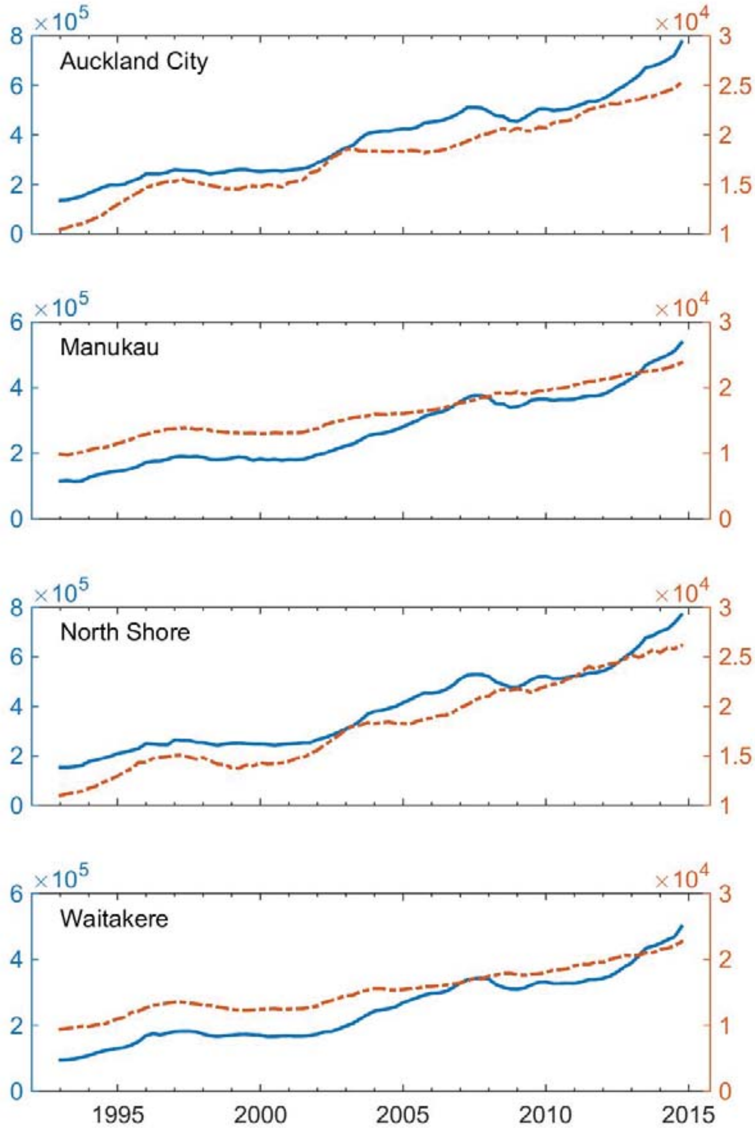

Figure A2: House Prices (solid line; left axis) and Rents (dashed line; right axis) in the Auckland Metropolitan Area

5.3 Data

Our real estate dataset spans Q1 1993 to Q4 2014 and covers all 72 Territorial Authorities (TAs) in mainland NZ under the TA06 geographic boundaries.

House Prices Our measures of regional house prices are based on the quarterly residential price indices published by QVNZ. These data span Q4 1989 through to Q4 2014 and cover 72 Territorial Authorities. QVNZ also publish these indices for the broader Auckland and Wellington Metro Areas, as well as the whole of New Zealand; these are used in our analysis of price-to-income ratios. The estimates for Q4 2014 was provisional at the time of writing. Linear interpolation was applied to each time series to infill any missing observations. QVNZ also publishes a monthly nominal (non-inflation adjusted) average price for all dwellings for all TAs dating back to December 2003. Price indices only reflect differences in the price level in a given year relative to a base year. Therefore, in order to obtain price-to-rent ratios we scale the price index by the average nominal house price in December 2014. Our final price series $P_{i,t}$ is therefore:

$$P_{i,t} = P^{\text{AVG}}_{i,\text{DEC2014}} \times I_{i,t} \div I_{i,\text{Q42014}},$$

where $P^{\text{AVG}}_{i,\text{DEC2014}}$ is the average price in December 2014 for region i, and $I_{i,t}$ is the residential price index in quarter t for region i. $P_{i,t}$ is therefore the QVNZ residential price index scaled to ensure that the index value for Q4 2014 coincides with the average house price in December 2014. Note that this scaling does not affect the econometric methodology used in the present work since the scaling factor simply induces a multiplicative constant in the price-to-rent ratio.

Rents Raw monthly data of average rent per week for each territorial region spanning from 1993 to 2014 was obtained from the Ministry of Business, Innovation & Employment (http://www.dbh.govt.nz/nz-housing-and-construction-quarterly-open-data). Linear interpolation was applied to each time series to infill any missing observations. The rent series were seasonally adjusted using X11, using a 2 x 12 filter for the trend component and a 3 x 3 filter for the seasonal component. Some of the time series exhibited large outliers. We therefore removed and linearly interpolated any single month that exhibited an absolute change greater than 5% relative to the X11 trend. Figure A5 demonstrates the effect of these adjustments made in the case of the Wellington City rent data.

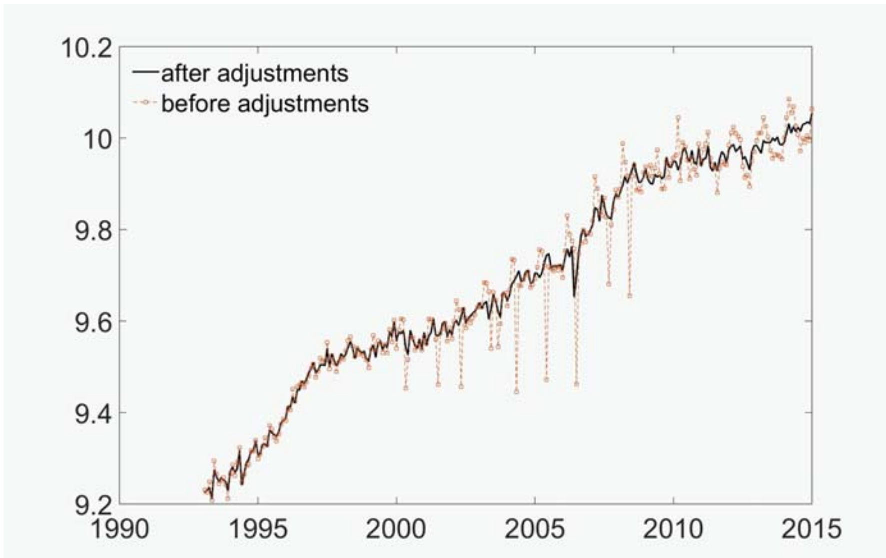

Figure A3: Wellington City Rents (in logarithms) before and after adjustments to account for seasonality and outliers.

Annualized average weekly rents were obtained by multiplying the weekly rental series by 52. Annualized quarterly rents were then obtained from the monthly series by taking within-quarter averages.

Incomes Statistics New Zealand's Earnings and Employment Survey (QEX) publishes average weekly earnings per full time equivalent (FTE) worker on a quarterly basis for Q3 1999 onwards. Earnings are geographically disaggregated by Regional Council. Of these, only the Auckland and Wellington Regional Councils approximate a metropolitan area: The Auckland Region approximates the Rodney, North Shore, Waitakere, Auckland City, Manukau, Papakura and Franklin TAs; while the Wellington Region approximates Wellington City, Lower Hutt, Upper Hutt, Porirua, Kapiti, South Wairarapa, Carterton and Masterton. We obtained total weekly earnings per FTE from infoshare (http://www.stats.govt.nz/infoshare/) before multiplying the figures by 52 to obtain annual earnings per FTE worker.

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