Unit Roots and Structural Breaks: A Survey of the Literature*

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Abstract

Since Perron (1989) the time series literature has emphasised the importance of testing for structural breaks in typical economic data sets and pronounced the implications of structural breaks when testing for unit root processes. In this paper we survey recent developments in testing for unit roots taking account of possible structural breaks. In doing so we discuss the distinction between taking structural break dates as exogenously determined, an approach initially adopted in the literature, and endogenously testing break dates. That is, we differentiate between testing for breaks when the break date is known and when it is assumed to be unknown. Also important is the distinction between discrete breaks and gradual breaks. Additionally we describe tests for both single and multiple breaks and discuss some of the pitfalls of the latter.

Keywords: Unit Root, Structural Breaks, Endogenous Breaks, Gradual Breaks, Multiple Breaks.

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1. Introduction

In the past three decades, empirical work in applied economic research has been fundamentally changed by a revolution in time series modelling. In particular, it is now widely accepted that there are substantial implications for empirical modelling when one or more of the time series being used is found to contain a unit root. Whether, in fact, typical economic data sets are unit root processes is a hotly debated topic. Nelson and Plosser (1982) were of the view that almost all macroeconomic time series one typically uses have a unit root. This was forcibly challenged by Perron (1989) who suggested that it may be necessary to isolate some unique economic events and consider them as changing the pattern of time series permanently. Consequently many time series should not be modelled by an $AR(p)$ process, where p denotes lag length, with fixed parameters in the deterministic components. Perron went on to suggest that the results of Nelson and Plosser (1982) were not decisive once rare occurrences or structural breaks were accounted for and that much of the persistence of time series was due to infrequent permanent shocks. The approach of identifying isolated economic events *a priori* has given way to a new literature which tests for breaks and break dates simultaneously. Whilst these new developments have partially overturned the initial results, it is certainly the case that work on structural breaks, initiated by Perron, has “dramatically altered the face” of applied time series analysis, according to Hansen (2001).

In this paper we consider developments since the original Perron (1989) paper. These include considering whether break dates should be determined endogenously (and so considered unknown), which extends the initial treatment by Perron of breaks as exogenous. This strand of early literature include papers by Christiano (1992), Zivot and Andrews (1992) and Banerjee, Lumsdaine and Stock (1992). One concern raised by these endogenous break tests was the treatment of breaks under the null hypothesis. Given that breaks were absent under the null there may be a tendency for these tests to suggest evidence of stationary with breaks, see Lee and Strazicich (2003).

More recently there has been a movement in the direction of modelling the type of break to particular non-linear cases and away from discrete breaks, as suggested by Maddala and Kim (1998) and operationalized by Saikkonen and Lütkepohl (2000). A third area we focus on in this paper is tests that consider the number of breaks by which a time series is affected. It should be noted that multiple breaks blur the distinction between a unit root process and a stationary series with breaks (see Hansen, 2001 for more on this matter), and that the actual tests create difficulties of practical implementation (see, for example, Perron, 2005).

This paper is set out as follows. Section 2 reviews the standard approach to testing for unit roots. Section 3 considers the Perron (1989) model. Section 4 reviews endogenous tests for breaks and break dates, whilst Section 5 considers non-linear breaks and Section 6 considers multiple breaks. Section 7 considers other issues. Section 8 reviews some empirical studies and Section 9 concludes.

2. Unit Roots and ADF Tests

Since Yule (1926), the importance of trends in statistical data has been recognised although the early work remained at best a statistical curiosity. Recent interested was intensified by innovations from Fuller (1976), Dickey and Fuller (1979) and Said and Dickey (1984) who developed tests to identify particular forms of non-stationarity. The emphasis lay on economic interpretations of relationships between data that contained unit roots and also the importance of nonstationary data when attempting to avoid the problem of a spurious regression in estimation.[1] The main thrust of the literature on unit roots concentrates on whether time series are affected by transitory or permanent shocks. This can be tested by the so-called *Augmented* Dickey Fuller (ADF) model which is set out as follows

$$\Delta y_t = \rho y_{t-1} + \sum_{j=1}^{p-1} \gamma y_{t-j} + \mu_t + u_t \qquad (1)$$

where y_t is a time series of T observations and $\mu_t = \mu_0 + \mu_1 t$ are deterministic terms (if $\mu_0 \neq 0$ there is a constant, and deterministic trend when $\mu_1 \neq 0$). The ADF test statistic has a null hypothesis of a unit root process (i.e. $\rho = 0$) against the alternative of a stationary ($\rho < 0$ and $\mu_1 = 0$) or trend stationary ($\rho < 0$ and $\mu_1 \neq 0$) process.

[1] Work by Granger and Newbold (1974) on estimation with nonstationary data first identified the problem of spurious regression and Engle and Granger (1987) provided the mechanics to identify long-run relationships using cointegration.

An issue often raised in the time series literature is the difficulty of differentiating between trend stationary and difference stationary processes. Deterministic trends do not always appear to be linear and shocks sometimes have permanent effects. Another major concern has been the low power of ADF tests and the inability to reject a false null of unit root, see for example De Jong *et al.* (1992). The ADF-GLS test of Elliott, Rothenborg and Stock (1996) achieves improvements in power by estimating the deterministic regressors before estimating the autoregressive parameter. Noting that increasing the number of deterministic components (from no constant, to constant, to trend and constant) reduces the critical values and hence the ability to reject the null of unit root (or the power of ADF tests) Elliott *et al.* (1996) have developed tests based on GLS detrending. These tests are found to have both improved power and size properties compared to the conventional OLS-based ADF tests, see Elliott *et al.* (1996).

3. Exogenous Structural Breaks

The possible importance of structural breaks for the implementation and interpretation of unit root tests was first emphasised by Perron (1989) and Rappoport and Reichlin (1989). Perron (1989) suggested that structural change in time series can influence the results of tests for unit roots. In particular, time series for which an uncritical application of ADF-type tests infers the existence of a unit root may often better be characterised by a single *permanent* break in a deterministic component of a stationary or trend-stationary process. Perron's results are based on the following general ADF model with shifts in mean and trend

$$\Delta y_t = \rho y_{t-1} + \sum_{j=1}^{p-1} \gamma y_{t-j} + \mu_t + u_t \qquad (2)$$

where $\mu_t = \mu_0 + \mu_0^s d_{tTB} + \mu_1 t + \mu_1^s (t-T_B) d_{tTB}$ are the possible deterministic terms (which contains a constant when $\mu_0 \neq 0$, and deterministic trend when $\mu_1 \neq 0$). The break date is at time T_B.

In particular, Perron (1989) identified three trend break models based on equation (2): a **crash** model which contains a linear trend with an intercept shift which is as follows;

$$\mu_t = \mu_0 + \mu_0^s d_{tTB} + \mu_1 t \qquad (3)$$

$$d_{tTB} = \begin{cases} 0, & t < T_B \\ 1, & t \geq T_B \end{cases} \quad (4)$$

a **changing growth** linear trend model with a change in slope of the linear trend and the two segments joined at the break date (this may characterise a productivity slowdown);

$$\mu_t = \mu_0 + \mu_1 t + \mu_1^s (t-T_B) d_{tTB} \quad (5)$$

$$d_{tTB} = \begin{cases} 0, & t < T_B \\ 1, & t \geq T_B \end{cases} \quad (6)$$

and finally a **combined model** with intercept and slope change.

$$\mu_t = \mu_0 + \mu_0^s d_{tTB} + \mu_1 t + \mu_1^s (t-T_B) d_{tTB} \quad (7)$$

$$d_{tTB} = \begin{cases} 0, & t < T_B \\ 1, & t \geq T_B \end{cases} \quad (8)$$

Each of these three models has a unit root with breaks under the null hypothesis since the dummy variables are incorporated in the estimated regression under the null. The alternative hypothesis is a broken trend stationary process. The break date was identified *ex ante* by economic information, for example, the Great Crash and the productivity slowdown of the 1970s in the US.

Perron (1989) conducted a Monte Carlo study and found that with a significant shift and using standard ADF tests one could rarely reject the unit root hypothesis, even in cases where we have a stationary process with a broken trend. Although Elliott *et al.* (1996) with a GLS correction was able to improve upon the power of OLS-based ADF tests, this is also susceptible to breaks in the original series. Cook and Manning (2004) using Monte Carlo simulation report the disappointing performance of both OLS-ADF and GLS-ADF tests in the presence of breaks.

4. Endogenous Structural Breaks

It is without doubt that Perron's (1989) approach and results were influential. Nevertheless, the Perron (1989) method of assuming the break date as exogenously determined and known *ex ante* has often been considered inappropriate in the subsequent theoretical and empirical literature. According to Christiano (1992), Banerjee, Lumsdaine and Stock (1992), Zivot and Andrews (1992), Perron and Vogelsand (1992) and Chu and White (1992), identification of the break date may not be unrelated to the data and if the critical values of the test assume the opposite, there may be substantial size distortions (i.e. the tests will have a tendency to over reject the null hypothesis of unit root). The main innovation of these papers is to suggest that the date of the break should be identified endogenously when testing for breaks. Intuitively, the tests apply the Perron (1989) methodology for each possible break date in the sample, or some part of that sample, and then choose the break at the point where evidence against the null is most strong.

The endogenous structural break test of Zivot and Andrews (1992) is a sequential test which utilises the full sample and uses a different dummy variable for each possible break date. Here the break date is selected where the *t*-statistic from an ADF test of unit root is at a minimum (i.e. most negative). Consequently a break date will be chosen where the evidence is least favourable for the unit root null. The Zivot and Andrews (1992) minimum *t*-statistic has its own asymptotic theory and critical values.[2] The latter are more negative than those provided by Perron (1989) and may suggest greater difficulty in rejecting the unit root null (which we discuss in greater detail in section 7 below).

Banerjee *et al.* (1992) also tests for endogenous break dates and utilises sequential, rolling and recursive tests. The non-sequential tests use sub-samples to determine the number of breaks and can be viewed as not using the full information set, which may have implications for the power of these tests. Tests include the max DF statistic, the min DF statistic and the difference between the two statistics.

Zivot and Andrews (1992) and Banerjee *et al.* (1992) test the joint null hypothesis of a unit root with no break in the series. As a consequence, accepting the null hypothesis in the context of the Zivot and Andrews (ZA) and Banerjee *et al.* (B) tests does not imply unit root but rather unit root without break. Perron (1994), on the other hand, considers a test of the unit root hypothesis where the change in the slope is allowed

[2] Zivot and Andrews (1992) provides both asymptotic and small sample critical values.

under both the null and the alternative hypotheses. Critical values are derived for ZA and B tests assuming no structural breaks under the null. Nunes, Newbold and Kuan (1997) suggest there may be some size distortions where such critical values are used in the presence of structural breaks under the null.[3] Lee and Strazicich (1999) discuss the source of the size distortion, and Perron (2005, p. 55) suggests that there may be some loss in power.

5. Non-linear Breaks and GLS Detrending

Perron (1989) and much of the literature that followed dealt with the case in which a break occurs during one period only. However, it may be more reasonable to think that breaks occur over a number of periods and display smooth transition to a new level. Saikkonen and Lütkepohl (2002, ET) and Lanne, Lütkepohl and Saikkonen (2002, JTSA)[4] develop such a model which adds to the deterministic term shift functions of a general nonlinear form $f_t(\theta)'\gamma$. In a model with a linear trend term and shift,

$$y_t = \mu_0 + \mu_1 t + f_t(\theta)'\gamma + z_t \tag{9}$$

where θ and γ are unknown parameters and z_t are residual errors. In first difference form equation (9) becomes

$$\Delta y_t = \mu_1 + \Delta f_t(\theta)'\gamma + \nu_t \tag{10}$$

The shift function attempts to characterise whether the break is abrupt and complete within one time period or more gradual. We set out both in a formal sense.

Consider the simple shift function with break at time T_B

$$f_t^{(1)} = d_{1t} := \begin{cases} 0, & t < T_B \\ 1, & t \geq T_B \end{cases} \tag{11}$$

The parameter θ is not involved in the model and γ is a scalar. This leads to a dummy variable with shift date T_B. This may be useful in situations where structural change is

[3] Garcia and Perron (1995) consider breaks in real interest rates and estimate structural break dates using a Markov Switching model.

[4] See also Leybourne, Newbold and Vougas (1998) where the break is modelled as a smooth transition in linear trend which is endogenously determined. Maddala and Kim (1998) also suggest that gradual structural breaks should receive more attention in the literature.

simple and complete in one period but it may not where the changing economic environment operates with something akin to a lag.

A more general shift function which allows for sharp, one-time shifts and a more gradual shift to a new level beginning at time T_B can be expressed as

$$f_t^{(2)}(\theta) = \begin{cases} 0, & t < T_B \\ 1 - \exp\{-\theta(t - T_B + 1)\}, & t \geq T_B \end{cases} \qquad (12)$$

θ and γ are scalar parameters. Where $\theta \to \infty$ the shift function becomes a simple (0, 1) dummy variable.

Estimation of the parameters $\eta = (\mu_0, \mu_1, \gamma')'$ is obtained by minimising the generalised sum of squared errors of equation (10). This amount to, under the null hypothesis, minimising

$$Q_p(\eta, \theta, \alpha^*) = (Y - Z(\theta)\eta)'\Sigma(\alpha^*)^{-1}(Y - Z(\theta)\eta) \qquad (13)$$

where α^* is the vector of coefficients in $\alpha^*(L)$, $\Sigma(\alpha^*) = Cov(V)/\sigma_u^2$, $V = (\nu_1,\ldots,\nu_T)'$ the error vector of the model, $Y = [y_1, \Delta y_2,\ldots,\Delta y_T]'$ and $Z = [Z_1: Z_2: Z_3]$ with $Z_1 = [1,0,\ldots,0]'$, $Z_2 = [1,1,\ldots,1]'$, and $Z_3 = [f_1(\theta),\Delta f_2(\theta),\ldots,\Delta f_T(\theta)]'$.

Saikkonen and Lütkepohl (2002) and Lanne *et al.* (2002) suggest estimating the deterministic term of equation (9) first, following the approach of Elliott *et al.* (1996) using GLS de-trending. Consequently this deterministic component is subtracted from the original series and then ADF tests are applied to the adjusted series. It may be obvious in some situations that a break has occurred at a particular date (for example the Great Crash with Perron's (1989) empirical model and unification in a study of German monetary policy by Lütkepohl and Wolters (2003)).

Additionally, the approach is extended to a situation of an unknown break date by Lanne *et al.* (2003). A different asymptotic distribution is utilised when a linear trend is incorporated and there may be an improvement in power when a trend is not present Lütkepohl (2004). Hence all prior information should be utilised when deciding whether a deterministic trend is important.

Two parameters have to be identified: the lag length of the ADF test and the break date. If the break date is known then it should be imposed, and subsequently identification of the lag length is required. If the date of the break is known it can be imposed and then the *AR* identified by standard procedures. In situations where the break date is unknown, Lanne *et al.* (2003) recommend that a generous lag be first utilised to obtain the break and then a more detailed analysis of the *AR* order be pursued primarily in an attempt to improve the power of the test. Non-standard critical values come from Lanne *et al.* (2002) and depend on whether a linear trend is excluded from the tests.[5]

[5] ADF tests robust to structural breaks and utilising GLS detrending tests have also been proposed by Perron and Rodriguez (2003).

6. Multiple Structural Breaks

In addition to relaxing the assumption that breaks are known and discrete, further assumptions of Perron's (1989) initial paper have been examined in the literature. In particular the assumption of only one structural break has come under consideration and the possibility of multiple breaks is tested. However, as Hansen (2001) points out, the distinction between a series with a unit root and a stationary series with non-constant deterministic components is less clear when we consider the case of more than one break. We firstly consider the case of two breaks and then generalise further by considering multiple breaks. Early work in this area includes papers by Lumsdaine and Papell (1997), Clemente *et al.* (1998) and Lee and Strazicich (2003).

6.1 Two Structural Breaks

Lumsdaine and Papell (1997) further the work of Zivot and Andrews (1992) to allow for two endogenous breaks under the alternative hypothesis and additionally allow for breaks in the level and the trend. Series are generally interpreted as broken trend stationary if the null hypothesis of unit root is rejected in favour of the alternative of two breaks. Lee and Strazicich (2003) suggest that spurious rejection problems may arise akin to that with Zivot and Andrews with a break under the null hypothesis.

Consequently, Lee and Strazicich (2003) consider the case of whether there are two breaks, potentially under the null hypothesis, and report evidence of improved power properties against Zivot and Andrews (1992) and Lumsdaine and Papell (1997). They provide a minimum Lagrange Multiplier test with breaks in the level and trend, which is not subject to spurious rejection in the presence of a break under the null and the authors suggest that the size properties remain accurate for this test. Clemente, Montañés and Reyes (1998) base their approach on Perron and Vogelsang (1992) but allow for two breaks.

Additionally Papell and Prodan (2003) take issue with this interpretation of the alternative of trend stationarity. If there are two breaks and these are offsetting, the series is trend stationary. On the other hand if the breaks are not offsetting the series is broken trend stationary (for example the breaks could be in the same direction or in opposite directions but of different sizes). Papell and Prodan (2003) consequently propose a test based on restricted structural change which explicitly allows for two offsetting structural changes.

6.2 Multiple Breaks

Lumsdaine and Papell (1997) considered multiple breaks. Ohara (1999) utilises an approach based on sequential t-tests of ZA to examine the case of *m* breaks with unknown break dates.[6] The author argues that failure to account for the actual number of breaks will lead break tests to fail to reject the null of unit root.

Kapetanois (2005) examine the unit root hypothesis with drift but no breaks against a trend stationary alternative hypothesis with *x* breaks in the constant and/or trend. This also is a sequential approach and Kapetanois (2005) argues that it is computationally efficient. This is important in the context of the argument by Lee and Strazicich (2001) that the computational burden of tests with more than two breaks (for example via a grid search) would increase significantly with three or more breaks.

Again the tests which allow for the possibility of multiple breaks - Lumsdaine and Papell (1997), Ohara (1999) and Kapetanois (2005) - do not allow for breaks under the unit root null hypothesis. This may potentially bias these tests.

[6] Critical values for the case of two breaks are provided in Ohara (1999).

Table 1: Unit Root Tests and the Nelson and Plosser Data Set

	Model	**# of Breaks**	**Unit Root**	**Stationary (with possible breaks)**
Nelson and Plosser (1982)	ADF	0	13	1
Perron (1989)	Exogenous breaks	1	3	10
Zivot and Andrews (1992)	Endogenous Breaks	1	10	3
Lumsdaine and Papell (1997)	Endogenous Breaks	2	8	5

7. Unit Roots and Structural Breaks: Applied Papers

One of the most influential studies of the unit root properties of actual economic data was by Nelson and Plosser (1982) who considered whether US macroeconomic data were nonstationary. Abstracting from the possibility of structural breaks in the time series, the authors examined 14 macroeconomic time series over the period 1909 to 1970 and discovered that 13 contained a unit root (in particular, the unemployment rate did not contain a unit root). This led many researchers to conclude that nonstationarity was pervasive in typical macro data sets and empirical solutions to deal with nonstationary data should be pursed. The conclusion is that time series are influenced by a number of permanent shocks.

Perron (1989) reconsiders the Nelson-Plosser data set and applied his modified DF test. He discovered that there was broken trend stationary for 10 out of 13 series where the break was identified *ex ante*. The three series considered as containing a unit root were consumer prices, velocity and interest rates. In contrast Zivot and Andrews (1992) examines the importance of the endogenous assumption and rejected the unit root null for only three out of 13 variables (nominal and real GNP and IP) using bootstrapped critical values.[7] This lends support to Nelson and Plosser's (1982)

[7] Zivot and Andrews (1992) make a distinction between asymptotic critical values and finite sample critical values obtained by bootstrap methods. When using asymptotic critical values only seven series fail to reject the unit root null.

original conjecture. However, as suggested above the ZA test may have some size problems due to the fact that breaks are not allowed under the null hypothesis.

Lumsdaine and Papell (1997) re-examine the Nelson and Plosser data set by testing for unknown break dates and considering the possibility of more than one break. They reject the unit root null for five of the 13 US macroeconomic variables.[8] Again however breaks are not allowed under the null hypothesis of unit root.

In terms of other data sets that have been considered, typically the literature on unit roots and breaks suggests macroeconomic aggregates are broken trend stationary but prices or financial variables are unit root: Papell and Prodan (2003). Ben-David, Lumsdaine and Papell (2001) apply the approach of Lumsdaine and Papell to an international dataset for 16 countries. In three quarters of the countries there is evidence of two breaks. With the two break model the unit root null is rejected in 50% more cases than in the one break model.

8. Other Issues

In this section we consider other issues related to the testing of unit roots while accounting for structural breaks. We consider testing the null of stationarity, examining alternative approaches to identifying the break dates, the examination of panel methods, long memory and structural breaks and we discuss further developments in the literature.

Another approach to testing for unit roots with breaks is to consider nonstationarity as the alternative hypothesis. Lee and Strazicich (2001) propose a test for stationarity with endogenously determined break dates which is a variant of the Kwiatkowski *et al.* (1992) test. Lee et al. (1997) suggest that the original Kwiatkowski *et al.* (1992) tests are also sensitive to structural breaks. This is a minimum *t*-statistic where the null hypothesis implies a stationary time series with a break and contrasts with the null of unit root minimum *t*-statistic which provides the least favourable break date for the unit root null. Instead with Lee and Strazicich break points are chosen which

[8] Ben-David and Papell (1995) examine a greater span of data than is typical in empirical studies (over 100 years of data). They use sequential tests provided by ZA and Banerjee *et al.* and find that they can

give most favourable results for stationarity with a break. The authors use Monte Carlo simulations to suggest that the test performs reasonably well, when the structural break is large, in identifying the break date. Also the test has reasonable power. Harvey and Mills (2004) also consider a test with a stationary process as the null hypothesis against an alternative of unit root. Additionally, their test allows for smooth transition in linear trend under the null hypothesis.

Alternative approaches to estimating break dates have been proposed using Bayesian procedures and also Markov Switching methods. Kim and Maddala (1991) consider multiple unknown breaks using BIC criteria and Gibbs Sampling. Garcia and Perron (1996) identify breaks using MS methods, based on work by Hamilton (1989), which also identifies the break date. This work assumes a number of regimes (two and three) to identify the break dates in real interest rates. This has implications for identifying the break date. Markov switching methods have also been used by Murray and Nelson (2002), who use a parametric bootstrap of a Markov switching model for real GDP, and Nelson, Piger and Zivot (2001).

An approach to testing for a stochastic trend in a multivariate setting with known break points is provided by Busetti (2002). This test considers the null that a number of series are stationary and with a similar trend with breaks, and has an alternative that at least one series is nonstationary. Bai, Lumsdaine and Stock (1998) also utilise multivariate methods when identifying confidence intervals around structural breaks. Additionally in a multivariate setting, there has been recent interest in nonstationary panel data methods accounting for structural breaks, including those by Tzavalis (2002), Murray and Papell (2002), Im et al. (2005) and Westerlund (2006).

An alternative question to that of testing for unit root in a univariate context is an examination of persistence in time series in the presence of structural breaks. This issue is examined by Diebold and Inoue (2001), Kurozumi (2005) and Busetti and Taylor (2004).

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reject the unit root null in 20 of the 32 time series using a 10% significance level. This contrasts with only 2 rejections at the 5% level in the absence of breaks.

9. Conclusion

This paper considers the literature on testing for unit roots in the presence of structural breaks. We emphasise, consistent with Perron (1989), that where breaks are not fully accounted for unit root tests will have a tendency to accept a false null of nonstationarity (i.e. they have low power). We also outline developments in the literature since Perron (1989). In particular, we discuss endogenous breaks, proposed *inter alia* by Zivot and Andrews (1992) and Banerjee *et al.* (1992). These tests emphasise that identifying break dates should take place when testing the null otherwise there may be a tendency to accept the alternative of stationarity with breaks. Although these early endogenous breaks provided more evidence in favour of the unit root null, they have themselves been questioned on the basis of not allowing for: breaks under the null, multiple breaks, a stationary null and gradual breaks.
There is no doubt that examining time series for the presence of breaks is an important component of any empirical analysis. There are two further related issues that we have not explored in this review, and that we shall simply bring to the reader's attention at this point. The first of these is the use of time series for forecasting purposes; the second is the possible superiority of testing for structural breaks within a multivariate or cointegration framework, rather than the univariate frameworks we have been examining here.

Whether univariate break models forecast well is a moot point, with Hansen (2001) suggesting that they do not. However, Pesaran and Timmerman (2004) present analytical results which imply that it is costly to ignore structural breaks in terms of the correlation between forecast and actual outcome and also in terms of direction of outcome.

This leads to the suggestion that maybe multivariate models will perform better. Methods based on cointegration incorporating breaks have also been proposed by Gregory and Hansen (1996) and Saikkonen and Lütkepohl (2000) and potentially these perform better than the univariate approaches.

In terms of a test that has been developed to provide confidence intervals around breaks, Bai, Lumsdaine and Stock (1998) suggest that the width of the asymptotic confidence interval around a break date is inversely related to the number of series that have a common break date. Therefore the gains to utilising a multivariate approach when identifying breaks are substantial.

A final point that should be noted is the converse of much of our discussion before. And that is the implications of testing for breaks in the presence of nonstationary data. Testing a series for structural break when the series is otherwise nonstationary will affect whether there is evidence of a structural break (see Perron, 2005).

10. Software

All of the tests reviewed in this survey paper can be implemented in programmable or quasi-programmable econometric software packages such as GAUSS, TSP and RATS. For such software packages, associated web sites often contain libraries of routines or procedures donated by users of those packages that contain ready-made implementations. We list a few examples below for the RATS package. Additionally, authors occasionally supply their own software implementations. One notable example is the Jmulti package, available at www.jmulti.de . This implements the tests proposed by Saikkonen and Lütkepohl (2002), and also provides tests for unknown break dates. The package consists of a Java program and runs on Windows (98SE and later) and Linux.

Rats implementations: www.estima.com (see "Procedures and Examples")

(1) Zivot and Andrews	Sequential Test
(2) Banerjee et al. tests	Rolling, recursive and sequential tests.
(3) Perron (1997)	Endogenous breaks

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