City Relative Price Dynamics in Australia: Are Structural Breaks Important?

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Abstract: This paper examines the dynamic behaviour of relative prices across seven Australian cities by applying panel unit root test procedures with structural breaks to quarterly CPI data for 1972Q1-2011Q4. We find overwhelming evidence of convergence in city relative prices. Three common structural breaks are endogenously determined at 1985, 1995, and 2007. Further, correcting for two potential biases, namely Nickell bias and time aggregation bias, we obtain half-life estimates of 2.3-3.8 quarters that are much shorter than those reported by previous research. Thus, we conclude that both structural breaks and bias corrections are important to obtain shorter half-life estimates.

JEL Codes: C33; E31; R19

Keywords: Relative price convergence; Structural break; Panel unit root test; Half-life; Time aggregation bias.

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I Introduction

There is a growing literature on relative price convergence across different cities or regions within a country. This literature was originally motivated by a desire to develop a better understanding of the deviations from the international purchasing power parity (PPP). The PPP hypothesis, based on the law of one price, implies that, “once converted to a common currency, national price levels should be equal” (Rogoff, 1996). The test of this hypothesis essentially involves finding evidence of mean-reversion in real exchange rate. Numerous empirical studies using a variety of datasets and empirical methods emerged over last several decades. The results have been mixed: while some studies find evidence of mean reversion, others do not. Even in some cases of mean reversion, the speed of convergence has been found to be extremely slow. The slow mean reversion is known as the “PPP puzzle” (a la Rogoff, 1996). The literature has explored various factors that help explain the rejection of the PPP hypothesis as well as the puzzle. Some of these factors, such as tariff and non-tariff barriers, fluctuations in nominal exchange rates, heterogeneity of consumption baskets that are used to construct consumer price indices in different countries, are not relevant while considering price indices for different cities or regions within the same country. Thus, intra-

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1 The existing literature primarily focuses on convergence of both aggregate as well as individual prices across different cities in the U.S. For example, Culver and Papell (1999), Cecchetti et al. (2002), Chen and Devereux (2003), Nath and Sarkar (2009), Sonora (2009), Chmelarova and Nath (2010), Basher and Carrion-i-Silvestre (2009, 2011), Huang et al. (2011), Huang et al. (2012), Hegwood and Nath (2012) examine price index convergence across major U.S. cities. While Chen and Devereux (2003) and Basher and Carrion-i-Silvestre (2009) consider absolute price convergence, others investigate relative price convergence. All these studies use aggregate price indices. However, they were preceded by two influential studies – Engel and Rogers (1996) and Parsley and Wei (1996) – that look into the disaggregate prices of various commodities across the U.S. cities. Recently, Crucini and Shintani (2008) have used micro-level price data to investigate persistence of PPP deviations across 13 U.S. cities. The studies that use city level CPI data from other countries include Carrion-i-Silvestre et al. (2004) for Spain, Chaudhuri and Sheen (2004) for Australia, Sonora (2005) for Mexico, and Busetti et al. (2006) for Italy.
national price data provide an opportunity to conduct a natural experiment to understand the deviations from PPP.

The study of within-country relative price movements is also important because of their implications for resource allocations and regional growth. For example, inflation differentials across cities – implied by relative price movements – determine the differences in real wages and real interest rates, which in turn influence the directions of labour and capital flows, respectively. In particular, persistent differences (in case of PPP violation) may lead to severe misallocations of resources with consequent suboptimal regional patterns of growth and overall inefficiency.

In this paper, we examine the dynamics of relative prices across seven capital cities in Australia using quarterly data on CPI from 1972Q1 to 2011Q4. In particular, we investigate the importance of structural changes in relative price convergence. To the best of our knowledge, the only study on the relative prices across Australian cities is by Chaudhuri and Sheen (2004) (hereafter, CS). They apply both univariate and panel data techniques to aggregate as well as disaggregate CPI data for seven cities from 1972Q3 to 1999Q1. The current study uses an extended dataset for the same seven cities. Also, it focuses on the dynamics of aggregate CPI and uses panel data methods only. Most importantly, we incorporate structural breaks that are determined endogenously, and examine their implications for relative price behaviour. While CS recognise the potential significance of structural changes, their investigation relies on analyses of different sample periods selected on the basis of exogenous policy changes. Like most studies in this literature, we estimate half-life – a measure of the speed of convergence. In addition to correcting for small-sample

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2 Following the seminal contribution of Perron (1989), inclusion of mean shifts (representing structural breaks) has been a way of finding support for the PPP hypothesis and resolving the PPP puzzle. Some prominent examples are: Dornbusch and Vogelsang (1991), Perron and Vogelsang (1992), Culver and Papell (1995), and Hegwood and Papell (1998, 2002) with only one structural break; and Lumsdaine and Papell (1997) and Papell and Prodan (2006) with two breaks. The studies that use structural breaks in the panel context include Papell (2002), Im et al. (2005), Breitung and Candelon (2005), Narayan (2008), and Lin and Lee (2010).
bias, as in CS, we correct for an additional bias that arises due to time aggregation of price data in the panel estimation of half-life.

It is important to recognise the significance of including structural breaks in the unit root test in the context of the PPP theory. In the literature, a rejection of the unit root null is typically interpreted as evidence in support of PPP. Thus, it implies that after a temporary deviation, the real exchange rate returns to a constant mean. However, when structural breaks are included, a rejection of the unit root null indicates mean reversion to shifting means. In that case, the long-run PPP may not always hold. The reversion to mean that is subject to occasional structural changes is called Quasi Purchasing Power Parity (QPPP) by Hegwood and Papell (1998) and Qualified Purchasing Power Parity (QPPP) by Papell and Prodan (2006).

Our paper is closely related to Sonora (2009), Basher and Carrion-i-Silvestre (2009, 2011), Huang et al. (2011) and Hegwood and Nath (2012). Applying unit root test procedures that incorporate structural breaks to annual city CPIs across major cities in the U.S., these studies find overwhelming evidence of relative price convergence. Sonora (2009), Basher and Carrion-i-Silvestre (2011), and Hegwood and Nath (2012) also find that inclusion of structural breaks reduces the half-life estimates.

We apply panel unit root test procedures with and without structural breaks to quarterly CPI data for seven Australian cities between 1972Q1 and 2011Q4. We find overwhelming evidence of convergence in city relative prices. Three common structural breaks are endogenously identified in 1985, 1995, and 2007. Further, correcting for two potential biases, namely Nickell bias and time aggregation bias, we obtain half-life estimates of 2.3 - 3.8 quarters that are much shorter than those reported by CS. Thus, we conclude that both

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3 As Papell and Prodan (2006) discuss, if there is a one-time shift in the mean and the series reverts to shifting means, the long-run PPP does not hold in the sense that it does not return to the long-run mean. With multiple breaks, say two breaks, the long-run PPP holds only if the shifts are offsetting and the series returns to a constant mean.
structural breaks and bias corrections are important to obtain shorter half-life estimates. These results are robust to shorter sample periods as well as lower frequency data (annual in our case) with longer sample period.

The rest of the paper is organised as follows. Section II discusses the data and methodology used in the analysis. In Section III, we present various panel unit test results and half-life estimates for relative prices across Australian cities. The results are reported for cases with and without structural breaks. Section IV discusses of the economic significance of the structural breaks identified in the models of relative prices. In the final section, we summarise and conclude.

II Data and Methodology

(i) Data

We obtain quarterly CPI data for seven Australian cities for the period: 1972Q1 - 2011Q4, from the Australian Bureau of Statistics (ABS). The cities in our sample are the capital cities of the Australian states and the Australian Capital Territory: Adelaide, Brisbane, Hobart, Melbourne, Perth, Sydney, and Canberra.\(^4\) Although quarterly data are available since September 1948, a single CPI value was duplicated for several consecutive quarters for each city prior to 1972. This seems to indicate that data were collected at infrequent and irregular intervals before 1972, and therefore we exclude them from our sample of quarterly data. We use the following equation to construct the relative price series for each city:

\[
\begin{align*}
    r_{i,t} &= 100 \times \left( \ln P_{i,t} - \ln P_t \right)
\end{align*}
\]

where \(r_{i,t}\) is the logarithm of relative price and \(P_{i,t}\) is the CPI in city \(i\) in year \(t\), and \(P_t\) is the simple average of city CPIs.\(^5\) Note that this relative price represents the percentage deviation

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\(^4\) We exclude Darwin for which CPI data are available only since 1980.

\(^5\) In Australia, national CPI is calculated as the weighted average of the city CPIs. If we use the weighted instead of simple city average, the results do not change qualitatively.
of CPI in a city from the national average CPI. The city average CPI captures the common time effect component of relative prices.

(ii) Methodology

We use panel unit root test procedures to examine mean-reversion in relative prices. To evaluate the importance of structural changes, we first conduct these tests with no structural breaks.

Panel Unit Root Test with No Structural Breaks

The test is in the Augmented Dickey-Fuller (ADF) framework and involves estimating the following regression:

\[ \Delta r_{i,t} = \mu_i + \rho_{i} r_{i,t-1} + \sum_{j=1}^{k_i} \epsilon_{i,j} \Delta r_{i,t-j} + \epsilon_{i,t} \]  

The subscript \( i = 1, \ldots, N \) indexes the cities in the panel and \( t \) indexes time period. In this specification, the intercepts, \( \mu_i \), and lag lengths, \( k_i \), are allowed to vary across cities to capture the city-specific idiosyncracies. We use feasible generalised least squares (FGLS) seemingly unrelated regression (SUR) to estimate (2). This method accounts for contemporaneous and serial correlation, both of which are likely to be present in city relative prices. The number of lagged differences, \( k_i \), is determined using the general-to-specific method suggested by Campbell and Perron (1991) and Ng and Perron (1995). This method involves setting a maximum lag length, \( k_i^{max} \), and paring it down to the number of lags where the lagged difference is significant at the 10% level. We start with a maximum lag of 8 quarters for each city.

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6 In the international PPP literature, this relative price would be equivalent to real exchange rate. Although a numeraire currency is chosen for calculating real exchange rate, we use the average city CPI, an approach previously adopted by Cecchetti et al. (2002), Chen and Devereux (2003), Nath and Sarkar (2009), and Basher and Carrion-i-Silvestre (2011).

7 Our methodology and empirical strategy are similar to those in Hegwood and Nath (2012).

8 See Murray and Papell (2000).
The null hypothesis is that each series contains a unit root, \( H_0: \rho_i = 0 \) for all \( i \). The alternative hypothesis is \( H_1: \rho_i = \rho < 0 \), that is, all of the series are stationary. This alternative hypothesis requires a homogenous \( \rho \), as in Levin et al. (2002).\(^9\) Note that the distribution of the panel unit root test statistic is not standard. Therefore, we use Monte Carlo methods involving 5000 replications to calculate critical values that reflect the structure of our panel, accounting for both serial and contemporaneous correlations.\(^10\)

**Panel Unit Root Test with Structural Breaks**

We now discuss a panel unit root test procedure that uses an Additive Outlier (AO) model framework where structural changes take place instantaneously. This model has been adapted for non-trending data incorporating one or more shifts of the intercept.\(^11\) This panel unit root test comprises two stages. In the first stage, we estimate the following equation using the panel of city relative prices:

\[
r_{i,t} = \mu_i + \sum_{l=1}^{m} \delta_{i,l}D_{I_{i,t}} + u_{i,t}
\]

where \( D_{I_{i,t}} \) is the intercept break dummy and \( D_{I_{i,t}} = 1 \) for all \( t > SB_i \) (the structural break date) and 0 otherwise; and \( m \) is the number of breaks in (3).\(^12,13\) The second stage involves regressing the first difference of the residuals, \( u_{i,t} \)'s on their lagged value and lagged differences as follows:

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\(^9\)A less restrictive alternative hypothesis that at least one of the series is stationary, which allows \( \rho \) to be heterogeneous, as in Im et al. (2003), would not be any more informative if we do reject the null, which is the case in this paper.

\(^10\)For the details on this method, see Hegwood and Papell (2007).

\(^11\)This is a panel adaptation of the univariate test in Perron and Vogelsang (1992). They include an additional set of ’crash’ dummies. For a discussion on the panel adaptation, see Murray and Papell (2000).

\(^12\)To be consistent with the PPP theory, we do not include a time trend and only allow for breaks in the intercept. However, Obstfeld (1993) develops a model in which real exchange rates contain a deterministic trend. His model draws on ideas from Balassa (1964) and Samuelson (1964) and argues that productivity differentials between countries determine the domestic relative prices of nontradables, leading to trend deviations from PPP in the long-run.

\(^13\)We impose a restriction by forcing the break date(s) to be the same for all cities. Thus, we are focusing on structural breaks that are common to all cities in the sample. Allowing different breaks for each city also reduces the degrees of freedom and the power of the test. Furthermore, since common breaks usually reflect the effects of national and international events, it is relatively easier to discuss their economic significance.
As in the panel unit root test with no structural breaks, the number of lagged differences, \( k_i \), is determined by the general-to-specific method. (3) and (4) are estimated sequentially for each possible break date, \( SB_l = k_{max}^l + (8 \times m), \ldots T - \{8 \times (m_{max}^l - m)\} - 1 \), where \( k_{max} \) is the maximum lag length, \( m_{max} \) is the maximum number of breaks, and \( T \) is the number of observations. The period that minimises the \( t \)-statistic on \( \rho \) is chosen to be the break date. The null hypothesis of a unit root is rejected if the absolute value of the (minimum) \( t \)-statistic on \( \rho \) is greater than the appropriate critical value. As before, the critical values are calculated using Monte Carlo methods.

We then use two simple information-based criteria to determine the appropriate number of breaks. These criteria are: Bayesian Information Criterion (BIC) as suggested by Yao (1988) and a modified Schwarz’ criterion (LWZ) as suggested by Liu et al. (1997). According to Bai and Perron (2003), these two criteria perform reasonably well when there is no serial correlation in the errors. The specification of (4) does not allow serial correlation in the error term and it seems to be appropriate to use these information-based criteria.

**Unbiased Half-Life Estimates with Structural Breaks**

As mentioned earlier, half-life is commonly used as a measure of the speed of convergence. It is the time required for any deviation from PPP to dissipate by one half. In an AR(1) case, half-life is calculated as follows:

\[
\Delta u_{i,t} = \rho u_{i,t-1} + \sum_{j=1}^{k_i} \varepsilon_{i,j} \Delta u_{i,t-j} + \varepsilon_{i,t}
\]

\( (4) \)
\[ h(\rho) = -\frac{\ln(2)}{\ln(\rho)} \]  

where \( h(\rho) \) is the half-life and \( \rho \) is the AR coefficient.\(^{16}\) As Choi \textit{et al.} (2006) discuss, there are three potential sources of bias in panel data estimation of the half-life. \textit{First,} if the autoregressive coefficients are significantly different across cities (that is, there is sufficient heterogeneity in the dynamic behaviour of relative prices across cities), then panel estimation of a common autoregressive coefficient will be biased upward and so will be the implied half-life. \textit{Second,} if the sample is small, the inclusion of a constant in the estimation of a dynamic regression introduces a downward bias and this is true in the panel context as well.\(^{17}\) \textit{Finally,} the time-averaging (also referred to as time aggregation) of some price data introduces a moving average structure into the regression error.\(^{18}\) Since this is often ignored in the panel estimation of the autoregressive models of city relative prices, it introduces an additional upward bias in the AR coefficient.

Under the alternative hypothesis of the panel unit root test procedure discussed above, the AR coefficients (\( \rho_i \) s) are homogeneous. Thus, if the null hypothesis is rejected (which is the case for our dataset), then the upward bias due to heterogeneity in dynamic behaviour of prices is no longer a matter of concern. Thus, the panel estimates of autoregressive coefficient and half-life for city relative prices would involve only two biases: a downward bias due to small sample size and an upward bias due to the moving average error term introduced by time aggregation of data. We use a fixed effects panel generalised least squares (GLS) estimation technique that incorporates structural breaks and also controls for cross-sectional...

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\(^{16}\) For higher-order autoregressive models, (5) would approximate the true half-life. For such models, the exact half-life can be computed by impulse response analysis. The problem with general ARMA models is that the impulse response may be non-monotonic, resulting in multiple half lives.

\(^{17}\) Nickell (1981) first discusses this small-sample bias in the panel context and therefore it has been known as the ‘Nickell bias’.

\(^{18}\) For a discussion on the time aggregation bias, see Imbs \textit{et al.} (2005).
dependence. To sketch an outline of the procedure, suppose relative price in city \(i\) follows an AR(1) process:

\[
    r_{i,t} = \mu_i + \sum_{l=1}^{m} \delta_{i,l} Dl_{i,t} + \rho r_{i,t-1} + u_{i,t}
\]

(6)

where \(\mu_i\) is a city-specific constant; \(i = 1, 2, \ldots, N\); and \(t = 1, 2, \ldots, T\). \(Dl_{i,t}\) is a dummy variable for the structural break, where \(Dl_{i,t} = 1\) if \(t > SB_i\) and 0 otherwise. In the presence of time aggregation, the regression error has a moving average (MA) structure. Suppose \(u_{i,t}\) follows an MA(1) process:

\[
    u_{i,t} = \nu_{i,t} + \lambda \nu_{i,t-1} \quad \text{and} \quad \nu_{i,t} = \gamma_i \theta_{i} + \zeta_{i,t}
\]

(7)

where \(\gamma_i\)'s are factor loadings, \(\theta_i\) is the common shock, and \(\zeta_{i,t}\)'s are serially and mutually independent. The factor loadings and the error covariance matrix are estimated by iterative method of moments, and then the estimated covariance matrix is used to obtain the feasible GLS estimate of \(\rho\). Note that this estimated covariance matrix includes both the contemporaneous and the long-run covariance. We then adjust the estimated autoregressive coefficient for the Nickell bias, the time aggregation bias, and the combined Nickell and time aggregation bias as discussed in Choi et al. (2006) and use these bias-corrected estimates of autoregressive coefficient in (5) to obtain various unbiased estimates of the half-life to price index convergence among Australian cities.

III Empirical Results

(i) Panel Unit Test Results

Table 1 first presents the panel unit test results for the cases with and without structural breaks for the full sample: 1972Q1 – 2011Q4. Note that we conduct the panel unit root tests with 1, 2, 3, and 4 structural breaks and calculate respective values of BIC and LWZ to

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19 This technique has been adapted from Phillips and Sul (2004) to include structural breaks.
20 Time aggregation of the data introduces an interaction between the Nickell bias and the time aggregation bias, which requires additional adjustment in the estimation of the autoregressive coefficient. For a discussion, see Choi et al. (2006). The combined Nickell and time aggregation bias correction incorporates this adjustment.
determine the optimal number of breaks. Both these criteria indicate that the model with three breaks is the best and therefore we report the results for this case only.\textsuperscript{21, 22} The breaks are identified at 1985Q1, 1995Q2, and 2007Q2. The null hypothesis of a unit root is rejected at the 5\% level for both cases.\textsuperscript{23} These results are consistent with the panel results reported in other studies, particularly with those reported for Australian cities by CS. However, for appropriate comparison with their study, we also report the results for the sample period: 1972Q3 – 1999Q1, in Table 1. Again, the unit root null is overwhelmingly rejected for the cases with no breaks and two breaks. If we include more than two breaks, some of the identified break dates are too close and therefore we decide to go with a maximum of two breaks.\textsuperscript{24} Thus, these panel unit root test procedures - with and without structural breaks - find overwhelming evidence in support of convergence in Australian city relative prices.

[Insert Table 1]

(ii) Unbiased Half-life Estimates

In Table 2, we report the autoregressive coefficients and implied half-lives with no bias corrections (col. 1 – 2) and combined Nickell and time aggregation bias corrections (col. 3 – 8). We first present the estimates for the full sample with and without structural breaks. In Australia, price data on some items (such as milk, bread, fresh meat and seafood, fresh fruit and vegetables, alcohol, tobacco, women’s outerwear, project homes, motor vehicles, petrol and holiday travel and accommodation) are collected monthly while for others they are collected quarterly. There are a few items such as education, for which price data are collected at much longer intervals. Therefore, we present three alternative scenarios under

\textsuperscript{21} That is, it has the lowest value of BIC and LWZ. However, we do not report the BIC and LWZ values for different models to conserve space. Interested reader may obtain the results from the authors.\textsuperscript{22} We choose the maximum possible number of breaks (4 in our case) in an \textit{ad hoc} manner. Given the length of our sample period, this choice seems reasonable.\textsuperscript{23} For the case with three structural breaks, computing the critical values using the Monte Carlo method takes enormous amount of time and therefore we conduct only 500 replications.\textsuperscript{24} With three breaks, the dates are identified at 1988Q4, 1991Q3, and 1996Q3. Between one break and two breaks, two breaks have smaller BIC and LWZ.
which time aggregation bias is corrected: (1) data collection frequency of 3 assuming that
data are collected monthly; (2) data collection frequency of 1 assuming that data are collected
quarterly; and (3) an intermediate frequency of 2.\textsuperscript{25}

[Insert Table 2]

As the results show, with no bias correction and no structural breaks, the estimated half-
life is 8.2 quarters. With structural breaks alone, the estimated half-life decreases by about
55\% to 3.7 quarters. Corrected for Nickell and time aggregation biases, it further decreases to
2.3 to 2.5 quarters (about 72 – 70\% lower). To compare our half-life estimates with those
reported by CS, we also present the autoregressive coefficients and implied half-life estimates
for the sample period 1972Q3 – 1999Q1 in Table 2. They report bias-corrected
autoregressive coefficients in the range of 0.89 - 0.90 and implied approximate half-lives of
5.8 - 6.7 quarters.\textsuperscript{26} Our results with Nickell bias correction for the case with no structural
breaks reported in col. 7 – 8 (0.893, 6.1) are consistent with those results. However, when we
include structural breaks and correct for both Nickell and time aggregation bias, the estimated
half-lives are in the range of 2.2 - 2.4 quarters.

(iii) Panel Unit Root Test and Hal-life Results for Annual Data

Although most studies applying panel test procedures to annual data on city CPI (e.g.
Cecchetti \textit{et al.} 2002) reject the null hypothesis of a unit root, they often report a somewhat
puzzling result of extremely slow speed of convergence in relative prices. However, for
Australia, CS cannot reject the null hypothesis of a unit root while using annual data from
1972 to 1998. We, therefore, examine if we can find evidence of mean reversion in city
relative prices using annual data for a longer period of time. Furthermore, we investigate if

\textsuperscript{25} Note that since we are using quarterly data, there will be no correction for time aggregation with frequency 1.
That is, the autoregressive coefficients and half-life estimates reported in col. 7 - 8 are essentially corrected for
Nickell bias only.
\textsuperscript{26} See row 1 of Table 4 in CS.
inclusion of structural breaks and correction of various biases help understand these puzzling results. Taking averages of quarterly data, we construct annual CPI data for the period from 1949 to 2011. We then conduct the panel unit root tests with no structural breaks and up to 4 structural breaks as before. Table 3 reports the panel unit test results along with the autoregressive coefficients and implied half-lives. We include the results for three structural breaks in 1964, 1984, and 2005.27

[Insert Table 3]

The first two rows indicate that the null hypothesis of a unit root is rejected at the 5% level for both cases: with no and three structural breaks. However, the half-life estimates of 9 years for the no-break case (without and with bias corrections) are similar to those reported for the U.S. cities by Cechetti et al. (2002). The fact that bias corrected autoregressive coefficients (and, therefore, half-lives) are larger suggests that the Nickell bias outweighs the time aggregation bias. When we include structural breaks, the half-life estimates with bias corrections range between 2.7 - 3.2 years. When we consider annual data for the period between 1972 and 2011, the sample period for which we examine relative price dynamics using quarterly data, the estimated half-lives are much shorter than for the longer sample, indicating faster convergence. However, with no structural breaks, they are still much longer compared to those obtained with quarterly data. This result accords well with the general conclusion of CS. Interestingly, when we include three structural breaks and correct for Nickell and time aggregation biases, we obtain half-life estimates in the range of 0.7 - 0.8 year. They compare reasonably well with the corresponding bias-corrected half-life estimates of 3.8 quarters (0.95 year) and 2.3 quarters (0.6 year) using quarterly data.

27 BIC and LWZ values provide conflicting choices as for the optimal number of structural breaks. While BIC indicates that the model with 1 break is the best, LWZ indicates that the model with 4 breaks is the best. However, in case of the model with 4 breaks, the first two break dates are identified only 4 years apart. Therefore, we decide not to go with the 4 breaks model. Among others, the model with 3 breaks has the lowest LWZ value and visually fits the data well. Moreover, the second and the third breaks almost coincide with the breaks identified in our model with quarterly data.
We further examine annual data for the sample period: 1972 – 1998, for which CS are unable to reject the null of a unit root for city CPI. Nevertheless, they report half-life estimates that range from 2 to 3.9 years. In contrast, we reject the unit root null for relative prices using panel unit root test with no structural breaks. The half-life estimates are 2.6 to 2.7 years. However, if we correct for Nickell bias only (akin to CS), the half-life estimate is 4.7 years. With two structural breaks, the unit root null is rejected and the half-life estimates decrease to 0.8 – 1.3 years. These half-life estimates are similar to those with quarterly data for the sample period: 1972Q1 – 2011Q4.

Overall, panel unit root tests using annual data overwhelmingly reject the null hypothesis of a unit root in relative prices irrespective of whether we include structural breaks or not. Furthermore, the half-life estimates, even after correcting for Nickell bias and time aggregation bias, are larger with annual data than quarterly data when no structural breaks are included. This conclusion about half-life accords well with the findings by CS. However, when we include structural breaks, the half-life estimates decrease substantially and they are quantitatively similar for quarterly and annual data.

IV Potential Explanations of the Structural Breaks

In the current study, the structural breaks are determined endogenously by data. These are common breaks with heterogeneous mean shifts across seven cities. In this section, we try to understand the common (national level) events that took place around the break dates identified above and had differential effects on the price level in different cities. Note that the structural break dates identified above are not independent of the sample period or of the data frequency. However, for the same sample period, the breaks identified with quarterly and annual data are close to each other. For example, with quarterly data, the break dates are identified at 1985, 1995, and 2007 while, with annual data, they are identified at 1987, 1995,
and 2006. In this section, we will focus on the first set of breaks identified for quarterly data from 1972 to 2011.

[Insert Figure 1]

In order to help understand the potential mechanisms through which common events may have caused these mean shifts, we first plot the relative price series along with the shifting means in Figure 1. We make the following observations. First, in 1985, the mean shifted upward for Adelaide, Canberra, and Melbourne and downward for the rest. Adelaide, Brisbane, and Sydney experienced upward mean shifts in 1995. Further, there were upward shifts in Adelaide, Brisbane, Canberra, and Perth in 2007. Second, the mean shifted upward for Adelaide and downward for Hobart at all break dates. For these two cities, the general price level has been continuously moving away from the national average: in positive direction for Adelaide and in negative direction for Hobart. That is, the cost of living is continuously rising in Adelaide while it is continuously falling in Hobart relative to the national average. In other cities, they are meandering around the national average. Third, the year-to-year variations in relative prices have gone down in all cities during almost all intervals between subsequent breaks.28 We now discuss major national events that occurred around the structural breaks with potential effects on city relative prices for each break date separately.

(i) First Structural Break in 1985

The first break in 1985 coincided with the aftermath of the recession of 1982-83, that witnessed large fiscal expansion and several important policy reforms. The strong growth during 1984-85 was fuelled by investment in private dwelling, private non-dwelling construction, and increased capital expenditure in public enterprises. However, there was no

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28 The standard deviation of relative prices increased slightly between 1985 and 1995 only in Hobart and Melbourne and, after 2007, in Melbourne.
consensus on the appropriate monetary policy. As the central bank abandoned monetary (M3) targeting, both nominal and real interest rate rose sharply in 1985 and the interest rate volatility increased during the late 1980s. This was particularly harmful for interest rate sensitive industries and, depending on the spatial distribution of these industries, would have differential effects on growth and inflation across regions.

The most important development around this structural break date with potentially differential effects across cities was perhaps the trade liberalisation measures undertaken by Australia. Australia ‘opted out’ of the post-war rounds of trade liberalization under GATT as its proposal to put full employment before freeing trade as the aim of the prospective International Trade Organization was not accepted by the major trading nations (Capling, 2000). Most Australian industries were protected behind relatively high trade barriers and Australia gained little from free trade unlike other OECD countries. Since around 1985, however, these trends have been reversed. A sharp depreciation of the Australian dollar after its floating in December 1983 and a series of policy measures to improve international competitiveness of the economy spurred the exports of manufacturing goods and services.29 The states of Victoria (VIC) and South Australia (SA) with large concentration of manufacturing and service enterprises benefitted the most. The upward shift of the mean relative prices after 1985 for Adelaide and Melbourne may have been a reflection of this development. In contrast, Tasmania, despite having a fair share of manufacturing activities, missed out largely due to relatively low labour utilisation rate (about 15 percent more than the national average at the time) that failed to pick up.

(ii) Second Structural Break in 1995

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29 These reforms included the deregulation of the financial system, reductions in tariffs and other trade barriers, the removal of most restrictions on foreign investment, etc.
During 1993-98 there was an acceleration of productivity growth in the Australian economy, partly due to a significant increase in business investment. Furthermore, total hours worked as well as employment rose sharply in 1995, in excess of 4% on a year-to-year basis (ABS, 2012a; 2012b). The working age population started to show an upward trend for the first time during 1994-95 (ABS, 2012c). This is evident in a strong increase in the labor force participation rate in 1995. Most gains in terms of growth in state share of output percolated to New South Wales (NSW), Queensland (QLD), and Western Australia (WA). A key feature of the mid-1990s is that it marked the secular decline in the importance of manufacturing industries and the rise of services. This structural shift had regional effects because of the spatial distribution of these services. For example, financial and insurance services were concentrated in NSW and VIC while ‘other business services’ that include information, media and telecommunications; rental, hiring and real estate services; professional scientific and technical services; administrative and support services are concentrated in QLD and SA; and, to some extent, retail and wholesale trade are concentrated in QLD, NSW, and VIC. These sectors attracted large private investments, driving up the capital-labour ratios and real wages in these sectors. This services boom is reflected in rising relative prices in Adelaide, Brisbane, and Sydney.

Another major development around this break date is that the Reserve Bank of Australia (RBA) adopted an inflation target of “2-3 percent per annum, on average over the course of business cycle” in 1993. This target was then formalised in an agreement between the Howard Government and the Governor of RBA in 1996. Furthermore, the federal government confirmed the de facto independence of RBA. The change in the stance of monetary policy was immediately visible through a sharp rise in both nominal and real interest rates in 1995 in response to the rising inflationary expectations. The mortgage rate on

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30 The productivity growth accelerated from a long run average of 1.2% to 2.4% per year during this period of time (Parham, 1999). Business investment as a ratio of GDP rose from a little over 10% in 1992 to more than 14% in 1997 (RBA, 2012).
new housing loans reached a record high of 10.5%. Other interest rates such as small business loans and swap rate with 3-year maturity rose to record high levels in two decades. These developments are likely to have differential effects in different regions of the country.  

Furthermore, the mid-1990s also marked the beginning of an upward trend in the inflow of long term and permanent immigrants to Australia (ABS, 2012d). NSW and VIC already had a substantial stock of immigrants. Since the mid-1990s, QLD became the new destination for overseas immigrants (ABS, 2012e). The consequent rise in the demand for residential dwellings contributed to the rise in housing prices, particularly in Brisbane, which in turn had a positive impact on Brisbane CPI.

*(iii) Third Structural Break in 2007*

The period 2006-07 marked the last phase of expansion of the world economy before the global economic crisis. Australian economy enjoyed a growth-surge since the mild recession of 2001-02 up until this time, mainly due to exploding commodity prices driven by the growth of China and, to some extent, India. The growth of output was accompanied by rising inflation during this period. The state share of output rose sharply for the mining states of QLD and WA while the shares of all other states went down. The GDP share of mining industry increased from around 4% in 2002-04 to about 10% in 2007-08 (ABS, 2012f). Thus, the external commodity price boom seems to have shifted the mean relative prices upward in Brisbane and Perth. In contrast, mean relative prices either fell (e.g. in Hobart, Melbourne, and Sidney) or changed little (e.g. in Adelaide, Canberra). In general, the volatility of relative prices decreased significantly in almost all cities during the post-2007 period. This seems to reflect the success of inflation targeting of the monetary policy by the central bank.

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31 Using city-level price data for the U.S., Fielding and Shields (2011) show that monetary policy has differential effects on city prices depending on city-specific economic characteristics including the composition of local industry, bank size, house prices, and the age distribution of the population.
V Conclusion

Applying panel unit root test procedures with and without structural breaks to quarterly CPI data for seven Australian cities from 1972Q1 to 2011Q4, we examine the dynamic behaviour of relative prices across these cities. We find overwhelming evidence of convergence in city relative prices. Three common structural break dates are endogenously determined at 1985, 1995, and 2007. Further, correcting for two potential biases, namely Nickell bias and time aggregation bias, we obtain half-life estimates of 2.3 – 3.8 quarters that are much shorter than those reported by CS. Thus, we conclude that both structural breaks and bias corrections are important to obtain shorter half-life estimates. These results are robust to shorter sample period and lower frequency data (annual in our case) with longer sample period.

The fiscal expansion and international trade liberalisation along with the floating of the Australian exchange rate in the mid-1980s; the productivity growth and changes in monetary policy stance during the mid-1990s; and, finally, the international commodity price boom during the mid-2000s seem to have been the triggers of the structural breaks in relative prices identified by our analysis. These events have differential long-term effects on relative prices across cities primarily due to the differences in the mixture of industries and economic activities.
<table>
<thead>
<tr>
<th>Sample period: 1972Q1 – 2011Q4</th>
<th>Estimated test statistic</th>
<th>5% critical value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No structural breaks</td>
<td>-5.34</td>
<td>-4.47</td>
</tr>
<tr>
<td>Three structural breaks</td>
<td>-11.21</td>
<td>-10.50</td>
</tr>
<tr>
<td>(Break dates: 1985Q1, 1995Q2, and 2007Q2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample period: 1972Q3 – 1999Q1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No structural breaks</td>
<td>-6.68</td>
<td>-4.38</td>
</tr>
<tr>
<td>Two structural breaks</td>
<td>-9.90</td>
<td>-8.52</td>
</tr>
<tr>
<td>(Break dates: 1988Q1 and 1997Q1)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: The critical values are generated from Monte Carlo simulations.
<table>
<thead>
<tr>
<th>Panel Feasible Generalised Least Square (FGLS) Estimation of $\rho$ and Implied Half-life</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sample period: 1972Q1 – 2011Q2</strong></td>
</tr>
<tr>
<td>No structural breaks</td>
</tr>
<tr>
<td>$\hat{\rho}$</td>
</tr>
<tr>
<td>(1)</td>
</tr>
<tr>
<td>Half-life</td>
</tr>
<tr>
<td>(2)</td>
</tr>
<tr>
<td>Combined Nickell and time aggregation bias correction</td>
</tr>
<tr>
<td>Data collection frequency $= 3$</td>
</tr>
<tr>
<td>$\hat{\rho}$</td>
</tr>
<tr>
<td>(3)</td>
</tr>
<tr>
<td>Half-life</td>
</tr>
<tr>
<td>(4)</td>
</tr>
<tr>
<td>Data collection frequency $= 2$</td>
</tr>
<tr>
<td>$\hat{\rho}$</td>
</tr>
<tr>
<td>(5)</td>
</tr>
<tr>
<td>Half-life</td>
</tr>
<tr>
<td>(6)</td>
</tr>
<tr>
<td>Data collection frequency $= 1$</td>
</tr>
<tr>
<td>$\hat{\rho}$</td>
</tr>
<tr>
<td>(7)</td>
</tr>
<tr>
<td>Half-life</td>
</tr>
<tr>
<td>(8)</td>
</tr>
</tbody>
</table>

| Three structural breaks                        |
| (Break dates: 1985Q1, 1995Q2, and 2007Q2)     |
| $\hat{\rho}$                                |
| (3)                                          |
| Half-life                                    |
| (4)                                          |

| **Sample period: 1972Q3 – 1999Q1**            |
| No structural breaks                          |
| $\hat{\rho}$                                |
| (1)                                          |
| Half-life                                    |
| (2)                                          |
| Two structural breaks                         |
| (Break dates: 1988Q1 and 1997Q1)             |
| $\hat{\rho}$                                |
| (3)                                          |
| Half-life                                    |
| (4)                                          |
## Table 3

### Panel Unit Root Test Results and Estimated Half-lives with Annual Data

<table>
<thead>
<tr>
<th>Sample period: 1949 – 2011</th>
<th>Autoregressive coefficients and implied half-life</th>
<th>Nickell and time aggregation bias correction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimated test statistic</td>
<td>5% critical value</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No structural breaks</td>
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<td>-4.52</td>
</tr>
<tr>
<td>Three structural breaks</td>
<td>-11.02</td>
<td>-9.47</td>
</tr>
<tr>
<td>Break dates: 1964, 1984, and 2005</td>
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</tr>
<tr>
<td>No structural breaks</td>
<td>-4.93</td>
<td>-4.10</td>
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<tr>
<td>Three structural breaks</td>
<td>-12.23</td>
<td>-9.73</td>
</tr>
<tr>
<td>No structural breaks</td>
<td>-7.02</td>
<td>-4.73</td>
</tr>
<tr>
<td>Two structural breaks</td>
<td>-11.26</td>
<td>-9.09</td>
</tr>
<tr>
<td>Break dates: 1980 and 1987</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
References


Australian Bureau of Statistics, 2012d, *Australian Demographic Statistics*, ‘Table 1. Population change, Summary – Australia (‘000)’, Time series spreadsheet, cat. no. 3101.0, viewed 18 December 2012:  


