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Identifying Multiple Structural Breaks in Exchange Rate Series in a Finance Research

Alireza Zarei[1]*, Mohamed Ariff[2], Law Siong Hook[2] and Annuar Md Nassir[2]

[1]*Department of Financial Mathematics and Statistics, Sunway University, Malaysia*
[2]*Faculty of Economics and Management, University Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia*

ABSTRACT

This paper describes how to resolve a recurrent research problem in finance research, that is, how to identify and then take steps to correct structural breakpoints in time series data sets. A review of finance literature suggests that the familiar method of identifying breaks is by using news reports of events, which is not accurate in a formal sense, and will likely introduce estimation errors in research. There exist formal models, which are used to accurately identify breaks especially in long-time series to pre-test exchange rate data series as a pre-analysis step to accurately locate breaks that will help control estimation errors introduced from breakpoint impacts. The findings from testing four-country data series, using 651 months data of each country, suggested that the method described in this study identified breakpoints accurately, which was also verified using graphs. Therefore, it is suggested that this process is helpful for researchers to formally identify structural breakpoints as it greatly improves the robustness of estimation of exchange rate behaviour (apart from other financial variables).

Keywords: Multiple Structural breaks; Time series analysis; Exchange rates; Bai-Perron Model

INTRODUCTION

This paper reports new findings on an important empirical research problem of how to identify structural breaks in exchange rate behaviour so that the impacts of serious disturbances, known as breakpoints in the series, could be designed to be controlled when time series data on exchange rates are used by finance or accounting researchers. For example, several studies identified breaks or disturbances based on newspaper reports: Asian Financial Crisis breakpoints were identified in the time series as the observations over July, 1997

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E-mail addresses:
alirezaz@sunway.edu.my (Alireza Zarei),
ariff13@gmail.com (Mohamed Ariff),
lawsh@upm.edu.my (Law Siong Hook),
annuar@upm.edu.my (Annuar Md Nassir)
* Corresponding author

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and October, 1998, and Global Financial Crisis breakpoints were specified for observations during April, 2007 to October, 2009 (Ariff *et al*., 2012). It is notable that there has been a great deal of attention in statistic and econometric research papers devoted to detecting structural breaks in long-length time series data sets, while most finance researchers use news reports of dates and then specify dummy variables to control the effect from major breaks. Hence, relying on event identification using a more rigorous method is better than to assume the breaks from newspaper reports.

Scholars in econometrics and statistics have suggested test models for analysing structural changes – call it disturbance that tweaks the data set substantially away from its normal path when such off-normal disturbances occur. Such tests could be routinely applied in finance research in order to statistically identify breaks. More importantly, there has been a growing improvement in developing multiple breakpoint tests (Andrews, Lee, & Ploberger, 1996; Garcia & Perron, 1996; Liu, Wu, & Zidek, 1997). Recent tests developed by Bai and Perron (1998; 2003) constitute an efficient algorithm based on dynamic programming method to obtain global minimisers of the sum of squared residuals in a simple regression test model under a very general framework that allows for both pure and partial structural changes. By imposing a common structure, the tests control for different serial correlations, data distributions and the errors across segments. That process is superior to using news reports to specify breaks.

This study provides an empirical implementation example by applying the method of Bai and Perron (1998; 2003) using exchange rate time series for a sample of four major countries with data stretching over a long length of 55 years of monthly observations. Our concern here is to identify all breaks in this long time series to ensure that the dates of breaks are not assumed from news reports but are quantitatively identified.

Researchers on exchange rates have obviously paid little attention to this aspect, so our continuing research on exchange rate effect (for example, Ariff & Zarei, 2015) is based on this method of identifying and then naming the crises periods embedded in the data set we use. Thus, we hope to add this method as a rigorous pre-analysis filtering procedure as shown in this paper to be used on exchange rates or other time series. This is our motivation for conducting and reporting the results in this paper.

The remainder of this paper is organised as follows: In Section 2, a brief review of some papers on this topic is given before describing the hypothesis and model development in Section 3. Findings are presented and discussed in Section 4 and conclusion is provided in Section 5.

LITERATURE ON STRUCTURAL BREAKS

The literature on structural change test development starting from the 1960s is substantial; the more important papers are reviewed in this paper. Prior to this date, it was customary to pre-identify the break using news reports and then specifying dummy variables to represent the break points, as was done in classic papers in the pre-1960s. A very preliminary test model of structural break was developed by Chow (1960). The testing procedure requires *a priori* known dates of pre- and post- break points to be tested for equality using a classic F-statistic: note that the initial anchor is on news reports.

The test gained huge popularity following over many decades despite the limitation of a method based on *a priori* identification of break dates. Quandt (1960) developed a modified version of Chow's model taking the largest F-statistic over all possible break dates. In this way, the break dates can be identified without a need for a specific *priori* imposition of break dates. This method can be implemented by estimating the parameters in the sequence of Chow's F-statistics as a function of candidate break dates so as to establish any systematic variation in the behaviour of sub-samples before and after the candidate break date.

Andrews (1993) and Andrews and Ploberger (1994) derived the limiting distribution of the Quandt results and developed related test statistics. The Quadnt-Andrew's framework, as it was named later, was further extended in Bai (1997) and Bai and Perron (1998, 2003) to allow for multiple unknown breakpoints. In long time series, as in this research, the data series do have multiple breakpoints.

This method presents an efficient algorithm to obtain global minimisers of the sum of squared residuals. The issues concerning the structure and distribution of errors, as well as the number of breaks, are addressed in their paper to provide a general framework that captures different levels of serial correlation in the errors and so the resulting different distributions of the data. Of advantages arising from this methodology, it can be noted that events which may foster any structural change can be identified accurately and quantitatively.

There are few other published works on this topic such as those by Sims (1980) and Gujarati (1978). Some papers suggest tests based on pre-identifying the disturbances, and are similar to the Chow's (1960) suggestion. Bai-Perron test is considerably superior to all the previous suggestions, and is based on a rigorous statistical method of identifying disturbances.

HYPOTHESIS, MODEL DEVELOPMENT AND DATA SERIES

In this section, a test hypothesis was tested using the Bai-Perron model; there is a short discussion of the behaviour of the time series as we operationalised the method to identify multiple structural breaks in a long time series. The assumption is that there ought to be some breaks in a long length time series because of changes in monetary policy actions, or simply the effect of one or more crises that affects exchange rates periodically. The discussion has so far indicated the possible methods to identify breakpoints, and that Bai-Perron method is perhaps suitable. Consistent with the above discussions, therefore, the hypothesis of this study is:

Hypothesis: There is no significant structural change or disturbance denoting instability in the behaviour of nominal exchange rate over the 55-year test period.

Bai and Perron (2003) proposed a multiple linear regression with *m* breaks as in:

$$y_t = x'_t\beta + z'_t\delta_1 + u_t, \qquad t = 1,\ldots,T_1,$$
$$y_t = x'_t\beta + z'_t\delta_2 + u_t, \qquad t = T_1 + 1,\ldots,T_2,$$
$$y_t = x'_t\beta + z'_t\delta_{(m+1)} + u_t, \quad t = T_{m+1},\ldots,T. \qquad (1)$$

where, *m* is the number of breaks in the *m* + 1 regimes, y_t is the observed dependent variable at time *t*, while x_t and z_t are vectors of covariates and β and δ are the corresponding vectors of coefficients. u_t is disturbance term at time *t*. The $(T_1 \ldots T_m)$ are the breakpoints or indices which are explicitly treated as unknown. The aim of this test is thus to estimate the unknown regression coefficients together with the break points when number of observations on the dependent and the vectors of covariates (y_t, x_t, z_t) are available. "*The problem of testing for multiple structural breaks is addressed by Sup Wald Type tests with null hypothesis of no break versus an alternative hypothesis of an arbitrary number of breaks, which allows for a specific to general modelling strategy in consistent determination of appropriate number of breaks*" (Bai & Perron, 2003, p. 2).

This study applies Bai and Perron's (2003) test to investigate structural changes by identifying parameter instability locations in our monthly exchange rates data set over 1960-14 (651 x 4 countries), which is a long time series as accessed from IMF CD-ROM database. The data series are month-end observations on each currency, where Eviews 8 is used. The countries included are Belgium, Canada, France and Japan. The analysis was conducted on each country separately so that the reliability of the results across similarly affected economies could be also verified.

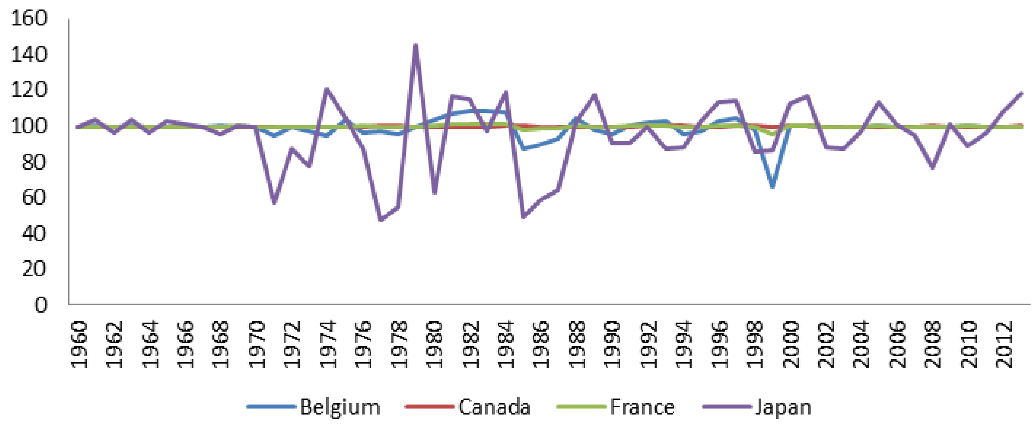

Fig.1: Plots of Four Country Exchange Rate Behaviour over 55 years (Base=100 in 1960)

We chose only four countries as a preliminary effort to find that the tests are suitable for application across many more countries. The exchange rates are against the US dollar since the currency is the most liquid trade currency; therefore, it is likely to have efficient market-clearing accuracy. The results are discussed in the next section.

Plots are of the exchange rates of four countries included in this study, as shown in Fig.1. For this purpose, an index (base year = 100) was constructed for respective exchange rates to examine the fluctuation of the time series. It is evident that Japanese Yen is highly volatile; some large changes symptomatic of several structural break events, and this is possibly due to monetary policy actions, economic shocks and crises over the period.

In order to examine the normality assumption of data, a summary of descriptive statistics is provided in Table 1. The data used for this analysis are over the whole sampled period. The bilateral nominal exchange rates were used with US dollar being the denominator. The statistics can be verified from the table, i.e. from the mean value in column two of the table.

TABLE 1
Descriptive Statistics on Exchange Rates of Four Countries, Percentage

	Mean	**Median**	**Std. Dev.**	**Skewness**	**Kurtosis**	**Observations**
Belgium	30.237	35.743	19.749	-0.543	1.816	651
Canada	1.183	1.156	0.166	0.668	2.432	651
France	4.179	4.937	2.283	-0.334	2.264	651
Japan	205.181	153.600	103.180	0.413	1.566	651

Annual per cent change in exchange rates.

The statistics summarised in this table is meant to judge the means and standard deviations of the four time series. The series appear to be normally distributed as can be verified from the means and medians, which are close to one another. In addition, the skewness is close to 0, while the kurtosis is closer to 2 than far away from it.

The measure of dispersion, standard deviation in exchange rate for Japan, is larger than other exchange rates in view of the high exchange rate fluctuations in Japan, whereas the Canadian dollar is the least fluctuating currency against the US dollar. The statistics on skewness and kurtosis fulfil the assumption of normal distribution of data.

Application of Eviews Software

The estimation procedure in Eviews 8 for this study is based on a simple regression equation under a least square specification; with the nominal exchange rate (NER) playing the role of dependent variable regressed against a single (constant) regressor. The modelling therefore can be represented as:

$$NER_t = constant + \varepsilon_t \quad (2)$$

In order to allow for serial correlation in the errors, a quadratic spectral kernel was specified based on HAC covariance estimation with the use of pre-whitened residuals, whereby the kernel bandwidth is determined using the Andrews AR(1) method.

Eviews Version 8 satisfies the condition for such an implementation. In examining multiple breakpoint tests, three different methods are considered. As *a priori* requirement for all three methods, the distributions of errors are allowed to differ across breaks which in turn satisfy the heterogeneity of errors. The default method for investigation of multiple structural change, as outlined in the studies of Bai (1997) and Bai and Perron (1998), is known as sequential testing $l + 1$ of versus l breaks.

At the second stage, the global Bai-Perron break method is applied, which is meant to examine the alternative hypothesis of globally optimised breaks against the null of no structural breaks, along with the corresponding *UDmax* and *WDmax* tests, which are interpreted later on in discussing the findings. Finally, at the third stage, the method of global information criteria was applied, as it does not require computation of coefficient covariance compared to the previous two methods of break selection criteria.

This study applied the global information criteria to estimate breakpoints using global minimisers of the sum of squared residuals. The LWZ criteria were chosen as the selection criterion for the optimum number of breaks after initial testing. The selection of optimum number of breaks was based on three different selection criteria, namely, sequential, Bayesian Information Criterion (BIC) and a modified Schwarz Criterion (LWZ). According to Bai and Perron (2003), LWZ performs better compared to the other two criteria under the no-break null hypothesis. The results on multiple structural break test the results from exchange rates over the 55-year test period, which are reported as obtained from joint model testing procedure developed in Bai and Perron (2003).

The discussion on the procedure using Eviews software indicates that it is feasible to adopt this as a pre-screening procedure when exchange rate series is used in the on-going research on monetary theory testing as in Ariff and Zarei (2015).

FINDINGS FROM THE STRUCTURAL BREAKPOINT TEST

A time-series analysis regarding multiple structural breakpoints is first described to facilitate the interpretation of results presented in this section. Results for each country from using monthly observations are reported in Table 2, in which model specification details and test statistics are given.

The estimation procedure is based on running a regression with a constant as regressor ($Z_t = [1]$) that accounts for potential serial correlation via non-parametric adjustments; for each country, we get 4 test results respectively for four countries. The number of breaks allowed by the Bai-Perron model is five at most, with a trimming set at ε = 0.15 that is used to adjust the estimates with a minimum of 15 observations within each segment. The coefficient of the breakpoints and the standard errors (shown in parentheses) are in the lower panel of the table. The specific dates at which the breakdown occurs are identified for each country as the month in which the break commenced, and identified in a graph when that ends. Note that the breakpoint started in that month, so a researcher should consider controlling the impact at this month in order to neutralise the breakpoint impacts.

TABLE 2
Multiple Breakpoint Test: Exchange Rate (Monthly Data)

Specifications							
$Z_t = [1]$	$q = 1$		$p = 0$	h=15		$m = 5$	
Tests							
Belgium	$SupF_T(1)$ 378.1*	$SupF_T(2)$ 388.7*	$SupF_T(3)$ 302.5*	$SupF_T(4)$ 200.6*	$SupF_T(5)$ 3687.4*	$UDmax$ 3687.4*	$WDmax$ 8091.4*
Canada	$SupF_T(1)$ 4.504	$SupF_T(2)$ 5.475	$SupF_T(3)$ 12.384*	$SupF_T(4)$ 11.132*	$SupF_T(5)$ 9.046*	$UDmax$ 12.384*	$WDmax$ 19.852*
France	$SupF_T(1)$ 113.7*	$SupF_T(2)$ 74.58*	$SupF_T(3)$ 56.62*	$SupF_T(4)$ 44.18*	$SupF_T(5)$ 1013.3*	$UDmax$ 1013.3*	$WDmax$ 2223.6*
Japan	$SupF_T(1)$ 0.475	$SupF_T(2)$ 12.514*	$SupF_T(3)$ 19.798*	$SupF_T(4)$ 33.512*	$SupF_T(5)$ 180.16*	$UDmax$ 180.16*	$WDmax$ 395.35*

Maximum Breaks = 5= m; Trimming Percentage = 15 = critical number of observations as defined in the model; Significance Level = 0.05; *p* and *q* are respectively vectors of covariates.

The test statistics reported underneath the specifications are used to determine the number of breaks for each country, as can be verified by the significance of operator $SupF_T(k)$, where k denotes the number of breaks. SupF type test considers the hypothesis of no structural break ($m = 0$) versus $m = k$ breaks. In the tests of this study, a maximum of 5 breaks were noted. The number of breaks found ranges from 3 to 5 with Canada (see Table 2) having the lower number of breaks identified. The double maximum statistics (*UDmax* and *WDmax*) are used to test the null hypothesis of no structural break against the alternative of an unknown number of breaks. Given the significance of all double maximum statistics, as denoted by star (*), the presence of at least one structural break is confirmed.

The second part of the results is reported in Table 3. The letters shown in bold indicate the actual breaks identified by the test model. For example, in the case of Belgium, four breaks are identified, which are in month-1 (1973), month-10 (1981), month-11 (1989), and month-12 (1998). Going back to the reported news, the 1973 breakpoint arose from the Smithsonian Agreement; 1989 is related to the announcement of Euro (€), while 1998 is the date of implementation of the Euro currency. Similar interpretations can be applied to France.

The test applies three break-selection criteria to identify the optimum number of breaks, as specified in the upper half of Table 2. SupF(k) indicates the significance of k breaks. The final choice is made based on the LWZ criteria (Liu *et al*., 1997), which are robust to serial correlation problems and the test performs relatively well.

The statistics would have us believe that almost all the countries experienced a structural break at a date around the breakdown of Bretton Woods Agreement, that is, in 1971-1973 (Smithsonian Agreement was withdrawn in 1973).

TABLE 3
Multiple Breakpoint Test and Exchange Rate (Monthly Data)

Panel B:

Number of Breaks Selected

	Belgium	Canada	France	Japan
Sequential	1	0	1	0
LWZ	4	3	4	5
BIC	4	4	4	5

Estimates with *n* Breaks

	$\hat{\delta}_1$	$\hat{\delta}_2$	$\hat{\delta}_3$	$\hat{\delta}_4$	$\hat{\delta}_5$	$\hat{T}_1$	$\hat{T}_2$	$\hat{T}_3$	$\hat{T}_4$	$\hat{T}_5$
Belgium	3.895 (0.01)	3.547 (0.07)	3.819 (0.18)	3.504 (0.04)	- 0.189 (0.14)	**1973 M1**	**1981 M10**	**1989 M11**	**1998 M12**	-
Canada	0.039 (0.01)	0.213 (0.01)	0.362 (0.01)	0.072 (0.02)	*N/A*	**1978 M7**	**1994 M1**	**2004 M9**	-	-
France	1.621 (0.02)	1.511 (0.04)	1.939 (0.12)	1.701 (0.02)	- 0.188 (0.14)	**1973 M1**	**1981 M5**	**1989 M10**	**1998 M12**	-
Japan	5.88 (0.00)	5.72 (0.10)	5.43 (0.04)	4.91 (0.07)	4.72 (0.05)	**1969 M8**	**1977 M9**	**1986 M1**	**1994 M2**	**2006 M2**

- Indicates the observations from where there is no break.

Canada is the only country which experienced breakdown at a later point than the actual breakdown of Bretton Woods, for reasons peculiar to that region: 1978 was a year of economic decline in the US, with which Canada had major connection.

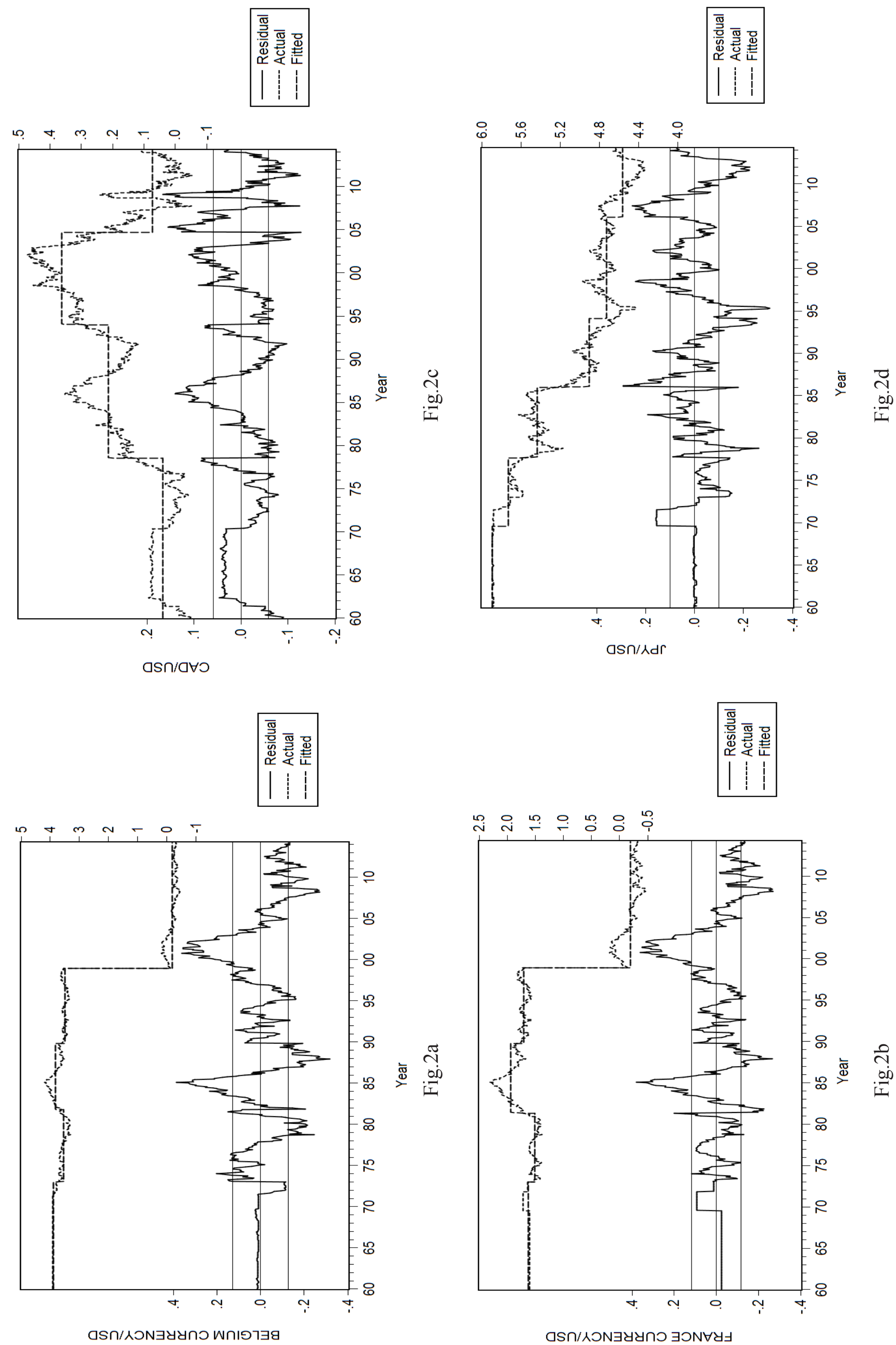

Fig.2a

Fig.2b

Fig.2c

Fig.2d

Fig.2: Multiple Structural change Graphs, Bilateral Exchange rates

The other important breakdown is related to late 1990s among European countries arising from the Euro currency leading to a change in those economies' behaviour of exchange rates. The analysis was only conducted on monthly data to improve the precision of test results. If the annual data series were used, the years identified in this paper would prominently be identified as the years of the breakdown. Fig.2 provides four plots, one for each country, on how the data series can be depicted in terms of the breakpoints. For example, Belgium and France experienced the same breakpoints since both countries were affected by the introduction of the Euro currency in 1998-9.

In the case of Belgium (see Fig.2a), four breakpoints were identified in the plot, as shown at the top of that graph; 1973; 1981; 1989; 1998. The plot for France is identical to that of Belgium as both countries with common currency are within the EU region (since 1998) experiencing similar breakpoints. Canada (Fig.2c) had three breaks: 1978 due to tightening of monetary policy to contain high inflation; 1994 due to Mexican Peso Crisis; 2004 due to a sudden appreciation of Canadian dollar. In 1969, Japan experienced its first break due to the adoption of special drawing rights; 1977 witnessed the impact of the global high oil price crisis; 1994 coincided with the stock market crash in Japan; 1986 is the year when the implementation of Plaza Accord designed slowly appreciated the Yen against the US dollar; 2006 had a break ahead of the Global Financial Crisis.

The explanations for the breakpoints are sourced from accessing events in www.bbc.com; there are other event identifying databases, which anyone could also consult. The results presented in this section appear to verify what one sees in recorded events in the news from this source.

CONCLUSION

This paper started with the aim to identify and apply a formal research process to determine the structural breaks in the exchange rate time series data over 55 years relating to four OECD countries. This paper reports the results of this research for four countries so as to establish evidence on the applicability of a testing methodology described in this paper. This identification process could well be adopted for other time series analyses that require formally identifying structural breaks.

It is believed that a formal method to pinpoint the breakpoints will certainly be desirable to one that relies on specifying multiple dates based on newspaper reports, which is the most commonly followed practice in the research literature to resolve this important data problem. The Bai-Perron method, which we operationalised using standard software in this paper, is based on having no *a priori* reasoning, and is extracted from the correlation behaviour of the time series to identify when the breaks occur. The model identifies the date(s) accurately, so that this procedure, if followed as a pre-analysis step before subjecting the data set to analysis, could improve the accuracy of findings on exchange rate (or other) behaviour. Further tests with a larger sample of countries would help to generalise our findings to a greater number of countries.

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