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Are The Real Exchange Rate Indices of Australia Non-Stationary in the Presence of Structural Break?

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Abstract

This paper examines the time series properties of real exchange rate indices of Australia in the presence of structural break. Traditional unit root procedures have low power when structural break is ignored. By including structural change in the data, Perron's (1997) Additive Outlier model was found optimal. Three indices (Trade-weighted index (TWI), Export-weighted index (EWI) and Import-weighted index (IWI) are found to be stationary while G7 GDP-weighted index (G7WI) was found non-stationary. The estimated break dates correspond to the period of huge real GDP downturn in Australia (early 1990s), and the global recession in the early 1980s affecting the G7 countries.

Key Words: Real exchange rate, purchasing power parity, unit root, structural break.
JEL Classification: F13, F31, F41

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Introduction

The real exchange rate (RER) of a country plays a pivotal role in the economic performance of a country. There is a consensus among economists and policy makers that stability in real exchange rate promotes economic growth and welfare while a misaligned real exchange rate hinders export growth and generates macroeconomic instability such as, external debt crisis, deterioration in the agricultural sector and trade balance, undermines economic reforms and free market policies, etc. These mal-adjustments occur through transmission of wrong signals to economic agents.

Edwards (1989) makes a distinction between equilibrium real exchange rates and misaligned real exchange rates. "The equilibrium RER is a general equilibrium concept and is defined as the relative price of tradables to nontradables that results in the simultaneous attainment of equilibrium in the external sector and in the domestic (that is, nontradable) sector of the economy. When the RER is in equilibrium the economy is accumulating (or decumulating) assets at the "desired" rate, and the demand for domestic goods equates its supply" Edwards (1988: 4). There are a few implications with the concept of equilibrium RER (ERER). These are (1) ERER is affected by changes in "fundamentals", (2) there is no single ERER but a path of ERER over time, (3) the path of ERERs is affected not only by the current values of the "fundamental" determinants, but also by their expected future values, and (4) permanent and transient changes in the "fundamentals" will affect ERER differently. In contrast, a misalignment of the RER occurs due to large and persistent differences between actual and equilibrium real exchange rates.

Like other relative prices, real exchange rate (RER) – the price ratio of tradable to nontradable goods – is affected by real and nominal disturbances, which may be either long lasting or transient. A real exchange rate reacts to a series of real and nominal disturbances, including international terms of trade shocks, government expenditure patterns, trade restrictions, net capital inflow, foreign aid flow and technological progress, as well as to expansionary macroeconomic policies and nominal devaluation.

Blundell-Wignall *et al*. (1993) has identified three statistically significant determinants of the Australian real exchange rate. These are: terms of trade; net foreign liabilities; and real long-term interest differentials. This result is also confirmed by the findings of Gruen and Wilkinson (1994) and many others.

The central objective of this paper is test for unit roots of RER in the presence of endogenously determined structural break in the time series. Rather than relying upon the conventional Dickey-Fuller (DF), Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests which suffer from power deficiency in the presence of structural break in time series data, this study will test for unit roots in the presence of structural break. Thus far no study exists which employs endogenously determined structural break in the data. It may be mentioned here that most of the existing studies on the Australian RER were conducted in the early 1990s when the notion of structural break and its impact on time series properties was virtually non-existent in the econometric literature. This is the first study that employs real exchange rate data of Australia and tests the null hypothesis of unit root in the presence of endogenous structural break.

The result of the unit root test is crucial since it will indicate whether the long run Purchasing Power Parity (PPP) holds or not. PPP is one of the most crucial conditions in international finance because many models of exchange rate determination are premised on the assumption that PPP holds on a continuous basis. Short run deviations from PPP are significant, while in the long run, the deviations from PPP are eliminated slowly over time. To highlight this point in simple terms, let us define s_t be the Australian dollar price of a unit of foreign currency, p_t the Australian price level, p_t* the foreign price level and q_t the real exchange rate, with all variables expressed in natural logarithms. Thus the real exchange rate, q_t can be expressed as follows:

$$q_t = s_t + p_t^* - p_t$$

In the absolute sense, the nominal exchange rate (s_t) is proportional to the relative price ratio (p_t/p_t^*) thus rendering the real exchange rate (q_t) to remain constant over time.

If q_t changes over time and follows a stationary ARMA (p,q) process, then deviations from PPP are transient and will be eliminated over time. It is common knowledge that short run deviations from PPP are perfectly consistent with efficiently functioning financial markets. However, if the movement in q_t follows a non-stationary ARMA process, then the deviations will not be eliminated over time resulting in the failure of PPP in the long run.

Past studies on testing for unit roots of RER of Australia are sparse. As alluded earlier these limited number of studies have used the traditional unit root tests which suffer from power deficiency. So far empirical results are mixed. By employing the ADF test and quarterly data from 1973 Q1 to 1995 Q3, Bagchi *et al*. (2004) finds the RER of Australia to be integrated of order 1. Bagchi *et al*. (2004:80) defined the bilateral real exchange rate (q) = $eCPI^{US}/CPI^{Aus}$, where, e = nominal exchange rate and CPI^{US}, CPI^{AUS} represent the consumer price indices of the US and Australia respectively. This definition of RER is extremely restrictive and does not capture the overarching influence of relative prices and bilateral exchange rates of the trading partners. Hence, the result obtained by Bagchi *et al*. (2004) can be suspect.

In earlier empirical research, the Australian real exchange rate was characterised as a unit-root process (Blundell-Wignall and Gregory (1990), Blundell-Wignall, Fahrer and Heath (1993) and Gruen and Wilkinson (1994). Gruen and Kortian (1996:10) "estimate the real exchange rate models over the post-float period; a sample so short that tests of non-stationarity generates ambiguous results". Tests on a longer sample of Australia's trade-weighted real exchange rate suggest it is stationary, possibly around a trend (Gruen and Shuetrim 1994:353). Tarditi (1996), using Reserve Bank of Australia quarterly data from 1973 Q4 to 1995 Q2, found the trade-weighted real exchange rate to be stationary around a trend by using the ADF test and Kwiatkowski *et al*. (1992) test. These unit root tests were carried out while trying to establish the fundamental determinants of the RER of Australia.

It seems that the choice of a particular test method and the length of the sample period can influence the result to a large extent. Further, none of these studies took into account the presence of structural break in the data and the profound influence it can have on the dynamic time series properties of the data as is revealed by the latest literature on the subject. Thus, we enter this debate by taking issue with the unit root testing procedure by including the influence of structural change in the Australian economy. We can, thus, assess whether the presence of structural break has any perceptible influence on the result.

The structure of the paper is as follows: In Section II we define the concept and various measurements of RER in Australia. In this section we also discuss the evolution of the exchange rate regime in Australia over time. Section III briefly discusses the inadequacies of the traditional unit root tests and the potential problems that can arise from the use of these tests. This section leads on to a succinct review of the contemporary unit root tests in the presence of structural break in the data series (Appendix 1). Section IV presents the empirical results based on the choice of the optimal model. Section V summarises the findings of this study.

II Definition and Calculation of Real Exchange Rate (RER)

Real exchange rate (RER) can be defined as the ratio of the relative price of tradables (P_T) with respect to nontradables (P_{NT}).

$$\textbf{RER} = \frac{\textbf{Price of Tradables}}{\textbf{Price of Nontradables}} = \frac{\mathbf{P_T}}{\mathbf{P_{NT}}}$$

RER is a broad summary measure of the prices of one country's goods and services relative to those of another country or group of countries and thus measures the international competitiveness (McKenzie, 1986: 69) of an economy. External competitiveness generally implies the ability of a nation to expand its shares in both domestic and external markets. In a wider view, competitiveness for a country extends not only to earning sustainable and high incomes but also to maintaining and improving social and environmental standards.

In theory, calculating RER is relatively straightforward. That is, RER calculation depends on the nominal exchange rate and the relative price levels. But in practice there are numerous complexities that are elaborately pointed out by Ellis

(2001) and McKenzie (1986). These complexities include choices of weighting schemes and frequencies, price deflators, index number formulae and sets of countries to include. The relative importance of a nation's trading partners seems a natural basis for evaluating changes in external competitiveness.

The Reserve Bank of Australia (RBA) uses this approach in its published trade-weighted index (TWI). "The weights are derived as the share of total trade (exports plus imports) with each country, as measured in balance of payments statistics. In the RBA TWI, the weights are based on annual data and revised annually in most cases. An alternative approach could be to use weights that change more or less frequently, or that are based on rolling averages of trade shares. The methodology for deriving import or export-based weights is essentially identical (Ellis, 2001:18). The data for the trade-weighted, import-weighted, export-weighted and G7 GDP-weighted indices are available at http://www.rba.gov.au/Statistics/.

Evolution of Exchange Rate Regimes in Australia

Since the nominal exchange rate plays a vital role in the determination of RER it is important to understand the evolution of exchange rate regimes in Australia. For a detailed history of the evolution of Australia exchange rate regimes, refer to Nguyen (1993:469-476).

Under the Bretton Woods System, the domestic currency (which was the Australian Pound until decimalisation converted it into Australia dollar in 1966) was pegged to the British Pound, which in turn was fixed against the US dollar. After the collapse of the Bretton Woods system, Australia pursued an exchange rate policy that combined some flexibility as well as some control by the Reserve Bank of Australia (RBA). The RBA pegged the currency with a basket of currencies of its trading partners (the TWI). This policy was relaxed to allow the TWI to vary in accordance with other macroeconomic policies that were considered to be appropriate. In 1983, the Australian dollar was completely floated with limited intervention from the RBA. The RBA intervened occasionally for "smoothing" and "testing" purposes. Smoothing operations are undertaken by the RBA for elimination of perceived excessive volatility in the forex market while testing is conducted to evaluate how strong the market's sentiment is in either direction. Thus, the current system is one of limited intervention. Edison *et al*. (1999) studied the effects of intervention by the RBA on the level and volatility of the Australian dollar and found the effects to be modest on both the level and the volatility of the Australian dollar.

III Unit Root Test in the Presence of Structural Break

It is widely known that macroeconomic time series often experience structural break. Examples of structural break can be regime change, change in policy direction, external shocks, war etc. that may affect economic time series. Structural break can create difficulties in determining whether a stochastic process is stationary or not. Perron (1989) showed that in the presence of a structural break in time series, many perceived non-stationary series were in fact stationary. Perron (1989) re-examined Nelson and Plosser (1982) data and found that 11 of the 14 important US macroeconomic variables were stationary when known exogenous structural break is included. However, subsequent studies using endogenous breaks have countered this finding with Zivot and Andrews (1992) concluding that 7 of these 11 variables are in fact non-stationary.

Perron (1989) allows for a one time structural change occurring at a time T_B ($1 < T_B <$ T), where T is the number of observations. Subsequent to Perron's (1989) study more models were developed allowing for a single or multiple structural breaks. A review of these models is given in Appendix 1.

IV Data, Estimation and Result

In this study we included four types of real exchange rate indices as identified by the Reserve Bank of Australia. These are (1) Trade-weighted index (TWI); (2) Import-weighted index (IWI); (3) Export-weighted index (EWI); and (4) G7 GDP-weighted index (G7WI). Data is extracted from http://www.rba.gov.au/Statistics/. The real exchange rate indices are reported in Table A.1 in the Appendix. The variables are all converted to natural logarithms. The sample period for the first three series is from 1970 Q2 to 2004 Q4, while the coverage of the fourth variable is from 1980 Q1 to 2004 Q4. For the first three indices (TWI, IWI, EWI) the sample period is long which covers both the managed and floating rate regimes. For (G7WI) the sample period is relatively short.

Estimation: Shrestha-Chowdhury (2005) General-to-Specific Search Procedure

Given the complexities associated with testing unit roots among a plethora of competing unit root models discussed in Appendix 1, there is a need for a general-to-specific testing procedure to determine the stationarity of a time series. The researcher has to apply certain judgement based on economic theory in order to make assumptions about the nature of the time series. But such assumptions may not be always true and may lead to misspecification and totally wrong inferences. For these reasons, one faces the problem of selecting an appropriate method of unit root test.

Against this backdrop, we have followed the sequential procedure developed by Shrestha and Chowdhury (2005) in selecting an optimal method and model of the unit root test. The Shrestha-Chowdhury general-to-specific model selection procedure is outlined in Appendix 2.

Results

The results of the unit root test conducted employing the Shrestha-Chowdhury sequential search procedure allowing for one unknown structural break in the time series is presented in Table 1. We have exhaustively estimated all the models listed in Appendix 1. These models include: Zivot and Andrews (1992), Perron and Vogelsang's (1992) Innovational Outlier and Additive Outlier models, and Perron's (1997) Additive Outlier model and Innovational Outlier models I and II.

Based on the sequential search procedure an optimal model of unit root test was achieved with Perron's (1997) Additive Outlier (AO) model. We have reported the results obtained via Perron's (1997) AO model. The estimation results of other models can be obtained from the author. Theoretically, Perron's (1997) model is more comprehensive than the other competing models.

Table 1 Perron (1997) Additive Outlier Model Results

Variables	*Tb*	*k*	*t*	*DT*	$T_\alpha = 1$	*Result*
TWI	1990:3	11	**	**	-4.8436	Stationary
IWI	1989:2	11	**	**	-4.6612	Stationary
EWI	1991:3	11	**	**	-5.1479	Stationary
G7WI	1982:4	11	**	**	-4.4031	Non-stationary

Note: Critical values for $T_\alpha = 1$ *at 5% is -4.65 for 150 observations & -.4.83 for 100 observations (Perron 1997:363).*
* *Significant at 5% level.*
** *Coefficient close to zero and T-statistics significant at 5% level.*

Of the four real exchange rate indices we found three indices (Trade-weighted index (TWI), Export-weighted index (EWI) and Import-weighted index (IWI) to be stationary while G7 GDP-weighted index (G7WI) was found to be non-stationary. Given the largeness of the sample size of TWI, IWI and EWI it is not surprising to find the absence of unit roots i.e., the above RER indices are all mean-reverting. Since this is the case, PPP would serve as a good approximation of economic behaviour in the long run. In terms of policy this has huge implications. This will allow the decision makers of making predictions about future movement of the exchange rate or alternatively decide on fixing parities between currencies based on the real exchange rate. By contrast, the relative smallness of the sample size renders the G7 GDP-weighted index (G7WI) non-stationary i.e., non mean-reverting. This will imply that PPP would not be of much help to policy makers.

In Table 2 we summarise the salient features of the past work done in this area and we compared them with our current findings. Most the past studies found the TWI to possess unit root. Two things can contribute to this result: 1. the smallness of the sample size and more importantly, 2. disregarding structural break in data when there is once. Smallness of the sample size prevents the mean-reversal process to work since the timeframe is insufficient for mean-reversal to work. Perron (1989) showed that in the presence of a structural break in time series, many perceived non-stationary series were in fact stationary.

Table 2 Comparison of Past Results with the Author's Findings

Author(s)	**TWI**	**EWI**	**IWI**	**G7-GDPWI**	**Sample Period**	**Test Method**	**Remarks**
Blundell-Wignall & Gregory (1990)	NS	NC	NC	NC			
Blundell-Wignall & Fahrer & Heath (1993)	NS	NC	NC	NC	RBA data. 1973:2 to 1992:3	ADF	Power deficiency
Gruen & Wilkinson (1994)	NS	NC	NC	NC	RBA data. 1969:4 to 1990:4	ADF	Power deficiency
Gruen, & Shuetrim (1994)	S around a trend				RBA data. 1970:1 to 1993:4	ADF	Power deficiency
Gruen & Kortian (1996)	Ambiguous	NC	NC	NC	RBA data. 1984:1 to 1993:4	ADF & others	Power deficiency
Tarditi (1996)	S around a trend	NC	NC	NC	RBA data. 1973:4 to 1995:2	ADF & others	Power deficiency
Bagchi *et al.* (2004)	NS	NC	NC	NC	Own calculation. 1973:1 to 1995:3	ADF	Power deficiency
Present author	**S**	**S**	**S**	**NS**	RBA data. 1970:4 to 1995:2	Perron Additive Outlier model	Robust

Note: S = Stationary; NS = Non-stationary and NC = Not calculated.

The endogenous structural break dates for these variables are 1990 Q3 (for TWI); 1991 Q3 (for EWI); 1989 Q2 (for IWI) and 1982 Q4 (for G7WI). The estimated break dates mostly correspond to the period of huge real GDP downturn in Australia (early 1990s) due to “the financial excesses of the 1980s reached such a scale that the 1990 recession was inevitable” according to the former Governor of the Reserve Bank of Australia, Ian McFarlane. Australia was virtually alone in the world experiencing a recession at that point in time. In the early 1980s the global recession adversely affected the G7 industrialised countries which spilled over to Australia.

Some advanced economies, notably Japan and West Germany (members of G7 countries) fared better than others during the 1970s. All members of G7 countries, however, confronted persistent combinations of high inflation, high interest rate, severe unemployment and sluggish economic growth in the 1980s. OPEC's transformation of the world energy market increased inflation by raising not only gasoline and home-heating fuel charges but also the prices of all the important manufactures into which petroleum enters, among them chemical fertilisers, plastics, synthetic fibres and pharmaceutical products. These higher prices reduced purchasing power in much the same manner as would a severe new tax. Reduced purchasing power in turn depressed sales of consumer items, resulting in layoffs of factory and sales personnel. The entire procedure had a spiralling effect in all sectors of the economy of these countries.

V Summary and Conclusion

In this paper we tried to study the dynamic time series properties of four real exchange indices for a small, open developed country – Australia. Three innovations are present in this study. These are 1. Four types of RER indices are included (TWI, IWI, EWI & G7WI) and tested for stationarity. In previous studies only TWI was considered 2. Unit root tests that took into account the presence of structural break are employed. 3. To select the optimal model among a bevy of competing models, a general-to-specific search procedure was used to select the optimal model.

Using a novel general-to-specific search procedure we found that Perron’s (1997) AO model was the optimal model in determining the time series properties of the variables under consideration. Our findings show that three indices ((Trade-weighted index (TWI), Export-weighted index (EWI) and Import-weighted index (IWI)) were indeed stationary thus vindicating the presence of long run PPP. This is in sharp contrast to the findings of past studies. Majority of past studies, using traditional unit root test methods and ignoring structural break in the data, found the TWI of Australia to be non-stationary. In this study the structural break dates for the various indices look plausible, coinciding with Australia's recession in the early 1990s and the global recession of the early 1980s. This study adds a new dimension concerning the dynamic properties of Australia's vital macroeconomic variable.

Appendix 1

A Brief Review of Unit Root Tests in the Presence of Structural Break in the Data

As mentioned earlier, structural break can create difficulties in determining whether a stochastic process is stationary or not. Perron (1989) showed that in the presence of a structural break in time series, many perceived non-stationary series were in fact stationary. Perron (1989) pioneered unit root tests that allow for one structural break. The following models were developed by Perron (1989) for three different cases. The notations used in equations 1-17 are the same as in the original papers.

Null Hypothesis:

Model (A) $y_t = \mu + dD(TB)_t + y_{t-1} + e_t$ (1)

Model (B) $y_t = \mu_1 + y_{t-1} + (\mu_2 - \mu_1)DU_t + e_t$ (2)

Model (C) $y_t = \mu_1 + y_{t-1} + dD(TB)_t + (\mu_2 - \mu_1)DU_t + e_t$ (3)

where $D(TB)_t = 1$ if $t = T_B + 1$, 0 otherwise, and

$DU_t = 1$ if $t > T_B$, 0 otherwise.

Alternative Hypothesis:

Model (A) $y_t = \mu_1 + \beta t + (\mu_2 - \mu_1)DU_t + e_t$ (4)

Model (B) $y_t = \mu + \beta_1 t + (\beta_2 - \beta_1)DT_t^* + e_t$ (5)

Model (C) $y_t = \mu_1 + \beta_1 t + (\mu_2 - \mu_1)DU_t + (\beta_2 - \beta_1)DT_t + e_t$ (6)

where $DT_t^* = t - T_B$, if $t > T_B$, and 0 otherwise.

Model A permits an exogenous change in the level of the series whereas Model B permits an exogenous change in the rate of growth. Model C allows change in both. Perron (1989) models include one known structural break. These models cannot be applied where such breaks are unknown. Therefore, this procedure is criticised for assuming known break date which raises the problem of pre-testing and data-mining regarding the choice of the break date (Maddala and Kim 2003:401). Further, the choice of the break date can be viewed as being correlated with the data.

Presence of a Single Break Date Which is Unknown

Despite the limitations of Perron (1989) models, they form the foundation of subsequent studies that we are going to discuss. Zivot and Andrews (1992), Perron and Vogelsang (1992), and Perron (1997) among others have developed unit root test methods which include one unknown structural break.

Zivot and Andrews (1992) models are as follows:

Model with Intercept

$$y_t = \hat{\mu}^A + \hat{\theta}^A DU_t(\hat{\lambda}) + \hat{\beta}^A t + \hat{\alpha}^A y_{t-1} + \sum_{j=1}^{k} \hat{c}_j^A \Delta y_{t-j} + \hat{e}_t \quad (7)$$

Model with Trend

$$y_t = \hat{\mu}^B + \hat{\beta}^B t + \hat{\gamma}^B DT_t^*(\hat{\lambda}) + \hat{\alpha}^B y_{t-1} + \sum_{j=i}^{k} \hat{c}_j^B \Delta y_{t-j} + \hat{e}_t \quad (8)$$

Model with Both Intercept and Trend

$$y_t = \hat{\mu}^C + \hat{\theta}^C DU_t(\hat{\lambda}) + \hat{\beta}^C t + \hat{\gamma}^C DT_t^*(\hat{\lambda}) + \hat{\alpha}^C y_{t-1} + \sum_{j=1}^{k} \hat{c}_j^C \Delta y_{t-j} + \hat{e}_t \quad (9)$$

where, $DU_t(\lambda)$ = 1 if t > $T\lambda$, 0 otherwise;

$DT_t^*(\lambda) = t - T\lambda$ if $t > T\lambda$, 0 otherwise.

The above models are based on the Perron (1989) models. However, these modified models do not include DT_b.

On the other hand, Perron and Vogelsang (1992) include DT_b but exclude *t* in their models. Perron and Vogelsang (1992) models are given below:

Innovational Outlier Model (IOM)

$$y_t = \mu + \delta DU_t + \theta D(T_b)_t + \alpha y_{t-1} + \sum_{i=1}^{k} c_i \Delta y_{t-i} + e_t \quad (10)$$

Additive Outlier Model (AOM) – Two Steps

$$y_t = \mu + \delta DU_t + \tilde{y}_t \quad (11)$$

and

$$\tilde{y}_t = \sum_{i=0}^{k} w_i D(T_b)_{t-i} + \alpha \tilde{y}_{t-1} + \sum_{i=1}^{k} c_i \Delta \tilde{y}_{t-i} + e_t \qquad (12)$$

$\tilde{y}$ in the above equations represents a detrended series y.

Perron (1997) includes both t (time trend) and DT_b (time at which structural change occurs) in his Innovational Outlier (IO1 and IO2) and Additive Outlier (AO) models.

Innovational Outlier Model allowing one time change in intercept only (IO1):

$$y_t = \mu + \theta DU_t + \beta t + \delta D(T_b)_t + \alpha y_{t-1} + \sum_{i=1}^{k} c_i \Delta y_{t-i} + e_t \qquad (13)$$

Innovational Outlier Model allowing one time change in both intercept and slope (IO2):

$$y_t = \mu + \theta DU_t + \beta t + \gamma DT_t + \delta D(T_b)_t + \alpha y_{t-1} + \sum_{i=1}^{k} c_i \Delta y_{t-i} + e_t \qquad (14)$$

Additive Outlier Model allowing one time change in slope (AO):

$$y_t = \mu + \beta t + \delta DT_t^* + \tilde{y}_t \qquad (15)$$

where $DT_t^* = 1(t > T_b)(t - T_b)$

$$\tilde{y}_t = \alpha \tilde{y}_{t-1} \sum_{i=1}^{k} c_i \Delta \tilde{y}_{t-i} + e_t \qquad (16)$$

The Innovational Outlier models represent the change that is occurring is gradual whereas Additive Outlier model represents the change that is occurring is rapid. All the models considered above report their asymptotic critical values.

Power of the Tests

Regarding the power of tests, the Perron and Vogelsang (1992) model is robust. The testing power of Perron (1997) models and Zivot and Andrews models (1992) are almost the same. On the other hand, Perron (1997) model is more comprehensive than Zivot and Andrews (1992) model as the former includes both t and DT_b while the latter includes t only.

Unit Root Tests in the Presence of Multiple Structural Breaks

More recently, additional test methods have been proposed for unit root test allowing for multiple structural breaks in the data series (Lumsdaine and Papell 1997; Bai and Perron 2003). They find evidence of more cases of the null hypothesis rejection under this procedure than when only one structural break is allowed.

Lumsdaine and Papell (1997) procedure enable us to capture two structural breaks in the time series. The procedure that is proposed by Lumsdaine and Pappell (1997) (henceforth LP) is an extension of model C of Zivot and Andrews (1992) or model 2 of Perron (1997). Using innovational outlier (*IO*) framework, LP procedure is a modified version of ADF test augmented by two endogenous breaks in both the time trend and the intercept. The LP model is written as follows:

$$\Delta y_t = \hat{\mu} + \hat{\alpha} y_{t-1} + \hat{\beta} t + \hat{\theta} DU1_t + \hat{\gamma} DT1_t + \hat{\omega} DU2_t + \hat{\psi} DT2_t + \sum_{i=1}^{k} \hat{c}_i \Delta y_{t-i} + \hat{e}_t \qquad 17$$

where *DU1t*=1 if *t*>*TB1* and zero otherwise, *DU2t*=1 if *t*>*TB2* and zero otherwise, *DT1t*= *t*- *TB1* if *t*>*TB1* and otherwise zero, and *DT2t*=*t*- *TB2* if *t*> *TB2* and otherwise zero.

While the two dummy variables *DU1t* and *DU2t* capture structural changes in the intercept at time *TB1* and *TB2* respectively, the other two dummy variables *DT1t* and *DT2t* capture shifts in the trend variable at time *TB1* and *TB2* respectively. As before, the optimal lag order (*k*) is determined based on the *t*-Sig method in which the maximum lag order (*k* max) is set at 12. Further, the break dates (*TB1* and *TB2*) are estimated by minimising the value of the *t* statistic for α.

Appendix 2

Shrestha-Chowdhury (2005) Sequential Search Procedure for Unit Root Test

The Shrestha-Chowdhury general-to-specific sequential procedure involves the following steps:

Step 1. Run Perron (1997): Innovational Outlier Model (*IO2*)

As mentioned earlier, this model includes t (time trend) and DT_b *(time of structural break), and both intercept (DU) and slope (DT).*

- Check *t* and DT_b statistics
- If both *t* and DT_b are significant, check *DU* and *DT* statistics
- If both *DU* and *DT* are significant, select this model
- If only *DU* is significant, go to Perron (1997): *IO1* model.

This model includes t (time trend) and DT_b *(time of structural break), and DU (intercept) only.*

- If only *DT* is significant, go to Perron (1997): Additive Outlier model (*AO*)

This model includes t (time trend) and DT_b *(time of structural break), and slope (DT) only.*

In some cases, *t* and DT_b may be insignificant in IO2 but significant in IO1 or AO. Therefore, IO1 and AO tests should be conducted after IO2 in order to check the existence of such a condition.

Step 2. If only *t* is significant in Stage 1, go to Zivot and Andrews (1992) models:

Zivot and Andrews (1992) models include t but exclude DT_b*.*

- Run Zivot and Andrews test with intercept, trend, and both separately and compare the results. Select the model that gives the results consistent with the economic fundamentals and the available information.

Step 3. If only DT_b is significant in Stage 1, go to Perron and Vogelsang (1992) models:

Perron and Vogelsang (1992) models include DT_b *but exclude t.*

- Run *IOM* and *AOM*. Compare the statistics and select the appropriate model.

Step 4. If both t and DT_b are not significant in Stage 1, this implies that there is no statistically significant time trend and/or structural break in the time series. In such a case, certain judgement is to be used to select the test method.

The rationale behind employing the above sequential procedure is that the inclusion of irrelevant information and the exclusion of relevant information may lead to misspecification of the model. For example, the Perron 1997 – IO2 model includes t, DT_b, DU and DT. If the test results of a time series show that the DT is not relevant or significant, then using this model (IO2) for that time series involves the risk of the misspecification, because the irrelevant information (DT) is included in the model. In this case, the model that includes t, DT_b and DU, but excludes DT should be preferred. This means that Perron 1997-IO1 model may be appropriate for this time series. If in a model t, DT_b, DU and DT are significant, then using the Perron 1997 – IO1 model will be inappropriate and will lead to misspecification since Perron 1997 – IO1 model excludes DT.

Table A.1 Trade-weighted, Import-weighted, Export-weighted and G7 GDP-weighted Real Exchange Rate Indices of Australia

	Real Trade Weighted Index March 1995=100	Real Import Weighted Index March 1995=100	Real Export Weighted Index March 1995=100	Real G7 GDP Weighted Index March 1995=100
Jun-1970	152.1	147.9	161.4	
Sep-1970	150.0	145.9	159.2	
Dec-1970	149.7	145.7	158.8	
Mar-1971	150.8	146.5	159.9	
Jun-1971	150.4	145.9	159.6	
Sep-1971	151.3	146.7	160.3	
Dec-1971	152.5	148.3	160.8	
Mar-1972	150.3	146.4	157.5	
Jun-1972	149.1	145.3	156.0	
Sep-1972	150.5	147.2	157.1	
Dec-1972	151.1	148.2	157.3	
Mar-1973	164.5	162.0	169.8	
Jun-1973	167.1	164.9	171.3	
Sep-1973	168.9	166.7	172.7	
Dec-1973	178.9	177.4	182.4	
Mar-1974	182.5	181.6	185.6	
Jun-1974	177.5	176.2	180.2	
Sep-1974	183.7	182.1	187.3	
Dec-1974	164.4	162.3	168.0	
Mar-1975	167.3	164.8	170.9	
Jun-1975	168.1	165.6	171.6	
Sep-1975	165.7	163.5	169.8	
Dec-1975	171.1	168.7	176.0	
Mar-1976	172.1	169.8	176.8	
Jun-1976	172.1	170.5	175.7	
Sep-1976	173.3	172.1	176.1	
Dec-1976	163.3	162.3	165.9	
Mar-1977	152.1	150.9	154.5	
Jun-1977	151.8	150.9	153.4	
Sep-1977	150.0	149.3	151.1	
Dec-1977	148.1	147.7	147.8	
Mar-1978	145.6	144.9	145.4	
Jun-1978	142.0	142.2	140.3	
Sep-1978	136.7	137.4	133.5	
Dec-1978	135.3	135.8	132.3	
Mar-1979	134.6	134.5	132.8	
Jun-1979	134.5	133.6	134.1	
Sep-1979	134.6	132.8	135.1	
Dec-1979	133.9	131.5	135.7	
Mar-1980	132.5	129.8	135.1	127.6
Jun-1980	132.5	130.2	134.3	128.5
Sep-1980	134.0	131.9	135.1	130.4
Dec-1980	134.6	133.1	135.2	132.2
Mar-1981	137.4	136.3	137.8	136.2
Jun-1981	140.1	138.9	141.5	139.0
Sep-1981	145.6	144.6	147.7	143.8
Dec-1981	143.9	142.8	145.7	141.5
Mar-1982	141.6	140.3	144.1	138.9
Jun-1982	140.6	139.1	143.8	137.3
Sep-1982	137.5	136.0	141.6	134.2

Table A.1 (cont.) Trade-weighted, Import-weighted, Export-weighted and G7 GDP-weighted Real Exchange Rate Indices of Australia

Dec-1982	136.2	134.8	140.0	132.2
Mar-1983	134.1	133.1	136.7	130.5
Jun-1983	127.7	126.5	130.7	123.0
Sep-1983	132.1	131.0	135.3	127.2
Dec-1983	136.9	136.0	139.7	132.2
Mar-1984	140.6	139.8	143.5	136.0
Jun-1984	137.4	136.6	140.3	132.8
Sep-1984	134.0	132.7	138.0	127.7
Dec-1984	138.2	136.9	142.6	131.4
Mar-1985	128.9	127.7	133.3	122.1
Jun-1985	112.9	111.6	117.0	106.4
Sep-1985	116.0	114.7	119.9	109.5
Dec-1985	109.4	108.1	112.6	103.7
Mar-1986	109.4	108.0	112.4	103.3
Jun-1986	108.1	106.8	110.4	103.0
Sep-1986	93.5	92.1	95.5	88.3
Dec-1986	99.0	97.3	101.6	93.0
Mar-1987	100.4	98.4	103.2	94.5
Jun-1987	104.3	102.3	106.7	99.4
Sep-1987	106.1	104.0	108.5	101.3
Dec-1987	100.9	98.9	103.2	96.8
Mar-1988	101.8	100.0	103.7	98.4
Jun-1988	109.8	108.0	111.4	106.9
Sep-1988	118.3	116.7	119.9	115.4
Dec-1988	121.3	119.8	122.7	118.7
Mar-1989	124.5	123.0	125.8	122.2
Jun-1989	117.6	116.2	118.9	115.6
Sep-1989	117.5	115.8	119.0	115.0
Dec-1989	120.5	118.6	122.3	116.8
Mar-1990	119.2	116.6	121.9	113.6
Jun-1990	121.1	118.1	124.2	114.5
Sep-1990	123.0	120.0	126.1	116.6
Dec-1990	114.8	112.5	117.3	109.2
Mar-1991	115.3	112.8	118.0	109.3
Jun-1991	118.2	115.8	120.6	113.3
Sep-1991	119.8	117.5	122.1	115.1
Dec-1991	116.4	114.2	118.7	111.1
Mar-1992	111.3	109.1	113.6	106.0
Jun-1992	111.9	109.6	114.3	106.5
Sep-1992	104.8	102.5	107.1	99.2
Dec-1992	102.1	100.4	103.7	97.8
Mar-1993	101.4	100.1	102.7	97.9
Jun-1993	98.6	97.8	99.4	96.4
Sep-1993	94.8	94.4	95.3	93.6
Dec-1993	94.9	94.5	95.4	93.8
Mar-1994	102.0	101.7	102.4	100.0
Jun-1994	101.6	101.4	101.7	100.1
Sep-1994	101.1	101.0	101.2	100.1
Dec-1994	102.7	102.6	102.7	102.0
Mar-1995	100.0	100.0	100.0	100.0
Jun-1995	92.7	93.3	92.2	94.2
Sep-1995	97.8	97.9	97.7	98.3
Dec-1995	100.8	100.5	101.2	100.6

Table A.1 (cont.) Trade-weighted, Import-weighted, Export-weighted and G7 GDP-weighted Real Exchange Rate Indices of Australia

Mar-1996	102.9	102.5	103.3	102.7
Jun-1996	107.8	107.5	108.1	108.4
Sep-1996	107.7	107.2	108.4	107.9
Dec-1996	109.5	108.8	110.3	109.4
Mar-1997	110.7	109.9	111.6	110.8
Jun-1997	109.7	109.0	110.4	110.1
Sep-1997	106.8	106.0	107.7	106.0
Dec-1997	107.5	104.4	110.8	100.2
Mar-1998	111.0	105.7	116.8	97.6
Jun-1998	104.9	100.0	110.3	92.8
Sep-1998	101.5	96.4	107.0	88.8
Dec-1998	98.6	94.3	103.3	88.6
Mar-1999	100.8	96.8	105.1	91.1
Jun-1999	105.5	101.4	110.0	96.0
Sep-1999	104.6	100.7	108.8	95.4
Dec-1999	102.3	98.7	106.0	93.4
Mar-2000	101.8	98.4	105.3	93.4
Jun-2000	96.5	93.5	99.6	88.8
Sep-2000	96.0	92.9	99.2	87.9
Dec-2000	91.4	88.4	94.7	82.8
Mar-2001	92.7	89.0	96.7	82.7
Jun-2001	92.1	88.3	96.2	81.8
Sep-2001	91.9	88.1	96.1	81.7
Dec-2001	92.8	88.6	97.2	81.7
Mar-2002	95.6	91.0	100.5	84.2
Jun-2002	98.8	94.2	103.8	87.9
Sep-2002	95.8	91.3	100.5	85.2
Dec-2002	98.2	93.6	103.2	87.0
Mar-2003	101.9	97.2	107.2	90.7
Jun-2003	108.4	103.2	114.3	96.3
Sep-2003	111.4	106.4	117.2	99.6
Dec-2003	117.6	112.5	123.4	105.0
Mar-2004	123.4	118.1	129.4	110.4
Jun-2004	116.7	111.7	122.5	104.7
Sep-2004	115.4	110.5	121.2	103.7
Dec-2004	120.2	115.2	126.1	108.1
Mar-2005	122.2	117.4	127.7	110.5
Jun-2005	122.3	117.7	127.5	111.3

Source: *Data is extracted from http://www.rba.gov.au/Statistics/.*

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