Copious structural shifts in exchange rates of the South African rand (post-1994): Do they matter (for unit root testing)? What are the most likely triggers?

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Copious structural shifts in exchange rates of the South African rand (post-1994): Do they matter (for unit root testing)? What are the most likely triggers?*

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Abstract

There is a theoretical case for real exchange rates to be stationary, but conventional unit root tests generally find nonstationarity in most economic data expressed in nominal terms; exchange rates in particular. Perron (1989) questioned the latter interpretation on the basis that the presence of a unit root may be a manifestation of not allowing for structural change – a finding reaffirmed later by Zivot and Andrews (1992) and Clemente *et al* (1998) when single and double sudden and gradual endogenous breakpoints are accounted for in unit root tests. This paper considers testing for structural breaks and unit roots – in the presence of structural shifts – in the univariate data generating process (DGP) of the key nominal foreign exchange rates of the South African rand. Additionally, the connexions between the timing of the structural shifts and important economic and noneconomic events are explored.

Keywords: Exchange rates; unit root; nonstationarity; stationarity; trend, structural breaks.

JEL Code: C22 and F31

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1 Introduction

More and more countries are lifting international capital controls and adopting less rigid exchange rate systems leading to an increasingly sophisticated global financial market and new exchange rate dynamics. In econometrics, probing the univariate characteristics of time series is a long-established starting point in the preliminary analysis phase of a research paper. Although nominal exchange rate series in first-difference form are generally stationary, a property of nominal exchange rate series in their level form is that they are random walks; that is, they are nonstationary. Structural break or parameter stability tests are crucial for at least two reasons. To start with, the presence of structural breaks may reduce the power of unit root tests – a stationary time-series may appear to be nonstationary when there are structural breaks in the intercept or trend, or both the intercept and trend, leading to bias towards accepting the null hypothesis of a unit root. Also, the presence or absence of structural breaks in a sample period influences the choice of time series model used to predict or improve understanding of the dynamic properties of the data – some parametric models assume a constant linear dynamic structure over time whilst structural break models are appropriate where the dynamics change permanently in a way that cannot be predicted by the history of the data.

The overriding reason or motivation for writing this paper is to establish whether the presence of a unit root in the key nominal exchange rates of the rand may be indicative of the failure to account for structural change in the conventional (non)stationarity tests, resulting in unit root behaviour being equated with persistence of shocks or structural shifts. The overall aim of this paper can probably best be represented with the question: Do the unit root test results change when endogenously identified structural change is accounted for? Perron (1990) empirically showed that the existence of a structural shift in a stationary series may result in nonrejection of a unit root bias with more evidence against misconstrued unit roots in some data by Zivots and Andrews (1992) and Lee and Strazicich (2001). Therefore, a potential problem posed by excluding structural breaks in the unit root tests is that the tests without breaks might be spurious and we won't know unless we investigate.

The South African rand (henceforth referred to as the rand), one of the most liquid emerging market currencies traded in a floating exchange rate regime, and relatively under-researched, makes it an interesting candidate for study. For any random sample period, the data generating process for an exchange rate is unknown, and may differ not only across different bilateral exchange rates but the characteristics of an index of its trade-weighted exchange rate may also be at variance with that of its sub-indices of the bilateral exchange rates. Hence, as opposed to the study of a single nominal foreign exchange rate of the rand, the United States (US) dollar/rand exchange rate in most research, this paper broadens the analyses of the univariate characteristics of the exchange rates to the four most traded currencies against the rand, as well as the 15-currency basket nominal effective exchange rate of the rand. Also, because, the sole reliance on a single test by some previous studies can be misleading, a confirmatory unit root test approach - applying unit root tests in conjunction with stationarity tests - is pursued here. (The data are simply uninformative when neither test rejects the null hypothesis.) Three striking findings in the regression estimation results are uncovered. Firstly, several statistically significant structural breaks are evident in the data (at the 95% and 99% confidence levels). We also find convincing evidence that all the exchange rate levels are nonstationary and $I(1)$, even in the presence of structural breaks at the 1% level of significance. However, anomalies or contradictions are uncovered in the pound/rand exchange rates at the 95% level of confidence. A further important uncovering is that the unit root test t-statistics for yen/rand lie much closer to their corresponding asymptotic 5% level critical values when structural shift is accommodated – consistent with Perron (1989) results which showed that the power to reject a unit root decreases when the stationarity alternative is true and a structural break is ignored. An adjunct to the latter two findings – the wide-range and diverse set of structural change triggers in the rand – is also a vital contribution to empirical work on the rand.

The structure of the paper is as follows. Section 2 reviews some of the standard and structural break adapted unit root tests literature followed by a presentation of the methodological approaches in section 3. The latter includes the econometric strategies of the confirmatory analysis approach to stationarity – the joint use of stationarity and unit root tests – and unit root tests in the absence and presence of structural break dummies. In section 4, we describe and conduct the aforementioned tests on the data, present, interpret and critically evaluate the results, and identify important events that might have caused structural shifts in the various exchange rate series. Section 5 offers some conclusions – findings and shortcomings of the econometric tools employed – based on the finite sample analyses and provides direction for future research.

2 Background Literature Review

Many international studies have investigated nonstationarity of financial time series data. In recent years, endogenous structural shifts in univariate time series in both theoretical and applied research have received a great amount of attention. Literature on unit root tests can be classified into two categories. The first group of studies, also referred to as the 'traditional unit root tests', (Dickey-Fuller, 1979; Said and Dickey, 1984; Phillips and Perron, 1988; Kwiatkowski *et al*, 1992; Elliott *et al*, 1996) is those that test for unit roots without accounting for structural change in a series. Advanced tests principally modify the traditional tests either to increase the power of the test or/and test the opposite null hypothesis. In general, in finite samples, it has been difficult to reject the null hypothesis of a unit root or accept the null of stationarity in bilateral nominal exchange rates in the absence of structural change dummy regressors – a difficulty more pronounced under the post-Bretton Woods 'floating' exchange rate system in more modern economies. Unit root tests by Meese and Singleton (1982) on weekly data for the Swiss, Canadian, and deutschemark exchange rates against the U.S. dollar for the period January 1976 to July 1981 uncover that the processes generating these exchange rates are well documented by random walks. This supports Cornell (1977) and Mussa's (1979) conjecture that the major nominal exchange rates post-Bretton Woods are nonstationary. Formal procedures for estimating lag length (Geweke and Mees, 1981) also suggest that exchange rates follow first-order AR processes. And more recently, Lu and Guegan (2011) find that almost all of 23 daily nominal bilateral foreign exchange rates examined exhibit unit roots (see discussion on page 5) - so do many other studies for the intermediate sample period 1983 to 2010. As variables behave differently in distinct time periods and relationships between variables may vary over time, structural breaks in univariate (and multivariate) analysis are topics that have spawned wide ranging discussion in econometric theory. The second group of studies (Perron, 1989 and 1990; Zivot and Andrews, 1992; Perron and Volgesang, 1992; Clemente *et al*, 1998) apply unit root tests in the presence of structural shift in the parameters. Recent tests introduce two structural breaks in the specifications of the models – an innovation to the single structural shift tests. However, utilising unit root tests with the 'actual' number of structural breaks, at best, ensures that the results are not spurious. Glynn *et al* (2007) and Byrne and Perman (2007) review the recent developments in testing of the unit root in the presence of structural change – a survey of the literature on unit root tests and structural breaks.

Diverting momentarily from the core analysis of this paper – unit roots and structural breaks in nominal exchange rates – there is a theoretical case for real exchange rates to be stationary. The absolute purchasing power parity (PPP) theory states that the price of a basket of goods & services consumed by a typical household should be identical in both countries when denominated in the same currency (contingent on some simplifying assumptions). Thus, PPP predicts that a rise (fall) in the domestic price level, *ceteris paribus*, will be associated with a equiproportionate appreciation (depreciation) of the nominal value of foreign currency in terms of the domestic currency. A testable implication is that real exchange rates should be mean reverting, at least in the long run (Cheung and Lai, 1994). The alternative *ex ante* PPP theory suggests a martingale process with no mean reversion for real exchange rates. Cheung and Lai's (*ibidem*) results – from the Dickey-Fuller Generalised Least Squares (DF-GLS) test – are shown to be more favourable to the hypothesis of mean reversion in real exchange rates in contrast to the standard Dickey-Fuller (DF) test results. The results obtained by Perron and Volgesang (1992) strongly suggest that both the United States (U.S.)/Finland real exchange rate based on the consumer price index (CPI) and U.S./United Kingdom (U.K.) real exchange rate based on the gross national product (GNP) deflator are stationary series in the presence of a one-time shift in the mean of the series; the unit root can be rejected at the 5% significance level but nonstationary if the break is not allowed for. Akinboade and Makina (2006) test for mean reversion and structural breaks in the key real exchange rates of the rand (1978 to 2002). Traditional ADF, PP and Kwiatkowski *et al* (1992) tests – without allowing for structural changes - fail to reject the null of a unit root in the real exchange rates of the rand series at the 5% marginal significance level (Akinboade and Makina, 2006). However, their structural break unit root tests results are contrasting - the unit root test including sharp double breaks support stationarity of the rand's bilateral real exchange rates while the comparative test incorporating gradual shifts do not support mean reversion. The latter findings thus highlight that evidence of (non)stationarity also depends on how the breaks are modelled – abrupt versus slow changes in a series.

It is well known that conventional augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) stationarity tests on the US dollar/rand exchange rates form part of the preliminary analysis of several papers where the foreign exchange rate is an explanatory and/or dependent variable in the empirical analysis. In a very recent comparative study, Lu and Guegan (2011) examine unit roots and the long range dependence of the popular 23 daily nominal bilateral foreign exchange rates, including the rand: Brazilian real, Canadian dollar, Chinese yuan, Danish kroner, Hong Kong dollar, Indian rupee, Japanese yen, Malaysian ringgit, Mexican new peso, Norwegian kroner, Singapore dollar, South African rand, South Korean won, Sri Lankan rupee, Swedish kroner, Swiss franc, New Taiwan dollar, Thai baht and Venezuelan bolivares, all to one U.S. dollar, along with the rates of U.S. dollar to one Australian dollar, to one euro, to one New Zealand dollar and to one British pound. Several sample sizes T from 100 to 3000 are considered in this study. Consistent with most empirical results, the existence of unit root (at the 95% confidence level) is popular for most of the nominal exchange rate series, including the South African rand, when structural breaks are not included in the specifications of the unit root test models. There are several innovations in this study: i) a much broader set of unit root tests in the non-structural break and structural shift frameworks are applied; ii) these tests are applied to several nominal bilateral and effective exchange rates of the rand; and, iii) a more recent sample period of financial market history (1995 to 2010) is investigated where shocks to asset prices are increasingly becoming the order of the day – a further motive for exploring structural change.

3 Methodology

3.1 *Traditional stationarity tests*

Voluminous empirical evidence shows that asset prices such as exchange rates generally follow a random walk; that is, they are nonstationary. Therefore, the results from regressions involving nonstationary time series are spurious (nonsensical) or have dubious (questionable) value. Graphing variables against time and eyeballing the series should always be the first step in any time series analysis. Computing and analysing the sample autocorrelation coefficients (ACs) and partial autocorrelation coefficients (PACs) is a second preliminary test for nonstationarity. Also, instead of testing the statistical significance of any individual autocorrelation coefficient, we can estimate the Q-statistic developed by Box and

Pierce (1970) to test the joint hypothesis that all the ACs up to certain lags are simultaneously equal to zero. The Ljung-Box (LB) statistic is a variant of the Box-Pierce Q-statistic.[1] Both statistics test for white noise. Although in large samples both Q- and LB-statistics follow the chi-square distribution,χ^2, with m degrees of freedom, the LB-statistic has been found to have better (more powerful, in the statistical sense) small-sample properties than the Q-statistic; the distribution is highly skewed on the right, but becomes increasingly symmetrical as the number of degrees of freedom increases.

Just inspecting the graphs of the levels of the time series and autocorrelation coefficients is inadequate. A formal test of stationarity (or nonstationarity) that has become widely popular is the unit root test. A number of unit root tests can be found in the literature. However, there is no uniformly most powerful test of the unit root hypothesis. For this reason, four conventional but different unit root tests are applied to test the null hypothesis of a unit root or the null hypothesis of stationarity: the augmented Dickey-Fuller (ADF) test (Said and Dickey, 1984), the Phillips-Perron (PP) test (Phillips and Perron, 1988), Kwiatkowski, Phillips, Schmidt and Shin (KPSS) test (Kwiatkowski *et al*, 1992) and the Dickey-Fuller Generalised Least Squares (DF-GLS) test proposed by Elliott, Rothenberg and Stock (ERS) (Elliot *et al*, 1996). The simple Dickey-Fuller (1979) unit root test assumes that the error term u_t is uncorrelated (u_t are independently and identically distributed); that is, the series is a first-order autoregressive, *AR(1)*, process with white noise errors. The ADF test adjusts the DF test to take care of possible serial correlation in the error terms – evident in many financial time series – through construction of a parametric correction for higher-order correlation. Thus, the number of lagged difference, k, terms to include is often determined empirically to minimise the information criterion. Ng and Perron (2001) examined a range of criteria, concluding with a recommendation of the modified Akaike information criterion (MAIC). The MAIC dominates other modified criteria such as the modified Schwarz information criterion (MSIC); it is shown to lead to substantial size improvements over standard modified information criteria in all the unit root tests considered as the latter are not sufficiently flexible for unit roots and tend to select values of k that are generally too small for unit root tests to have good sizes. An alternative strategy of controlling for higher-order serial correlation, and possibly heteroskedasticity as well is the Phillips-Perron (PP) unit root test, an extension of the DF test, which uses nonparametric statistical methods to take care of the serial correlation in the error terms without adding lagged difference, k, terms.[2] In principle, the PP test should be more powerful and often preferred to the ADF test as it deals more efficiently with serial correlation. However, the PP test has serious size distortions in finite samples when the DGP has a predominance of negative autocorrelations in first differences (Phillips and Per-

[1] Developed by Ljung and Box (1978).

[2] Parametric tests are statistical tests based upon the assumption that the data are sampled from a Gaussian distribution while nonparametric tests do not make assumptions about the population distribution.

ron, 1988).[3] A second problem with the PP test is its high sensitivity to model misspecification (the order of autoregressive and moving average components). Along the lines of the ADF test, a more powerful variant is the Dickey-Fuller test with generalised least squares (DF-GLS) proposed by Elliott, Rothenberg and Stock (ERS, 1996). This test differs from the common augmented Dickey-Fuller test because the time series is transformed via a generalised least squares regression prior to performing the test. This test has the best overall performance in terms of small-sample size and power (ERS, 1996); it has substantially improved power when an unknown mean or linear trend is present (ERS, 1996). It is well known that ADF unit root tests fail to reject the null hypothesis of a unit root for many time series, and that allowing for error autocorrelation using the PP test does not necessarily improve these results. To verify that we have not committed a 'Type II error" – the probability of accepting a false null hypothesis – we can test the alternative hypothesis that the time series is stationary, $H_0 : Y_t \sim I(0)$. One such test is the KPSS unit test proposed by Kwiatkowski *et al* (1992), conducted under the null of trend stationary and level stationary. It differs from the other unit root tests described here in that the series Y_t is assumed to be (trend-) stationary under the null. The KPSS test complements the above standard unit root tests since it can distinguish levels that appear to be stationary, those that appear to have a unit root, and those that are not sufficiently informative to be sure whether they are either.

3.2 *Stationarity tests in the presence of structural breaks*

Because of events like the great depression (1930s), oil price shocks (1970s), abrupt policy changes (such as a switch in exchange rate system and monetary policy regime in South Africa in 2000), and so on, models with constant parameters or coefficients have been found to perform poorly in explaining and forecasting univariate (and multivariate) relationships and analysing the effect of policy changes (Maddala and Kim, 1998). A well-known problem in the unit root literature is the potential for a series which exhibits structural shifts to fail to reject the unit root null; that is, a stationary time series may appear nonstationary when there are structural breaks in the intercept or trend or both the intercept and trend. Put differently, the presence of structural breaks reduces the power of the basic unit root tests (such as the DF, ADF, PP, DF-GLS and KPSS tests). To detect or nullify the presence of exogenous structural changes in the univariate DGP, Chow's breakpoint test for a known structural break(s) can be evaluated for an *AR(1)* process (Chow, 1960). Where there is no *a priori* to expect a structural break, the Quandt-Andrews (QA) breakpoint test for one or more unknown structural breakpoints in the sample period can be applied to an *AR(1)* process with drift. This test is basically a rolling Chow breakpoint test; *id est*, a single Chow breakpoint test is performed at every observation between the two dates, or observations, τ_1 to τ_2 (Andrews, 1993; and Andrews

[3] Size distortion means that the tests will have a tendency to over reject the null hypothesis of unit root.

and Ploberger, 1994). Perron (1989) showed that the power to reject a unit root decreases when the stationarity alternative is true and a structural break is ignored.

A more efficient and diverse unit root test that allows for some sort of structural instability in an otherwise deterministic model is the Zivot-Andrews or "Zandrews" test devised by Zivot and Andrews (1992); a variation of Perron's (1989) test for unit root with a structural break in which the unknown breakpoint is estimated (the unknown breakpoint is endogenised) rather than fixed (known breakpoint is exogenous). This procedure allows for a single structural break in the intercept or trend or both the intercept and trend of the series, as determined by a systematic search over possible breakpoints, and then conducts a DF-style unit root test inclusive of the estimated optimal break. To detect the optimal lag, a sequential t-test is employed where the degree of augmentation with additional lags of the dependent variable ensures that the residuals are sufficiently whitened. To test for a unit root against the alternative of a one-time structural break, the Zandrews test uses the following three models,

$$(ModelA) : \Delta Y_t = \beta_1 + \beta_2 t + \delta Y_{t-1} + \gamma DU_t + \sum_{i=1}^{k} \alpha_i \Delta Y_{t-i} + \varepsilon_t \tag{1}$$

$$(ModelB) : \Delta Y_t = \beta_1 + \beta_2 t + \delta Y_{t-1} + \theta DT_t + \sum_{i=1}^{k} \alpha_i \Delta Y_{t-i} + \varepsilon_t \tag{2}$$

$$(ModelC) : \Delta Y_t = \beta_1 + \beta_2 t + \delta Y_{t-1} + \gamma DU_t + \theta DT_t + \sum_{i=1}^{k} \alpha_i \Delta Y_{t-i} + \varepsilon_t \tag{3}$$

where DU_t is an indicator dummy variable for a mean shift occurring at each possible break-date (T_b) while DT_t is the corresponding trend shift variable where

$$DU_t = \left\{ \begin{array}{c} 1...if \quad t > T_b \\ 0...otherwise \end{array} \right\} and$$

$$DT_t = \left\{ \begin{array}{c} t - T_b...if \quad t > T_b \\ 0....otherwise \end{array} \right\}.$$

Model A permits a one-time change in the level of the series, model B allows for a one-time change in the slope of the trend function, and model C combines one-time changes in the level and the slope of the trend function of the series. The null hypothesis in all three models is $\delta = 0$, which implies that the series $\{Y_t\}$ contains a unit root with a drift that excludes any structural break, while the alternative hypothesis $\delta < 0$ implies that the series is a trend-stationary process with a one-time break occurring at an unknown point in time.

To test for the unit root hypothesis allowing for a possible change in the level of the series occurring at an unknown point, Perron (1990) considered an *additive outlier* (AO) *model* for a discrete change in mean and an *innovative outlier* (IO) *model* appropriate for a gradual change in the series mean. Perron and Volgesang (1992) proposed similar tests for single breaks. Under the single break additive outlier (AO1) model, for a fixed value of the breakpoint T_b, the following two-step procedure is used. First, the deterministic part of the series is removed using the estimates of the regression

$$Y_t = \mu + \delta DU_t + \tilde{Y}_t \quad t = 1, ..., T \tag{4}$$

where $\tilde{Y}_t$ denotes the residuals and

$$DU_t = \left\{ \begin{array}{l} 1...if \quad t > T_b \\ 0...otherwise \end{array} \right\}$$

under the null hypothesis of a unit root. The residuals $\left(\tilde{Y}_t\right)$ are then regressed on their lagged values and lagged differences

$$\tilde{Y}_t = \sum_{i=0}^{k} \omega_i DT_{t-i} + \alpha \tilde{Y}_{t-1} + \sum_{i=1}^{k} c_i \Delta \tilde{Y}_{t-i} + e_t \quad t = k+2, ..., T. \tag{5}$$

In the AO1 model, equation (5), the change is assumed to take effect instantaneously. In particular, the effect of the change on the level of the series $\left\{\tilde{Y}_t\right\}$ does not depend on the dynamics exhibited by the correlation of the structure of $\left\{\tilde{Y}_t\right\}$ (Perron and Volgesang, 1992). The IO1 model is estimated using the finite-order autoregressive model

$$Y_t = \mu + \delta DU_t + \theta DT_t + \alpha Y_{t-1} + \sum_{i=1}^{k} c_i \Delta Y_{t-i} + e_t \quad t = k+2, ..., T. \tag{6}$$

under the null hypothesis of a unit root, $\alpha = 1$(which also implies $\delta = 0$). The IO1 model allows for a change in the intercept term that is supposed to affect the level of the series $\left\{\tilde{Y}_t\right\}$ gradually – there is a transition period.

An obvious weakness of the Zandrews, and the above AO and IO strategies, is their inability to deal with more than one break in a time series. To address this problem, Clemente, Montanes, and Reyes (CMR) (1998) proposed tests that would allow for two events within the observed history of a time series, either an AO2 model or an IO2 model. The former captures two abrupt changes in the series (that is, two discrete changes in the coefficients of a function) while the latter allows for two gradual shifts in the mean of the series (*id est*, two gradual changes in the coefficients of a function). This taxonomy of structural breaks follows from Perron and Vogelsang's work (1992). The CMR double-break counterparts for equations (4), (5) and (6) above are:

$$Y_t = \mu + \delta_1 DU_{1t} + \delta_2 DU_{2t} + \tilde{Y}_t, \tag{7}$$

$$\tilde{Y}_t = \sum_{i=0}^{k} \omega_{1i} DT_{1t-i} + \sum_{i=0}^{k} \omega_{2i} DT_{2t-i} + \alpha \tilde{Y}_{t-1} + \sum_{i=1}^{k} c_i \Delta \tilde{Y}_{t-i} + e_t, \tag{8}$$

$$Y_t = \mu + \delta_1 DU_{1t} + \delta_2 DU_{2t} + \theta_1 DT_{1t} + \theta_2 DT_{2t} + \alpha Y_{t-1} + \sum_{i=1}^{k} c_i \Delta Y_{t-i} + e_t, \quad (9)$$

respectively. The appropriate procedure is to implement the AO and IO models for two structural breaks, respectively. If their estimates show that there is no evidence of a second break in the series, then the single structural break tests, AO1 and IO1, should be used.

4 Data and Empirical Estimates

4.1 *Data*

The sample period covers 13 March 1995 to 31 August 2010. The time horizon of the sample is motivated by the South Africa Reserve Bank's (SARB's) reversion to a single exchange rate mechanism on March 13, 1995.[4] This empirical analysis uses the levels of the indirect nominal foreign exchange rates of the rand;[5] these rates are spot quotes rather than the actual spot transaction prices. Quote data are indicative rather than firm, and actual foreign exchange market trade data for the sample period are virtually nonexistent; indicative means that the bank or dealer posting such prices is not committed to trade at them, but generally will.

Four daily nominal bilateral exchange rates (NBERs) of the rand with the highest transactions volumes are examined: US dollar/rand (USD/ZAR); the euro/rand (EUR/ZAR);[6] the British pound (sterling)/rand (GBP/ZAR); and the Japanese yen/rand (JPY/ZAR). The daily NBERs are the 10h30 weighted average midpoint rates of the major South African banks and each bank's exchange rate weighting is based on the relative size of its transactions in the foreign exchange market.

To consider aggregated information, the levels of the nominal effective exchange rate (NEER) of the rand - a 15-currency basket of South Africa's major trading partners - is also examined. The currencies in the basket and their weights, expressed as percentages in descending order of importance, are: Euro (34.82), US dollar (14.88), Chinese yuan (12.49), British pound (10.71),

[4] The dual exchange rate system, introduced in response to internal and external socio-economic and political pressures in the mid-1980s, consisted of the commercial rand for current account transactions and the financial rand which applied to investment and disinvestment by nonresidents.

[5] The indirect foreign exchange rates of the rand (foreign currency per unit of rands) are used to ensure that the nominal bilateral exchange rate (NBER) quotations are consistent with the nominal effective exchange rate (NEER) - SARB calculates the indirect NEER of the rand. Depreciation of the rand is indicated by a fall in a nominal bilateral exchange rate or exchange rate index in the case of the nominal effective exchange rate.

[6] The euro was introduced to world financial markets as an accounting currency in 1999 and launched as physical coins and banknotes in 2002. It replaced the former European Currency Unit (ECU) at a ratio of 1:1. To extrapolate the euro/rand exchange rate for the period pre-1999, we use the ECU/rand exchange rate, a common practice in most empirical studies surveyed.

Japanese yen (10.12), Swiss franc (2.83), Australian dollar (2.04), Indian rupee (2.01), Swedish krona (1.99), South Korean won (1.96), Hong Kong dollar (1.48), Singapore dollar (1.40), Brazilian real (1.37), Israeli shekel (1.11), and Zambian kwacha (0.80). The individual NBERs in this basket are calculated along the same lines as those for the four major currencies discussed above and the base year of the NEER index is the year 2000.

Daily exchange rate data was provided by the South African central bank – SARB.[7] Due to the well-known fact that activity in the foreign exchange market slows down decidedly over the weekend and certain holiday periods, weekends and South African public holidays are explicitly excluded so as not to confound the distributional characteristics of the various series by these largely deterministic calendar effects. Although the cuts do not capture all the holiday market slowdowns such as holidays of the G4, they do succeed in eliminating the most important such daily calendar effects.[8] After filtering the data for calendar effects – weekends and local public holidays – the full daily frequency sample consists of 3865 observations.

4.2 *Preliminary stationarity and structural break test results*

A plot of the exchange rate series suggests that all the daily series are nonstationary; stochastic random processes with negative drift (Panel diagram 1, Appendix). Again, the autocorrelation coefficients generated by a random walk series without drift indicate nonstationarity. The autocorrelation coefficients for the daily series decline very slowly as the lag lengthens and remain high at approximately 0.7 even up to 200 lags. The dramatic decline in the partial autocorrelation coefficients indicates that a large proportion of correlation between nonadjacent observations is due to the correlations they have with intermediate observations. The LB-statistics and their corresponding p-values also reinforces our hunch of nonstationarity.

Graphically, a structural break appears when we see a sudden or gradual shift in a time series. Conspicuous and subtle infrequent large fluctuations evident in the empirical process of each time series suggest that each data series may have one or more structural breaks (Panel diagram 1, Appendix).

4.3 *Unit root tests without structural breaks estimates*

The relatively less robust unit root tests - ADF and PP tests – are implemented using a simple strategy, similar to that proposed by Volgesang (1998) for testing for the presence of a linear trend. This test involves the following procedure. First estimate the general model with a constant and trend. If no trend is detected, perform a unit root test invariant to the mean under the null; if a trend is

[7] The SARBS's bilateral exchange rates have four decimal places whilst the 15-basket currency effective exchange it compiles has only two decimal places.

[8] The extent of calendar effects in the rand exchange rates, and other domestic financial asset prices, is an empirical question that needs to be addressed on its own in future research.

detected, perform a unit root test invariant to linear trend under the null (Ayat and Burridge, 2000). Consistent with the overwhelming international empirical results, on the basis of graphical analysis, the autocorrelation coefficients, and the traditional formal unit root tests without structural breaks, there is convincing evidence that all the key four nominal bilateral exchange rates of the rand and the 15-curency basket nominal effective exchange rate of the rand are nonstationary at the 1% and 5% significance levels, and almost all series are $I(1)$ at higher confidence levels – evidence of nonstationarity of the pound/rand after first differencing from the DF-GLS and KPSS tests at the 5% level, in conflict with the ADF and PP test results, indicates that there may be some, but not considerable, doubt as to the properties of the 1st-difference of the pound/rand exchange rate.[9] These contradictory results uncovered highlight the importance of carrying out diverse unit root tests and testing both the null hypothesis of a unit root and the null hypothesis of no unit root. The joint use of stationarity and unit root tests is called confirmatory analysis. Part of the reason for undertaking several stationarity and nonstationarity tests is that there exists no uniformly most powerful test. Nevertheless, given the substantially improved power of the DG-GLS and KPSS tests, one can infer with a greater degree of confidence that the pound/rand series is an $I(2)$ process.

4.4 *Structural breaks estimation results*

We first apply the Quandt-Andrews (QA) test to an *AR(1)* process with drift to capture the unknown breaks – and also to verify suspected breaks – in the univariate DGP for each exchange rate series. In the 'pure structural change model', all the parameters (constant and *AR(1)* coefficient in this case) are subject to shift – the QA test will tell us only if the regressions in two or more sub-samples are different without telling us whether the difference is on account of the intercepts or the slopes, or both. The 'partial structural change model' tests for structural change in a subset of the parameters. The QA unknown breakpoint test statistics are given in Table 1 (Appendix). The higher the F-value, the greater is the imposed constraint of a model without a break. All the summary statistics from the 'pure structural change' model estimations fail to reject the null hypothesis of no structural breaks. In stark contrast, the 'partial structural change' model detects shifts in all the individual parameters – means and *AR(1)* coefficients - at the 95% confidence interval. Perron (2006) notes that using the latter group of models where only some of the parameters are allowed to change can be beneficial in terms of obtaining more precise estimates; the main advantage of imposing restrictions on the number of coefficients to be tested is that much more powerful tests are possible. What does the presence of structural breaks imply for the test results reported in section 4.3? The results are spurious or at least suspect! Conventional unit root tests generally find nonstationarity in most economic data expressed in nominal terms; exchange rates in particular.

[9] To conserve space, the preliminary and conventional unit root test results are not reported here. The results may, however, be requested from the author.

Perron (1989) questioned the latter interpretation on the basis that the presence of a unit root may be a manifestation of not allowing for structural change – a finding reaffirmed later by Zivot and Andrews (1992) and Clemente *et al* (1998) when single and double abrupt and gradual endogenous breakpoints are accounted for in unit root tests. (The likely causes of the breaks in Tables 1 and 2 are explored at the end of this uncovering in section 4.5).

The results for the unit root tests in the presence of structural breaks are presented in Table 2 (Appendix). In all instances, we reject the null that structural shifts do not exist – all p-values for the dummy variables coefficients are equal to or less than 0.02. (We do not report the individual statistics here but they may be requested from the author.) However, despite the structural breaks, in almost all instances, we fail to reject the null hypothesis of unit roots when taking into account the existence of different types of structural breaks through the Zandrews, AO1, AO2, IO1 and IO2 tests; consistent with the results obtained from the unit root test without structural breaks. Again, as was the case in the unit root tests without structural breaks in the previous section, one of the pound/rand unit root test results are potentially conflictive. When considering the possibility of a single innovational outlier in the latter exchange rate series, we reject the null hypothesis of nonstationarity at the 5% level of significance but not at the 1% significance level. This is consistent with nonlinear unit root results, for example, by Chortareas and Kapetanious (2004), on the behaviour of the Japanese yen against the currencies of other G7, and the Asian and Pacific rim countries, which have stubbornly challenged the generally held view that financial time series are nonstationary. Perron (1989) showed that the power to reject a unit root decreases when the stationarity alternative is true and a structural break is ignored. This is indeed the case here, for example, the Zandrews break in intercept, Clemio1 and Clemio2 structural break unit root test t-statistics for yen/rand in Table 2 (Appendix) now lie much closer to their corresponding asymptotic 5% level critical values when structural shift is accommodated. Recognising that the above results are derived through endogenously determining the presence of at most two structural breaks, it is highly probable that the series contain more than two breaks thus raising the probability of finding evidence of stationarity in some series; the yen/rand in particular.

Should we be concerned about the conflicting pound/rand results cited above? Not overly concerned. If the double break Clemente *et al* estimates show that there is evidence of a second break in the series, then the results derived from the original Perron–Volgesang single break tests are placed in doubt, as this is evidence that the model excluding a second structural break is clearly misspecified by the omission of a relevant explanatory dummy variable. Perhaps, the incompatible results for the pound/rand and the fact that allowing for two structural shifts detects shifts at breakpoints different from the one in the single structural change model points to developing new unit root tests where multiple shifts (more than two structural changes) are tested for – extensions of the Clement *et al* tests employed above.

On the technical front, it is worth reporting one important challenge when implementing some of the structural break unit tests using Stata version 12.

The execution time seems to increase dramatically as the sample sizes rise. It took more than two days for double structural break tests to report results for one series; that is, the programme had to run for more than 48 hours. The AO2 and IO2 code contain a few loops based on the number of observations and the number of lags, and there is even a double loop over the number of observations. These loops require an amount of processing time that seems to increase more than proportional as the sample size grows.

What can one infer from the unit root results with breaks and without breaks? Theoretically, when there are several structural breaks, the standard unit root tests are biased toward the nonrejection of the unit root null. The results here indicate that this bias is not sufficiently significant to produce conflicting results. However, the nonrejection of a unit root, even when including two structural breaks, does not necessarily imply that the data are indeed nonstationary – allowing for more than two structural breaks (which appear plausible in the graphs) may suggest otherwise. In Tables 1 and 2 (Appendix), a large number of potential breaks are identified suggesting both constructing (and coding) of unit root tests with multiple structural breaks, that capture more than two shifts, and new t-statistic asymptotic critical values simultaneously.

4.5 *Structural breakpoints and potential causes*

In this section, we tabulate the structural breakpoints identified in section 4.4 and pinpoint important – economic and noneconomic – events that may have triggered the structural shifts in the means and/or coefficients of the regressions of the univariate DGP models. Table 3 (Appendix) presents the months encompassing the various structural breakpoints detected in Tables 1 and 2, the sign of each shock (negative or positive) and the potential events that may have caused these shifts that are identifiable using various and diverse prominent historical business and economic reports; mainly the SARB quarterly bulletins and occasional papers.[10] We first explicate the likely sources of the structural breakpoints in chronological order of each shift before categorising the numerous likely sources of structural shift. To uncover structural breaks, the data was trimmed to exclude at least 10% and at most 15% of the observations in the sample – depending on the statistical technique used – so that breaks cannot be detected closer to the two ends of the sample. Therefore, the results here do not imply that there are no breaks in 1995 and 2009/10.

Exchange rates are susceptible to a wide range of shocks and the double-breaks evident from the results of the AO2 and IO2 models are not surprising. And although the nominal exchange rate series may not be adequately characterised by single shifts (QA, Zandrews, AO1 and IO1 models), the single break unit root tests do identify breaks which coincide with important events – these may well be detected as breaks when a multiple structural break test that allows for more than two structural shifts is applied. There are many and diverse con-

[10] Aron (1999) also documents some of these factors that may have triggered the 1996 and 1997 crises periods.

tributing factors to the ongoing shifts in the key nominal bilateral and effective foreign exchange rates of the rand. Condensed, these include, *inter alia*:

- economic and noneconomic shocks, including geo-political uncertainty and instability;
- macro- and microeconomic shocks;
- real and financial sector shocks;
- shocks in real and nominal variables, including oil price shocks;
- demand- and supply-side shocks;
- internal and external shocks;
- positive and negative shocks;
- economic fundamentals and government policy/regulation shifts and credibility shocks;
- actual and expected events;
- rumours and facts; and
- risk and safety.

Parameter instability stemming from both domestic and international developments is unsurprising for a small open emerging economy with generally increasing exchange rate flexibility, and pervasive financial market reforms, over the sample period. The rand is highly sensitive to global risk appetite – changes in risk sentiment underpin much of the short-run movements in the rand. Risk is captured directly and indirectly in the influences listed above. A common source of structural shift across exchange rates is conspicuous during the 1998 East-Asian contagion. The world remains vulnerable to repeated oil price shocks and the rand is getting it by the barrel load. None of the tests capture the 1995 exchange rate mechanism change and exchange control relaxation, the U.S. subprime market or credit crunch woes beginning in 2007 and the fears of sovereign debt crisis around the world from late 2009 which intensified in early 2010 amid concerns of looming PIGS countries debt defaults;[11] especially Greece, at least initially. This may be explained by the lagged transmission effect on the foreign exchange market – rand exchange rates in particular – combined with the trimming of a significant percentage of the data at both ends of the 13 March 1995 to 31 August 2010 sample spectrum, and the dominance of events preceding 2007 on the rand. Also worth noting is the timing of the breakpoints in the US dollar/rand exchange rates – more often than less, the structural shifts in this

[11] The acronym PIGS refers to the economies of Portugal, Italy, Greece, and Spain – often in regard to matters relating to sovereign debt markets. Its extension, PIIGS, encompasses Ireland.

series either precede or almost coincide with those in the other series. Finally, negative shocks dominate – almost 65% of the shocks identified are negative shocks. The results of this analysis raise several questions. Should we be prepared for and concerned about a new era of more frequent shocks to floating exchange rates? What are the implications for other financial asset prices, economic growth, income distribution, the forecasting ability of economic models and economic policymakers?

5 Concluding remarks and discussion

A growing empirical literature has emerged in recent years in search of structural breaks in univariate time series data. The endogenisation of breakpoints has had a major impact on unit root testing. Eyeballing the South African rand exchange rate time series, copious structural breaks are apparent in the data, the principal motivation for writing this paper. These several shifts are not surprising given the extensive financial market liberalisation that has been implemented in a small open economy such as South Africa since 1995. Why is the presence of structural shift critical? The answer is unsophisticated: When there are structural breaks, the various standard unit root test statistics are biased toward nonrejection of the unit root null or nonacceptance of the stationarity null, implying that, often, nonstationarity indicative in the data, applying conventional unit root tests, may be invalidated when structural shifts are integrated in the tests. There are three key findings in this study which have implications for future work. Firstly, the results show overwhelming support for both structural shifts in the DGP and nonstationarity – the single or double structural breaks are statistically significant and the unit root test statistics suggest that all the levels are $I(1)$ at the 1% level of significance both in the absence and presence of structural breaks. So in this case, accounting for structural breaks does not change the results – but might in other cases. Secondly, some doubt is placed on the stationarity of the 1st-difference series of the pound/rand returns at the 5% confidence level by the DF-GLS and KPSS tests which imply that shocks have a permanent effect in strongly intertwined markets and a nonlinear (quadratic) trend is most probably present in this data. Why exactly the pound/rand behaves differently is an empirical question that needs to be explored in future research. The convergence of the t-statistics for the yen/rand towards their critical values when breaks are allowed for in the unit root tests is also a significant discovery.

However, the models used flag some important concerns. The linear unit root test models and accounting for a maximum of two structural changes in each series prompts future research in applying nonlinear unit root tests with multiple structural breakpoint tests – it is more reasonable to think that breaks occur over several periods, a notion corroborated by eyeballing the series. Also, the power of nonlinear models is considerably higher than that of linear versions. So including nonlinear parameters together with multiple structural changes further diminishes the problem of model misspecification and thus spurious results.

Expanding unit root tests to encompass more than two breaks, deriving the new asymptotic distributions, writing the programmes or code to run both nonlinear stationarity tests and multiple structural break tests is a challenging task, a further direction for research on the dynamics of the foreign exchange rates of the rand. (Standard econometric software packages do not include nonlinear unit root tests.) However, Lee and Strazicich's (2001) argue that the computational burden of the tests with more than two breaks (for example via a grid search) would increase significantly – evident when running the tests for two breaks as opposed to one break in the above analysis. So, the analysis in this paper is limited by the current state of knowledge in this area (as are all other applied papers).[12] Byrne and Perman (2007) also raise the following important issue that requires investigation in future research: "the possible superiority of testing for structural breaks within a multivariate or cointegration framework, rather than the univariate frameworks". Glynn *et al* (2007) note that the development in this area is very limited making it a strong candidate for future research. Glyn *et al*'s (*ibidem*) survey also concludes that there is no consensus on the most appropriate methodology to perform unit root tests, but addressing the aforementioned issues will go a long way in improving the power of unit root testing.

The deliberate univariate analyses carried out in this paper – an introductory element of a broader study of the dynamics of the foreign exchange rates of the South African rand being undertaken by the author – helped us understand some of the basic characteristics of South African foreign exchange rate data. The importance of unit root testing can also be viewed from a different angle: 'A better understanding of the dynamics of a variable improves the forecasting abilities of models'. In summary, in order to obtain a richer understanding of the dynamics of the foreign exchange rates of the South African rand and increase the size and power of unit root tests, as already noted above, nonlinear unit root tests in a multivariate and multiple structural break (more than two breaks) set-up is prescribed for future research – a strong contender in the author's near-term research plan. However, some of the proposed advanced work in unit root testing would require collaborative work with scientists in the field of programing (to write the new code) and statistics (calculate new t-statistics critical values) – which is feasible and being considered.

Notwithstanding the aforementioned shortcomings of the econometric tools, the approach in this paper is a significant contribution towards a more rigorous study of the DGP of the nominal bilateral and effective exchange rates of the rand by applying a broader set of confirmatory stationarity tests together with a better specification of the unit root tests – by incorporating structural shifts – a notable difference from *extant*, published literature on the univariate analysis of the nominal exchange rates of the rand time series.

[12] Quote from Smyth and Inder (2004): "Once econometric time series testing becomes sufficiently advanced to consider more than two structural breaks, tests will also need to be developed to determine the optimal number of structural breaks. When these advances occur in unit root testing, the impact of events such as the Great Leap Forward and market reforms on real output and other variables can be tested within a more comprehensive framework."

Software

All of the results reported in this paper were generated using Eviews7 and StataSE12.1; including StataSE12.1 user written commands to implement the Zandrews, IO and AO structural break unit root tests.

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APPENDIX

Table 1: Quandt-Andrews breakpoint test for an *AR(1)* with drift (exchange rate levels)

	Pure structural change model			Partial structural change model					
				intercept			ρ		
	Maximum *F*-statistic value	Breakpoint	*p*-value	Maximum *F*-statistic value	Breakpoint	*p*-value	Maximum *F*-statistic value	Breakpoint	*p*-value
USD/ZAR	8.1210	06 Jul 1998	0.1961	15.2247	06 Jul 1998	0.0022	12.4326	06 Jul 1998	0.0084
EUR/ZAR	9.6504	06 Jul 1998	0.1088	14.6380	20 Dec 2001	0.0030	12.1221	20 Dec 2001	0.0098
GBP/ZAR	8.7791	06 Jul 1998	0.1529	17.0274	06 Jul 1998	0.0009	13.8456	06 Jul 1998	0.0043
JPY/ZAR	9.6390	15 Jan 1999	0.1093	11.1781	15 Jan 1999	0.0152	8.6440	19 May 2000	0.0492
NEER	9.6761	06 Jul 1998	0.1077	13.7839	20 Dec 2001	0.0045	12.5065	20 Dec 2001	0.0082

Notes: H_0: No breakpoints within the "trimmed" data. H_1: One breakpoint within the "trimmed" data. The maximum *F*-statistic is the maximum of the individual Chow *F*-statistics. Since the original equation was linear, the LR and Wald *F*-statistics are identical. The distribution of these test statistics is non-standard and becomes degenerate as τ_1 approaches the beginning of the sample, or τ_2 approaches the end of the sample. Andrews (1993) developed their true distribution and Hansen (1997) provided approximate asymptotic *p*-values. To compensate for this behaviour, it is generally suggested that the ends of the equation sample be excluded in the testing procedure. We use the standard 15% level for "trimming" - we exclude the first and last 7.5% of the observations.

Table 2: Unit root tests with structural breaks results (exchange rate levels)

	USD/ZAR		EUR/ZAR		GBP/ZAR		JPY/ZAR		NEER		Asymptotic critical values	
Test	*t*-statistic	Break point	*t*-statistic	Break point	*t*-statistic	Break point	*t*-statistic	Break point	*t*-statistic	Break point	1%	5%
Zandrews: break in intercept	-3.157 (3)	22 Oct 2002	-2.981 (6)	06 Apr 1998	-2.593 (6)	15 Aug 1997	-4.138 (6)	15 Jun 1998	-3.126 (6)	07 Apr 1998	-5.43	-4.80
Zandrews: break in trend	-2.636 (3)	29 Jun 1998	-2.805 (6)	04 Oct 2001	-2.954 (6)	29 Jun 1998	-3.051 (6)	30 Nov 1999	-2.825 (6)	15 Dec 2000	-4.93	-4.42
Zandrews: break in intercept and trend	-4.191 (3)	16 Oct 2002	-3.282 (6)	30 May 2003	-3.446 (6)	26 Sep 2002	-4.163 (6)	15 Jun 1998	-3.993 (6)	13 Nov 2002	-5.57	-5.08
Clemao1	-2.725 (11)	07 Jul 1998	-2.946 (11)	28 Jun 2001	-2.745 (8)	07 Jun 1998	-2.814 (12)	21 Sep 1998	-2.473 (11)	07 Jul 1998	-4.29	-3.56
Clemao2	-2.944 (0)	08 Mar 2000	-2.860 (8)	07 Jul 1998	-2.789 (11)	07 Jul 1998	-3.363 (12)	21 Sep 1998	-2.767 (11)	07 Jul 1998	5.96	-5.49
		14 May 2003		04 Sep 2001		06 Jun 2001		14 Jan 2004		15 Jan 2001		
Clemio1	-3.719 (12)	13 Feb 1996	-3.021 (3)	11 Sep 2000	-4.508 (6)	30 Jan 1996	-4.235 (3)	11 Jun 1998	-3.310 (3)	3 Apr 1998	-4.97	-4.27
Clemio2	-2.771 (12)	13 Jan 2000	-3.365 (5)	02 Apr 1998	-4.632 (6)	30 Jan 1996	-5.017 (5)	11 Jun 1998	-3.072 (5)	03 Jun 1998	5.96	-5.49
		11 Nov 2002		03 Jul 2001		05 Apr 2006		15 Jan 2004		12 Sep 2000		

Notes: The unit toot test hypotheses are H_0: unit root (nonstationary), H_1: no unit root (stationary). Lags are specified in parentheses. Dummy or structural shift variable hypotheses are: H_0: no breakpoint(s) within data; H_1: one or two breakpoints within data.

For the Zandrews statistics, lags are selected via the *t*-test similar to the method implemented in DF-GLS in that you are looking to reject the null of a unit root in the process. We use the standard 15% level for "trimming" where we exclude the first and last 7.5% of the observations.

In the AO-IO tests, the appropriate lag order is determined by a set of sequential *F*-tests and the minimal *t*-ratio is compared with critical values provided by Perron and Vogelsang (1992) and Clemente *et al* (1998), as they do not follow the standard DF distribution. For the AO-IO tests, we use the standard 5% level for "trimming" from each end of the sample; that is 10% of the observations are excluded (consistent with empirical studies surveyed). Lags are reported in the parentheses, alongside each *t*-test statistic.

Table 3: Structural shifts in foreign exchange rates of the rand

Period	*Shock*	*Potential causes*
January 1996 - February 1996	(-)	# Rand suffered a speculative currency attack, triggered in February
	(-)	# Shift in SARB's intervention policy in foreign exchange market
August 1997	(-)	# Southeast-Asian financial markets contagion erupted in July 1997 in Thailand
April 1998 - September 1998	(-)	# Southeast-Asian financial markets contagion spreads to other emerging markets in April and May
	(-)	# Russian debt default in August
	(-)	# Build-up in SA's net open forward position (NOFP)
January 1999	(-)	# Brazilian real crisis
November 1999	(-)	# Millennium changeover raises emerging market risk
	(-)	# Oil price shock
January 2000 - December 2000	(-)	# Monetary policy and exchange rate regime shifts in South Africa – adoption of inflation targeting and free float exchange rate system in February
	(-)	# US dollar strength, coupled with concerns about worsening SA's balance of payments and regional economic and political stability (March - May)
	(+)	# International rating agency upgrades SA's long-term foreign-currency debt in June
	(-)	# Rise in emerging market risk in Q4
January 2001 - December 2001	(+)	# Expectation of sizable inward FDI flows (De Beers) and Standard and Poors' reaffirms SA's investment grade foreign-currency rating (January - February)
	(-)	# Rand crisis on the back of concerns about domestic fundamentals, anticipated policy shifts, rumours and declining commodity prices (July - December)
	(-)	# Global financial market turmoil due to terrorist attacks on the U.S.A. in September
September 2002 - November 2002	(+)	# Sharp rand appreciation due to decline in perceived risks associated with SA
May 2003	(+)	# Strong domestic macroeconomic fundamentals bolster rand
	(+)	# Prudent macroeconomic policy commitments by policymakers
	(+)	# Upgrading of SA's foreign and local sovereign debt ratings and stable economic outlook
	(+)	# Continued dollar weakness against international currencies in general
January 2004	(-)	# Profit taking, fall in financial asset prices & concerns about SA's widening current account deficit
April 2006	(+)	# Positive international rating agency and central bank announcements, euro strength and renewed appetite for emerging market financial assets

Panel diagram 1: Daily indirect foreign exchange rates of the rand (13 March 1995 - 31 August 2010)

USD/ZAR

EUR/ZAR

GBP/ZAR

JPY/ZAR

NEER