2007

Unit root tests and structural breaks: a survey with applications

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Abstract
The theme of unit roots in macroeconomic time series have received a great amount of attention in terms of theoretical and applied research over the last three decades. Since the seminal work by Nelson and Plosser (1982), testing for the presence of a unit root in the time series data has become a topic of great concern. This issue gained further momentum with Perron's 1989 paper which emphasized the importance of structural breaks when testing for unit root processes. This paper reviews the available literature on unit root tests taking into account possible structural breaks. An important distinction between testing for breaks when the break date is known or exogenous and when the break date is endogenously determined is explained. We also describe tests for both single and multiple breaks. Additionally, the paper provides a survey of the empirical studies and an application in order for readers to be able to grasp the underlying problems that time series with structural breaks are currently facing.

Keywords
Unit root, Structural Breaks, Multiple Breaks

Disciplines
Business | Social and Behavioral Sciences

Publication Details
This article was originally published as Glynn, J, Perera, N and Verma, R, Unit root tests and structural breaks: a survey with applications, Revista de Métodos Cuantitativos para la Economía y la Empresa = Journal of Quantitative Methods for Economics and Business Administration, 3(1), 2007, 63-79.

Unit Root Tests and Structural Breaks: A Survey with Applications

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ABSTRACT

The theme of unit roots in macroeconomic time series have received a great amount of attention in terms of theoretical and applied research over the last three decades. Since the seminal work by Nelson and Plosser (1982), testing for the presence of a unit root in the time series data has become a topic of great concern. This issue gained further momentum with Perron's 1989 paper which emphasized the importance of structural breaks when testing for unit root processes.

This paper reviews the available literature on unit root tests taking into account possible structural breaks. An important distinction between testing for breaks when the break date is known or exogenous and when the break date is endogenously determined is explained. We also describe tests for both single and multiple breaks. Additionally, the paper provides a survey of the empirical studies and an application in order for readers to be able to grasp the underlying problems that time series with structural breaks are currently facing.

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JEL Classifications: C12, C22,

1. Introduction

During the last three decades, the methods of estimation of economic relationships and modeling fluctuations in economic activity have been subjected to fundamental changes. The method of estimation of the standard regression model, Ordinary Least Square (OLS) method, is based on the assumption that the means and variances of these variables being tested are constant over the time. Variables whose means and variances change over time are known as non-stationary or unit root variables. Therefore, incorporating non-stationary or unit root variables in estimating the regression equations using OLS method give misleading inferences. Instead, if variables are non-stationary, the estimation of long-run relationship between those variables should be based on the cointegration method. Since the testing of the unit roots of a series is a precondition to the existence of cointegration relationship, originally, the Augmented Dickey-Fuller (1979) test was widely used to test for stationarity. However, Perron (1989) showed that failure to allow for an existing break[1] leads to a bias that reduces the ability to reject a false unit root null hypothesis. To overcome this, Perron proposed allowing for a known or exogenous structural break in the Augmented Dickey-Fuller (ADF) tests. Following this development, many authors including, Zivot and Andrews (1992) and Perron (1997) proposed determining the break point 'endogenously' from the data. Lumsdaine and Papell (1997) extended the Zivot and Andrews (1992) model to accommodate two structural breaks. However, these endogenous tests were criticized for their treatment of breaks under the null hypothesis. Given the breaks were absent under the null hypothesis of unit root there may be tendency for these tests to suggest evidence of stationarity with breaks (Lee and Strazicich, 2003). Lee and Strazicich (2003) propose a two break minimum Lagrange Multiplier (LM) unit root test in which the alternative hypothesis unambiguously implies the series is trend stationary.

The objective of the paper is to survey the recent development of unit root hypotheses in the presence of structural change at the unknown time of the break. The salient feature of the paper is to propose a treatment of this important topic in a non technical way. The structure for the rest of paper is as follows. Section 2 discusses the conventional unit roots tests, which do not take into account structural breaks. Section 3

[1] This may be the change in the series as a result some unique economic events.

explains the unit root testing that takes into account one structural break. Unit root testing that takes into account multiple structural breaks are presented in Section 4. In section 5, the authors review some empirical studies and demonstrate the application of the techniques presented in the previous sections. Finally, in section 6, the authors present some concluding remarks.

2. Traditional Unit Root Tests

Nelson and Plosser (1982) argue that almost all macroeconomic time series one typically uses have a unit root. The presence or absence of unit roots helps to identify some features of the underlying data generating process of a series. In the absence of unit root (stationary), the series fluctuates around a constant long-run mean and implies that the series has a finite variance which does not depend on time. On the other hand, non-stationary series have no tendency to return to long-run deterministic path and the variance of the series is time dependent. Non-stationary series suffer permanent effects from random shocks and thus the series follow a random walk.

If the series is non-stationary and the first difference of the series is stationary, the series contains a unit root. The commonly used methods to test for the presence of unit roots are the Augmented Dickey-Fuller (ADF) tests (Dickey and Fuller, 1979 and 1981). The main thrust of the unit root literature concentrates on whether time series are affected by transitory or permanent shocks. This can be tested by the ADF model, which is primarily concerned with the estimate of α. In the following equation, we test the null hypothesis of $\alpha = 0$ against the alternative hypothesis of $\alpha < 0$:

$$\Delta y_t = u + \beta t + \alpha y_{t-1} + \sum_{i=1}^{k} c_i \Delta y_{t-1} + \varepsilon_t \qquad (1)$$

where Δ denotes the first difference, y_t is the time series being tested, *t* is the time trend variable, and *k* is the number of lags which are added to the model to ensure that the residuals, ε_t are white noise[2]. Schwarz Bayesian Criterion (SBC) and Akaike Information Criterion (AIC) are used to determine the optimal lag length or *k*. Non-rejection of the

[2] This means ε_t has zero mean and constant variance that is uncorrelated with ε_s for $t \neq s$

null hypothesis implies that the series is non-stationary; whereas the rejection of the null indicates the time series is stationary.

3. Unit Root Tests in the presence of Structural Break

The debate on unit root hypothesis underwent renewed interest following the important findings of Nelson and Plosser (1982). The traditional view of the unit root hypothesis was that the current shocks only have a temporary effect and the long-run movement in the series is unaltered by such shocks. The most important implication under the unit root hypothesis sparked by Nelson and Plosser (1982) is that the random shocks have permanent effects on the long-run level of macroeconomics; that is the fluctuations are not transitory.

These findings were challenged by Perron (1989), who argues that in the presence of a structural break, the standard ADF tests are biased towards the non-rejection of the null hypothesis. Perron argues that most macroeconomic series are not characterized by a unit root but rather that persistence arises only from large and infrequent shocks, and that the economy returns to deterministic trend after small and frequent shocks. According to Perron, 'Most macroeconomic time series are not characterized by the presence of a unit root. Fluctuations are indeed stationary around a deterministic trend function. The only 'shocks' which have had persistent effects are the 1929 crash and the 1973 oil price shock' (1989, pp. 1361).

Perron's (1989) procedure is characterized by a single exogenous (known) break in accordance with the underlying asymptotic distribution theory. Perron uses a modified Dickey-Fuller (DF) unit root tests that includes dummy variables to account for one known, or exogenous structural break. The break point of the trend function is fixed (exogenous) and chosen independently of the data. Perron's (1989) unit root tests allows for a break under both the null and alternative hypothesis. These tests have less power than the standard DF type test when there is no break. However, Perron (2005) points out that they have a correct size asymptotically and is consistent whether there is a break or not. Moreover, they are invariant to the break parameters and thus their performance does not depend on the magnitude of the break.

Based on Perron (1989), the following three equations are estimated to test for the unit root. The equations take into account the existence of three kinds of structural breaks: a 'crash' model (2) which allows for a break in the level (or intercept) of series; a 'changing growth' model (3), which allows for a break in the slope (or the rate of growth); and lastly one that allows both effects to occur simultaneously, i.e one time change in both the level and the slope of the series (4).

$$x_t = \alpha_0 + \alpha_1 DU_t + d(DTB)_t + \beta t + \rho x_{t-1} + \sum_{i=1}^{p} \phi_i \Delta x_{t-1} + e_t \qquad (2)$$

$$x_t = \alpha_0 + \gamma DT_t{}^* + \beta t + \rho x_{t-1} + \sum_{i=1}^{p} \phi_i \Delta x_{t-1} + e_t \qquad (3)$$

$$x_t = \alpha_0 + \alpha_1 DU_t + d(DTB)_t + \gamma DT_t + \beta t + \rho x_{t-1} + \sum_{i=1}^{p} \phi_i \Delta x_{t-1} + e_t \qquad (4)$$

Where the intercept dummy DU_t represents a change in the level; $DU_t = 1$ if $(t > TB)$ and zero otherwise; the slope dummy DT_t (also $DT_t{}^*$) represents a change in the slope of the trend function; $DT^* = t - TB$ (or $DT_t{}^* = t$ if $t > TB$) and zero otherwise; the crash dummy $(DTB) = 1$ if $t = TB + 1$, and zero otherwise; and TB is the break date. Each of the three models has a unit root with a break under the null hypothesis, as the dummy variables are incorporated in the regression under the null. The alternative hypothesis is a broken trend stationary process.

However, Perron's known assumption of the break date was criticized, most notably by Christiano (1992) as 'data mining'. Christiano argues that the data based procedures are typically used to determine the most likely location of the break and this approach invalidates the distribution theory underlying conventional testing. Since then, several studies have developed using different methodologies for endogenously determining the break date. Some of these include Banerjee, Lumisdaine and Stock (1992), Zivot and Andrews (1992), Perron and Vogelsang (1992), Perron (1997) and Lumsdaine and Papell (1998). These studies have shown that bias in the usual unit root tests can be reduced by endogenously determining the time of structural breaks.

Zivot and Andrews (1992) endogenous structural break test is a sequential test which utilizes the full sample and uses a different dummy variable for each possible break date. The break date is selected where the t-statistic from the ADF test of unit root is at a minimum (most negative). Consequently a break date will be chosen where the evidence is least favorable for the unit root null. The critical values in Zivot and Andrews (1992) are different to the critical values in Perron (1989). The difference is due to that the selecting of the time of the break is treated as the outcome of an estimation procedure, rather than predetermined exogenously.

Even though Banerjee, Lumisdaine and Stock (1992) use endogenous structural break test, the tests are rolling and recursive tests. The numbers of breaks are determined by non-sequential tests which use sub-samples. This can be viewed as not having used the full information set, which may have implications for the power of these tests.

This work was extended by Perron and Vogelsang (1992) and Perron (1997) who proposed a class of test statistics that allows for two different forms of structural break. These are the Additive Outlier (AO) and Innovational Outlier (IO) models. The AO model allows for a sudden change in mean (crash model) while the IO model allows for more gradual changes. Perron and Vogelsang (1992, pp.303) argue that these tests are based on the minimal value of *t* statistics on the sum of the autoregressive coefficients over all possible breakpoints in the appropriate autoregression. While Perron (1997, pp. 356), 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 under a less stringent assumption". Perron and Vogelsang (1992) applied these two models for non-trending data (raw data), while Perron (1997) modified them for use with trending data.

Applying the procedure for testing the unit root hypothesis, which allows for the possible presence of the structural break, has at least two advantages. First, it prevents yielding a test result which is biased towards non-rejection, as suspected by Perron (1989). Second, since this procedure can identify when the possible presence of structural break occurred, then it would provide valuable information for analyzing whether a structural break on a certain variable is associated with a particular government policy, economic crises, war, regime shifts or other factors.

However, two important issues need to be raised here. Firstly, the power of these tests has been questioned by Perron himself and others. The issue has been raised by some authors to the trade-off between the power of the test and the amount of information incorporated with respect to the choice of break point (Perron 1997, pp.378). Secondly, these tests only capture the single most significant break in each variable, raising the question: what if there are multiple breaks in each individual variable? We now turn our discussion to multiple breaks in a time series.

4. Multiple Structural Breaks

Several studies[3] argue that only considering one endogenous break is insufficient and leads to a loss of information when actually more than one break exists (Lumsdaine and Papell (1997). Lumsdaine and Papell (1997) introduce a procedure to capture two structural breaks and argue that unit roots tests that account for two significant structural breaks are more powerful that those that allow for a single break. Lumsdaine and Papell extend the Zivot and Andrews (1992) model allowing for two structural breaks under the alternative hypothesis of the unit root test and additionally allow for breaks in level and trend.

Others who have considered multiple breaks are Clemente, Montañés and Reyes (1998) who base their approach on Perron and Vogelsang (1992) but allow for two breaks. Ohara (1999) utilizes an approach based on sequential t-tests of Zivot and Andrews to examine the case on *m* breaks with unknown break dates. He provides evidence that unit root tests with multiple trend breaks are necessary for both asymptotic theory and empirical applications. Papell and Prodan (2003) propose a test based on restricted structural change, which explicitly allows for two offsetting structural changes.

These endogenous break tests that allow for the possibility of one or multiple breaks; Zivot and Andrews, Banerjee *et al*., Perron (1997), Lumsdaine and Papell(1997) and Ohara (1999) do not allow for break(s) under the null hypothesis of unit root and thus derive their critical values accordingly[4]. This may potentially bias these tests. Nunes *et al* (1997) show that this assumption leads to size distortions in the presence of a unit root with a break and Perron (2005, pp.55) suggests that there may be some loss of power. Furthermore, Lee and Strazicich (2003) demonstrate that when utilizing these endogenous break unit root tests, researchers might conclude that the time series is trend stationary when in fact the series is non-stationary with break(s). In this regard ‘spurious

[3] Ben-David *et al* (2003) argue that failure to allow for multiple breaks can cause the non-rejection of the unit root null by these tests which incorporate only one break. Lumsdaine and Papell (1997) argue that consideration of only one endogenous break may be not sufficient and under such circumstances it could lead to loss of information. Maddala and Kim (2003) believe that allowing for the possibility of two endogenous break points provides further evidence against the unit root hypothesis.

[4] This hypothesis differs from Perron’s (1989) exogenous break unit root tests, which allows for the possibility of a break under both the null and the alternative hypothesis.

rejections' may occur. Thus, as pointed out by Lee and Strazicich (2003), a careful interpretation of results in empirical work is required.

The minimum Lagrange Multiplier (LM) unit root test proposed by Lee and Strazicich (2003)[5] not only endogenously determines structural breaks but also avoids the above problems of bias and spurious rejections. Furthermore, the Lee and Strazicich (2003) procedure corresponds to Perron's (1989) exogenous structural break (Model C) with change in the level and the trend. Lee and Strazicich's (2003)[6] model allows for two endogenous breaks both under the null and the alternative hypothesis. They show that the two-break LM unit root test statistic which is estimated by the regression according to the LM principle will not spuriously reject the null hypothesis of a unit root.

5. Empirical Studies

In this section, we, firstly, review the work of many authors based on the data set used by Nelson and Plosser (1982). Secondly, we review the studies by some authors on different data sets from various counties. Finally, we apply the tests discussed in the previous sections to Indian economic data.

Nelson and Plosser Data

Using annual data for 14 macroeconomic variables from the Unites States of America over the period 1909 to 1970, Nelson and Plosser (1982) could not reject the unit root hypothesis with the standard ADF test for 13 of them including Gross National Product (GNP). They conclude that these series behave more like a random walk than like transitory deviations from steadily growing trend. This led many researchers to believe that time series are influenced by the number of permanent shocks. Subsequent empirical findings such as Stulz and Wasserfallen (1985) and Wasserfallen (1986) supported the unit root hypothesis in the sense that most of the US macroeconomic variables are not stationary at level.

Perron (1989) using the Nelson and Plosser data set allows for a known single break date methodology to test for the presence of unit root. He chooses the stock market

5 Initially, Amsler and Lee (1995) designed their invariant Lagrange Multiplier (LM) unit root test with one exogenous break.

6 If only one break is significant, Strazicich *et al.* (2004) recommend running the one-break LM unit root test proposed by Lee and Strazicich (2004).

crash of 1929 as a break point that permanently changed the level of series. Peron's result challenged most of Nelson and Plosser's conclusions. He rejects the unit root null for 11 series that Nelson and Plosser found to be non-stationary. The results confirmed the view that where there is a structural break, the ADF tests are biased towards the non-rejection of the unit root. He proposes that such a series are better described as stationary around a trend with a structural break in 1929. Perron also applies the same test using quarterly postwar real GNP series for the US economy from1947:1 to 1986: III. He includes a one-time change in the slope of the deterministic trend in 1973 due to the oil price shock. The quarterly GNP series is also found to be stationary.

Zivot and Andrews (1992) who test for a single endogenous break date find less evidence against the unit root hypothesis than Perron (1989) does. Zivot and Andrews provide evidence that confirmed Nelson and Plosser's findings, in the sense that the results are mostly in favour of the integrated model. Zivot and Andrews (1992) reject the unit root at the five percent significance level for only three out of 13 variables using the Nelson and Plosser data. However, the results for nominal GNP, real GNP and industrial production are consistent with Perron's as these variables are rejected even after the break was endogenously determined. Lumsdaine and Papell (1997) re-examine the Nelson and Plosser data for two endogenous breaks, finding more evidence against unit roots than Zivot and Andrews but less than Perron (1989). Using finite-sample critical values, they reject the unit root null for five series at the five percent significance level, the three series found by Zivot and Andrews plus employment and capita real GNP. As suggested by various authors, these endogenous tests have some size problems as the break(s) are considered only under the alternative hypothesis.

Lee and Strazicich (2003) also applied their two-break minimum LM unit root test to Nelson and Plosser's (1982) data and compared it with the two-break Lumsdaine and Papell test. They find stronger rejections of the null using the Lumsdaine and Papell test than the LM test. At the five percent significance level, they reject the null for six series with the Lumsdaine and Papell test and four series with the LM test. Only the unit root null of industrial production and the unemployment rate are rejected by both the Lumsdaine and Papell and LM tests. Furthermore, Lee and Strazicich point out that the null is rejected at the five percent significance level for real GNP, nominal GNP, per-capita real GNP and employment using the Lumsdaine and Papell test, but the null for these variables is only rejected at the higher significance level with the LM test. A summary of the unit root tests using the Nelson and Plosser data set is given below in Table 1.

Table 1: Unit Root Tests with the Nelson and Plosser's Data (1982) Set

Empirical Studies by:	Model	Unit Root (with possible breaks)	Stationary (with possible breaks)
Nelson and Plosser (1982)	ADF test with no break	13	1
Perron (1989)**	Exogenous with one break	3	11
Zivot and Andrews (1992)*	Endogenous with one break	10	3
Lumsdaine and Papell (1997)*	Endogenous with two breaks	8	5
Lee and Strazicich (2003)**	Endogenous with two breaks	10	4

* Assume no break(s) under the null hypothesis of unit root.
** Assume break(s) under both the null and the alternative hypothesis.

Other studies

There have been a number of other studies that test for an endogenous one break model in both the intercept and slope. These include Raj (1992) who tests for per capita real Gross Domestic Product (GDP) for nine countries; Perron (1994) tests for real GDP for 11 countries; and Ben-David and Papell (1995) tests for both aggregate and per capita real GDP for 16 countries. These studies reject the null of unit root for half the countries. In comparison, Ben-David, Lumsdaine and Papell (2003) apply the Lumsdaine and Papell (1997) approach for two structural breaks to an international dataset for 16 countries. They reject the unit root hypothesis for three-quarters; 24 out of 32 cases. This is fifty percent more rejections than in models that allow for a single break.

Banerjee, Lumsdaine, and Stock (1992) using postwar data for seven OECD countries, were not able to reject the unit root hypothesis for five countries (France, Germany, Italy, United Kingdom, and US). However for Canada and Japan, the unit root is rejected against the alternative of a stationary broken trend.

Ghatak (1997) tests the unit root hypothesis under structural breaks for 12 macro-economic time series data for India for the period 1900-1988. He finds that the conventional ADF tests allowing for no structural breaks cannot reject the unit root hypothesis for any of the series supporting Nelson and Plosser (1982). Allowing for exogenous breaks in the level and rate of growth, Ghatak finds that Perron's (1989) tests reject the unit root hypothesis for three series. The Zivot and Andrews tests (1992) for endogenous breaks for India confirm the Perron's test and lead to the rejection of the unit root null hypothesis for three more series.

Strazicich *et al* (2004) apply the endogenous two-break LM unit root test for annual data on per capita GDP for 15 OECD countries for the period 1870-1994 to determine if per capita incomes are stochastically converging. They find that 10 of the 15 log relative income series reject the null of unit root at the ten percent significance level, concluding that significant support for income convergence among OECD countries. Strazicich *et al* (2004) find stronger support for convergence than previous studies which are conducted without structural breaks.

Application to Indian Data

In this section, we use Indian data from 1950 to 2005 to illustrate the testing of unit root hypothesis with structural breaks. The data includes annual Gross Domestic Savings (GDS), Gross Domestic Investment (GDI) and Goss Domestic Product (GDP). The first stage tests for unit root without allowing for any structural breaks. The empirical evidence reported in Table 2 indicates that the ADF test for GDS and GDI are stationary while the unit root null for GDP cannot be rejected at the five percent significance level.

However, the criticism of the conventional ADF method was that the failure to allow for existing breaks leads to a bias that reduces the ability to reject a false unit root null hypothesis. Therefore, in the next stage, we test whether the unit root tests for the variables were biased because possible breaks in the series were ignored. We consider two cases: (1) one-break endogenous model (Perron 1997); and (2) two-break endogenous model (Lee and Strazicich 2003). We reject the unit root null for GDP with both one and two-break models at the five percent significance level. Thus, the GDP data for India supports Perron's (1989) findings that failure to allow for an existing break leads to a bias that reduces the ability to reject a false unit root null hypothesis.

Table 2: Unit Root Tests with Indian Data

Variables	ADF Tests	Perron (97) IO Model*	Perron (97) AO Model*	Lee and Stratizich (2003) **
LGDS	Stationary	Stationary with one break	Stationary with one break	Stationary with two breaks
LGDI	Stationary	Stationary with one break	Stationary with one break	Stationary with two breaks
LGDP	Unit root	Stationary with one break	Stationary with one break	Stationary with two breaks

* Assume no break under the null hypothesis of unit root.
In the IO model (Innovational Outlier model), changes are assumed to take place gradually, allowing for a break in both the intercept and slope and in the AO model (Additive Outlier), changes are assumed to take place rapidly, allowing for a break in the slope
** Assume breaks under both the null and the alternative hypothesis.

6. Concluding Remarks

The main objective of the paper has been to review the recent developments in testing of the unit root hypotheses in the presence of structural change. This survey reveals that there is a significant amount of literature that has focused on the unit root hypothesis in the presence of structural change. The original, Augmented Dickey-Fuller tests was criticized on the basis of a failure to allow for an existing break leading to a bias that reduces the ability to reject a false unit root null hypothesis. To overcome this, Perron (1989) initially proposed a one known or exogenous structural break in the Augmented Dickey-Fuller tests. As a result of the personal judgment involved in determining the breaks, Zivot and Andrews (1992) and Perron (1997) proposed determining the break point 'endogenously' from the data. Lumsdaine and Papell (1997) extended the Zivot and Andrews (1992) model to allow for two structural breaks. Unlike Perron's (1989) null hypothesis, these endogenous tests assume no breaks under the unit root null. Given the breaks are absent under the null hypothesis of unit root there may be tendency for these tests to suggest evidence of stationarity with breaks (Lee and Strazicich, 2003). The two-break Lee and Strazicich (2003) procedure not only allows for the breaks to be determined endogenously from the data but breaks are allowed under both the null and the alternative hypothesis.

The secondary objective of the paper was to review empirical studies based on the Nelson and Plosser (1982) data and other studies. Nelson and Plosser (1982) cannot reject the unit root hypothesis with the standard ADF test for 13 of them including GNP. Perron (1989) using the Nelson and Plosser data set allows for a known single break date as the stock market crash of 1929 rejects the unit root null for 11 series that Nelson and Plosser found to be non-stationary. Zivot and Andrews (1992) who test for a single endogenous break date find evidence that confirmed Nelson and Plosser's findings, in the sense that the results are mostly in favour of the integrated model. Zivot and Andrews (1992) reject the unit root at the five percent significance level for only three out of 13 variables using the Nelson and Plosser data. Lumsdaine and Papell (1997) re-examine the Nelson and Plosser data for two endogenous breaks, finding more evidence against unit roots than Zivot and Andrews but less than Perron (1989). Lee and Strazicich (2003) also applied their two-break minimum LM unit root test to Nelson and Plosser's (1982) data and compared it with the two-break Lumsdaine and Papell test. They find stronger rejections of the null using the Lumsdaine and Papell test than the LM test.

The empirical evidence based on the Indian data shows that savings and investment series are stationary with a break. This is consistent with the results obtained by the conventional ADF unit root test without a break. However, GDP is found to be non-stationary using the conventional ADF test, but stationary with breaks at the five percent level with both Perron's (1997) one break model and Lee and Strazicich (2003) two break model.

We conclude that there is no consensus on the most appropriate methodology to perform unit root tests or no consensus about the empirical results of unit root tests has emerged from this survey. An important point to note here is that testing for structural breaks when the series is otherwise non-stationary will affect whether there is evidence of a structural break.[7]

The development of testing for unit roots with structural breaks in the univariate framework raises a question of incorporation of breaks in the cointegration framework. The basic question here is how we can incorporate breaks of each time series into the cointegration framework. The development in this area is very limited and is indeed an area for further research. Methods based on cointegration incorporating breaks have been proposed by Gregory and Hansen (1996) and Saikkonen and Lütkepohl (2000) and potentially these perform better than the univariate approaches.

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[7] See Perron (2005).

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