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# Structural Breaks in Renewable Energy in South Africa: A Bai & Perron Break Test Application[*][†]

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**Abstract**

South Africa has been struggling to cope with its energy demand. In order to remedy the problem, the government of South Africa has committed itself to pursuing renewable energy as a viable alternative to traditional sources such as fossil fuels. The aim of this study is to understand whether or not the policies pursued by the South African government in the period 1990-2010 have had any effect on the behaviour of consumers and producers of renewable energy. To this end, the Bai & Perron (1998, 2003) break test methodology is employed to understand how renewable energy production and consumption series have evolved over this period. Deviations from the base case are then explained in the South African economic and policy context.

**Keywords:** renewable energy; policy analysis; Bai and Perron; break-point

## 1 Introduction

Concerns over environmental quality and climate change have risen globally in recent times (Stern, 2006). Governments worldwide have started adopting policies to promote the use of renewable energy (RE from now on in the text) as a sustainable alternative. These include the governments of BRIC (Brazil, Russia, India, China) members (Zhang, Li, Cao & Wu 2011a). South Africa, aiming at making energy more sustainable whilst continuing to promote access of the rural poor to energy, has committed itself to pursuing RE as a viable alternative to traditional energy sources such as coal (DME, 2003).

The South African government first acknowledged the importance of energy from renewable sources in the White Paper on Energy in 1998, stating that

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it intended to provide "focused support" for the implementation of RE in the country. The White Paper on RE of 2003 (DME, 2003) however marked the first time that RE took centre stage in the South African policy environment, as opposed to a smaller part of a larger plan. In this white paper, the government outlined numerous actions it intended to take over the course of the next decade to promote the implementation of RE in South Africa.

It is from these commitments from government that the present study derives its main purpose to understand whether government commitments targeted at RE sources have changed the behaviour of consumers and producers of RE over the period 1990-2010. To do so, the Bai & Perron (1998, 2003) structural break test methodology is applied and the results thereof investigated for potential causes, amongst which RE policy actions by government is but one.

The study is therefore structured as follows: The first section or introduction sets the context. The second section provides a background to the RE environment in South Africa, focusing on prominent policies during the period 1990-2010. The third section investigates the application of the Bai & Perron (1998, 2003) methodology. The fourth section provides econometric considerations regarding structural breaks, as well as a brief overview of the evolution of the structural break literature in econometrics. The fifth section describes the methodology to be followed in this study, whilst the sixth section briefly discusses the data used in the study. The seventh section discusses the empirical results, whilst the eighth section discusses them within the South African economic and policy context. The ninth section concludes the study and offers policy insights.

## 2 Background Analysis

RE in South Africa is almost exclusively in the form of biomass consumption (IEA, n/d). The largest consumers of this type of energy are rural households who depend upon this form of energy for a large portion of their energy needs, particularly for cooking and heat (StatsSA, 2005; Banks & Schafller, 2006). Despite being connected to the national grid as part of South Africa's numerous electrification programs, many households still prefer to use biomass as their primary source of heat and cooking. This is particularly true for poorer households (Davis, 1998; Madubansi & Shackleton, 2006). When Madubansi and Shackleton (2006) investigated the behaviour of five rural villages following electrification, they found that there was no change in fuelwood consumption despite these villages receiving free basic electricity of 5-6 kWh per month. These users and this sector should be borne in mind when investigating structural breaks in RE in South Africa, since they constitute such a large share of RE consumption and production. Naturally, the government of South Africa may also be responsible for structural breaks through the various RE policies it has enacted.

The first broad goals set by government with regard to the RE sector came about in 1998 in the form of the White Paper on Energy published by the then

Department of Minerals and Energy (DME). The South African government committed itself to providing "focused support for the development, demonstration, and implementation of RE sources for both small and large scale applications" (DME, 1998). This included information and education to various stakeholders, along with active promotion in support of the implementation of renewable energies. The government also identified the use of renewables in remote areas where grid supply for electricity may be impractical and acknowledged that RE sources may be the cheaper option in many cases. Government thus undertook to actively support the deployment of RE sources in rural communities in particular. Furthermore, government noted that a lack of standards and guidelines in the industry contributed to user uncertainty with regard to cost effectiveness, as well as reliability of RE systems. In this light, government committed itself to the establishment of guidelines and standards that would, at least for the time being, be voluntary to adhere to (DME, 1998).

In 2003, government published the White Paper on RE. Here, the government for the first time adopted a fixed target of 10 000 GWh per year as a goal for 2013 (DME, 2003). This amounted to roughly 4% of gross final demand projected for the year 2013 (DME, 2003). Government committed itself to the establishment of an environment that is conducive to the development and implementation of RE using various tools. The five main categories of tools that are identified are financial instruments, legal instruments, technology development, awareness and capacity building, along with technology support centres. Some of the policies that fall under these five pillars include (DME, 2003):

- Monitoring and evaluation of the effectiveness of financial incentive schemes;
- Designating NERSA to manage and implement a tariff structure to promote the development of RE, including feed-in tariffs;
- Enactment of laws and other regulatory instruments in the petroleum industry to promote locally produced biodiesel;
- Monitoring and support of research programs into RE with the goal of developing and promoting RE as a source of energy;
- Fostering international cooperation in the field of RE;

In pursuing the abovementioned actions, the government of South Africa is following in the footsteps of the Chinese government which has had considerable success through the provision of funding incentives for RE (Zhang, Zou & Cao, 2011b).

One of the financial instruments government highlighted in the *White Paper* of 2003 for promoting RE was the so called feed-in tariff. The feed-in tariff guarantees the price that a RE producer can expect to receive for the production of energy from a renewable source (Couture & Gagnon, 2010). The National Energy Regulator of South Africa (NERSA) requested feedback on the topic in 2007, and in 2009 the NERSA approved feed-in tariffs for various sources of

RE (NERSA, 2009). These tariffs are denoted in South Africa by the acronym REFIT (RE Feed-In Tariff)

These policies have been effectively deployed[1] hence in Germany, Spain, Portugal and Denmark (Couture & Gagnon, 2010). In the case of Spain, RE feed-in tariffs have been particularly successful, in part due to the economies of scale that exist in the RE sector (Del Rio Gonzalez, 2008). Therefore the protection the Spanish government afforded to renewable energies helped them "get off the ground" in the initial turbulent phases. According to Couture and Gagnon (2010), feed-in tariffs are also good for reducing risk in the RE sector, since they provide a guaranteed fixed stream of revenue that is independent of the prevailing electricity prices. Indeed, if these tariffs are also adjusted for inflation, the number of investors that are willing to invest in RE rises significantly (Couture & Gagnon, 2010). This has been echoed by the Spanish experience, where the resulting markets have been stable and attractive to investors (Del Rio Gonzalez, 2008). Overall, a well-structured feed-in tariff system can significantly reduce the risk associated with renewable energies (Couture & Gagnon, 2010). This is of particular interest since Pegels (2010) points out that the market for RE in South Africa is quite young and volatile and this increases market risk for renewable energies.

There have been further developments since the year 2009, including the abandonment of the feed in tariff system in favor of the Independent Power Producer Program, and the release of the Integrated Resource Plan. These are not discussed here however due to the fact that they fall outside the sample period and are therefore unlikely to have caused structural breaks in the period under investigation.

# 3 Literature Review

The core of the Bai & Perron (1998, 2003) approach is to estimate whether there has been structural change in the way two or more time series are related over time. One application of this is to investigate whether exogenous shocks are capable of driving these changes. Therefore, a review of practical applications in both policy analysis in energy, as well as in topics further afield, is presented in this section. For an overview of non-energy as well as energy related studies, see Table 1.

## 3.1 *Bai & Perron applied to RE consumption and production series*

Within the RE literature, the most relevant papers for the purposes of the current study are those of Zhang *et al.* (2011b) and Zhang *et al.* (2011a). Zhang *et al.* (2011b) investigated the impact of energy policies as a whole in the US, as well as in China. These authors found that Chinese policies supporting rural

[1] leading to large increases in the use of RE.

energy consumption from renewable sources, particularly for small scale hydro power plants, led to a rise in the proportion of RE as a fraction of total energy consumed. Therefore, China as a country became more ‘renewable intensive’ following these policies. In the case of the US, the Clinton Administration’s RE push seems to have yielded results, since the only trend break for the US RE production series was positive. Two notable policies on RE immediately predate this break. The first is the “Million Solar Roofs” plan, which saw a drop in the price of producing solar electricity in subsequent years. The second is that the Clinton Administration proposed an energy quota system which would see the share of RE in total energy output rise to 7.5% in 12 years. The study none the less provides evidence in favour of the positive impacts policy can have on RE, without specifying the specific policy’s impact (Zhang *et al.*, 2011a).

In an expansion of the work of Zhang *et al.* (2011b), Zhang *et al.* (2011a) specifically investigate RE production and consumption. Zhang *et al.* (2011a) aims to determine whether policy has been effective in the BRIC countries, also through the use of the Bai & Perron (1998, 2003) methodology. The authors find that RE policies in China and Brazil have been effective and improved the future prospects regarding RE production as well as consumption, whilst the results in the case of India are more ambiguous. Russian policy seems to be ineffectual (Zhang *et al.*, 2011a). A summary of these results is provided in Table 1.

The two successful candidates of the BRIC group achieve their success in different ways. China places a lot of emphasis on financial incentives as well as research and development to make RE more feasible at a sector level. Brazil, on the other hand, engages in mandated policies that are tailored towards one particular sector (Zhang *et al.*, 2011a). Thus it may be said that policy changes can effectively drive economic agents to change their behaviour, whether this be voluntary or mandatory. The Bai & Perron (1998, 2003) methodology is

## 3.2 *Bai & Perron applied to energy efficiency and oil time series*

Within the energy broader literature, the Bai & Perron (1998, 2003) methodology has been applied both in its own right as the focus of a paper, as well as part of a barrage of tests in other papers. Bhaskara Rao & Rao (2009) investigated energy efficiency in Fiji, to determine whether external oil price shocks can bring about higher energy efficiency. Applying the Bai & Perron (1998, 2003) technique, they found that the Fijian economy became more energy efficient after the oil crisis of 1981-1983. Liddle (2012) investigated energy efficiency in the OECD countries and confirmed the results of Bhaskara Rao & Rao (2009). In addition to oil shocks, these authors also found that policy has a large role to play for energy intensity overall. Policies that subsidise energy prices may prevent economies from becoming more efficient and thus exhibiting downward trends (Liddle 2012). Thus it can be said that policy, as one type of exogenous shock, may even prevent structural breaks in energy time series, as well as cause them.

In terms of the oil market, Mensi, Hammoudeh & Yoon (2014) found that output decisions by the Oil Producing and Exporting Countries (OPEC) body have a strong effect on the volatility of market prices and not only on price levels. This study found that whilst the series for oil prices and returns are volatile in nature, they are significantly less volatile when the Bai & Perron (1998, 2003) methodology is applied to allow for structural breaks. The break dates largely coincide with the announcement of a "cut" or "maintain" decision with regard to output by OPEC. In other words, a large part of the volatility can be explained by structural breaks where a particularly more or less volatile period is brought about by an OPEC policy decision. (Mensi, Hammoudeh & Yoon, 2014). The Bai & Perron (1998, 2003) methodology has also been applied in fields outside of energy economics, including the relationship between substitute products (Kristofersson & Anderson, 2006), changes in the behaviour of terrorists (Enders & Sandler, 2005) as well as changes in the unemployment in the wake of recessions (Papell, Murray & Ghiblawi, 2000).

## 3.3 *Unit root properties of energy time series*

The properties of energy time series are a matter of debate in the literature with studies arguing for and against the existence of unit roots. In the case of a unit root, policy shocks in any time period will have a permanent effect in all subsequent time periods. In the case of desirable outcomes such as RE promotion, any policy that has a positive effect on RE production or consumption will see this effect last indefinitely into the future (Smyth, 2013). For a mathematical discussion of how non-stationarity can affect the impact of a policy over time, see Hamilton (1994).

## 3.4 *Structural breaks, trends and unit roots*

Of particular importance to unit root testing in time series with trends is the issue of structural breaks illustrated by Perron (1989). The basic idea is that testing for stationarity around a trend may not yield consistent results if there is some break in the trend during the period under investigation. Ignoring the possibility of a break in the trend may lead to the over-acceptance of the null hypothesis of a unit root in a time series which is in fact stationary, albeit around a broken trend (Perron, 1989).

This problem has been investigated by numerous studies in the energy literature. Unit root testing without the possibility of a structural break yields an acceptance of the unit root hypothesis in most cases. Where the possibility of up to two structural breaks is accounted for, the majority of studies have led to a rejection of the unit root hypothesis when dealing with energy consumption from various sources. The methods used to account for unit roots in the presence of trend shifts are varied, however broadly yield the same results, namely that when structural breaks are ignored, most series are non-stationary and when structural breaks are accounted for, most series are stationary. This holds both when individual series are examined with various techniques, as well as when the series are examined together as a panel with various tests (Smyth, 2013). For a showcasing of selected studies, see Table 3.

Importantly even if a time series is found to be stationary, this does not mean that policy effects are necessarily transient. If a time series is break stationary, policy may still have an effect if the long run growth path (or trend) of the time series is altered. This is what Zhang *et al.* (2011a) found for RE production and consumption in BRIC. The majority of the series examined there exhibited stationarity around a broken trend. The authors concluded that policy interventions in China and Brazil have indeed positively affected RE consumption and RE production by permanently increasing the growth rate of these two variables over time by raising the trajectory of their long run growth path. In other words, RE policies in China and Brazil caused a positive structural break (Zhang *et al.*, 2011a).

## 3.5 *Econometric considerations of structural break*

In his influential paper, Perron (1989) assumed that a structural break can be determined exogenously *ex ante*. The researcher would specify the break date and test to ascertain whether this break date yields a stationary process. However, the literature eventually moved away from this exogenous determination of break dates towards endogenous determination (Glynn, Perera & Verma, 2007). In these tests however, there often exists a maximum number of breaks that the series may exhibit. The case of Lee & Strazicich (2003) is a prime example. In this case, the maximum number of breaks that are permissible is set at two (Lee & Stratzicich, 2003). The Bai & Perron (1998, 2003) approach advocated in this paper does not set such a low bound on the number of structural breaks and thus may be more appropriate for analysing series that are more volatile in nature, where there is no reason to expect a maximum of two breaks.

In fact, the Bai & Perron (1998, 2003) methodology is an expansion of the work of Quandt (1960) which allowed for the endogenous determination of only one structural break by conducting a repetitive Chow (1960) break-point test at every observation.

It should be emphasized that the Bai & Perron (1998, 2003) approach is not a unit root test, but a modelling approach in the presence of structural breaks with the goal of determining the break dates endogenously. The approach does allow for testing for sub-trend stationarity in an autoregressive setup, by using additional tests on segments separated by break dates, but this is not its purpose. In fact, the Bai & Perron (1998, 2003) methodology is designed to look for structural breaks between any number of series. However, the equation under investigation is specified as an autoregressive series (or something similar), then the structural breaks detected by the Bai & Perron (1998, 2003) approach can be interpreted as structural breaks in the way that the series evolves over time. These break dates are then comparable with the break dates presented by other specifically time series and stationarity testing techniques, such as the techniques presented in Table 4, since they are based on the same type of equation: the autoregressive equation.

Since many changes exist in the policy environment in South Africa in a relatively short period and the Bai & Perron (1998, 2003) methodology allows for more than just two structural breaks, it seems like the natural choice when compared with the other structural break tests highlighted above.

# 4 Methodology

The overall methodology can be broken down into three steps. The first involves investigating the unit root properties of the time series. Should a series prove to be non-stationary, then the Bai & Perron (1998, 2003) technique may be appropriate to attempt to account for any structural breaks and reveal the dates of these structural breaks. The second step is then to investigate the unit root properties of the individual segments, split by the break dates given by the Bai & Perron (1998, 2003) analysis, to see whether or not the structural breaks account for the non-stationarity observed in step one. The third step then involves using Ordinary Least Squares regression analysis using dummy variables to account for the break dates. This allows the modeller to estimate the directionality of the breaks given by the Bai & Perron (1998, 2003) methodology.

## 4.1 *Testing for stationarity: The Dickey-Fuller Approach*

Whilst a multitude of tests exist in the literature for the examination of stationarity, the test chosen here is the Dickey & Fuller (1979) test, due to its considerable popularity.

## 4.2 *The Bai & Perron (1998, 2003) set up*

The methodology proposed by Bai & Perron (1998, 2003) allows the modeller to estimate structural breaks endogenously. In other words, the timing of the breaks need not be known beforehand. The following sections are based exclusively on the Bai & Perron (1998, 2003) papers unless stated otherwise.

We start by considering the general case for a time series $T = 1, 2, 3...T$ with $m$ structural breaks, allowing for $m + 1$ partitions in the series. Some of the coefficients, contained in a matrix labelled $\beta$, remain constant over the entire time series (or over all partitions) whilst others, contained in a series of matrices labelled $\delta$ represent the coefficients that are estimated for each individual partition 1 to $m + 1$.

The method by which the coefficients in $\beta$ and $\delta$ are estimated is that of ordinary least squares (OLS). In essence, the parameters contained in the $\beta$ and $\delta$ matrices are selected in such a manner as to minimize the sum of the squared errors. Mathematically speaking, the objective function for this minimization can be given by:

$$(Y - X\beta - \bar{Z}\delta)'(Y - X\beta - \bar{Z}\delta) = \sum_{i=1}^{m+1} \sum_{t=T\,i-1+1}^{T_i} [y_t - x_t'\beta - z_t'\delta_i]^2 \qquad (1)$$

Where the sum of squared residuals is calculated first across all time points in a given segment 1 to $m+1$. In the end, all of the errors in the individual segments are summed up to obtain a global sum of squared residuals given by $S_T(T_1, T_2, ...T_m)$ which are specific to the break dates $(T_1, T_2, ...T_m)$.

### 4.3 *Testing for the maximum number of break dates*

Bai & Perron (1998, 2003) propose a sup-F type test, to test the null hypothesis of 0 breaks versus some arbitrary number of breaks, $m = k$. In such a case, it is possible to construct an $F$-test in the following manner, where break dates $(T_1, T_2, ...T_k)$ are not investigated directly, but indirectly using the fraction of the series in which the date appears. Specifically, $\frac{T_i}{T} = \lambda_i$ for $i = 1, 2...k$:

$$F_T(\lambda_1, \lambda_2...\lambda_k; q) = \left(\frac{T-(k+1)q-p}{kq}\right) \frac{\hat{\delta}' R'(R(\bar{Z} M_x \bar{Z})^{-1} R')^{-1} R\hat{\delta}}{SSR_k} \tag{2}$$

Where $R$ is the matrix that allows $(\hat{\delta}R) = \delta'_1 - \delta'_2, \delta'_2 - \delta'_3, ...\delta'_k - \delta'_{k+1}$. The matrix $M_x$ is defined such that $M_x = I - X(X'X)^{-1}X'$. Furthermore, $SSR_k$ is the sum of squared residuals under the alternative hypothesis. This value depends upon the break dates selected under the alternative, $(T_1, T_2, ...T_k)$ of $k$ breaks. Before the sup-F test can be conducted however, it is important to limit the possible break dates, such that they form part of the following set:

$$\wedge_\varepsilon = \{(\lambda_1, \lambda_2...\lambda_k); |\lambda_{i+1} - \lambda_i| \geq \varepsilon, \lambda_1 \geq \varepsilon, \lambda_k \leq 1 - \varepsilon\} \tag{3}$$

Where $\varepsilon$ is some arbitrarily small number, called a trimming parameter. The purpose of the trimming parameter is to indicate what the "shortest" possible length of a segment may be as a fraction of the total length of the time series. The trimming parameter is set to 0.15 for the current study, since a smaller trimming parameter would not leave sufficient observations to estimate some segments. The sup-F statistic can then be defined as follows:

$$F(k; q) = \sup_{(\lambda_1, \lambda_2...\lambda_k) \epsilon \wedge_\varepsilon} F_T(\lambda_1, \lambda_2...\lambda_k; q) \tag{4}$$

In essesnce, what the procedure attempts to do here is to maximize the F statistic. With the F statistic representing how much 'better' one model is than another, the nreaks dates are arranged such that they yield the largest F statistic for k arbitrary breaks. In other words, the 'best' model with k breaks is selected and compared with the base of no break. The null and alternative hypothesis for this test is thus specified as follows:

$$\begin{aligned} H_o &: m = 0 \\ H_a &: m = k \end{aligned}$$

This approach however requires that a specific number of breaks be given a priori. To allow breaks to be estimated endogenously, Bai & Perron (1998,

2003) suggest the use of a double-maximum test, referred to as Dmax test. In this case, only some upper bound of M breaks is specified. Expanding upon the supF test outlined, the Dmax test can be expressed as:

$$D\max F_T(M, q, a_1, a_2, ...a_M) = \max_{1\leq m\leq M} \; a_m \; \sup_{(\lambda_1,\lambda_2...\lambda_k)\epsilon\wedge_\varepsilon} F_T(\lambda_1, \lambda_2...\lambda_k; q) \tag{5}$$

In this specification, $(a_1, a_2, ...a_M)$ represent some fixed weights associated with breaks 1 to M. In such a case, the null and alternative hypothesis can be given as:

$$\begin{aligned} H_o &: \; m = 0 \\ H_a &: \; m \textit{ is between } 1 \textit{ and } M \end{aligned}$$

Bai & Perron (1998) note that the selection of these arbitrary breaks may introduce further information as to the likelihood of various numbers of breaks being selected, however acknowledge that this is a theoretically open ended question, since precise guidelines on the selection of weights do not exist.

Bearing this in mind Bai & Perron (1998, 2003) allow for two versions of the Dmax test, referred to as the UDmax and WDmax tests. The UDmax test sets the weights $(a_1, a_2, \ldots a_M)$ equal to unity. One problem with the UDmax approach is that if the outcomes are weighted equally, the power of the test decreases as the number of breaks m increases for a fixed sample. This is due to a drop in the critical values for large values of m. To overcome this problem Bai & Perron (1998) also propose a WDmax test where the asymptotic critical values are used to weight the likelihood of various outcomes. The two versions of the test can be expressed as follows:

$$UD\max F_T(M, q, a_1, a_2, ...a_M) = \max_{1\leq m\leq M} \; \sup_{(\lambda_1,\lambda_2...\lambda_k)\epsilon\wedge_\varepsilon} F_T(\lambda_1, \lambda_2...\lambda_k; q) \tag{6}$$

$$\begin{aligned} & WD\max F_T(M, q, a_1, a_2, ...a_M) \\ = \; & \max_{1\leq m\leq M} \frac{c(q, \alpha, 1)}{c(q, \alpha, m)} \sup_{(\lambda_1,\lambda_2...\lambda_k)\epsilon\wedge_\varepsilon} F_T(\lambda_1, \lambda_2...\lambda_k; q) \end{aligned}$$

Where $c(q, \alpha, m)$ represents the asymptotic critical for the test $\sup(\lambda_1, \lambda_2...\lambda_k)_{\epsilon\wedge\varepsilon} F_T(\lambda_1, \lambda_2...\lambda_k; q)$ for an arbitrary level of significance $\alpha$ and the number of that break, m. q represents as before the number of time varying parameters in the model. Thus as the critical values drop for higher levels of m, the weight assigned to that 'maximum' F statistic rises.

## 4.4 Testing for the number of break dates

In order to isolate the exact number of break dates, Bai & Perron (1998, 2003) advocate an F type test that will test the following hypothesis:

$$
\begin{aligned}
H_o &: \quad m = l \\
H_a &: \quad m = l + 1
\end{aligned}
$$

Should we fail to reject the null hypothesis, the inclusion of a further break does not allow for a better econometric fit between the dependent and independent variables than the set up under the null hypothesis. Should the null hypothesis be rejected, the additional break under the alternative hypothesis does a statistically significant better job of explaining the relationship between the variables. To locate the optimal number of break dates, this test is repeated l+1 times until we fail to reject the null hypothesis. The break dates under the null hypothesis are selected in such a manner that they minimize the sum of squared residuals as illustrated in the beginning of this section. The F-test statistic is expressed as follows:

$$
\begin{aligned}
F_T(l+1|l) \quad &= \quad \frac{\left\{ S_T(\hat{T}_1, \hat{T}_2, ...\hat{T}_l) - \min_{1 \leq i \leq l} \inf_{\tau \epsilon \wedge_{i\eta}} \right.}{\hat{\sigma}^2} \\
& \quad \frac{\left. S_T(\hat{T}_1, \hat{T}_2, ...\hat{T}_{i-1}, \tau, \hat{T}_{i-1}, \hat{T}_{i+1}, ...\hat{T}_l) \right\}}{\hat{\sigma}^2}
\end{aligned}
$$

Where the set $\wedge_{i\eta}$is defined as:

$$
\wedge_{i\eta} = \{\tau; T_{i-1} + (T_i - T_{i-1})\eta \leq \tau \leq T_i - (T_i - T_{i-1})\eta\} \tag{7}
$$

And $\hat{\sigma}^2$ is a consistent estimate of the residual variance under the null hypothesis of l breaks. The test thus involves investigating each individual Segment 1 up to l+1 of the model under the null hypothesis. Within each of these segments, the various break dates are then tested to see if a break date exists that can significantly reduce the sum of squared errors. In this case, $\eta$ is once again a trimming parameter that sets the minimum length that a segment must be if it is further broken up. As with the UDmax and WDmax tests, the trimming parameter is once again set to 0.15.

### 4.5 Investigating the unit-root properties of the segmented series

After the identification of the break dates, the unit root properties of the individual segments should be re-examined. Effectively, if the individual segments present evidence in favour of stationarity, then the cause of the non-stationarity identified prior to the segmentation of the series is likely to be a break in the trend or the mean level, which may be caused by a change in the RE environment. This is in line with the approach followed by Perron (1989) for accounting for structural breaks in a time series.

## 4.6 Determining break directionality

Once the break dates have been reliably confirmed by the Bai & Perron (1998, 2003) methodology, and the resulting segments are confirmed to be stationary, then it is possible to estimate exact impact of the breaks in a single equation using Ordinary Least Squares. In order to do this, dummy variables are used at each break date and capture the change in the variables contained in $\delta$. This approach will allow for all segments 2 to m+1 to be compared to segment 1. In other words, all subsequent breaks and the effects they had will be comparable directly as deviations from the base case before any breaks took place. The exact specification of the equations will however only be decided upon after the break dates are revealed through the application of the Bai & Perron (1998, 2003) methodology and hence these are discussed as part of the results section. This approach to estimating the directionality of the break is also followed by Zhang et al. (2011a).

## 4.7 Data

The data on RE for the current analysis was obtained from the International Energy Organisation (IEA) and consists of final renewable consumption as well as final renewable production data for the period of 1990 to 2010. In addition to RE consumption and production, total energy consumption and production data is also used from the same source. The total energy data contains energy produced from all sources, both renewable and non-renewable. The series to be examined are thus discussed below.

The data on RE consumption is given only at an aggregate level but contains all final consumption by both industries and households of all RE sources within a country. Importantly, RE for biomass is only considered if it is actually consumed for energy. Furniture sales, for example, do not form part of RE consumption, but the purchase of fuelwood does form part of it.

The RE supply data used here is disaggregated by source of production, where solid biomass accounts for over 98% of production for the entire period. Solid biomass includes items such as wood, dung, animal materials and any other solid biological matter to be burned for energy. As is the case with supply, any biomass produced for nonfuel purposes is excluded.

Both series are presented in their natural logarithm forms and are denoted henceforth as the Log of Demand (LOD) and Log of Supply (LOS).

In addition to examining RE series for their evolution in their own right, the share of RE consumption in total consumption, as well as the share of RE production in total energy production, will also be examined. These two series will henceforth be referred to as the share of demand (SOD) and share of supply (SOS) respectively. In both cases, it will be the amount of RE consumed or produced in any given year divided by the total energy in that year. Examining these two series will allow us to understand whether or not RE now features more prominently within the South African profile, even if there may exist no breaks in the evolution of RE in its own right. In the next section we shall examine these four series econometrically.

# 5 Presentation of Econometric Results

## 5.1 Results of the stationarity testing

A summary of the results of the stationarity testing is presented in Table 5. The only series that provides evidence in favour of stationarity is the SOD series. Hence, a prima facie case for structural breaks, as one potential cause of non-stationarity, exists in all but the demand share series.

## 5.2 Results of the Bai & Perron structural break methodology

With the unit root properties of the series in mind, all of the series are tested for structural breaks using the Bai & Perron (1998, 2003) methodology, with the break dates for the various series presented in Table 6. The UDmax and WDmax statistics both allowed for up to five breaks in the null hypothesis. More than five breaks is not possible, since the minimum segment size specified by the trimming parameter would be violated. In other words, allowing for more than five breaks would lead to a segment that is too small for the current methodology. In all but the SOD series, there exist up to five structural breaks according to these two statistics. Notably the UDmax and WDmax statistics always concur in their findings.

In order for the number of breaks to be determined for each series, the null hypothesis of l breaks is tested versus the alternative of l+1 breaks, until it is no longer possible to reject the null hypothesis. The column F Stat (1) indicates the test statistic for one structural break whilst the Break (1) column indicates the date where the F-statistic is maximized. F Stat (2) indicates the test statistic for 2. A rejection in this column is accompanied by the date where the F-statistic is maximized, in the column Break (2). The same logic applies to F Stat (3) as well as Break (3).

This process concludes that there are no structural breaks for the SOD series, since the null hypothesis of no breaks cannot be rejected in favour of an alternative hypothesis of one break. This is backed up by the UDmax and WDmax statistics, both of which indicate that the null hypothesis of no break cannot be rejected. In the case of the SOS series, the rejection of the null hypothesis of one break is confirmed at the 1% level of significance and the accompanying break date is 2004. The SOS series does not seem to present evidence of a second structural break, due to the low F test statistic for the null hypothesis of one break versus two. This result is consistent with the UDmax and WDmax statistics for this series, both of which reject the null hypothesis of at least one break in favour of the alternative hypothesis of between one and five breaks.

In the case of the LOS series, the null hypothesis of no structural breaks is rejected and the accompanying break date where the F-statistic is maximized is the year 2001. In the case of one break versus two, it is not possible to reject the null hypothesis and hence we conclude that the LOS series exhibits a structural break only in 2001. Once again, this result is consistent with the UDmax and WDmax tests, both of which reject the null hypothesis of no break in favour of the alternative hypothesis of at least one, but no more than five breaks.

When the LOD series is examined, the null hypothesis of no break is rejected in favour of the alternative hypothesis of one break. The year in which the F-statistic is maximised is the year 2001. When the null hypothesis of one break is compared to the alternative of two, the null hypothesis is once again rejected with the F-statistic in this case corresponding to a model that has a break in 2001 as well as in 1997. When the null of two breaks is compared to that of three breaks, the F statistic does not allow for rejection of the null hypothesis. The conclusion we come to is that this model has two structural breaks, one in the year 1997 as well as one in the year 2001. This is verified by the UDmax and WDmax test statistics, both of which see the null hypothesis of no structural breaks rejected in favour of the alternative of between one and five structural breaks.

## 5.3 Unit root properties of the individual segments

To understand whether or not the breaks were the cause of the non-stationarity in the time series, the results of the stationarity testing on the individual segments are presented below in Table 7. When the Dickey & Fuller (1979) unit root test is used, there exists some evidence in favour of stationarity. However, due to the extremely limited number of observations available for the unit root tests in each of the subsamples, it may be prudent to include a further unit root test. To this end, the Dickey-Fuller Generalized Least Squares (DF-GLS) test is used, which is based upon the work of Elliot, Rothenberg & Stock (1996). This test is selected due to the additional power it has compared to the traditional Dickey-Fuller test, especially in small samples (Elliot, Rothenberg & Stock, 1996).

When using the DF-GLS test, the evidence in favour of stationarity is overwhelming, with all of the subsamples stationary at the 5% level of significance, except for the second segment in the SOS series, which is stationary at the 10% level of significance.

This evidence provides support to the idea that the structural breaks observed are in fact breaks in the trend or level of an otherwise stationary series. In other words, individual events in the years identified in Table 5 may have caused the long run growth path of RE, in the case of LOS and LOD, to shift. In the case of the SOS series, the growth path did not shift but the share of RE in total energy supply changed.

## 5.4 Break directionality estimation

Based on the break dates provided by the diagnostic testing above, Table 8 illustrates the equations to be estimated for each of the series in order to capture the effects of the breaks in their particular dates. In this table, $S_D$ and $S_S$ represent the share of RE demand and supply in total demand and supply respectively. $R_D$ and $R_S$ represent the demand and supply of RE whilst $E_D$ and $E_S$ represent the total demand and total supply of energy in South Africa. C represents a standard intercept term whilst T represents time (in years) and is the trend variable. D represents a dummy variable that is one for the year starting in its subscript, as well as all subsequent years, and zero for the time periods before. In the case of the LOD equation, the 1997 dummy is active only for the years 1997-2000 and then 0 otherwise.

The SOD and SOS equations are estimated in their levels due to the easy interpretation thereof. The constant of the regression analysis is in both cases to be interpreted directly as the share of RE in either demand or supply shares. Any break in the year 2004 for the SOS share will easily be interpreted as a rise or drop in the percentage share of RE in supply at that time. In the case of the LOS and LOD series, a log-log approach is chosen in order to follow the approach of Zhang et al. (2011a) as well as to allow for the estimation of yearly growth rates through the trend variable. For a mathematical justification of this interpretation, see Gujarati & Porter (2009).

The results of the estimation of the equations in Table 8 are reported in Table 9. The Constant and Trend columns of the table indicate the values for the base case, whilst Constant 1997 and Constant 2001 columns indicate the departure from the base case. The same logic applies to Trend 1997 as well as Trend 2001. Worth noting is that all the variables are statistically significant, acting as an additional robustness check to the dates advocated by the Bai & Perron (1998, 2003) methodology.

The SOD series remains constant at approximately 15.8% throughout the period under examination, whilst the SOS series remains at approximately 11.5% for the duration of the perio 1990-2004. For the period 2004-2010, SOS was approximately 1.2% lower than in the base period of 1990-2004.

In terms of the LOS and LOD evolution over time, only the trends are investigated[2]. In the trends, there exists a negative break in the year 2001 in both series. In the period of 1990-2001, the growth rate of RE supply was approximately 1.9% per year, represented by the trend coefficient. In the period 2001-2010, that growth was lower by approximately 0.7 percentage points. In the case of RE demand, the base period of 1990-1997 experienced a growth rate of approximately 1.8% per year. During the period 1997-2001, this growth rate rose by approximately 0.3 percentage points compared to the base period of

[2] In the case of the evolution of RE over time, given by the LOS and LOD series, the constant is not to be interpreted. The reason for this is that the variable of interest is the trend variable which describes the evolution of RE consumption and production over time. The constant must be allowed to vary, otherwise there could be bias forced into the new trend parameters. However the constants themselves have no economic meaning in their own right in this case.

1997-2001. In the period 2001-2010, the rate of growth in RE demand dropped by approximately 0.6 percentage points relative to the base period of 1990-1997. Since the decrease in the period 2001-2010 is larger than the increase in the period 1990-1997, as well as the fact that both are compared to a common base period, it is possible to say that the period 2001-2010 experienced a lower growth rate of approximately 0.3 percentage points than the period 1997-2001.

# 6 Discussion of the results

The results above identify three break dates. Using the convention that the break date is defined as the first observation in the new partition, the break dates are 1997, 2001 and 2004 respectively. The discussion below focuses upon the effects of biomass, in particular wood, on the various indicators of RE supply and demand. The reason for this is the fact that biomass constitutes the largest component of RE demand as well as supply in South Africa, with over 98.5 percent coming from this source alone (IEA, n/d). Furthermore, all break dates are in years where there were changes in the biomass environment, as opposed to years of significant RE policy actions by government.

## 6.1 A break in LOD in 1997

In 1997 the White Paper on Sustainable Forest Development in South Africa was released. The objective of this policy was to promote the conservation of South African forests, whilst still benefiting the communities that depend upon them. As part of this white paper, the government declared that it would support re-distribution of excess production of wood from industrial forests to help ensure that the energy requirements of rural households are met (DWAF, 1997). This may manifest itself as a positive break in the consumption of household biomass and hence RE, but not a break in supply. The reason for this is that IEA statistics do not include commodity biomass unless it is specifically used for energy purposes (IEA, 2012). Therefore, some of the wood consumed by households would be recorded in consumption statistics but not in production statistics, since the production originally took place in non-fuel firms and sectors.

To understand why the share of RE in total energy consumption may not exhibit a break at this time, it is necessary to reflect upon a few methodological considerations. Since the break in RE consumption is rather small in this year and the share of RE in total energy also depends upon the behaviour of total energy, the change in behaviour of consumers in this smaller subsection of the energy market may not be enough to "rise above" the white noise in the share of RE series, which depends upon the total market as well and manifest in a break. Econometrically speaking, when the break in a series is small in magnitude, the power of the tests used here drop substantially (Bai & Perron, 2006). One possible way to identify such a subtle break is to use data of higher frequency, since the tests used here have lower power in smaller samples (Bai & Perron, 2006).

## 6.2 A break in LOD and LOS in 2001

Amongst the consumers of RE, households dominate the market with a share of approximately 98% which is used primarily for the purposes of cooking and heating within the household. In the case of cooking, 20% of the energy use by households comes from wood, whilst a further 21% comes from paraffin. For the purpose of heating, wood represents 24% of the energy use by households, whilst paraffin represents 14%. In both cases, the remaining energy use is almost exclusively sourced from electricity (StatsSA, 2005). Since paraffin and wood are being used for the same purpose in the households, namely to produce heat, these two products may be thought of as rivals in consumption. Furthermore they are purchased by the same consumers, namely poor households in rural areas who are exceptionally reliant on these sources of fuel (Davis, 1998). Any change in their relative prices may thus lead to one being favoured over the other.

In the year 2001, the South African government eliminated value added taxes (VAT) on the sale of paraffin with the goal of making fuel more affordable for poorer households (Government Gazette, 2003). Therefore the price of paraffin compared to its main rival in consumption dropped, making it a more favourable buy. To understand the cost of wood, even though many households in rural areas harvest wood for free (Davies, 1998; Madsubansi & Shackelton, 2007), wood burning has been associated with negative health effects, particularly from smoke inhalation (Shackleton et al., 2007). There exists thus an implicit cost in wood use. A lower price for paraffin may lead some households to switch over to the cleaner, smokeless fuel to avoid the implicit health cost in wood consumption. Overall, these effects would lead to a drop in the amount of biomass consumed and hence to the amount of RE consumed in South Africa.

In terms of RE supply, since many consumers now prefer the cleaner and relatively cheaper paraffin over wood and subsequently consume less wood, the supply of wood in these areas will drop. The key to understanding why wood supply reacts so quickly is to investigate the origins of wood supply, particularly in rural areas. Many households harvest wood free of charge (Davis, 1998; Madubansi & Shackleton, 2007) with the remainder purchasing it from local venders who themselves harvest it in the area (Madubansi & Shackleton, 2007). Since these are small scale producers with no capital investment, they are able to quickly adapt to changes in the market for wood and RE supply contracts along with RE demand in the same time period.

## 6.3 A break in SOS in 2004

A break in the SOS series but not in the LOS or LOD series indicates a possible change in the market for non-RE. The reason being that if RE did not grow at a slower rate, the only way for the share of RE in the total energy mix to drop is if non-RE grew slightly faster or experienced a once-off jump.

A surge in both the domestic and global prices of coal emerges as a possible culprit. According to data from the Department of Mineral Resources (DMR), domestic and international coal prices saw increases of 13% and 38% year-on-year respectively in the year 2004. The growth remains in the double digits, except for 2006, until a staggering growth of 41% and 104% respectively in the year 2008 (DMR, 2013). Whilst coal mines are large capital outlays and may take several years to construct or upgrade, they may be used more intensively to increase production slightly if prices rise enough. This rise in non-RE production would lead to a slight drop in the SOS series.

One might expect that the share of RE consumption in total energy consumption would react because of these price changes. Since coal is now more expensive, one may seek to consume less of it. However, the main consumer of coal in South Africa is primarily the industrial sector, representing approximately 65% of total coal consumption, with well over 95% of this consumption going to manufacturing and electricity alone (StatsSA, 2005). Whilst energy does represent a considerable cost for these two sectors, there exist no close substitutes for their industrial uses, especially in the short run, limiting their ability to adjust their demand. The remainder of coal produced in South Africa is consumed abroad, with exports comprising approximately 35% of total consumption. Households are responsible for a negligible share of under 0.1% of total final consumption of coal, however this does ignore their consumption of electricity that may be generated from coal.

In terms of RE behaviour, the lack of a break in the supply and demand series may stem from the fact that RE, in the form of wood, is supplied to and consumed by primarily poor households (Davis, 1998). Coal as a fuel source is practically unused by poorer households, with between only 3% and 4% of households in this category using coal at all (Davis, 1998). Therefore, even though in theory wood and coal may be substitutes, those who consume wood do not typically consume coal and would thus not change their consumption behaviour due to coal price changes, leaving RE demand and supply in the form of wood largely unaffected.

# 7 Conclusion

This study investigated the evolution of RE supply and demand in South Africa over the period 1990-2010 by using the Bai & Perron (1998, 2003) structural break test methodology. This study found that, whilst the government of South Africa has made considerable commitments to RE during this period, these have not yet led to the manifestation of structural breaks within the market for RE. The structural breaks that are observed in this study are more likely due to the effect of changes in the market for fuelwood in rural areas.

One possible explanation as to why breaks related to policy have not yet been observed is that the major overhaul of RE only started in 2003, where with the successful cases of China and Brazil, policies date back to the 1980's (Pousa et al., 2007; Zhang et al., 2011a; Liming, 2009). Only in 2003 did the government clearly declare its intentions in the White Paper on Renewable Energy. Before real economic behavioural changes are observed however, government must translate its intentions into actions through specific programs and interventions. The introduction of feed-in tariffs in 2009 marks the first major action undertaken to promote RE and thus this is the earliest possible break date related to these policies. Even then, the implementation and development of RE may take some time due to its novelty as well as relatively punitive costs.

Furthermore, the final possible break date in this analysis is allowed to be the year 2008 due to the trimming parameter of 0.15 being used. Allowing for later break dates will lead to degree of freedom problems in the econometric analysis. Therefore, policy may well already be having an effect, but has simply not been observed yet. When updated and reliable data for RE emerges, this analysis should then be conducted again for more accurate results.

Regarding potential future policy, this investigation does lend some evidence to the approach followed by Brazil where the government targeted specific forms of RE already prominent in the country to make a large impact, quickly (Zhang et al., 2011a; Pousa et al., 2007). In South Africa, policies geared towards biomass, especially in poorer rural areas would have a quick impact due to the size of this market. In the short term, promoting good ventilation during fuelwood burning could reduce the reliance on paraffin. Financial support for renewable forestry programs as well as community education programs are another way to promote RE from fuelwood. In cases where sustainable forestry is not possible, alternative RE sources such as solar power may take centre stage, provided that these sources are adapted to directly rival the consumption of wood in cooking and heating applications.

Finally, there is significant room for further research building upon this study. Firstly, given that the first large policy action in favour of RE, namely the REFIT tariffs, came into effect so close to the end of the sample, this study should be repeated in a few years' time when the impact of the REFIT tariffs will have had more time to reveal itself as well as in order to allow for sufficient time to have passed such that the methodology can econometrically detect a break based on these policies. Secondly, given that biomass dominates the RE scene in South Africa, a disaggregated investigation of various RE sources may yield interesting results, especially for sectors that government has been attempting to target recently. Thirdly, a disaggregation of biomass use by user may reveal interesting further trends on the behaviour of the industrial uses for biomass.

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**Table 1: Selected Studies on the Application of the Bai & Perron (1998, 2003) Structural Break Test Methodology**

| Authors | Relationship Investigated | Findings |
|---|---|---|
| Mensi, Hammoudeh &Yoon (2014) | Time series for both returns and volatility in the crude oil market. | Oil Producing and Exporting Countries (OPEC) decisions are "anticipated" by changes in volatility. Causes of breaks are exogenous and vary but include the Subprime Mortgage crisis of 2007 and the Asian financial crisis of 1997, amongst others. |
| Bhaskara Rao & Rao (2009) | Energy to output time series for Fiji. | Four large exogenous oil shocks are identified, amongst other potential shocks. The effect of the oil shocks was to drive up costs in the energy sector, which in turn responded by becoming more efficient, indicated by structural breaks after the crisis. |
| Zhang, Zou & Cao (2011b) | Energy consumption per capita, carbon emissions per capita, proportion of RE in production and oil reliance. | No breaks for energy consumption per capita. Energy strategy in this regard ineffective. Energy policies do not change carbon emissions. RE was affected by the Clinton Administration's numerous RE policies. The Regan Administration oil policies in the US did impact oil reliance. |
| Liddle (2012) | Data for OECD countries on energy efficiency (Energy to GDP ratios). | Oil crisis of the 1960's and 1970's likely to be the cause of structural breaks in most of the series. Environmental concerns in the late 1960's and early 1970's also suggested as possible causes for breaks. |
| Zhang, Li, Cao, Zhao & Wu (2011a) | BRIC REP and REC data. | RE production in China and Russia have had positive impact on REP and REC. Policy by the governments of these nations identified as likely causes of the structural breaks. Hence, exogenous policy shocks found to be effective. |
| **Select studies outside of the energy economics literature** | | |
| Kristofersson & Anderson (2006) | Price ratio between Fishmeal and Soybean meal. | Two structural breaks, both coinciding with exogenous supply shocks: The first a bad fishing season and the second due to an El Nino (weather) event that changed rainfall in the US for a season. |
| Enders & Sandler (2005) | Nature of terrorist attacks. Time series containing various types of attacks (Bombings, kidnappings etc.). | 9/11, an exogenous shock to these time series caused a structural break. Terrorists moved away from kidnappings towards bombings, for what are speculated to be ideological reasons. |
| Papell, Murray & Ghiblawi (2000) | Unemployment time series for various developed nations for the post World War II period. | Most countries show breaks in the post-World War II period. Speculate that unemployment may be permanently increased by recessions, amongst other exogenous shocks. |

**Table 2: Structural breaks in RE policy in BRIC**

| Country | Policy Drivers | Bai & Perron result |
|---|---|---|
| China | Three broad approaches: Technology standardisation and cost reduction, particularly for rural areas. Financial incentives for RE production. Support for research and development. (Zhang *et al*., 2011a; Liming, 2009). | Positive breaks identied |
| Brazil | Selected a particular sector to focus on: Biomass. Mandatory consumption, technological support and research incentives. (Pousa, Santos & Suarez, 2007; Zhang *et al*., 2011a). | Positive breaks identified |
| India | Financial incentives: reduced taxes on RE consumption and production. Low cost loans to RE ventures. Targeted subsidies, particularly for rural areas. (Zhang *et al*., 2011a; Liming, 2009). | Positive and negative breaks identified |
| Russia | Emphasis on technical RE research. Lack of policy drive towards renewable energies. (Zhang *et al*., 2011a). | No breaks identified. |

*Based on the findings of* (Zhang *et al*., 2011a).

### Table 3: Selected Studies on the Unit Root Properties of Energy Time Series

| Author: | Data for: | Type of Energy: | Test Applied: | Result: |
|---|---|---|---|---|
| Narayan & Smyth (2007) | 182 countries worldwide | Energy Consumption (per capita). | 1. Augmented Dickey-Fuller (ADF) (Dickey & Fuller, 1979).<br>2. Panel unit root test (Im, Pesaran & Shin, 2003). | 1. Stationarity in 31% of the individual series (countries).<br>2. Stationary without structural break. |
| Chen & Lee (2007) | 104 countries grouped into 7 regions | Energy Consumption (per capita). | 1. Panel unit root test (Carrion-i-Silvestre, Del Barrio-Castro & Lopez-Baso, 2005). | 1. Non-stationary when structural breaks disallowed.<br>2. Stationary when breaks allowed. |
| Lean & Smyth (2013) | All data is for the US | RE Production.<br>Biofuel production.<br>Biomass production. | 1. Schmidt and Phillips unit root test (Schmidt & Phillips, 1992).<br>2. Lee & Strazicich unit root test (Lee & Stratzicich, 2003). | 1. Non-stationarity when no structural breaks accounted for.<br>2. Non-stationarity when up to two structural breaks allowed for. |
| Hasanov & Telatar (2011) | 178 countries worldwide | Energy consumption per capita (annual data). | 1. ADF test (Dickey & Fuller, 1979).<br>2. Sollis(2004) non-linear structural break test (Sollis, 2004). | 1. ADF: 31% of countries stationary.<br>2. Solis: mixed evidence of stationarity. |
| Agnolucci & Venn (2011) | Industrial sectors in the UK | Energy consumption per capita. | 1. Lee & Strazicich unit root test. With up to two breaks (Lee & Stratzicich, 2003).<br>2. Im *et al*. (2003), Breitung (2000) Hadri (2000) Pesaran (2007) Maddala & Wu (1999) panel unit root tests with no structural breaks. | 1. Stationarity when allowing for at least one break. Only one sector is non-stationary with one break allowed for.<br>2. Non-stationarity with the majority of tests, however many limitations with these tests are highlighted. |
| Zhang, Li, Cao, Zhao & Wu (2011) | BRIC | RE production (REP) and RE consumption (REC). | Bai & Perron structural break test (Bai & Perron, 1998). | 1. No break for REP in Russia.<br>2. One or Two breaks for REP in Brazil, China and India – Break trend stationary.<br>3. One or Two breaks for REC in all countries – Break trend stationary. |

*Adapted from Smvth (2013)*

**Table 4: Overview of the Evolution of the Structural Break Literature**

| **Author** | **Contribution** |
|---|---|
| Dickey & Fuller (1979) | Allowed for testing of stationarity around a trend over time. |
| Perron (1989) | Recognized that the presence of structural breaks could lead to inaccurate ADF test results. Thus allowed for structural breaks to be determined exogenously. |
| Zivot & Andrews (1992) | Noted that exogenous determination of structural breaks may lead to data mining. Developed an approach to allow for structural breaks to be determined endogenously. |
| Lumsdaine & Papell (1997) | Expanded the endogenous unit root testing procedure to allow for two break points in a time series, as opposed to only one. |
| Lee & Stratzicich (2003) | Created an alternative null hypothesis to Lumsdaine & Papell (1997) that would allow for a unit root test where breaks are possible under the null and the alternative hypothesis. To date, the null assumed no structural breaks. |
| Bai & Perron (1998, 2003) | This is not a unit root test. However, it can estimate break dates in that it allows for stationarity tests to be conducted afterwards. The big advantage is that it does not specify the number of breaks to be used, and many sub-trend stationary processes can thus be examined. |

*Based on: Glynn et al. (2007)*

**Table 5: Dickey-Fuller Test Results**

| Series | Zero mean | Non-Zero Mean | Trend | Conclusion |
|---|---|---|---|---|
| SOD | 0.37 | -3.45** | -3.34* | Stationary, Non-Zero Mean |
| SOS | -0.65 | -1.20 | -2.53 | Non-Stationary |
| LOS | 3.74 | -0.99 | -0.95 | Non-Stationary |
| LOD | 1.96 | -1.33 | -1.31 | Non-Stationary |
| *Note: Stars denote the level of statistical significance: * - 10% Significance, **-5% Significance, *** 1% Significance.* | | | | |

**Table 6: Summary of Bai & Perron Results**

| Series | F Stat (1) | Break (1) | F Stat (2) | Break (2) | F Stat (3) | Break (3) | UDMax | WDMax |
|---|---|---|---|---|---|---|---|---|
| SOD | 3.28 | - | - | - | - | - | 3.28 | 4.96 |
| SOS | 44.35*** | 2004 | 7.08 | - | - | - | 44.35*** | 44.35*** |
| LOS | 95.91*** | 2001 | 4.82 | - | - | - | 95.91*** | 95.91*** |
| LOD | 193.938*** | 2001 | 19.96*** | 1997 | 2.55 | - | 527.73*** | 1034.717*** |
| *Note: Stars denote the level of statistical significance: * - 10% Significance, **-5% Significance, *** 1% Significance.* | | | | | | | | |

**Table 7: Stationarity Testing on Individual Segments**

| Series | LOD (1) | LOD (2) | LOD (3) | LOS (1) | LOS (2) | SOS (1) | SOS (2) |
|---|---|---|---|---|---|---|---|
| Year | 1990-1996 | 1997-2000 | 2001-2010 | 1990-2000 | 2001-2010 | 1990-2003 | 2004-2010 |
| ADF | -4.24 | D/F | -3.16 | -4.22** | -3.07 | -3.16** | -1.61 |
| DF-GLS | -4.08*** | -3.65** | -3.30** | -3.77** | -3.63** | -3.02*** | -1.97* |
| Conclusion | Stationary | Stationary | Stationary | Stationary | Stationary | Stationary | Uncertain |
| *Note: Stars denote the level of statistical significance: * - 10% Significance, **-5% Significance, *** 1% Significance.* D/F: Degrees of Freedom Limitation. | | | | | | | |
| ADF Critical Values: Fuller (1979), DF-GLS Critical Values: Elliot, Rothenberg & Stock (1996). | | | | | | | |

**Table 8: Relationships to be Estimated Based Upon the Bai & Perron Results**

| Series: | Equation: | Break Dates: |
|---|---|---|
| SOD | $S_D = \frac{R_D}{E_D} + \mu_t$ | None |
| SOS | $S_s = \frac{R_S}{E_S} + D_{2004} + \mu_t$ | 2004 |
| LOS | $R_s = C + D_{2001} + T + D_{2001}T + \mu_t$ | 2001 |
| LOD | $R_D = C + D_{1997} + D_{2001} + T + D_{1997}T + D_{2001}T + \mu_t$ | 1997, 2001 |

**Table 9: Econometric Results from Equations in Table 8**

| Series | Constant | Constant 1997 | Constant 2001 | Constant 2004 | Trend | Trend 1997 | Trend 2001 |
|---|---|---|---|---|---|---|---|
| SOD | 0.158*** | - | - | - | - | - | - |
| SOS | 0.115*** | - | - | -0.012*** | - | - | - |
| LOS | 9.239*** | | 0.096*** | | 0.019*** | - | -0.007*** |
| LOD | 8.932*** | -0.033*** | 0.075*** | | 0.018*** | 0.003*** | -0.006*** |

*Note: Stars denote the level of statistical significance: * - 10% Significance, **-5% Significance, *** 1% Significance.*