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Abbas Valadkhani
University of Wollongong, abbas@uow.edu.au

A. P. Layton
Queensland University of Technology

M. Pahlavani
University of Wollongong

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Abbas Valadkhani

Allan P. Layton

and

Mosayeb Pahlavani

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by

Abbas VALADKHANI
School of Economics and Information Systems
University of Wollongong
Wollongong NSW 2522, Australia
Email: abbas@uow.edu.au
Tel: +612-4221 4022
Fax: +612-4221 3725

Allan P. LAYTON
School of Economics and Finance,
Queensland University of Technology,
Brisbane, Qld 4001, Australia

and

Mosayeb PAHLAVANI
School of Economics and Information Systems
University of Wollongong
Wollongong NSW 2522, Australia

Abstract

This paper employs all available annual time series data to endogenously determine the timing of structural breaks for 10 macroeconomic variables in the Australian economy. The ADF (Augmented Dickey and Fuller) test and the LP (Lumsdaine and Papell, 1997) test are used to examine the time series properties of the data. The ADF test results provide no evidence against the unit root null hypothesis in all ten macroeconomic variables. After accounting for the two most significant structural breaks in the data impacting on both the intercept and trend, the results from the LP test indicate that the null of at least one unit root is rejected for four of the variables under investigation at the 10 per cent level or better. We also found that the dates of structural breaks in most cases point to: (a) the oil/wages shock occurring in the 1973-1975 period, (b) the 1990-1991 recession; (c) the culmination of financial deregulation and innovation in the late 1980s; and (d) the 1997 Asian crisis.

JEL classification numbers: C12, C22, C52.
Key words: Unit roots Hypothesis, structural breaks, and Australian economy

1. Introduction

The issue of structural change is of considerable importance in the analysis of macroeconomic time series. Structural change occurs in many time series for any number of reasons, including economic crises, changes in institutional arrangements, policy changes and regime shifts. An associated problem is that of testing the null hypothesis of structural stability against the alternative of a one or two-time structural break. Most importantly, if such structural changes are present in the data generating process, but not allowed for in the specification of an econometric model, results may be biased towards the erroneous non-rejection of the non-stationarity hypothesis (Perron, 1989; Perron, 1997; Leybourne and Newbold, 2003). The economic content of such a result is to incorrectly conclude that the series under investigation has a stochastic trend. This in turn implies that any shock – whether demand, supply, or policy-induced – to the variable will have effects on the variable into the very long run. It is therefore very important to allow for the presence of a structural break in the data so as to more reliably conduct the test of non-stationarity.

Conventionally, dating of the potential break is that it is assumed to be known *a priori*. Test statistics are then constructed by adding dummy variables representing different intercepts and slopes, thereby extending the standard Dickey-Fuller procedure (Perron, 1989). However, this standard approach has been criticized, most notably by Christiano (1992), who has argued that this approach invalidates the distribution theory underlying conventional testing.

In response, a number of studies have developed different methodologies for endogenising dates, including Zivot and Andrews (ZA, 1992), Perron (1997), Lumsdaine and Papell (1997) and Bai and Perron (2003). These have shown that by endogenously determining the time of structural breaks, bias in the usual unit root tests can be reduced. Perron and Vogelsang (1992) and Perron (1997) have proposed a class of test statistics which allows for two different forms of a structural break: namely, the Additive Outlier (AO) model, which is more relevant for series exhibiting a sudden change in the mean (the crash model), and the Innovational Outlier (IO) model, which captures changes in a more gradual manner through time. Perron (1997, p.356), for example, argues that "…if one can still reject the unit-root hypothesis under such a scenario it must be the case it would be rejected under a less stringent assumption".

The purpose of this paper is to employ the LP (Lumsdaine and Papell, 1997) test to examine the significance of two structural breaks in major macroeconomic series of the Australian economy using all available annual data The detection of structural breaks within these time series will present new and novel evidence of the impact of this important period of institutional and regulatory change. The macroeconomic series of the Australian economy examined are the natural logs of annual observations on: private real consumption, $Ln(C_t)$; government real consumption, $Ln(G_t)$; private real gross fixed capital formation, $Ln(Ip_t)$; public real gross fixed capital formation, $Ln(Ig_t)$; real exports, $Ln(X_t)$; real imports $Ln(M_t)$; real gross domestic product $Ln(GDP_t)$; employment $Ln(L_t)$; the consumer price index $Ln(P_t)$; and the money supply $Ln(M3_t)$.

The remainder of the paper is as follows. Section 2 briefly discusses the theoretical underpinnings of the LP test procedure. Section 3 presents the empirical results of the ADF and LP tests. Section 4 provides some concluding remarks.

2. The Lumsdaine and Papell Test Procedure

Many practitioners use the Augmented Dickey–Fuller (ADF) test to examine time series properties of the data. For the sake of comparison, the ADF regression is presented in the following equation:

$$\Delta y_t = \mu + \beta t + \alpha y_{t-1} + \sum_{i=1}^{k} c_i \Delta y_{t-i} + \varepsilon_t \tag{1}$$

Where y_t is the time series being tested, t is a time trend variable, Δ denotes the first difference operator, and k is the number of lags which are added to the model to ensure that residuals, ε_t, are white noise. The Schwartz Bayesian information criterion (BIC) is used to determine the optimal lag length or k.

Zivot and Andrews (1992) and Perron (1997) tests capture only one (the most significant) structural break in each variable. What if, there have been multiple structural breaks in a series? Considering only one endogenous break may not be sufficient and it could lead to a loss of information particularly when in reality there is more than one break (LP, 1997). On this same issue, Ben-David *et al* (2003) argued that "just as failure to allow one break can cause non-rejection of the unit root null by the Augmented Dickey –Fuller test, failure to allow for two breaks, if they exist, can cause non-rejection of the unit root null by the tests which only incorporate one break" (2003: 304). LP introduced a new procedure to capture two structural breaks. They argued that unit root test that account for two structural breaks (if significant) is more powerful than those, which only allows for one single break.

As an extension of the Zivot and Andrews (1992) test (model C), LP uses a modified version of ADF test which are augmented by two endogenous breaks as follows:

$$\Delta y_t = \mu + \beta t + \theta DU1_t + \gamma DT1_t + \omega DU2_t + \psi DT2_t + \alpha y_{t-1} + \sum_{i=1}^{k} c_i \Delta y_{t-i} + \varepsilon_t \tag{2}$$

Where $DU1_t$=1 if $t>TB1$ and otherwise zero; $DU2_t$=1 if $t>TB2$ and otherwise zero; $DT1_t$= $t-TB1$ if $t>TB1$ and otherwise zero; and finally $DT2_t$=$t-TB2$ if $t>TB2$ and otherwise zero.

Two structural breaks are allowed in both the time trend and the intercept and this model is referred to as CC model (similar to the Zivot and Andrews C model which only captured one break point) in the literature. The two indicator dummy variables (*i.e.* $DU1_t$ and $DU2_t$) capture structural changes in the intercept at time *TB1* and *TB2*, respectively. The other two dummy variables (*i.e.* $DT1_t$ and $DT2_t$) capture shifts in the trend variable at time *TB1* and *TB2*, respectively.

The optimal lag length (k) is determined based on the general to specific approach (the t test) suggested by Ng and Perron (1995). The "trimming region", in which we have searched for *TB1* and *TB2* cover the 05T-0.95T period. We have selected the break points (*TB1* and *TB2*) based on the minimum value of the t statistic for α. Using annual time series data, LP (1997) and Ben-David *et al* (2003) have assumed the lag length (k) to vary up to K_{max}=8.

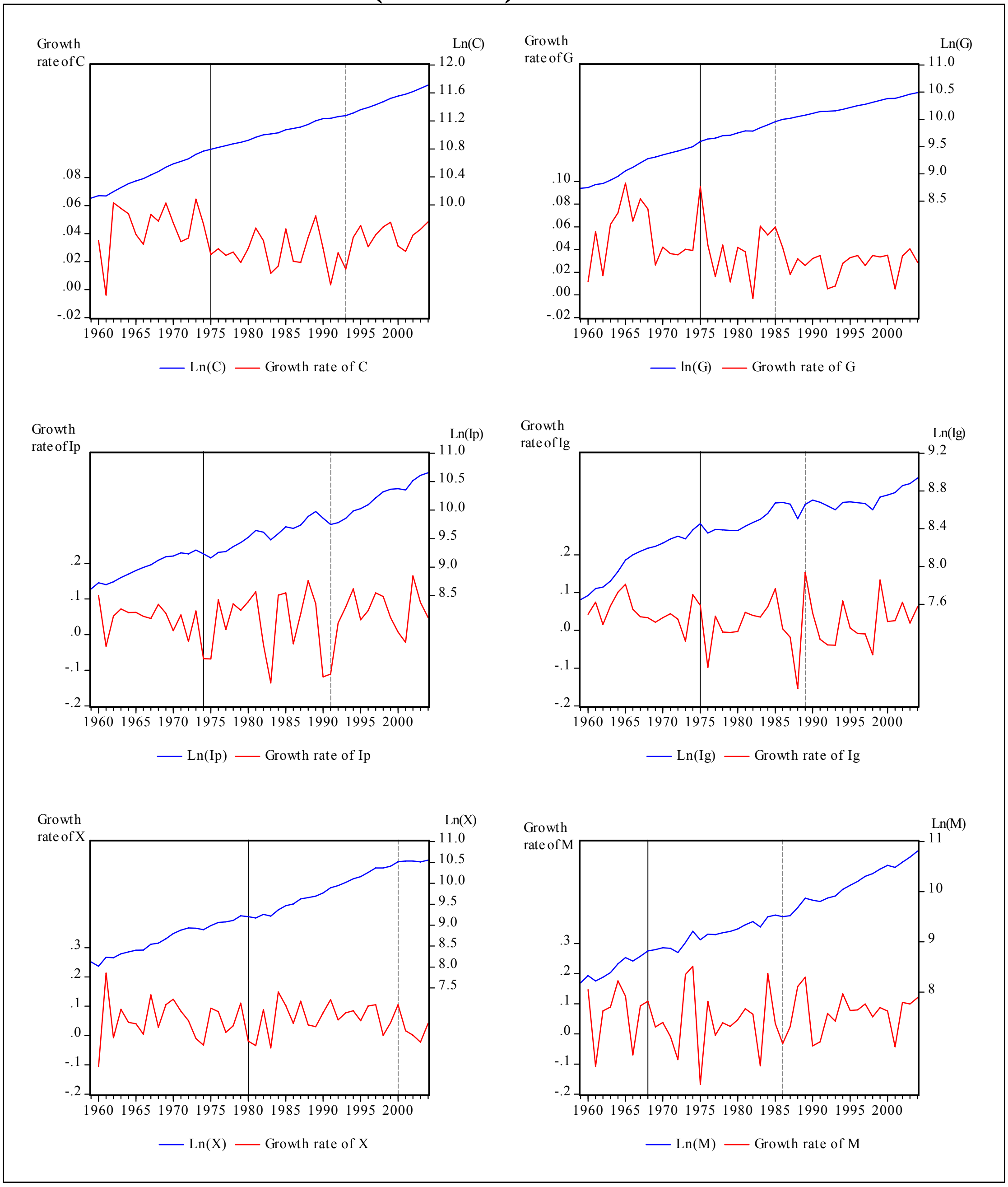
3. Empirical Results

Prior to estimating equation (2) in sequential and iterative manner it is useful to report the ADF test results and have a cursory look at the plots of the data employed in Figure 1 which also shows the sources of the data. The ADF test results presented in Table 1 clearly indicate that none of the ten variables employed in this empirical investigation is stationary at any conventional level. Without considering the break points, an informal inspection of the graphs of the variables shown in Figure 1 may also support the view that the series are not stationary. A more recent study by Pahlavani, Valadkhani and Worthington (2005) employ the IO and AO models and quarterly data on Australia's financial and monetary aggregates and conclude that after allowing for one structural break the non-stationarity of series remain unchanged. It is interesting to see how the unit root results can be affected if we allow for the existence of two structural breaks in the data. This paper below examines this important issue.

In the presence of two structural breaks and based on the LP test results presented in Table 2, four out of ten macroeconomic variables are now stationary at 10 per cent significance level or better. These variables are private consumption, imports, employment and the money supply. These results are consistent with the results obtained by Narayan and Smyth (2004, p.1) as they also find that the use of LP test rejects the null hypothesis of unit root in 7 out of 16 Australia's macroeconomic variables. However, they have not reported the estimated coefficients for θ, γ, ω and ψ and as such one cannot say anything about the statically significance of the resulting structural breaks (*i.e.* $DU1_t$, $DU2_t$, $DT1_t$ and $DT2_t$).

The reported *t* statistics in Table 2 for μ, β θ, γ, ω and ψ are significant in majority of cases. Given the fact that all of the estimated coefficients for the indicator and trend dummy variables are statistically significant for eight out of ten variables, one can argue that the estimated structural break dates are indeed significant and "not just included" in the model. Under these circumstances, the Zivot and Andrews (1992) and Perron (1997) tests which detect only one structural break can lead to biased results. In the case of GDP, three out of the four dummy variables (*i.e. DU1*, *DU2* and *DT2*) in the CC model are highly significant and as a result we have decided to accept the estimated results for this variable.

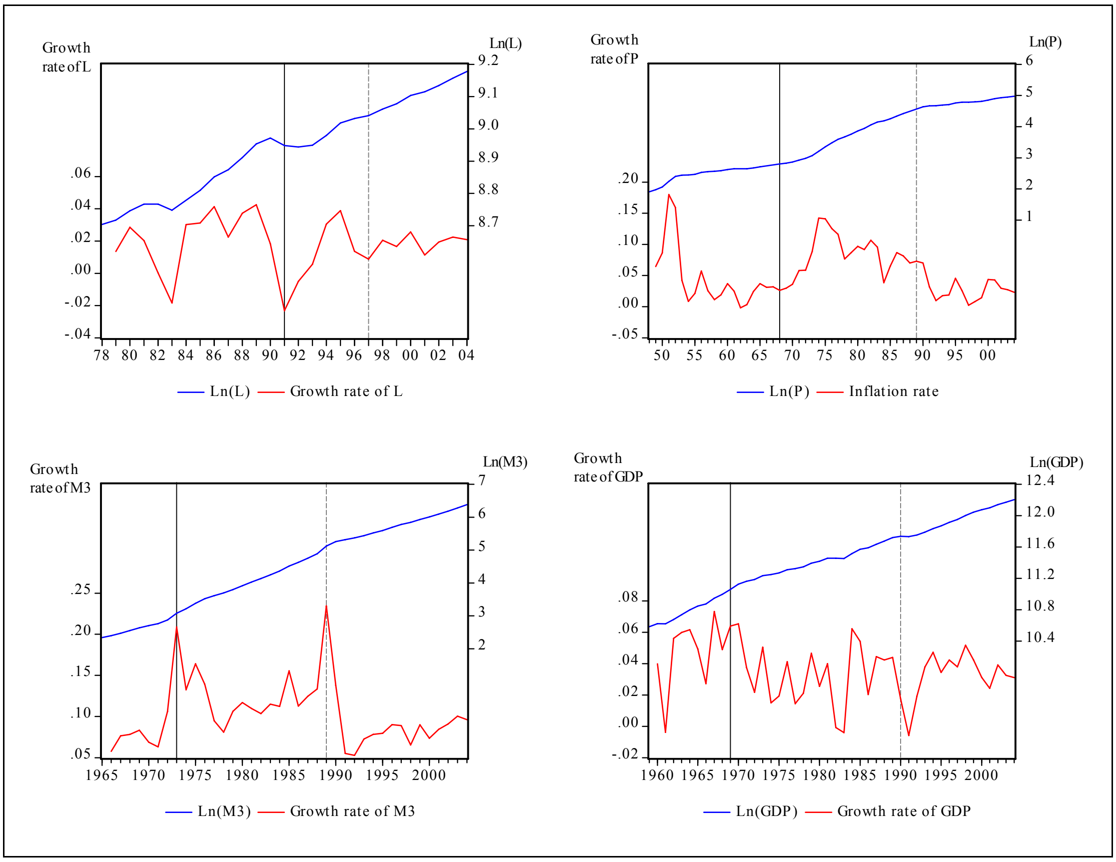
Figure 1: Plots of the actual data employed and the two endogenously determined structural breaks (continued)



Source: Australian Bureau of Statistics (2005a, 2005b, 2005c) and Reserve Bank of Australia (2005). The monthly and quarterly data are converted to annual data by the average observation method.

Note: The two endogenously determined times of structural break (*TB1* and *TB2*) are shown above with solid and dashed lines, respectively.

Figure 1: (continued) Plots of the actual data employed and the two endogenously determined structural breaks



Source: Australian Bureau of Statistics (2005a, 2005b, 2005c) and Reserve Bank of Australia (2005). The monthly and quarterly data are converted to annual data by the average observation method.

Note: The two endogenously determined times of structural break (*TB1* and *TB2*) are shown above with solid and dashed lines, respectively.

However in the case of real private investment both the estimated θ and γ capturing *TB1* are statistically insignificant, supporting the view that only one structural break (*i.e. TB2* shown by the dashed line in Figure 1) is highly significant. As can be seen from the corresponding graph of $Ln(Ip_t)$ in Figure 1 the break point *TB2* indicated by the dotted line is more pronounced than the solid line for *TB1*.

Table 2 also presents the time of structural breaks for each and every variables in the second column. For majority of the variables the endogenously determined break dates closely correspond to (a) the oil shock in the 1973-75; (b) the peak of financial reforms during the late 1980s; and (c) the profound effects of the very deep and prolonged 1990-1991 recession on the Australian economy. It should be noted that as a net energy exporter the 1973-74 oil price supply shock did not have the same deleterious effects in Australia as in other western countries around the world. However, a large current account surplus (with fixed exchange rates), along with a surge in nominal wages (about 25% annual growth in 1974), very significantly in advance of any productivity growth at the time, brought about Australia's own version of "stagflation" in the 1974-76 period.

Table 1: The ADF Test Results: $\Delta y_t = \mu + \beta t + \alpha y_{t-1} + \sum_{i=1}^{k} c_i \Delta y_{t-i} + \varepsilon_t$

Description	Available sample period	Variable	μ	β	α	k
Private consumption	1959-2004	$Ln(C_t)$	0.9524 (2.00)	0.0031 (1.84)	-0.0943 (-1.94)	1
Real government consumption	1959-2004	$Ln(G_t)$	0.4181 (1.29)	0.0009 (0.60)	-0.0422 (-1.10)	0
Real private gross fixed capital formation	1959-2004	$Ln(I_{Pt})$	2.8357 (2.91)	0.0143 (2.98)	-0.3449 (-2.89)	1
Real Public gross fixed capital formation	1959-2004	$Ln(I_{gt})$	1.5999 (2.83)	0.0039 (2.15)	-0.2025 (-2.74)	0
Real total exports	1959-2004	$Ln(X_t)$	2.2118 (2.73)	0.0167 (2.64)	-0.2926 (-2.66)	0
Real total imports	1959-2004	$Ln(M_t)$	3.0864 (3.07)	0.0218 (3.07)	-0.4018 (-3.03)	0
Real gross domestic product	1959-2004	$Ln(GDP_t)$	1.1674 (1.95)	0.0035 (1.73)	-0.1095 (-1.87)	0
Total employed persons	1978-2004	$Ln(L_t)$	4.0520 (3.67)	0.0091 (3.61)	-0.4971 (-3.65)	1
Consumer price index	1948-2004	$Ln(P_t)$	0.0726 (1.90)	0.0017 (1.33)	-0.0303 (-1.43)	2
Money supply (M3)	1965-2004	$Ln(M3_t)$	0.0874 (3.20)	0.0101 (1.55)	-0.0947 (-1.62)	1

Notes: (1) the null hypothesis of unit root cannot be rejected at the 5 and 10 per cent significance levels. (2) The figures in the parentheses are t ratios. (3) For compactness the estimated $c_i s$ are not reported but they are available from the authors upon request. (4) The optimal lag length (*k*) is determined by the Schwarz criterion.

Table 2: The Lumsdaine and Papell Test Results:

$$\Delta y_t = \mu + \beta t + \theta DU1_t + \gamma DT1_t + \omega DU2_t + \psi DT2_t + \alpha y_{t-1} + \sum_{i=1}^{K} c_i \Delta y_{t-i} + \varepsilon_t$$

Variable	*TB1* *TB2*	μ	β	θ	γ	ω	ψ	α	*k*
$Ln(C_t)$	1975 1993	12.4854 (9.86)	0.0591 (9.98)	0.3885 (9.37)	-0.0237 (-9.97)	-0.4579 (-9.09)	0.0123 (9.23)	-1.2510 (-9.84)*	1
$Ln(G_t)$	1975 1985	9.1003 (6.53)	0.0534 (5.45)	0.3059 (4.86)	-0.0166 (-4.38)	0.2333 (3.97)	-0.0071 (-3.27)	-1.0538 (-6.39)	5
$Ln(I_{Pt})$	1974 1991	8.7958 (6.38)	0.0528 (5.39)	-0.0583 (-0.76)	-0.0079 (-1.43)	-0.8960 (-5.01)	0.0220 (4.57)	-1.0308 (-6.32)	3
$Ln(I_{gt})$	1975 1989	19.3276 (5.10)	0.1444 (4.67)	1.5834 (4.27)	-0.0987 (-4.32)	0.8320 (3.71)	-0.0212 (-3.41)	-2.6181 (-5.06)	7
$Ln(X_t)$	1980 2000	5.6285 (5.48)	0.0415 (5.35)	-0.3362 (-4.13)	0.0086 (2.97)	2.1604 (3.04)	-0.0515 (-3.16)	-0.7014 (-5.43)	0
$Ln(M_t)$	1968 1986	10.4548 (6.96)	0.1105 (6.11)	0.4957 (4.56)	-0.0557 (-4.22)	-1.0010 (-5.85)	0.0348 (5.86)	-1.3131 (-6.97)**	1
$Ln(GDP_t)$	1969 1990	6.7387 (5.86)	0.0200 (5.32)	0.0698 (4.062)	0.0000 (0.00)	-0.1135 (-3.08)	0.0029 (2.54)	-0.6371 (-5.82)	8
$Ln(L_t)$	1991 1997	25.6180 (11.91)	0.0914 (13.52)	0.5434 (8.58)	-0.0437 (-9.67)	-0.2328 (-6.55)	0.0104 (5.24)	-3.0088 (-11.92)*	8
$Ln(P_t)$	1968 1989	0.6718 (5.37)	0.0122 (4.67)	-0.3555 (-4.09)	0.0154 (3.87)	0.6972 (4.90)	-0.0166 (-4.93)	-0.3304 (-5.81)	8
$Ln(M3_t)$	1973 1989	1.9724 (10.11)	0.0715 (7.74)	-0.1759 (-3.09)	0.0335 (4.06)	0.8637 (10.03)	-0.0292 (-9.87)	-0.9038 (-10.29)*	3

Notes: (1) * and ** indicate that the corresponding null is rejected at the 5 and 10 per cent levels, respectively. (2) The optimal lag length (*k*) is determined by the general to specific method (the *t* test). (3) Following LP (1997) and Ben-David *et al* (2003), with annual data we have also assumed that *Kmax*=8.

Figure 1 shows the log and the growth rate of each of the ten variables employed as well as their corresponding two structural breaks indicated by a solid line (*TB1*) and a dashed line (*TB2*), respectively. A cursory look at Figure 1 show that the resulting break dates coincide with major turnings points in **both** the intercept and the trend of the variables under investigation.

4. Concluding Remarks

This paper uses available annual data to determine endogenously the two most important years when structural breaks occurred in the ten major macroeconomic variables of the Australian economy. These variables are as follows: private real consumption, $Ln(C_t)$; government real consumption, $Ln(G_t)$; private real gross fixed capital formation, $Ln(Ip_t)$; public real gross fixed capital formation, $Ln(Ig_t)$; real exports, $Ln(X_t)$; real imports $Ln(M_t)$; real gross domestic product $Ln(GDP_t)$; employment $Ln(L_t)$; the consumer price index $Ln(P_t)$; and the money supply $Ln(M3_t)$. For this purpose we use both the ADF test and the LP (Lumsdaine and Papell, 1997) test to make robust conclusion about the time series properties of the data. It is found that according to the ADF test none of the variables under investigation is stationary. However, after allowing for two structural breaks, the LP test results indicate that the unit root null hypothesis is rejected at the 10 or 5 per cent levels for four out of ten variables. Most of structural changes are associated with either the 1973-75 oil shock or the peak of financial deregulation in the late 1980s or a severe recession engulfing the Australian economy in the early 1990s. This study sheds some light on the issue of structural breaks in the data and as such provides complementary evidence and useful results for future studies using macroeconomic variables. Since nonstationarity testing with multiple structural breaks may yield conflicting results to conventional ADF tests, future work could concentrate on such clear refinements.

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