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Testing for Structural Breaks in Australia's Monetary Aggregates and Interest Rates: An Application of the Innovational Outlier and Additive Outlier Models

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Abstract

This paper employs all quarterly time series currently available to endogenously determine the timing of structural breaks for various monetary aggregates and interest rates in Australia over the last thirty years. The Innovational Outlier model (IO) and the Additive Outlier model (AO) are then used to test for nonstationarity. After accounting for the single most significant structural break, the results from both models clearly indicate that the null of at least one unit root cannot be rejected for almost all series examined. The structural breaks found coincide with important policy changes during the period of financial deregulation starting in the 1980s.

I. INTRODUCTION

It goes without saying that 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 testing of the null hypothesis of structural stability against the alternative of a one-time structural break. 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).

Conventionally, dating of the potential break is assumed known *a priori* in accordance with the underlying asymptotic distribution theory. 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 argued that data-based procedures are typically used to determine the most likely location of a break: evidence of an endogeneity or sample selection problem. This invalidates the distribution theory underlying conventional testing.

In response, a number of studies have developed different methodologies for endogenising dates, including Zivot and Andrews (1992), Perron (1997), Lumsdaine and Papell (1998) 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), has 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.

The purpose of this paper is to employ the IO and AO models to examine structural breaks in money aggregates and interest rates associated with Australian financial deregulation from the 1980s. The detection of structural breaks within these time series will present clear and novel evidence of the impact of this important period of institutional and regulatory change. Perron (1997: 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 monetary aggregates and interest rate series examined are the natural logs of quarterly observations for the longest period available. The monetary measures are the monetary base (MB), M1, M3, and broad money (BM), measured in AUD billions and expressed in constant prices using the consumer price index (1989/90 = 100). The interest rate variables are RS (a short-term interest rate proxied by the yield on 90-day bank accepted bills and RL (a long-term rate proxied by the yield on 10-year Treasury bonds).

The remainder of the paper is as follows. Sections II and III briefly discuss the theoretical underpinnings of the IO and AO models, respectively. Section IV presents the empirical results and comparison is made between conventional unit root tests and those obtained with the IO and AO models. Section V provides some concluding remarks.

II. INNOVATIONAL OUTLIER MODELS

The IO1 model allows for gradual changes in the intercept and the IO2 model accommodates gradual changes in both the intercept and the slope of the trend function, such that:

$$\text{IO1:}\ x_t = m + q\,DU_t + b\,t + d\,D(T_b)_t + a\,x_{t-1} + \sum_{i=1}^{K} c_i \Delta x_{t-i} + e_t \tag{1}$$

$$\text{IO2:}\ x_t = m + q\,DU_t + b\,t + g\,DT_t + d\,D(T_b)_t + a\,x_{t-1} + \sum_{i=1}^{K} c_i \Delta x_{t-i} + e_t \tag{2}$$

where T_b denotes the time of break ($1<T_b<T$) which is unknown, $DU_t = 1$ if $t > T_b$ and zero otherwise, $DT_t = T_t$ if $t > T_b$ and zero elsewhere, $D(T_b)_t = 1$ if $t=Tb+1$ and zero otherwise, x_t is any general ARMA process and e_t is the residual term assumed white noise. The null hypothesis of a unit root is rejected if the absolute value of the *t*-statistic for testing $\alpha=1$ is greater than the corresponding critical value. Perron (1997) suggests that T_b (the time of structural break) can be determined by two methods. In the first approach, equations (1) or (2) are sequentially estimated assuming different T_b with T_b chosen to minimize the *t*-ratio for $a = 1$. In the second approach, T_b is chosen from among all other possible break point values to minimize the *t*-ratio on the estimated slope coefficient (g)

The truncation lag parameter or k is determined using the data-dependent method proposed by Perron (1997). In this the choice of k depends upon whether the *t*-ratio on the coefficient associated with the last lag in the estimated autoregression is significant. The optimum k (or k^*) is selected such that the coefficient on the last lag in an autoregression of order k^* is significant and that the last coefficient in an autoregression of order greater than k^* is insignificant, up to a maximum order k (Perron, 1997). With quarterly data, $k_{\max} = 8$

(Lumsdaine and Papell 1998). The IO2 model allowing for a change in both the intercept and slope is also specified.

III. ADDITIVE OUTLIER MODEL

In contrast to the gradual change in the IO model, the AO model assumes structural changes take place instantaneously. Testing for a unit root in the AO framework is then given by a two-step procedure (Perron, 1994). To start with, the trend is removed from the series:

$$y_t = m + b\,t + g\,DT_t* + \tilde{y}_t \qquad (3)$$

where $\tilde{y}_t$ is the detrended series. Since equation (3) assumes that a structural break only impacts on the slope coefficient, the following is then estimated to test for a change in the slope coefficient:

$$\tilde{y}_t = a\,\tilde{y}_{t-1} + \sum_{i=1}^{K} c_i \Delta y_{t-i} + e_t \qquad (4)$$

Similarly to the IO methodology, these equations are estimated sequentially for all possible values of T_b ($T_b = k + 2,..,T$-1) where T is the total number of observations so as to minimise the t-statistic for a =1. The lag length is data-determined using the general to specific, and the break date is assumed to be unknown and endogenously determined by the data. The null hypothesis is rejected if the t-statistic for a is larger in absolute value than the corresponding critical value. An alternative, which is more widely used is to select T_b as the value, over all possible break dates, that minimizes (or maximizes) the value of the t-statistic on g=0 (Harris and Sollis 2003). This approach has been used in this study.

IV. EMPIRICAL RESULTS

Table 1 presents the data definitions and sources of the monetary measures and interest rates examined. The results of conventional ADF tests (with constant and trend) up to a maximum of 5 truncation lags are also presented. As shown, all variables are non-stationary (contain at least one unit root) for the sample period under investigation. However, and as discussed earlier, applying the ADF unit root test may be biased towards non-rejection of the unit root hypothesis.

That said, there is little evidence as to which of the two models specified above is most appropriate to capture the effect of an endogenous structural break on the hypothesis tests. If a series truly exhibits a trend, then estimating a model (such as IO1) that does not have a trend variable may fail to capture some important characteristics of the data. On the other hand, if there is no upward or downward trend in the data, the test power to reject the no-break null hypothesis is reduced as the critical values increase with the inclusion of a trend variable (Ben David and Papell, 1997). Since visual inspection of the time series indicate upward or downward trends (see Figure 1), the IO2 model and the AO model (allowing for a change in slope) are used. Nonetheless, since $t_{\hat{g}}$ is highly significant in all estimates, the inclusion of a change (break) in slope is also justified *ex post*.

In order to decide which particular IO model is most relevant, the following model selection procedure is adopted. First, the least restrictive model (IO2) is estimated and if $t_{\hat{g}}$ is significant at the 5 percent level or better, then the results are reported in Table 2. If $t_{\hat{g}}$ is not statistically significant, then the results of an IO1 model are presented. Since $t_{\hat{g}}$ for all estimated equations are highly significant, only the results of the IO2 model are tabled. In order to determine the sudden effect of an unknown structural break, the AO model is also estimated and the results presented in Table 3.

Based on the results in Tables 2 and 3, the primary results of the analysis are as follows. First, the AO model statistics indicate that all series under investigation are non-stationary. This is consistent with the results of the ADF tests in Table 1. It then appears that capturing the most important structural break by the AO model has not challenged any inferences about time series property of the data garnered by conventional ADF tests. Similar results are obtained using the IO2 procedure, suggesting all variables are non-stationary with the exception of *MB*.

Second, the timing of any structural break (T_b, year and quarter) for each series using both the IO and AO approaches are shown in Tables 2 and 3, respectively. Possible causes of the structural breaks found in each series are presented in the last column of each table. The IO2 model shows that these dates closely approximate major policy changes occurring during financial deregulation in the 1980s.

The timing of the structural changes based on the IO2 model (impacting on both the intercept and the slope of each series) are represented by a solid line in Figure 1, with a dotted line for the AO model. Depending on the series in question there are between 113 and 181 quarterly observations covering the last three to five decades in Australian economic history.

Table 1. *Data description, sources and ADF test results*

Description of series	Variable	Source	Data available	ADF t-statistic	Optimal lag length[4]	Inference
Monetary base	MB		1975:01-2004:03	-2.776	1	Non-stationary
Currency	CUR		1959:03-2004:03	-3.365	4	Non-stationary
M1	M1	Reserve Bank of Australia Bulletin (2005), *Monthly Money and Credit Statistics*.	1975:01-2004:03	-2.066	1	Non-stationary
M3	M3		1965:01-2004:04	-1.014	1	Non-stationary
Broad money	BM		1976:03-2003:04	-2.143	3	Non-stationary
Consumer price index	P	Australian Bureau of Statistics (2005) *Consumer Price Index*, Cat. No. 6401.0	1976:03-2003:01	-1.430	5	Non-stationary
90-day bank accepted bills	RS	Australian Bureau of Statistics (2005) *Modellers' Database*, Cat. No. 1364.0	1955:01-2004:03	-1.584	5	Non-stationary
10-year Treasury bonds	RL		1959:01-2004:03	-0.974	4	Non-stationary

Notes: Akaike Information Criterion (AIC) used to determine the optimal lag length in the ADF equation (log form). Trend and intercept included.

Table 2. *IO model with a change in both intercept and slope*

Variable	Lag $\hat{e}$	$t_{\hat{b}}$	$t_{\hat{q}}$	$t_{\hat{g}}$	$\hat{a}$	$t_{\hat{a}}$	Inference	Break T_b	Possible causes
Ln(MB)	8	5.98	3.30	-2.39	0.63	-6.09	Stationary	1996q1	1996: – Wallis Inquiry into financial system established
Ln(M1)	1	-0.53	-1.812	2.25	0.91	-2.24	Non-stationary	1982q4	1982: – Removal of quantitative control on bank lending – Treasury bonds tender system introduced – Minimum terms on many other fixed deposits removed – End of quantitative lending guidance
Ln(RS)	5	2.74	3.57	-3.71	0.87	-3.90	Non-stationary	1980q3	1980: – Interest rate ceiling on bank deposit rates lifted
Ln(RL)	3	2.98	3.99	-4.08	0.90	-4.13	Non-stationary	1979q4	1979: – Establishment of the Campbell Committee – Treasury notes are offered at tender for the first time
Ln(M3)	1	2.99	-3.73	3.96	0.894	-3.80	Non-stationary	1980q3	1980: – Interest rate ceiling on bank deposit rates lifted
Ln(BM)	3	3.75	-3.49	3.50	0.81	-3.96	Non-stationary	1992q2	1992: – 1991/92 Recession – Review of credit risk management system conducted

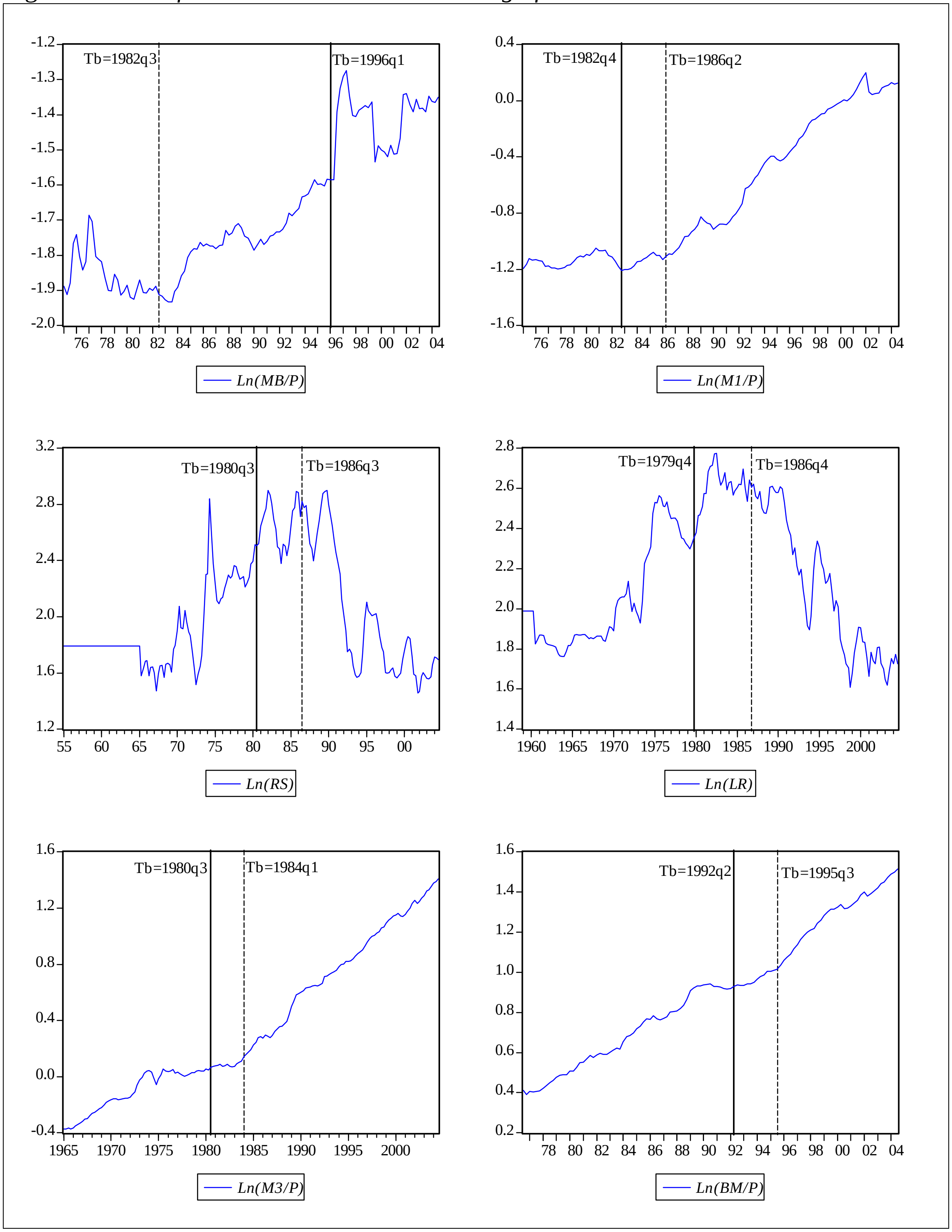
Notes: Where the number of observations is more than 100 (infinite sample), the critical values at the 1% and 5% are -5.68 and -5.05, respectively (Perron, 1997).

Table 3. *AO model with a change in slope only*

Variable	K	$\hat{g}$	$t_{\hat{g}}$	$\hat{a}$	$t_{\hat{a}}$	Inference	Break T_b	Possible causes
Ln(MB)	8	0.01	9.67	0.73	-3.87	Non-stationary	1982q3	1982: – End of quantitative lending guidance – The removal of minimum terms on many other fixed deposits – Treasury bonds tender system introduced
Ln(M1)	1	0.02	24.7	0.90	-2.40	Non-stationary	1986q2	1986: – Interest rate ceiling on new housing loans removed – Statutory reserve deposits phased out – Non-bank financial institutions permitted to issue payment orders
Ln(RS)	5	-0.03	-19.9	0.89	-3.52	Non-stationary	1986q3	
Ln(RL)	3	-0.02	-25.6	0.90	-3.72	Non-stationary	1986q4	
Ln(M3)	1	0.008	29.2	0.91	-3.40	Non-stationary	1984q1	1984: – Stock exchange deregulated – Saving banks offer cheque accounts – Non-bank financial institutions admitted as foreign exchange dealers – Bank deposit rate and maturity restrictions removed
Ln(BM)	3	0.003	8.02	0.89	-3.07	Non-stationary	1995q3	1995: – Banks allowed limited equity in small/medium businesses

Notes: Where the number of observations is more than 100 (infinite sample), the critical values at the 1% and 5% are -5.68 and -5.05, respectively (Perron, 1997).

Figure 1. *Plots of the series and estimated timing of structural breaks*



Note: The time (T_b) of structural breaks based on: (a) the IO2 model (impacting on both the intercept and the slope of each series) is shown by a solid line (b) the AO model (impacting on the slope only) is indicated by the dotted line.

It is interesting to observe that the results of both the IO2 and AO models indicate that endogenously determined structural changes coincide with the extensive program of financial deregulation.

Consider the example of the IO model (Table 2) and the *M1* monetary measure. As indicated, the most major structural break in this series (indicating a significant change in both the intercept and the slope) over the period 1975-2003 occurred in 1982q4. This particular break may be attributed to the gradual effects of several policy changes during this time, including: (i) the relaxation of the maturity restrictions on certificate of deposits; (ii) removal of some restrictions on Australian overseas investments; (iii) removal of quantitative controls on bank lending; and (iv) introduction of the new Treasury bonds tender system. In addition, a sudden change in the slope of *M1* as derived from the AO model occurred in 1986q2. One argument is that this particular structural break corresponds with several policy changes in 1986 including: (i) the removal of ceiling rates on new home loans: (ii) the abolition of statutory reserve deposits; and (c) regulatory permission for non-bank financial institutions to issue payment orders (Juttner and Hawtrey, 1997).

As another example consider the *M3* monetary measure. From the mid-1970s until 1985, monetary policy was conducted in Australia by targeting the annual growth of *M3*. However, this policy was then abandoned because deregulation of the financial system had made *M3* a misleading indicator of the stance of monetary policy (Grenville, 1990). Table 3 and Figure 1 indicate that this policy change caused a significant structural break in *M3* in 1984q1. It is also worth noting that none of the subsequent policy changes resulted in such an obvious change in the slope of *M3.* A change in both in the intercept and the slope of this series in 1980q3 is also detected with the IO model in Table 2.

V. CONCLUSION

This paper uses all available quarterly data to time endogenously the most important structural breaks in four monetary aggregates and two interest rate series in the Australian economy. Both the Innovational Outlier (IO) (assuming gradual changes in intercept and/or slope) and the Additive Outlier (AO) (assuming instantaneous changes in intercept) models are used. The results indicate that the most significant structural breaks detected over the more than thirty year sample period correspond to policy changes associated with financial deregulation in the 1980s.

That is, while there are other events that may have affected these time series over the sample period, major structural change is concentrated in the period of financial deregulation. This provides complementary evidence to models employing exogenously imposed structural breaks in the Australian macroeconomy.

The empirical results based on these models do not provide much evidence against the null hypotheses of unit roots in these series. In other words, despite considering structural breaks in all series, almost all monetary aggregates and financial variables examined are found to be I(1). This is consistent with the results obtained by conventional ADF testing. However, while Perron’s (1997) approach is the most advanced method to endogenously detect the single most significant structural break, these models are unable to identify multiple structural breaks. 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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