Non-renewable Resource Prices: Structural Breaks and Long Term Trends

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May 2009

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April 28, 2009

ABSTRACT

In this paper we examine the time series properties of nine non-renewable resources. In particular we are concerned with understanding the relationship between the number of structural breaks in the data and the nature of the resource price path, i.e. is it stationary or a random walk. To undertake our analysis we employ a number of relevant econometric methods including Bai and Perron's (1998) multiple structural break dating method. Our results indicate that these series are in many cases stationary and subject to a number of structural breaks. These results indicate that a deterministic model of resources prices may well be appropriate.

JEL codes: Q31, C12
Keywords: structural change, non-renewable resources, breaks, resource depletion

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1 Introduction

This paper analyses the behaviour of real prices of nine natural resources between 1870 and 1990 (coal, copper, lead, aluminium, iron, nickel, petroleum, silver and tin). The key theoretical issue motivating this research is whether or not exogenous shocks alter the resource price time path. For the most part the issue is not whether shocks are transitory or permanent. A quick look at many non-renewable resource series clearly shows that most of them contain evidence of some drift over the period under consideration. It appears to us that it is implausible that, over a sufficiently long period of time, real prices for these resources are stationary. Conclusions about the stationarity properties of real natural resource prices depend greatly on what time frame one uses. In terms of plausible explanations, three characterisations of long run change appear to be relevant (i) episodic mean shifts versus (ii) stationarity around deterministic trends versus (iii) stochastic trends. In this paper, our data and analysis supports the first explanation (episodic mean shifts) for the majority of non-renewable price series. The theory relating to the driving forces behind these price movements is more ambiguous. There exist a number of papers that have examined the issue of non-renewable resource price paths in an effort to understand which theory or theories best describes observed behaviour (e.g., Slade, 1982, Berck and Roberts, 1996, Ahrens and Sharma, 1997 and Lee et al., 2006). The econometric methods employed in these papers have followed broader trends in the time series literature. Using classical statistical methods, the non-renewable resources literature has considered the existence or otherwise of unit roots in the data, the existence of a single structural break in the data and most recently unit roots and two structural breaks. As is well known ignoring structural changes in classical unit root tests gives rise to a bias against rejecting the unit root null hypothesis. A recent paper by Lee et al. (2006) provides results that indicate all the data series enumerated above are stationary around a deterministic trend, with two structural breaks in the intercept and trend slope.

In this paper, we make a contribution to this literature by extending the type of econometric methods employed to examine these data. Specifically, we determine the presence (or otherwise) of structural breaks and test for unit roots in our time series data. The methods employed in this paper allow us to examine if there are more than two structural breaks in the data. The main reason for addressing this issue is that there is no *a priori* reason to assume that there are only at most two breaks in the data.

The classical approach employs tests for the number of structural breaks by constructing test statistics for the number of breaks using supremum F values which have non-standard distributions, essentially considering deviations from stability (Bai and Perron, 1998 and 2003). The null hypothesis is that regression coefficients remain constant, against the alternative that at least one coefficient varies over time. Allowing for μ-break points where the coefficients shift from one stable regression relationship to a different one, we have $\mu + 1$ segments where regression coefficients are constant. In practice the breakpoints are rarely given exogenously, but have to be estimated. Breakpoints are estimated by minimising the residual sum of squares. Tests are based on a sequence of F-statistics for a change at time t: the OLS residuals from a segmented regression, i.e. one regression for each subsample with breakpoint i are compared to the residuals from the unsegmented model. These F-statistics are then computed and the null hypothesis (stationarity) is rejected if their supremum F (or average or exp functional) is “too large”.

The structure of this paper is as follows. In Section 2 we briefly review the literature that has considered the time series properties of non-renewable resources. We also consider the literature that examines the validity of the Hotelling Principle, which provides a theoretical basis describing resource price paths. Next we describe the various econometric methods employed in the paper. The emphasis is on providing the reader with a clear overview of the methods employed. In Section 4 we provide a brief description of the data and in Section 5 we present our results. Finally, in Section 6 we conclude.

2 Non-Renewable Resources, Prices and Theory

There is a long and diverse literature that has examined price series behaviour of non-renewable resources. The motivation for this research is varied. For example, Barnett and Morse (1963) consider whether non-renewable resources are becoming more scarce as reflected by increasing prices. The question has subsequently been addressed by many authors including Smith (1979), Slade (1982), Berck and Roberts (1995), Aherns and Sharma (1997) and Lee et al. (2006). The findings in this literature are, at best, mixed. Thus, there continues to be more research published on this topic. A recent example is Svedberg and Tilton (2006) who have examined copper prices between 1870 and 2000, observing that the price path appears to display no upward or downward trend. At the same time, this research is also presented as a test of the Hotelling Principle (Hotelling, 1931) as noted by Lee et al. (2006).

The importance of time series properties in the these data has gradually been recognised in the literature. Initial research all but ignored time series properties but the development of time series methods brought with it a realisation that these prices also had to be examined using appropriate econometric methods. Indeed, Withagen (1998) in an informative review of the non-renewable resources literature argued that *"It should be worthwhile to investigate further the issue of unit roots in resource prices* (p. 629)."

To date, the results obtained in the literature about the behaviour of the price series are mixed, as Slade and Thille (2006) observe. However, in their analysis of product markets and forward markets for various metals, they assume that price data are mean-reverting. They support this view with two reasons, one of which is *"we feel that the evidence in favour of non-stationarity is not compelling* (page 241)."

Finally, it is important to note that there is related literature that has empirically tested the validity of the Hotelling Principle in a number of different ways. For example, some researchers have examined the properties of *in-situ* prices (e.g. Cairns and Davis, 2005 and Eisenhauer, 2005). The hypothesis being examined here is whether the present discounted value of resource to be mined equals the current market prices. This literature provides minimal support for the theory. In contrast Livernois et al. (2006) examine scarcity rents for timber. As they correctly observe, there is no reason why resource price paths cannot increase as well as decrease and still be consistent with Hotelling. As they explain, once activities such as exploration or technological change are included in the basic model, the price path no longer needs to rise at all points.

3 Methodology

3.1 Zivot and Andrews' procedure

Zivot and Andrews (1992) extend the familiar Dickey and Fuller (DF) procedure to allow for the simultaneous estimation of possible breakpoints for the intercept and slope of the trend model. Their method addresses possible problems which arise when choosing structural breakpoints by simple visual examination of the plots of the time series. Such issues arise because plots of drifting unit root processes can often be very similar to processes that are stationary about a trend with a break. Zivot and Andrews' (1992) test is based upon the recursive estimation of a test regression, where the test statistic is defined as the minimum t-statistic of the coefficient of the lagged endogenous variable. The null hypothesis of the ZA test is that the time series is integrated (i.e. has a unit root) and no exogenous structural break. The unit-root null hypothesis is rejected if the test-statistic is more negative than the critical value. If this is the case the time series are considered trend stationary about a deterministic trend with a single breakpoint.

3.2 Bai and Perron's approach for multiple structural breaks: The theory

Our empirical estimation method is concerned with testing or assessing deviations from stability in the classical linear regression model (for further details, see also Zeileis et al., 2003 and Kleiber and Zeileis, 2005):[1]

$$z_t = x_t^\top \beta_t + v_t \tag{1}$$

where at time t, z_t is the observation of the dependent variable, x_t is a $\lambda \times 1$ vector of regressors, (first component conventionally equals unity) and β_t is the $\lambda \times 1$ vector of regression coefficients, which may vary over time. We are testing the hypothesis that the regression coefficients remain constant over time:

$$H_0: \ \beta_t = \beta_0 \quad (t = 1, ..., n) \tag{2}$$

against the alternative that at least one regression coefficient varies over time (or is non-constant). In many practical contexts, it is plausible to assume that there exist μ breakpoints, where the regression coefficients shift from one stable regression relationship to a different one. As a result, there exist $\mu + 1$ segments in which the regression coefficients are constant. We can then rewrite the model as

$$z_t = x_t^\top \beta_j + v_t \qquad (t = t_{j-1} + 1, ..., t_j, j = 1, ..., \mu + 1) \tag{3}$$

where j indicates the segment index. In practical applications, these breakpoints k_j are rarely available exogenously (and they are usually unknown to us), so these have to be empirically determined. These breakpoints can be identified by minimising the residual sum of squares (RSS) for the equation given above. We thus have $\mathcal{G}_{\mu,n} = \{\lambda_1, ..., \lambda_\mu\}$ which denotes the set of identified breakpoints (or the μ-partition).

In the next step, Andrews and Ploberger (1994) type F statistics are employed to test against an alternative hypothesis indicating a single-shift of unknown timing, viz.

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[1] We employ `R` 2.9.0 [www.r-project.org] for our estimations and use the packages `strucchange` and `breakpoint` intensively.

model 3 with $\mu = 1$. Tests against this alternative are computed on the basis of a sequence of F statistics for a change at time t. OLS residuals $\hat{v}(t)$ obtained from a segmented regression which simply arises from one regression for each subsample, with breakpoint t, are compared to the residuals $\hat{v}$ computed from the unsegmented model using:

$$F_t = \frac{\hat{v}^\top - \hat{v}(t)^\top \hat{v}(t)}{\hat{v}(t)^\top \hat{v}(t)/(n - 2\lambda)} \tag{4}$$

Using this equation, F statistics are computed for $k = n_\theta, ..., n - n_\theta(n_\theta \geq \lambda)$. We reject H_0 if their supremum or average or exp functional is 'too' large (see Andrews and Ploberger, 1994). Hansen (1997) has provided an algorithm for computing approximate asymptotic p values for these tests, which is implemented in `R`. A trimming parameter (ϕ) can also be chosen. The trimming parameter is defined as the minimal segment size in one of two ways: (i) either as a fraction relative to the sample size or (ii) as an integer providing the minimal number of observations in each given segment. Consequently, the asymptotic distribution will depend on this trimming parameter through the imposition of the minimal length ϕ of a segment, as given by:[2]

$$\phi = \frac{\theta}{T} \tag{5}$$

Bai and Perron (1998, 2003) extend this approach to F tests for 0 vs. κ breaks and κ vs. $\kappa + 1$ breaks with arbitrary but fixed κ.

3.2.1 Dating structural changes

Once we obtain a μ-partition $t_1, ..., t_\mu$ the corresponding least squares estimates for the β_j can easily be obtained. The minimal residual sum of squares that results is given by

$$RSS(t_1, ..., t_\mu) = \sum\nolimits_{j=1}^{\mu+1} rss(t_{j-1} + 1, t_j) \tag{6}$$

where $rss(t_{j-1} + 1, t_j)$ denotes the minimal residual sum of squares in the jth segment. As a result, the problem of identifying (dating) structural changes involves finding the breakpoints $\hat{t}_1, ..., \hat{t}_\mu$ that minimise the objective function over all given partitions $(t_1, ..., t_\mu)$ with $t_j - t_{j-1} \geq n_\theta \geq \lambda$:

$$RSS(\hat{t}_1, ..., \hat{t}_\mu) = argmin_{(\hat{t}_1, ..., \hat{t}_\mu)} RSS(\hat{t}_1, ..., \hat{t}_\mu) \tag{7}$$

For equation 7, solving for global minimisers through a grid search is computationally burdensome. One solution is to make use of hierarchical algorithms involving recursive partitioning or joining of subsamples (but these will not necessarily identify the global minimisers). Bai and Perron (2003) provide a version of such a dynamic programming algorithm, involving pure and partial structural change models in an OLS regression context, which is adopted in implemented in the `R` package `strucchange`. The basic idea employed is that of the Bellman's principle, so that the optimal segmentation satisfies the recursion:

$$RSS(\mathcal{G}_{\mu,n}) = min_{(\mu n_\theta \leq t \leq n - n_\theta)} [RSS(\mathcal{G}_{\mu-1,t}) + rss(t + 1, n)] \tag{8}$$

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[2] We use ϕ between 0.1 and 0.15, as is conventionally recommended.

Table 1: Data Summary

Non-Renewable Resource	Abbreviation	Years
ALUMINIUM	AL	1895-1984
COAL	CL	1870-1990
COPPER	CP	1870-1990
IRON	IR	1870-1973
LEAD	LE	1870-1990
NICKEL	NI	1913-1990
PETROLEUM	PT	1870-1989
SILVER	SI	1870-1990
TIN	TI	1885-1990

It is sufficient to identify for each point t the 'optimal previous partner' provided t was the last breakpoint in an μ-partition.

4 Data

The nonrenewable natural resources data that we have used in this paper have previously been employed by Ahrens and Sharma (1997) and Lee et al. (2006).[3] There are 9 annual data series for dates between 1870 and 1990. All data has been deflated by using a suitable producer index. A summary of the data periods covered by each series is presented in Table 1.

As can be seen from the Table 1 the data periods vary somewhat. A complete description of the data construction and the various sources used can be found in Ahrens and Sharma (1997: 66-67). We can observe that all the metals data are either flat or downward sloping and that oil and coal are both increasing. Figures 1 and 2 show time series plots of all variables in levels. We can see two distinct features: fossil fuels based resources (CL and PT) seem to exhibit (upward) trends, while no such regularities are visible from an examination of prices for metallic resources (the other seven resources).

5 Empirical results

The problem we face in this context is that unit root tests have low power and they tend to be invalidated completely in the presence of structural breaks. Additionally, operationalising the Bai and Perron method of dating structural breaks in the presence of (potentially) m structural breaks requires that the regressors should be stationary. Figures 3 and za2 graphically represent results obtained from Zivot and Andrews unit root tests, which allow for a single break. Figure 5 shows graphs indicating results obtained from the Bai and Perron procedure for four commodities (other graphs are available from the authors on request). Figure 5 clearly identifies the number of breaks as well as break dates for each series considered.

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[3] The data has been generously provided by Mark C. Strazicich.

5.1 Results

Table 2 shows results obtained from the Zivot and Andrews (1992) procedure for each individual resource. Tables 5 introduces our extension to the existing literature by considering multiple breakpoints, and not simply restricting the analysis to the case of one or two possible breaks. In Table 5 we present results obtained from Bai and Perron's multiple break dating procedure, which is based on an empirical fluctuation process. Breaks within the data are identified through a combination of the use of BIC measure and the use of supremum-F tests.

Table 2: Zivot and Andrews Test Result

Resource	**Test Statistic**	**Significance**	**Break Date Identified**
Aluminium	-2.8495		1891
Coal	-4.8368	**	1969
Copper	-4.004		1916
Iron	-4.9145	**	1947
Lead	-5.1945	***	1945
Nickel	-4.5124		1923
Petroleum	-6.3029	***	1973
Silver	-3.5918		1961
Tin	-4.8746	**	1970
ZA test critical values:			
SL	1%	5%	10%
Value	-5.34	-4.8	-4.58
Symbol	***	**	*

Unit Root Tests With A Single Structural Break (no trend).
Null: Unit root is present .

Table 3: Bai and Perron Multiple Breakpoint Test Result

Resource	**Number of optimal breaks**	**Break Dates Identified**
Aluminium	2	1905, 1916
Coal	1	1915
Copper	1	1912
Iron	1	1884
Lead	4	1907, 1945, 1957, 1978
Nickel	1	1977
Petroleum	5	1881, 1893, 1905, 1917, 1973
Silver	1	1973
Tin	1	1931

Criterion used: minimise BIC.

6 Conclusion

In this paper we have examined the time series properties for nine nonrenewable resource price series. The motivation for undertaking this research is that by identifying the actual properties of the data series we are better able to comment on whether or not these resources are subject to increasing degrees of resource scarcity. To undertake this research we have employed relevant econometric methods, particularly the Bai and Perron type multiple break dating method, which complements and extends those previously employed in the literature.

The key result we obtain is that for almost all the series, except silver, we find the data to be stationary around multiple breaks (i.e. two or more breaks). We then use the Bai and Perron (1998, 2003) method to identify structural breaks in the data.

For the most part, the key issue not whether shocks are transitory or permanent. A quick look at the series clearly shows that most of the series contain evidence of some drift over the period (Figures 1 and 2). Moreover, it is implausible that over a sufficiently long period of time, real prices for these resources are stationary. Conclusions about the stationarity properties of real natural resource prices depend greatly on what time frame one uses. In terms of plausible explanations, the competition is between three characterisations of long run change: (i) episodic mean shifts versus (ii) stationarity around deterministic trends versus (iii) stochastic trends. Arguably, our data and analysis supports the first explanation (episodic mean shifts) for the majority of the series. There is room for speculation regarding the driving forces behind these price movements. These could include supply factors such as 'new' discoveries, innovation in extraction technologies, productivity changes, as well as changes in regulation, scarcity and monopoly power. We could also consider demand factors such as expanding world markets and technical change, as partly driving trends. Ultimately, one key question is whether these factors are more open to being puncutated by big episodic changes or a slow process of evolution.

One important observation that we can make as a result of our analysis is that the time series behaviour of these data are in contrast to the macro time series data that are commonly reported in the literature. These results are interesting especially as so many of these commodities are traded in financial markets and as a result we would expect to see the presence of unit roots. This tends to suggest that price behaviour in these markets is influenced by factors such as market structure (e.g. monopolies), new discoveries and other factors that influence the actual prices we observe. It also the case that the multiple breaks we observe, that punctate periods of relatively calm price movements, are driven by particular events. Indeed, in the natural resources literature (e.g., Radetzki, 2006) it is recognised that there have been major commodity booms. For example, there is a recognised boom in 1950-51 as a result of the Korean war and another in 1973-74 because of the emergence of OPEC. It is very likely that it is events like these that induce the structural breaks and outside of these periods real prices are relatively unchanged.

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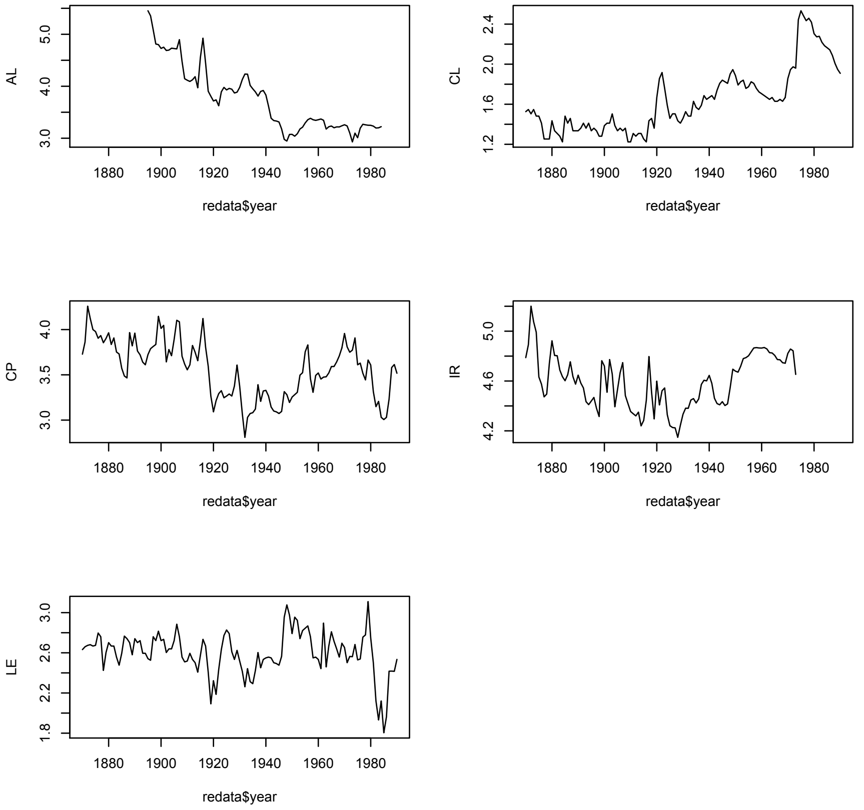

Figure 1: Series in levels (AL, CL, CP, IR and LE).

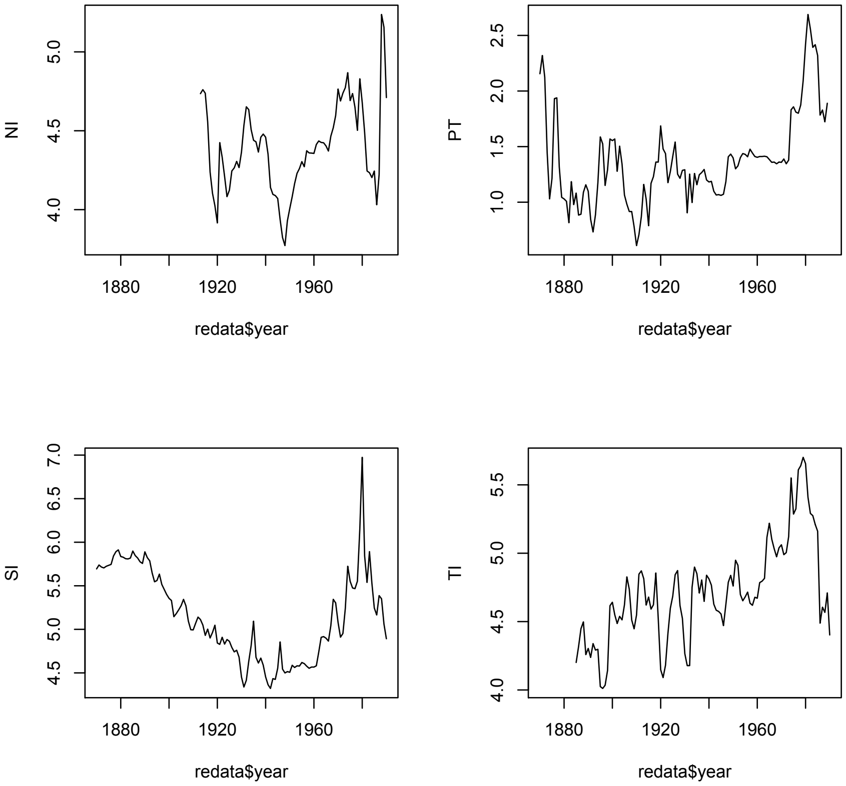

Figure 2: Series in levels (NI, PT, SI and TI).

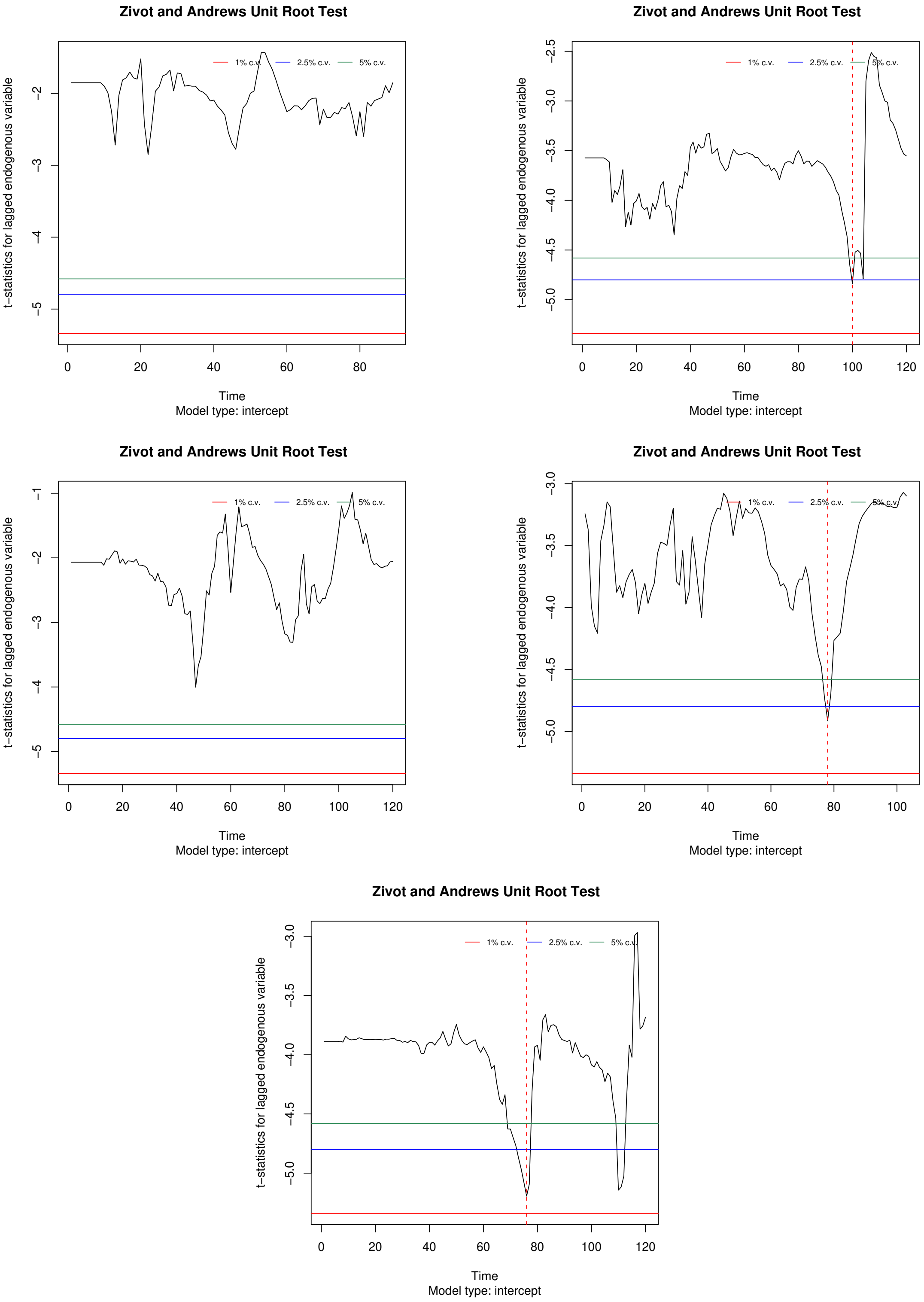

Figure 3: ZA Test results for: AL, CL, CP, IR, and LE.

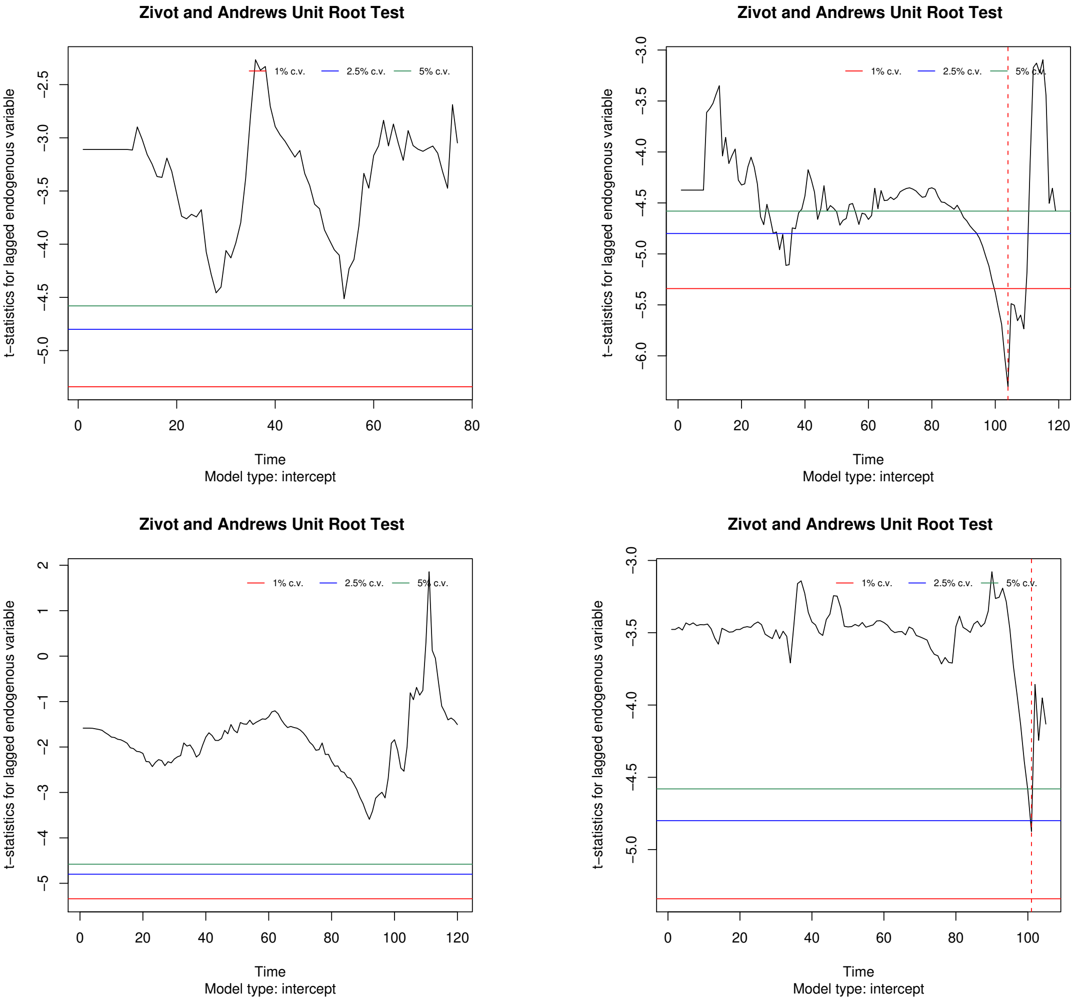

Figure 4: ZA Test results for: NI, PT, SI and TI.

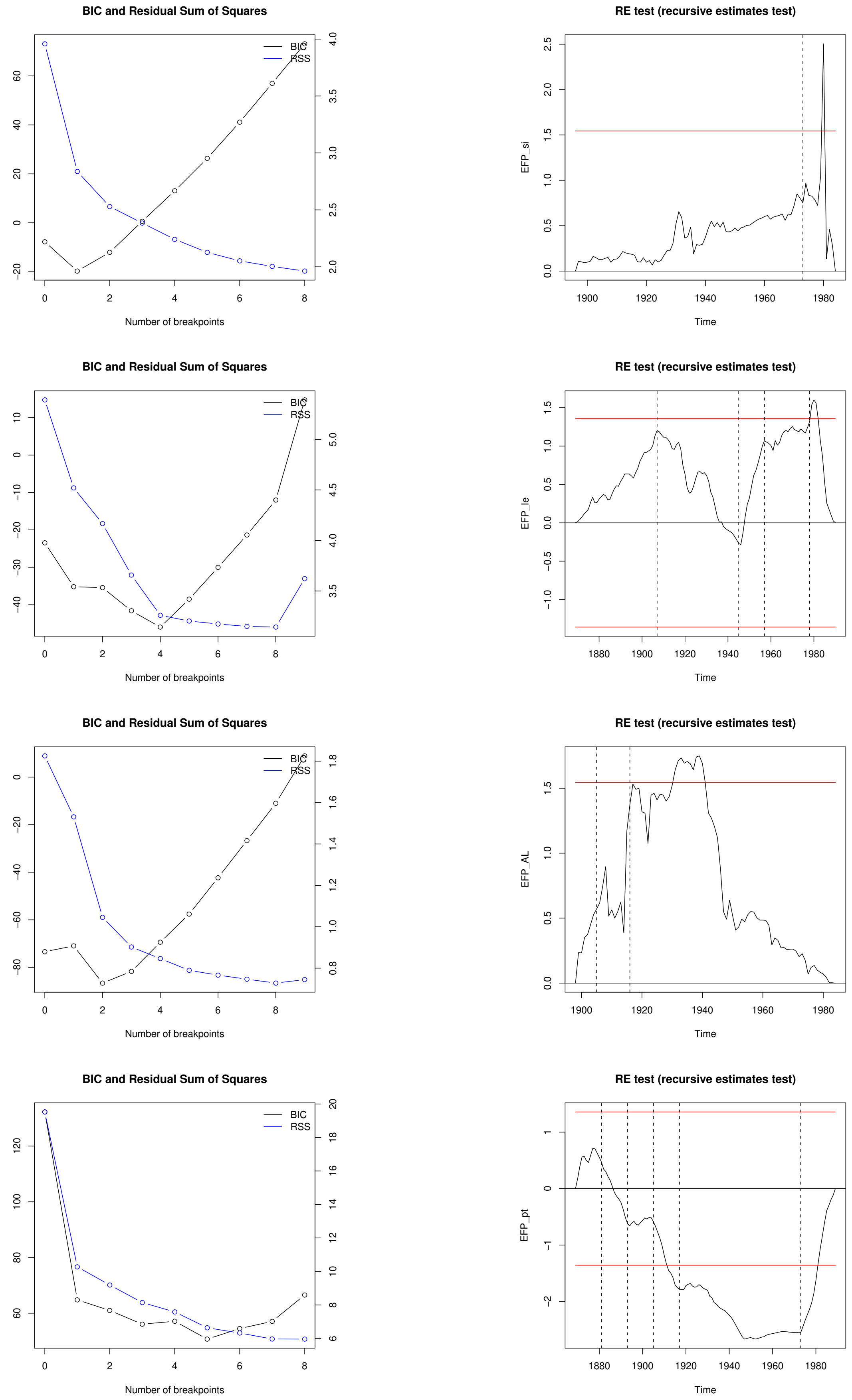

Figure 5: Bai and Perron test results for: Silver, Lead, Aluminium and Petroleum (top to bottom). Other results are available from the authors.