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## Exchange rate dynamics in South Africa

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### ABSTRACT

The structure of the nominal exchange rates in South Africa is examined by using fractional integration. We investigate the levels and the volatilities against the US dollar, the British pound, the Euro, the Japanese yen, the Chinese yuan, the Australian dollar, and the Botswanan pula. The results indicate that most series are unit root, I(1) and though there is some evidence of mean reversion, the orders of integration are close to 1, implying high levels of persistence. However, there is evidence of mean reversion for Botswana Pula in various subsamples. For the volatilities, the stationary long memory is observed in all cases.

### KEYWORDS

Exchange rate dynamics; long memory; persistence; South Africa

### JEL CLASSIFICATION

C1; C15; C22; C53; C75

### 1. Introduction

Instabilities in exchange rates, especially with the major trading currencies such as the United States dollar (USD), the British pound (GBR) and the euro (EUR), have become a major source of concern to all developing countries in relation to their currencies, including the South Africa rand (ZAR). This is because a significant amount of business and trade is transacted in these currencies; hence, an ability to control volatilities, induced mostly by the persistency of economic shocks and other unobserved factors, is essential, especially for policy formulation.

A number of research works, including but not limited to Gil-Alana (2000, 2004), Sauer and Bohara (2001), Benigno (2004), Tenrehyro (2007), Anderson et al. (2001), Caporale and Gil-Alana (2004), Caporale and Gil-Alana (2013) and Lo and Morley (2015), among others, have been conducted in this area, all in the 'name' of ascertaining the effects of exchange rate volatilities among currencies across the globe. For instance, Gil-Alana (2000) examined the real exchange rate data between the USA and five industrialized countries. His results indicate mean reversion if the disturbances are autocorrelated. Sauer and Bohara (2001) used a large panel of industrialized and developing countries to investigate the link between exchange rate volatility and exports and found different volatility measures, which indicated that negative effects exist for the exports of less-developed

countries (LDCs), especially from Latin America and Africa, but not for exports from Asian LDCs or industrialized countries.

Benigno (2004) also conducted a study on the effects of alternative monetary rules on real exchange rate persistence. By means of a two-country stochastic dynamic general equilibrium with nominal price stickiness and local currency pricing, they found no proportional relationship between the time during which prices remain sticky and the persistence of the response of the real exchange rate. Their research emphasized, to a certain extent, the role of interest rates smoothing policies and relative price stickiness within countries in understanding the relationship between the real exchange rate and monetary shocks. Caporale and Gil-Alana (2004) employed the concept of fractional integration and cointegration to model the deutschemark, DM – US dollar and the yen – US dollar real exchange rates in terms of both monetary and real factors, more specifically real interest rate and labour productivity differentials. Their results revealed that whereas the individual series were integrated of order 1, their long-run relationships were suspected to have a fractionally cointegrated structure. Tenrehyro (2007) investigated the effect of nominal exchange rate variability on trade, using a novel approach and presenting new estimates from a broad sample of countries from 1970 to 1997. The estimates indicated that nominal exchange rate variability has no significant impact on trade flows.

Anderson et al. (2011) employed high-frequency data on deutschemark and yen returns against the US dollar and constructed model-free estimates of daily exchange rate volatility and correlation that covered an entire decade. They found noteworthy results, which included a normality-inducing volatility transformation, high contemporaneous correlation across volatilities, evidence of long-memory dynamics in volatilities and precise scaling laws under temporal aggregation. Caporale and Gil-Alana (2013) analysed the long-memory properties of a high-frequency financial time series dataset. The paper focused on temporal aggregation and other features of the data, and how they might affect the degree of persistence. A fractionally integrated model was estimated with a variety of specifications for the error term. A lower degree of integration was found to be associated with lower data frequencies. In particular, for lower frequencies, values of  $d$  strictly smaller than 1 were found, implying mean-reverting behaviour; however, for higher data frequencies, the unit root null cannot be rejected, with data collected every 10 min. This was true for all four series examined, namely open, high, low and last observations for the US dollar/British pound spot exchange rate and for different sample periods.

Lo and Morley (2015) also investigated the persistence of real exchange rates using Bayesian methods. In comparison with standard grid-based estimation, the Bayesian approach completely captured the joint parameter uncertainty and uncertainty about complicated functions of the parameters, such as the half-life measure of persistence based on generalized impulse response functions. Again, model comparison was made through marginal likelihoods, which reflects the relative abilities of models to predict the data given prior beliefs about model parameters. The empirical results for real exchange rate data from the G7 countries suggested a general support for non-linearity, with the strength of the evidence depending on which country pair was being considered. They also found that model-averaged estimates of half-lives are almost always as small or smaller for the linear models alone, signifying that the purchasing power parity persistence conundrum is less of a conundrum than previously thought.

In the context of South Africa, Serenis and Tsounis (2014) examined the effect of exchange

rate volatility for a set of three African countries: Malawi, Morocco and South Africa to aggregate exports during the period: 1973Q1–1990Q1. It was claimed that exchange rate volatility causes a reduction in the overall level of trade. Empirically, researchers often utilize the standard deviation of the moving average of the logarithm of the exchange rate as a measure of exchange rate fluctuation. Results from Serenis and Tsounis (2014) suggested significant negative effects from volatility on exports for the three countries when a measure of unexpected fluctuation was used. Bah and Amusa (2003) used the autoregressive conditional heteroskedastic (ARCH) and general ARCH (GARCH) models to investigate the influence of the real exchange rate volatility on South Africa's export to its largest, single-nation trading partner – the United States (USA). The results indicated that volatility of the Rand's real exchange rate exerts a significant and negative effect on exports in both the long and short run, while weakening in real exchange rates has a positive impact on exporting activity. Therefore, a stable competitive exchange rate and sound macroeconomic fundamentals that enhance international competitiveness are necessary to ensure greater market penetration of South Africa's exports. Chinzara (2011) examined the macroeconomic uncertainty and conditional stock market volatility in South Africa by conducting a review on the literature dealing with the effects of exchange rate volatility on trade, obtaining results that were sensitive to the choices of the sample period, model specification, proxies for exchange rate volatility and countries considered. His results indicate that increased exchange rate volatility inhibits the growth of foreign trade.

It is clear from the above-mentioned studies that the influence of non-linearities and structural breaks, in the context of estimating persistence in volatility, has been relegated to the background. We, therefore, intend to fill this gap by examining the levels of the South African rand exchange rates and their associated volatilities against a group of currencies in an expanded daily exchange rate dataset using fractional integration. The choice of the currencies was based on the trade relations between South Africa and the countries under analysis.

This article takes a different perspective as far as exchange rates and their volatilities are concerned by taking non-linearities and structural breaks into account. To a large extent, we seek to examine long memory and also the degree of persistence of exchange rate levels and their volatilities, using in the latter case the squared returns as a proxy for the volatility. The rest of the article is organized as follows: [Section II](#) presents a review of the history of the exchange rates in South Africa; [Section III](#) briefly explains the modelling of exchange rates; [Section IV](#) focuses on the data and the methodology used in the article; [Section V](#) presents the results, while [Section VI](#) shows some concluding remarks.

## II. Exchange rates in South Africa

The revolutionary works of Edwards (1989), Ghura and Grennes (1993), Obadan (1994), Mkenda (2001), Miyakoshi (2003) and Joyce and Kamas (2003), among others, expressed their views on exchange rate determinants and behaviour. For instance, Edwards (1989) found that in the long run, only real variables will affect the stability of real exchange rates in a panel of 12 countries including South Africa. Nevertheless, real and nominal factors were found to be significant in driving exchange rates in the short run with no specific results for South Africa. Exchange rate determination can either be left to the forces of demand and supply or can be managed by the authorities. In one extreme, a country can implement a freely floating exchange rate system where the value of the currency is determined by the market forces of demand and supply. In this system, the authorities do not interfere in the foreign exchange market. This system (of a freely floating exchange rate system) is not practised by any country in the world. In the other extreme, monetary authorities may adopt a fixed exchange rate system. The fixed exchange rate system is still being employed by some countries such as Argentina and Estonia.

There have been many exchange rate regimes in South Africa since the end of the Bretton Woods System (Van der Merwe 1996, 2005). These include (a) a stage of direct monetary controls and the desire to sustain the stability of the rand exchange

rate during the 1970s; (b) a swing to more market-oriented measures and the implementation of money supply targets in the 1980s; (c) the era of easy-going inflation targeting and managed floating of the rand in the 1990s; and (d) the official adoption of inflation targeting and a floating exchange rate regime in February 2000.

The first chapter is the period that was linked to the Bretton Woods System of fixed exchange rates in the 1970s. To begin with, the South Reserve Bank (SARB) devalued the rand and pegged it against the US dollar since the domestic market could not support a free-floating exchange rate system due to the underdeveloped nature of the foreign exchange market. Nonetheless, an 'independent managed floating' exchange rate system was adopted in June 1974 to mirror the changes in the market rate of the ZAR/USD exchange, the essential balance of payments and domestic economic conditions. There were speculative attacks on the rand, which forced the authorities to change the exchange rate policy in June 1975 in favour of a ZAR/USD exchange rate. The rand moved with the dollar for long periods under restrictive control measures. A heavy reliance was placed on exchange controls, which deterred the inflow of foreign capital. Authorities saw this as an ineffective way of allocating the available foreign exchange, which led to the abandonment of this policy framework. Consequently, the authorities decided to implement more market-oriented measures and monetary targeting.

The status quo changed dramatically after the formation of the government of national unity in 1994, and the country became reintegrated in the world economy and in the global financial market. Accordingly, the monetary authorities began to remove virtually all exchange rate restrictions. This policy was largely successful and hence paved the way for the official adoption of inflation targeting and a floating exchange rate system in February 2000. Increasing food prices due to declining agricultural output, decreasing manufacturing output, volatility in the exchange rate of the ZAR/USD and low domestic growth, among others, pose serious challenges to monetary policy actions. Coupled with the performance of the informal inflation targeting prior to February 2000, this forced the monetary authorities to adopt inflation targeting to

further tighten three monetary policies. The authorities targeted 3–6% Consumer Price Index (CPIX) inflation to be achieved by the end of 2002. This policy has been largely successful, and the monetary authorities have decided to continue to apply the framework consistent with their mandate of price stability and a stable exchange rate system, this being the final monetary policy framework.

### III. A short review of exchange rates modelling

Forecasting exchange rate movements have always been an attractive issue in international finance literature. Hence, there is a vast amount of literature on both theoretical and empirical fronts, especially regarding the determination of exchange rates, mostly for developed economies. For developing economies however, the literature on the determination of exchange rate movements is virtually non-existent, in particular those discussing persistence in exchange rate volatility. From a theoretical point of view, the literature on exchange rate movements can be classified into two main categories – namely the chartists and the fundamentalists. The chartists consist of those studies whose models based their expectations on exchange rate fluctuations on its past movements, whereas fundamentalists encompass those studies that hinge on purely the fundamentals, so that when the exchange rate is driven away from the fundamentals, they form expectations that it will return in due course to the levels projected by the fundamentals. Most of the research that has been conducted to date regarding floating exchange rates tends to concentrate more on the fundamentals. Floating exchange rate models based on fundamentals are classified into two categories, namely, monetary and portfolio balance models. According to Neely and Sarno (2002), the monetary models of exchange rates can be further subdivided into two groups – the flexible-price model (Bilson 1978a, 1978b; Mussa 1976, 1979) and the sticky-price model (Dornbusch 1976). Etuk (2012) conducted a study on the exchange rate nexus between the naira–US dollar using an ARIMA–SARIMA model and found some seasonal effects between the two currencies. In another study, Li et al. (2011) examined the monthly seasonality of foreign exchange (FX) returns for eight major currencies (against the

US dollar) from 1972 to 2010 and found that five currencies exhibited significantly higher returns in the month of December and a significant reversal in January. This result was contrary to previous research which focused largely on the daily patterns within FX returns. Evans and Tawiah (2015) also looked at the effects of the seasonality of Ghanaian economic activities such as agriculture and consumption on the Cedi–US dollar exchange using ARIMA and X-12 models. It was found in the paper that depreciation of the Ghana cedi to the dollar followed a moving seasonality with a constantly repeating year-to-year pattern. Takaendesa (2006), using a VAR model, investigated the main determinants of the real exchange rate and the dynamic adjustment of exchange rates following shocks to those determinants, using quarterly South African data for the period 1975–2005. He found that terms of trade, domestic credit and openness are the only significant variables when explaining the variation in the real exchange rate.

Giot, Laurent, and Petitjean (2010) examined the relationship between volume and realized volatility. In contrast to prior studies, they decomposed realized volatility into two major components: a continuously varying component and a discontinuous jump component. Their results confirmed that the amount of trade is the dominant factor shaping the volume volatility relation, whatever volatility component is considered.

From the aforementioned models, it is clear that the incorporation of issues such as fractional integration, structural breaks and non-linearities in determining the movements in the exchange rates in South Africa is underwhelming and hence the need to conduct this study.

### IV. Data and methodology

We use daily data corresponding to the South African rand against the US dollar, the British pound, the Euro, the Japanese yen, the Chinese yuan, the Australian dollar, and the Botswana Pula, obtained from the South African Reserve Bank (SARB) website ([www.resbank.co.za](http://www.resbank.co.za)), for the time period from January 4, 2010 until November 27, 2018.

We use these currencies because they refer to the countries with the highest trading relationships

with South Africa. Figure 1 displays the time series plots.

Table 1 displays some descriptive statistics. We observe that the economies with the lowest mean exchange rates are Australia (0.111), China (0.641) and Botswana (0.844), while the country with the highest mean exchange rate is Japan (96,163.123). We also observe that Japan presents the highest standard deviation and

China the lowest one. This means that Japan is the most volatile country within this group, while China is the least one.

We use fractional integration methods. The idea behind this concept is that the number of differences required in a series to render it stationary  $I(0)$  may not necessarily be an integer number but any real one, including thus fractional values. We say that a process  $\{x_t, t = 0, \pm 1, \dots\}$  is integrated of

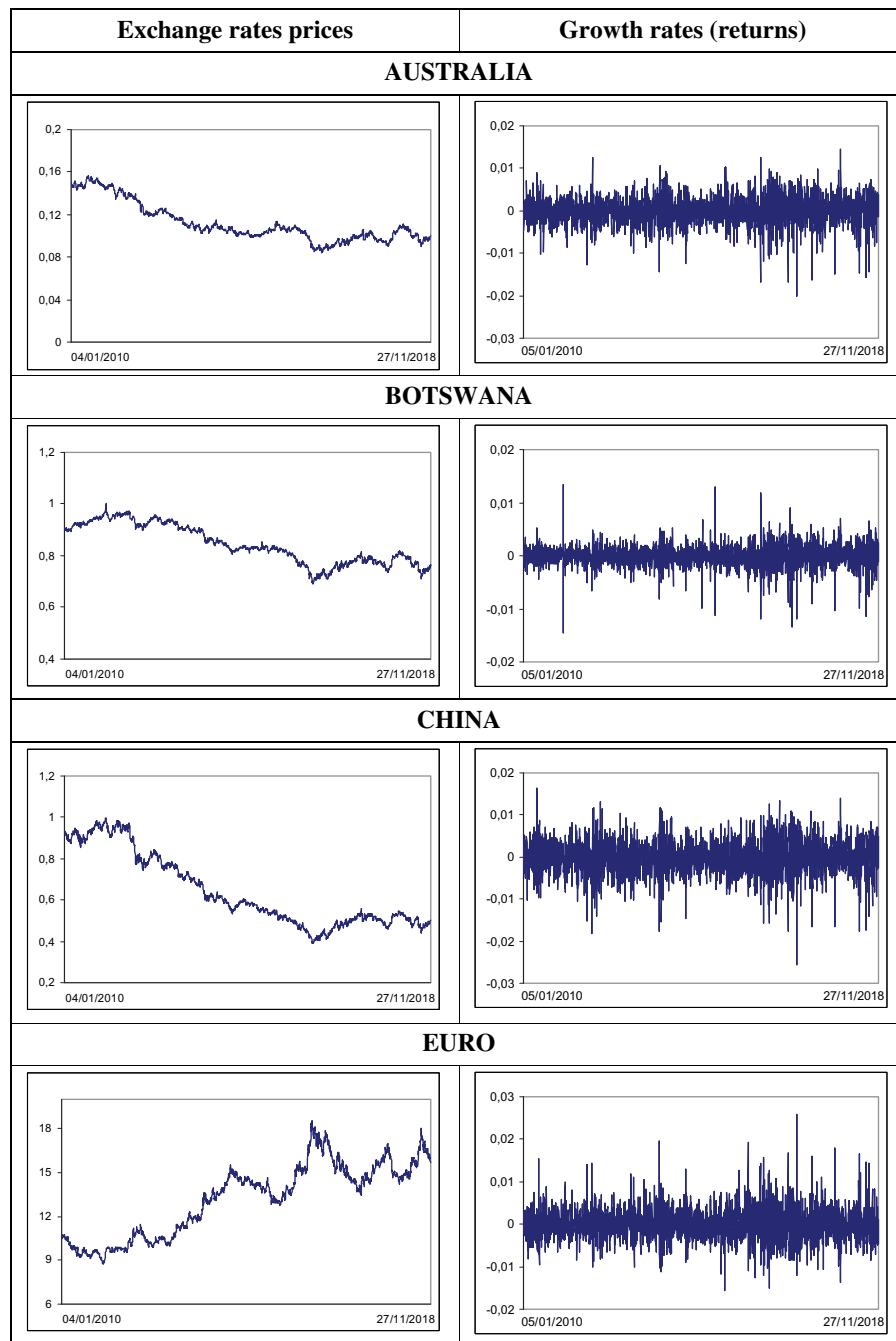


Figure 1. Time series plots.

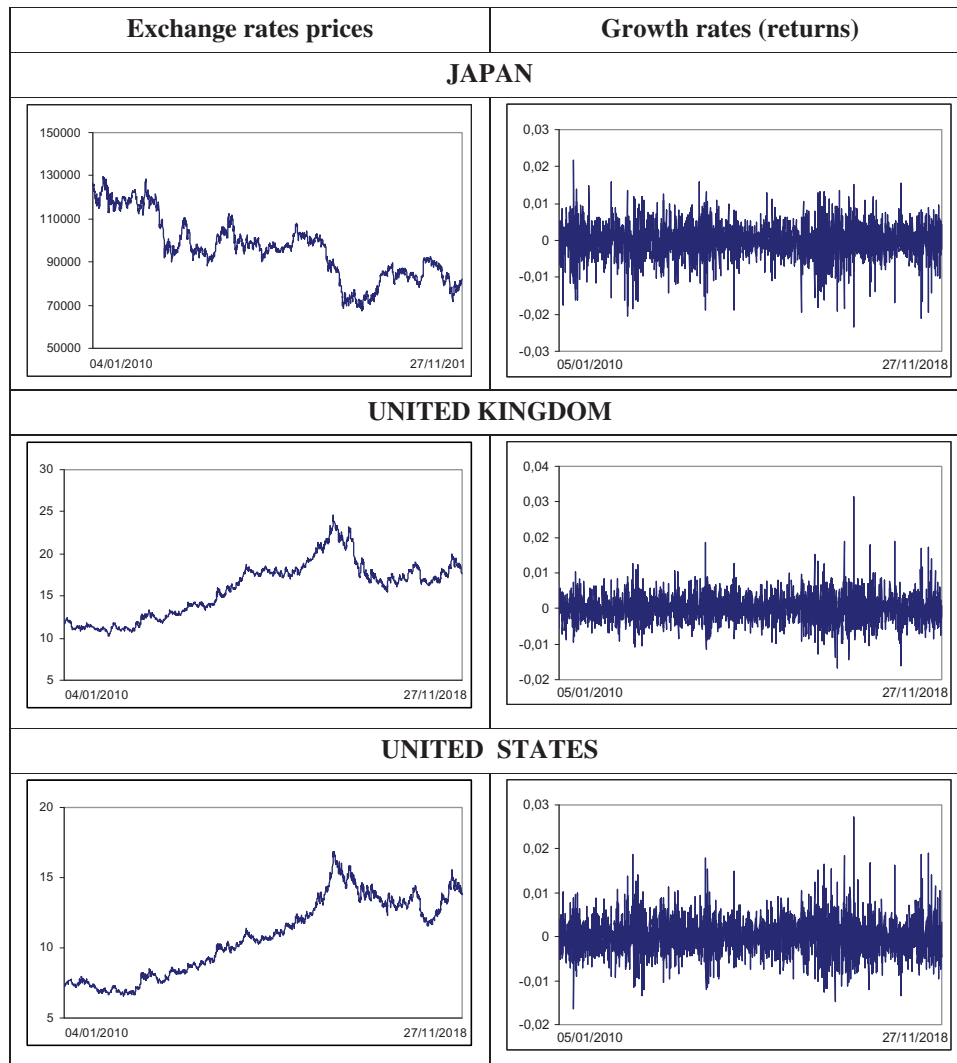


Figure 1. (Continued).

Table 1. Descriptive statistics\_Levels.

i) Original data				
Country	Mean	Std. Deviation	Max. value	Min. value
Australia	0.11195824	0.01817615	0.1572	0.0836
Botswana	0.84410346	0.07556261	1.0048	0.6936
China	0.64123673	0.17489824	0.9968	0.3895
Euro	13.1578959	2.48254606	18.5288	8.7648
Japan	96163.1235	14364.2796	129918	67336
U.K.	15.8939192	3.31382851	24.5257	10.2557
U.S.A.	10.7816579	2.74800664	16.8927	6.5962
ii) Logged transformed data				
Country	Mean	Std. Deviation	Max. value	Min. value
Australia	-0.95631069	0.06665553	-0.80354746	-1.07779372
Botswana	-0.07536358	0.03897786	0.00207963	-0.15889092
China	-0.20831986	0.11354473	-0.00139197	-0.40949254
Euro	1.11106922	0.08495276	1.26784729	0.94274201
Japan	1.97808525	0.06518708	2.11366933	1.82824731
U.K.	1.19149609	0.09321849	1.38962141	1.01096531
U.S.A.	1.01802485	0.11446138	1.22769907	0.81929382

order  $d$ , and denoted as  $x_t \approx I(d)$  if it can be represented as:

$$(1 - L)^d x_t = u_t, \quad t = 1, 2, \dots, \quad (1)$$

where  $L$  is the lag operator ( $Lx_t = x_{t-1}$ ) and  $u_t$  is  $I(0)$  indicating a covariance stationary process with a spectral density function that is positive and bounded at all frequencies in the spectrum.

In the context of  $I(d)$  models, the estimation of the differencing parameter  $d$  is crucial. Thus, if  $d = 0$ ,  $x_t$  is short memory or  $I(0)$ , while  $d > 0$  implies long-memory behaviour, so-named because of the strong degree of association between observations far distant in time. From a statistical viewpoint, 0.5 is another relevant value: if  $d < 0.5$ ,  $x_t$  is covariance stationary, while  $d \geq 0.5$  implies nonstationary (in the sense that the variance of the partial sums increases in magnitude with  $d$ ); finally, from an economic viewpoint,  $d = 1$  is also relevant:  $d < 1$  indicates mean reversion, with shocks disappearing in the long run, while  $d \geq 1$  shows a lack of mean reversion with shocks persisting forever. Therefore, the parameter  $d$  is very important to determine the degree of persistence in the data, and higher the value of  $d$  is, the higher the degree of persistence is, or alternatively, the lower the value of  $d$  is, the faster the convergence process of a series is to its original level after a shock.

We estimate the differencing parameter,  $d$ , by using both parametric and semiparametric techniques. Dealing with the parametric methods, we use the Whittle function in the frequency domain as proposed in Dahlhaus (1989) and implemented through the tests of Robinson (1994). Semiparametric methods, based on local Whittle methods (Robinson 1995; Shimotsu and Phillips 2006; Abadir, Distaso, and Giraitis 2007), will also be employed in the paper.

## V. Empirical results

This section is divided into two parts, one dealing with the levels (i.e. exchange rates) and the other dealing with their associated volatilities, measured in terms of both absolute returns and squared returns. These two measures have been widely employed in the literature to approximate the volatility of the processes. Absolute returns have been

employed in Ding, Granger, and Engle (1993), Granger and Ding (1996), Bollerslev and Wright (2000), Gil-Alana (2005), Sibbertsen (2004), Cotter (2005), Giles (2008) and Yang and Perron (2010), among many others. On the other hand, squared returns were used in Lobato and Savin (1998), Blair et al. (2001), Cotter (2005), Patton (2011), Jondeau (2015), etc.

## VI. Exchange rates in levels

The first thing we do in this section is to look at the level of the observed data, focussing on the degree of persistence by using fractional integration. Thus, the estimated model is the following one:

$$y_t = \beta_0 + \beta_1 t + x_t; \quad (1 - L)^d x_t = u_t, \quad t = 0, 1, \dots, \quad (2)$$

where  $y_t$  refers to each of the time series we observe;  $\beta_0$  and  $\beta_1$  are unknown coefficients referring, respectively, to the intercept and a linear time trend;  $x_t$  is supposed to be  $I(d)$  and, thus,  $u_t$  is  $I(0)$ ; and  $d$  is a real value that is estimated from the data along with the other parameters in the model.

Table 2 displays the estimates of  $d$  and their associated 95% confidence bands, in the model given by (2) under the assumption that  $u_t$  is a white noise process. We display the results for both the original data and the log-transformed data and present the results for two cases: (i) including an intercept and (ii) with an intercept and a linear time trend, marking in bold in the table the selected model for each case. We see that the time trend is statistically significant in the case of China (with both original and logged data) and also for the US logged data, and most of the estimated values of  $d$  are around 1.<sup>1</sup> In fact, the unit root null hypothesis cannot be rejected in five out of the seven exchange rates examined. The only evidence against the  $I(1)$  case is found in the cases of Botswana and Japan where the estimated value of  $d$  is found to be slightly below 1, and the unit root null is rejected in favour of mean reversion ( $d < 1$ ). This happens using both original and logged data.

Table 3 presents the results for the case of auto-correlated errors. The values are very similar to

<sup>1</sup>Note that under the unit root null hypothesis (i.e.  $d = 1$ ), the time trend disappears in (2) with  $t > 1$ .



**Table 2.** Estimates of  $d$  under the assumption of no autocorrelation.

	Original data		Log-transformed data	
	An intercept	A time trend	An intercept	A time trend
Australia	<b>0.97</b> ( <b>0.94, 1.01</b> )	0.97 (0.94, 1.01)	<b>0.97</b> ( <b>0.94, 1.00</b> )	0.97 (0.94, 1.00)
Botswana	<b>0.92*</b> ( <b>0.89, 0.95</b> )	0.91 (0.89, 0.95)	<b>0.92*</b> ( <b>0.89, 0.95</b> )	0.92 (0.89, 0.95)
China	0.97 (0.94, 1.01)	<b>0.97</b> ( <b>0.94, 1.01</b> )	0.97 (0.94, 1.00)	<b>0.97</b> ( <b>0.94, 1.00</b> )
Euro	<b>0.98</b> ( <b>0.95, 1.02</b> )	0.98 (0.95, 1.02)	<b>1.00</b> ( <b>0.96, 1.03</b> )	1.00 (0.96, 1.03)
Japan	<b>0.95*</b> ( <b>0.92, 0.99</b> )	0.95 (0.92, 0.99)	<b>0.96*</b> ( <b>0.93, 0.99</b> )	0.96 (0.93, 0.99)
U.K.	<b>1.00</b> ( <b>0.97, 1.03</b> )	1.00 (0.97, 1.03)	<b>1.00</b> ( <b>0.97, 1.03</b> )	1.00 (0.97, 1.03)
U.S.A.	<b>0.98</b> ( <b>0.94, 1.01</b> )	0.98 (0.94, 1.01)	0.97 (0.94, 1.01)	<b>0.97</b> ( <b>0.94, 1.01</b> )

In bold the selected model in terms of the deterministic components. \*: Evidence of mean reversion at the 5% level.

**Table 3.** Estimates of  $d$  under the assumption of autocorrelation.

	Original data		Log-transformed data	
	An intercept	A time trend	An intercept	A time trend
Australia	<b>0.95</b> ( <b>0.91, 1.01</b> )	0.96 (0.91, 1.01)	0.93 (0.88, 0.98)	<b>0.93*</b> ( <b>0.88, 0.98</b> )
Botswana	<b>0.94*</b> ( <b>0.90, 0.99</b> )	0.94 (0.90, 0.99)	<b>0.94</b> ( <b>0.90, 1.00</b> )	0.94 (0.90, 1.00)
China	0.96 (0.91, 0.99)	<b>0.96*</b> ( <b>0.91, 0.99</b> )	0.94 (0.90, 1.00)	<b>0.94</b> ( <b>0.90, 1.00</b> )
Euro	<b>0.96</b> ( <b>0.91, 1.01</b> )	0.96 (0.91, 1.01)	<b>0.97</b> ( <b>0.92, 1.02</b> )	0.97 (0.92, 1.02)
Japan	<b>0.96</b> ( <b>0.91, 1.02</b> )	0.96 (0.91, 1.02)	<b>0.97</b> ( <b>0.92, 1.01</b> )	0.97 (0.92, 1.01)
U.K.	<b>1.00</b> ( <b>0.94, 1.05</b> )	1.00 (0.94, 1.05)	<b>0.98</b> ( <b>0.94, 1.04</b> )	0.98 (0.94, 1.04)
U.S.A.	0.95 (0.89, 0.99)	<b>0.95*</b> ( <b>0.89, 0.99</b> )	0.95 (0.89, 0.99)	<b>0.95*</b> ( <b>0.89, 0.99</b> )

In bold the selected model in terms of the deterministic components. \*: Evidence of mean reversion at the 5% level.

those with uncorrelated errors in the sense that all of them are very close to 1. However, evidence of mean reversion takes place now for Botswana, China and the USA with the original data and for Australia and the USA with the logged-transformed data. Nevertheless, even in these cases, the estimated values of  $d$  are very large and close to 1, indicating a large degree of persistence.

Next, we estimate  $d$  using a semiparametric approach where no functional form is imposed on the error term. We use here a 'local' Whittle estimated in the frequency domain, as initially proposed by Robinson (1995) and later extended and improved by Shimotsu and Phillips (2006), Abadir, Distaso, and Giraitis (2007) and others. We use Robinson (1995) rather than these other methods since these require additional chosen-user

parameters, and the results will be then sensitive to the choice of these values.<sup>2</sup>

Table 4 displays the estimated values of  $d$  for a selected group of bandwidth numbers,  $T^m$ , with  $m = 0.30, 0.35, \dots, 0.60$ .<sup>3</sup> We see that most of the estimates are around 1, and evidence of mean reversion is only found in a couple of cases for Japan and Australia with the original data and for Japan with the logged ones.

We also look at the possibility of structural breaks. This is a very relevant issue, noting that many authors argue that fractional integration might be an artificial artefact generated by the presence of breaks which have not been taken into account (Diebold and Inoue 2001; Granger and Hyung 2004; Ben Nasr, Ajmi, and Gupta 2014; etc.). We conduct two approaches here: Bai and

<sup>2</sup>Given the nonstationary nature of the series under the study, the analysis was conducted in first differenced data, adding then the value of 1 to the estimated value of  $d$ .

<sup>3</sup>These values are those usually employed in most empirical applications.

**Table 4.** Estimates of  $d$  based on a semiparametric methods.

i) Original data							
Country / m	$\tau^{0.30}$	$\tau^{0.35}$	$\tau^{0.40}$	$\tau^{0.45}$	$\tau^{0.50}$	$\tau^{0.55}$	$\tau^{0.60}$
Australia	0.884	0.940	1.230	1.107	<b>0.873*</b>	0.906	0.918
Botswana	0.972	0.982	1.034	0.959	0.962	0.959	0.943
China	1.148	0.959	1.029	0.964	0.951	0.940	0.935
Euro	0.867	1.070	1.115	0.940	0.970	0.983	0.973
Japan	<b>0.664*</b>	0.840	0.949	<b>0.846*</b>	0.896	0.906	0.934
U.K.	1.165	1.220	1.098	0.953	0.937	0.985	0.972
U.S.A.	0.904	0.966	0.971	0.941	0.998	0.973	0.937
Lower 95%	0.752	0.787	0.824	0.854	0.880	0.900	0.918
Upper 95%	1,247	1.212	1.175	1.145	1.119	1.099	1.081

ii) Logged transformed data							
Country / m	$\tau^{0.30}$	$\tau^{0.35}$	$\tau^{0.40}$	$\tau^{0.45}$	$\tau^{0.50}$	$\tau^{0.55}$	$\tau^{0.60}$
Australia	0.813	0.899	1.237	1.121	0.883	0.920	0.925
Botswana	0.935	1.015	1.030	0.948	0.962	0.966	0.948
China	1.120	0.990	1.036	0.963	0.954	0.950	0.927
Euro	0.975	1.103	1.115	0.977	0.975	0.978	0.968
Japan	<b>0.692*</b>	0.899	0.980	0.876	0.921	0.927	0.943
U.K.	1.180	1.080	1.054	0.972	0.923	0.972	0.954
U.S.A.	0.992	0.950	0.983	0.959	0.982	0.964	0.934
Lower 95%	0.752	0.787	0.824	0.854	0.880	0.900	0.918
Upper 95%	1,247	1.212	1.175	1.145	1.119	1.099	1.081

\* and bold: Evidence of mean reversion ( $d < 1$ ) at the 5% level.

Perron (2003) and Gil-Alana (2008), the latter one being an extension of the former to the fractional case. The results were identical with the two methods, and four breaks were found in each series (see Table 5).

Most of the breaks take place at around (1) August and September 2011; (2) May and December 2013; (3) April and October 2015; and (4) April and December 2016. These significant dates may probably be related to the introduction of the Technical Economic Cooperation Programs (ITEC) which took place after South Africa was admitted as a BRICS member.

In Table 6, we have re-estimated the value of  $d$  for each subsample in each series, obtaining evidence of mean reversion (i.e.  $d < 1$ ) in some cases. In particular, for most of the rates, namely those of Australia, China, the euro, the UK and the US, the estimated value of  $d$  is significantly smaller than 1 for only the third subsample; for Japan, mean reversion is detected in the first and third subsamples, and for

**Table 5.** Break dates using Bai and Perron (2003).

Country	Breaks	Break dates
Australia	4	20/09/2011; 02/01/2014; 26/10/2015; 24/02/2017
Botswana	4	05/07/2012; 04/11/2013; 12/08/2015; 08/12/2016
China	4	20/09/2011; 17/05/2013; 29/05/2015; 24/10/2016
Euro	4	19/09/2011; 22/05/2013; 24/08/2015; 21/12/2016
Japan	4	10/08/2011; 27/12/2012; 24/08/2015; 21/12/2016
U.K.	4	21/09/2011; 31/05/2013; 21/04/2015; 23/08/2016
U.S.A.	4	21/09/2011; 21/05/2013; 24/07/2015; 29/12/2016

**Table 6.** Estimated values of  $d$  for each subsample.

Country	Sub-sample	Original data	Logged data
Australia	1st	0.96 (0.90, 1.03)	0.96 (0.90, 1.03)
	2nd	0.97 (0.90, 1.05)	0.96 (0.90, 1.04)
	3rd	<b>0.89* (0.84, 0.96)</b>	<b>0.89* (0.83, 0.96)</b>
	4th	0.95 (0.88, 1.04)	0.94 (0.87, 1.04)
	5th	1.01 (0.95, 1.09)	1.01 (0.95, 1.09)
Country	Sub-sample	Original data	Logged data
Botswana	1st	<b>0.92* (0.87, 0.98)</b>	<b>0.93* (0.87, 0.99)</b>
	2nd	<b>0.87* (0.80, 0.96)</b>	<b>0.86* (0.79, 0.95)</b>
	3rd	<b>0.77* (0.72, 0.84)</b>	<b>0.77* (0.72, 0.84)</b>
	4th	<b>0.89* (0.84, 0.97)</b>	<b>0.90* (0.84, 0.97)</b>
	5th	0.98 (0.92, 1.05)	0.98 (0.92, 1.05)
Country	Sub-sample	Original data	Logged data
China	1st	0.97 (0.91, 1.05)	0.98 (0.91, 1.05)
	2nd	0.95 (0.87, 1.05)	0.95 (0.87, 1.05)
	3rd	<b>0.86* (0.81, 0.92)</b>	<b>0.87* (0.81, 0.93)</b>
	4th	0.96 (0.89, 1.04)	0.96 (0.90, 1.04)
	5th	1.00 (0.93, 1.07)	1.00 (0.93, 1.07)
Country	Sub-sample	Original data	Logged data
Euro	1st	1.09 (1.02, 1.19)	1.09 (1.02, 1.18)
	2nd	1.03 (0.96, 1.13)	1.04 (0.96, 1.13)
	3rd	<b>0.93* (0.88, 0.98)</b>	<b>0.93* (0.88, 0.98)</b>
	4th	0.94 (0.88, 1.03)	0.94 (0.87, 1.02)
	5th	1.03 (0.96, 1.11)	1.02 (0.96, 1.11)
Country	Sub-sample	Original data	Logged data
Japan	1st	<b>0.88* (0.81, 0.96)</b>	<b>0.88* (0.81, 0.96)</b>
	2nd	1.01 (0.94, 1.10)	1.01 (0.93, 1.10)
	3rd	<b>0.92* (0.87, 0.98)</b>	<b>0.91* (0.86, 0.97)</b>
	4th	0.95 (0.89, 1.03)	0.95 (0.88, 1.03)
	5th	0.98 (0.92, 1.05)	0.98 (0.92, 1.06)
Country	Sub-sample	Original data	Logged data
U.K.	1st	1.08 (1.01, 1.17)	1.08 (1.01, 1.17)
	2nd	0.92 (0.85, 1.01)	0.92 (0.85, 1.01)
	3rd	<b>0.91* (0.85, 0.98)</b>	<b>0.91* (0.85, 0.98)</b>
	4th	1.03 (0.97, 1.10)	1.03 (0.97, 1.10)
	5th	0.99 (0.93, 1.06)	0.99 (0.93, 1.06)
Country	Sub-sample	Original data	Logged data
U.S.A.	1st	0.98 (0.92, 1.06)	0.98 (0.91, 1.06)
	2nd	0.93 (0.85, 1.03)	0.93 (0.85, 1.02)
	3rd	<b>0.85* (0.79, 0.92)</b>	<b>0.85* (0.79, 0.91)</b>
	4th	0.96 (0.90, 1.05)	0.96 (0.90, 1.04)
	5th	1.03 (0.97, 1.11)	1.03 (0.97, 1.11)

\* and bold: Evidence of mean reversion ( $d < 1$ ) at the 5% level.

Botswana in the first four subsamples, and these results hold in both the original and the log-transformed data. Thus, according to these results, mean reversion in the exchange rates with respect to most countries only takes place during the period between 2013 and 2015, and in the case of Botswana, in all cases except for the last period starting at 2017. Whether the exchange rates are fixed, floating or an intermediate arrangement, the objective of any regime including the Government of Botswana is the realization of a stable exchange rate. It has also been established that exchange rate policy is usually driven by two distinct, and sometimes competing, objectives: external competitiveness and maintenance of price stability. The first objective is aimed at improving the balance of payments, while the second objective is pursued insofar as low inflation is desirable from the point of view of

macroeconomic stability and to the extent that it also contributes to efficiency in resource allocation. Indeed, it is not surprising to find Botswana's exchange rate against the major trading currencies exhibiting a mean reverting behaviour because it considered as one of the stable and fast-growing economies in Africa. In fact, since 2013, there has been a decline in inflation from 5.5% in 2013 to 3.2% in 2018, which is largely contributed by the sound monetary policies put in place by the Government of Botswana. Botswana's economy was projected to grow at 4.8% and 6.7% in 2012 and 2013, respectively. Inflation remained high at 9.2% in December 2011 and above the Bank of Botswana's (BoB) objective range of 3–6%. However, it was expected to ease in 2012 and 2013 as below potential output in the mining sector and reduced public expenditure were expected to subdue growth in demand. Even though Botswana has experienced a drop in public trust in institutions, the country has maintained a high overall ranking in Africa, especially when it comes to development indices. The country was classified as one of the 10 poorest countries at the time of independence in 1966, and since then, it has become one of the most economically successful countries in the continent (Magang 2015; Good 2017; Manatsha and Maharjan 2009). Botswana has long been known for its political and economic success and it was ranked third in sub-Saharan Africa on the UNDP Human Development Index (HDI) in 2015 (UNDP 2015).

As a final analysis within this subsection based on the level of the exchange rates, we also examine the possibility of non-linearities in the data, and for this purpose, we use the methodology developed in Cuestas and Gil-Alana (2016), which is based on the Chebyshev's polynomials in time. In particular, we examine now the following model,

$$y_t = \sum_{i=0}^m \theta_i P_{iT}(t) + x_t, (1 - L)^d x_t = u_t, \quad t = 1, 2, \dots \quad (3)$$

where  $P_{iT}$  are the Chebyshev time polynomials defined by:

$$P_{0,T}(t) = 1,$$

$$P_{i,T}(t) = \sqrt{2} \cos(i \pi(t - 0.5)/T), \quad t = 1, 2, \dots, T; \\ i = 1, 2, \dots$$

where  $m$  indicates the degree of non-linearity. Thus, if  $m = 0$ , the model contains an intercept; if  $m = 1$ , it adds a linear trend; and if  $m > 1$ , the model becomes non-linear; and the higher the  $m$  is, the less linear the approximated deterministic component becomes.<sup>4</sup>

To allow for some degree of non-linearity, we suppose  $m = 3$ , and if  $\theta_2$  and/or  $\theta_3$  are statistically significant, we obtain evidence of non-linearities in the data.<sup>5</sup> Results are displayed in Table 7, and we observe that only  $\theta_2$  is significant in the case of China. The rest of the non-linear coefficients are all statistically insignificant providing no evidence of non-linear behaviour, at least of the form examined here.

## VII. Exchange rates in volatility

This section deals with the analysis of persistence in the volatility, measured in terms of both absolute and squared returns. Table 8 displays some descriptive statistics on the two variables. The country with the highest mean absolute returns is Japan (0.008) and the economy with the least value is Botswana (0.003). Looking at the squared returns, the highest values are those of the UK (0.0052), the US (0.0039) and China (0.0039) and the lowest one is Botswana (0.0011).

Tables 9 and 10 display the estimates of  $d$ , respectively, for the two cases of uncorrelated and

**Table 7.** Estimated coefficients in a non-linear model.

Country	d	$\theta_1$	$\theta_2$	$\theta_3$	$\theta_4$
Australia	0.97 (0.94, 1.00)	<b>0.1132</b> <b>(6.68)</b>	0.0152 (1.49)	0.0079 (1.51)	0.0028 (0.79)
Botswana	0.91 (0.88, 0.94)	<b>0.8158</b> <b>(15.70)</b>	<b>0.0690</b> <b>(2.23)</b>	0.0086 (0.50)	-0.0144 (-1.21)
China	0.96 (0.93, 1.00)	<b>0.6227</b> <b>(5.40)</b>	<b>0.1595</b> <b>(2.30)</b>	<b>0.0621</b> <b>(1.71)</b>	-0.0043 (-0.17)
Euro	0.98 (0.95, 1.02)	<b>14.2587</b> <b>(5.18)</b>	-2.2372 (-1.34)	-0.5179 (-0.61)	0.1471 (0.25)
Japan	0.95 (0.92, 0.98)	<b>104.0675</b> <b>(5.53)</b>	12.1563 (1.07)	2.0015 (0.33)	1.5849 (0.38)
U.K.	0.99 (0.96, 1.03)	<b>16.5613</b> <b>(4.59)</b>	-2.7126 (-1.24)	-1.3395 (-1.21)	0.7215 (0.97)
U.S.A.	0.97 (0.94, 1.01)	<b>10.8067</b> <b>(4.61)</b>	<b>-2.5856</b> <b>(-1.83)</b>	-0.3570 (-0.49)	0.4912 (0.99D)

In bold, significant coefficients at the 5% level.

<sup>4</sup>Hamming (1973) and Smyth (1998) contain a detailed description of these polynomials.

<sup>5</sup>Imposing  $m > 3$  in (3) resulted in insignificant coefficients, and using alternative models for the non-linear deterministic terms like the Flexible Fourier Function (FFF) approach of Gil-Alana and Yaya (2018), it also produced insignificant coefficients in all cases.

**Table 8.** Descriptive statistics\_Volatility.

Country	Mean	Std. Deviation	Max. value
Australia	0.00578257	0.00522136	0.04652002
Botswana	0.00345399	0.0034267	0.03339377
China	0.00733205	0.00625214	0.05921048
Euro	0.00674404	0.00600767	0.05963502
Japan	0.00845568	0.0074312	0.05414589
U.K.	0.0069458	0.00604987	0.07252345
U.S.A.	0.00760255	0.00644484	0.0625233

Country	Mean	Std. Deviation	Max. value
Australia	6.06885E-05	0.000130778	0.002164112
Botswana	2.3667E-05	6.8206E-05	0.00111514
China	9.28306E-05	0.000182876	0.003505881
Euro	8.15579E-05	0.000176338	0.003556336
Japan	0.0001267	0.0002461	0.00293178
U.K.	8.48287E-05	0.000192087	0.005259651
U.S.A.	9.93162E-05	0.000196583	0.003909163

**Table 9.** Estimates of  $d$  under no autocorrelation.

Series	Absolute returns	Squared returns
Australia	0.12 (0.10, 0.15)	0.12 (0.10, 0.15)
Botswana	0.17 (0.14, 0.20)	0.22 (0.18, 0.26)
China	0.13 (0.10, 0.15)	0.11 (0.09, 0.14)
Euro	0.14 (0.11, 0.16)	0.13 (0.10, 0.15)
Japan	0.17 (0.15, 0.19)	0.15 (0.13, 0.18)
U.K.	0.12 (0.10, 0.14)	0.09 (0.06, 0.11)
U.S.A.	0.12 (0.10, 0.15)	0.11 (0.09, 0.14)

**Table 10.** Estimates of  $d$  under autocorrelation.

Series	Absolute returns	Squared returns
Australia	0.17 (0.12, 0.22)	0.15 (0.11, 0.20)
Botswana	0.16 (0.13, 0.19)	0.05 (0.02, 0.08)
China	0.20 (0.16, 0.24)	0.16 (0.12, 0.20)
Euro	0.19 (0.16, 0.24)	0.15 (0.11, 0.19)
Japan	0.19 (0.15, 0.23)	0.13 (0.09, 0.17)
U.K.	0.18 (0.15, 0.23)	0.15 (0.11, 0.19)
U.S.A.	0.19 (0.16, 0.24)	0.15 (0.12, 0.19)

autocorrelated errors. The first thing we observe is that the estimates are all significantly positive, providing evidence of long memory and persistence in the volatility processes. For the absolute returns, the estimates range between 0.12 and 0.17 with no autocorrelation, and they are slightly higher (ranging between 0.16 and 0.20) with autocorrelation. Using the squared returns, there is higher dispersion, and the values range between 0.09 (the UK) and 0.22 (Botswana) under no autocorrelation and between 0.05 (Botswana) and 0.16 (China) with autocorrelation.

Finally, the semiparametric (Whittle) approach of Robinson (1995) is also implemented on the transformed return series, and the estimated values of  $d$  are reported across Table 11.<sup>6</sup> We observe that all of them are significantly higher than 0, once more showing long memory, and ranging now between 0.248 and 0.500 with the absolute returns

and between 0.179 and 0.500 with the squared returns.

## VIII. Conclusions

In this article, we have examined the dynamic structure of the exchange rates in South Africa by using fractionally integrated methods. For this purpose, we have used the daily structure of the South African rand against seven related currencies, namely the US dollar, the British pound, the euro, the Japanese yen, the Chinese yuan, the Australian dollar and the Botswana pula.

The analysis was conducted using both levels and volatilities. For the level, we use the original and the log-transformed data, while volatility was approximated by using absolute and squared returns, measuring this as the first differences of the logged series. Starting with the levels, we observe that most of the estimated values of  $d$  were around 1, implying  $I(1)$  behaviour, and though some degree of mean reversion is found in some cases, the values of  $d$  are very close to 1, indicating a large degree of persistence. The possibility of structural breaks was also examined, and two breaks were found in each of the series, in most cases at times related to the introduction of the Technical Economic Cooperation Programs (ITEC) which was after South Africa had been admitted as a BRICS member. Looking at the orders of integration at each of the subsamples in each series, we observe that mean reversion is only found in the subseries constrained between 2013 and 2015 in all cases except Botswana; for the latter country, mean reversion takes place in all subsamples except for the last period starting at 2017. Testing for the possibility of non-linearities and using Chebyshev's polynomial in time, we find only little evidence in the case of China.

Looking at the volatility, measured in terms of the absolute and squared returns, evidence of long-memory patterns is detected in all cases with the estimated values of  $d$  ranging in the stationary region ( $0 < d < 0.5$ ). This is consistent with many other empirical studies conducted in developed countries such as Gil-Alana (2000), Benigno (2004) and Caporale and Gil-Alana (2004), among others. The indication of persistence and non-mean reversion behaviour discovered in the various exchange rate series considered in this study implies that shocks

<sup>6</sup>Using Shimotsu and Phillips (2006) and Abadir, Distaso, and Giraitis (2007) produced essentially the same results.

**Table 11.** Estimates of  $d$  based on a semiparametric method.

i) Absolute returns							
Country / m	$\tau^{0.30}$	$\tau^{0.35}$	$\tau^{0.40}$	$\tau^{0.45}$	$\tau^{0.50}$	$\tau^{0.55}$	$\tau^{0.60}$
Australia	0.490	0.487	0.349	0.327	0.297	0.238	0.248
Botswana	0.500	0.345	0.401	0.362	0.340	0.367	0.310
China	0.337	0.247	0.267	0.297	0.347	0.360	0.333
Euro	0.409	0.267	0.400	0.322	0.302	0.274	0.266
Japan	0.294	0.310	0.329	0.337	0.363	0.338	0.340
U.K.	0.500	0.412	0.393	0.356	0.365	0.377	0.291
U.S.A.	0.391	0.298	0.278	0.289	0.317	0.366	0.352
Lower 95%	-0.274	-0.212	-0.175	-0.145	-0.119	-0.099	-0.081
Upper 95%	0.274	0.212	0.175	0.145	0.119	0.099	0.081

ii) Squared returns							
Country / m	$\tau^{0.30}$	$\tau^{0.35}$	$\tau^{0.40}$	$\tau^{0.45}$	$\tau^{0.50}$	$\tau^{0.55}$	$\tau^{0.60}$
Australia	0.433	0.356	0.347	0.319	0.260	0.207	0.190
Botswana	0.354	0.178	0.284	0.243	0.205	0.195	0.179
China	0.315	0.215	0.292	0.303	0.292	0.287	0.266
Euro	0.497	0.261	0.376	0.275	0.268	0.208	0.202
Japan	0.240	0.203	0.258	0.258	0.290	0.247	0.279
U.K.	0.500	0.400	0.404	0.341	0.301	0.268	0.215
U.S.A.	0.379	0.283	0.333	0.322	0.283	0.291	0.275
Lower 95%	-0.274	-0.212	-0.175	-0.145	-0.119	-0.099	-0.081
Upper 95%	0.274	0.212	0.175	0.145	0.119	0.099	0.081

will, in general, have permanent effects. The implication of this is that monetary policymakers and government may consider passing a new monetary policy or possibly bring back the exchange rate targeting policy which was adopted between 1960 and 1998, together with discretionary monetary policy, monetary-aggregate targeting and an eclectic approach, in order to control the rand in the face of the volatilities of other currencies. Moreover, our measures of persistence in exchange rate volatilities allow us to establish cross-country comparisons, and it is deduced that significant differences arising between these countries may be related to the different monetary institutions governing each of them.

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