# Exchange rates and oil prices in Africa: A nonlinear relationship?

**Simeon Coleman**
*Nottingham Trent University*

**Juan Carlos Cuestas**
*Nottingham Trent University*

**Estefanía Mourelle**[†]
*Universidade da Coruña*

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**Abstract**

In this paper we aim at providing further insights into the determinants of real exchange rates for a pool of African countries. By means of cointegration techniques and nonlinear dynamics, we find that, for some of this countries, the real exchange rates are determined by shocks in the real price of oil.

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[†]Corresponding author: Facultad de Ciencias Económicas y Empresariales, Universidade da Coruña, Campus de Elviña, s/n, 15071 A Coruña, Spain. e-mail: emourelle@udc.es.

# 1 Introduction

Recent years have seen a resurgence in the debate on the pros and cons of exchange rate policy amendments around the world. For example, the much debated policy implications of China's announcement of a number of changes to its foreign exchange regime on July 21, 2005 *vis-à-vis* reaction by US and Asian economies has sparked an increase in the number of empirical studies examining the topic (see Makin, 2009). In light of such examples, and the policy implications of exchange rate movements, analysis of exchange rates and their dynamics has become a cornerstone of the decision-making process in international markets. Two points are worthy of note: First, since Edwards 1989, the degree of exchange rate misalignment has been associated with extent of over- or under-valuation of currencies and is typically used as a yardstick for economic integration (*or the lack of it*)in the real markets of countries. Second, rigorous examination of the real exchange rate (hereafter RER) has become even more important in view of the crucial role that misalignment has assumed in explaining economic underdevelopment (see World Bank, 1984; Dollar, 1992; Edwards,1988; Ghura and Grennes, 1993; Rodrik, 1994; Yotopoulos, 1996). In fact, RER may affect long run growth *via* sectoral allocation of resources and also influence export performance, hence the trade balance (See Hinkle and Montiel, 1999). This is a crucial feature of RERs, that they may serve as a means of promoting (or undermining) economic growth, a particularly important fact for developing economies (see examples Razin and Collins, 1997); and Faria and Leon-Ledesma, 2003).

Typically, the two main sources of fluctuations in the RER include the *financial markets* view (*a la* Dornbusch's (1976) "disequilibrium approach") in which shocks in money markets lead to volatility in exchange rate markets as an equilibrating mechanism, particularly when prices are slow to adjust (see Frankel and Rose, 1996; Chen, 2004). The second approach, the *real economy* view (*a la* Stockman, 1980), attributes fluctuations in RER to shocks in factors influencing output, such as government expenditure, labour supply or productivity (see Zhou, 1995; Bjornland, 2004).

From the empirical point of view, Rogoff (1996) and Evans and Lothian (1993) claim that RER misalignment from the fundamental equilibrium may be due to real shocks, and among them, supply shocks may be behind the empirical failure of the PPP theory (Edwards, 1987). This is corroborated by Gruen and Wilkinson (1994), who find that the RER of Australia can be explained by shocks to the goods and services and real interest rate differentials. Moreover, Chen and Rogoff (2003), Cashin, *et al.* (2004) and Camarero *et al.* (2008) find evidence of long run dependence of the RER on prices of primary products for some developing countries, which explains RER misalignment, from the supply side. Finally, Amano and van Norden (1995, 1998a, 1998b) find that, for some industrialised countries, real oil prices and real interest differentials play a major role in the long run equilibrium of those countries' RER.

From the theoretical point of view, Neary (1988) and Blundell-Wignall and Gregory (1990) justify the role of real shocks, proxied by terms of trade, on the RER long run behaviour. In the same spirit, Cashin *et al.* (2004) find that the effect of commodity terms of trade is similar to the Balassa-Samuelson effect on RER. To sum up, the key point lies in identifying the long run driver of the RER. By doing so, some insights into the determinants of the exchange rates will be gained, which will lead to a better understanding of the variable, as well as serve to help foreign exchange policy design. Against this background, the determinants most commonly cited in the literature include productivity, real interest rate differentials, relative per capita GDP and relative fiscal position (*vis-à-vis* trading-partner countries), terms of trade and trade openness. According to MacDonald and Ricci (2004), these are, at least, the basic explanatory variables for developing economies like the African countries considered in our empirical work.

Due to the more inherent complexities underlying the latter, and the potential policy implications it offers, the *real economy* view appears to have enjoyed much more attention in the empirical literature, and one this paper seeks to contribute to. Along these lines and owing to the important role played by real price of oil *vis-à-vis* economic growth, it is instructive for research to incorporate oil price shocks into the decision making process. Although several studies have confirmed the important impact of oil prices on the RER, the literature has mainly focussed on the US and other developed economies (see examples Zhou, 1995; Amano and Norden, 1998b; Chaudhuri and Daniel, 1998; Dibooglu and Koray, citeyearDibooglu01). While African countries form the bulk of developing economies, not much attention has been paid to the role of real oil prices on RER of African countries. Individually, African economies are not among the highest consumers of oil, but collectively their imports and consumption of oil become significant. [1]

Surveys of exchange rate models point out that monetary models for RER determination are unsatisfactory, in particular in the post Bretton-Woods period (Meese, 1990; Mussa, 1990; Backus, 1984, among others). Also, these authors tend to agree that a random walk outperforms traditional models of exchange rate determination, in terms of forecasting. The reasons for RER deviations from its fundamental equilibrium can either be structural changes in the fundamentals, or due to random components.

Given the empirically established relationship with economic performance in the literature, an analysis of the recent history of country's RER would lead to better knowledge of its behaviour and subsequently guide policymakers in their decisions to promote economic growth. Significantly, very little, if any, empirical studies on this topic have been done for developing economies. With African countries falling into this category, it is of significant policy interest to investigate the behaviour of their RER and the role they can play as a tool for policymaking in improving their economic standing. This forms the basis and purpose of this research, i.e. to analyse the evolution of the RER in a group of African countries, so as to understand how they evolve and how they should, if possible, be managed to boost economic growth.

Contributions to the literature on developing economies highlight how they are severely

[1] See Country Energy Data and Analysis page of US Energy Information Administration website.

affected by external influences. Given that they are usually oil importing economies, oil prices fluctuations become striking factors to take into account. First, real oil prices might be a proxy for exogenous changes of the terms of trade, and arguably the most important exchange rate long run determinant (Amano and van Norden, 1998b). Second, movements in oil prices may be linked to wealth transfers among oil-importing and oil-exporting countries, i.e. to the balance of payments and international portfolio choices (Golub, 1983, Ozturk *et al.*, 2008). Therefore, the effects of movements in oil prices may be through different transmission channels. The study of this relationship has received much more attention in the literature after the 1973-1974 oil price crisis (Ozturk *et al.* 2008), but less so in the case of African economies. This paper seeks to contribute to the empirical literature in this field and, on this basis, we propose the use of the real price of oil as the main long-run determinant of RERs for a group of developing, specifically, African countries. The paper then investigates the evidence of a (uni- or bi-lateral) long-run relationship between the countries' RERs and real oil prices.

The remainder of the paper is organised as follows. The next section describes the econometric methodology we employ. Section 3 presents the empirical evidence and preliminary analysis. Section 4 summarizes the main findings and offers some relevant policy implications. Section 5 concludes.

# 2 Econometric Methodology

## 2.1 Cointegration analysis

In order to explain the long run determinants of the African RER, we apply the Johansen cointegration approach (Johansen, 1988, and Johansen and Juselius,1990). The empirical analysis is based on the following vector error correction model of order $p$, VECM($p$),

$$\Delta x_t = \sum_{i=1}^{p-1} \Gamma_i \Delta x_{t-i} + \alpha\beta' x_{t-1} + \alpha\delta_0 Ds_t + \Phi_1 Dp + \mu_0 + \varepsilon_t \tag{1}$$

where $x_t$ is a vector of $I(1)$ variables, i.e. RER and real oil price, $\mu_0 = \alpha\beta_0 + \alpha_\perp\gamma_0$, so that $\beta_0$ is a drift restricted in the cointegrating space and $\gamma_0$ is equal to zero, $\delta_0$ is the coefficient for the mean shift that does not cancel out in the cointegrating space and finally, the coefficient $\Phi_1$ captures the effect of outlier dummies in the dynamics of the process. Initially, we aim at estimating the long run elasticities of real oil prices on the RER. Exogeneity of the dependent variable is not imposed, but tested instead. In addition, we test for the stability of the parameters by applying the Hansen and Johansen (1999) test for the long run parameters $\beta$ and the loadings, $\alpha$.

Although cointegration techniques might indeed reveal a long run relationship between African RERs and real oil prices, it will be characterised as a linear one. Given this fact, the following question immediately arises: do short-run deviations of exchange rates from their equilibrium state exhibit a linear or nonlinear behaviour?. The key point is that exchange rates might re-adjust to equilibrium in a different way depending on the evolution of certain variable(s), so nonlinearities may affect the response of exchange rates to such deviations. In fact, detecting nonlinearities, i.e. investigating data-generating processes of inherently asymmetric realisations, has long been of interest to applied economists. More recently, a number of empirical works have found evidence of nonlinear evolution in observed economic series (see examples, van Dijk and Franses (1999), Öcal and Osborn (2000), Skalin and Teräsvirta (2002), and Sensier *et al.* (2002). In this vein, this is the focus of the next stage of the current investigation.

## 2.2 Nonlinear framework

### 2.2.1 The specification

The long-run relationship between African exchange rates and real oil prices revealed by the cointegration techniques are based upon a linear specification of the dynamics. In practice, this restriction may be misplaced, and (non)linearity modelling may be more appropriate.

Amongst the most usual nonlinear specifications, we have the Smooth Transition (ST) model, which is the framework we apply in this paper. STs belong to the family of state-dependent models where the data-generating process is a linear one that switches between a certain number of regimes according to some rule. This parameterisation has several advantages, including being flexible enough to capture different types of nonlinearity; standard nonlinear estimation techniques can be used; and there exists a well-defined modelling cycle in the literature (Granger and Teräsvirta (1993), Teräsvirta (1994, 1998) and van Dijk *et al.* (2002), among others, describe STs in detail).

In this paper we resort to the greatest generalization of the ST model, the Smooth Transition Regression (STR). This specification contains an endogenous structure, as well as exogenous variables. Let $y_t$ be a stationary, ergodic process, and, without loss of generality, only one exogenous variable $x_t$. The STR model is defined as

$$y_t = w_t'\pi + (w_t'\theta)F(s_t; \gamma, c) + u_t \tag{2}$$

where $w_t = (1, y_{t-1}, ..., y_{t-p_1}; x_t, x_{t-1}, ..., x_{t-p_2})'$ is a vector of regressors, $\pi = (\pi_0, \pi_1, ..., \pi_p)'$ and $\theta = (\theta_0, \theta_1, ..., \theta_p)'$ are parameter vectors $p = (p_1 + p_2 + 1)$, and $u_t$ is an error process, $u_t \sim Niid(0, \sigma^2)$. The transition variable, $s_t$, can be a lagged endogenous variable, an exogenous variable or just another variable.

The function $F(s_t; \gamma, c)$ is the transition function, customarily bounded between 0 and 1, making the STR coefficients vary between $\pi_j$ and $\pi_j + \theta_j$ $(j = 0, ..., p)$ respectively.

The transition function contains the slope parameter $\gamma$ and the location parameter $c$. The former points out how rapid the transition between the extreme regimes is, whilst the latter indicates the threshold between these regimes. The transition variable and the associated value of $F(s_t)$ determine the regime at each $t$.

The usual formulations for $F$ are the logistic and the exponential function. A proper selection of $F$ is a main issue in such nonlinear analysis, since Logistic STR (LSTR) and Exponential STR (ESTR) models describe quite different types of behaviour. The logistic function implies extreme regimes associated with $s_t$ values far above or below $c$, where dynamics may be different. In the exponential case, the extreme regimes are related to low and high absolute values of $s_t$, with rather similar dynamics, which can be different in the transition period.

Accordingly, the exponential model appears to be the most suitable for describing the evolution of the exchange rates. The reason is that this specification permits incorporation of the location parameter into the equilibrium RER value, and the dynamics of the variable would vary depending on the distance from the equilibrium state. In the last case, there would not be differences between largely overvalued or largely undervalued exchange rates.

Two questions arise. On the one hand, according to the debate in the introduction, we consider two main forces to be driving the nonlinear behaviour in the exchange rates, i.e. idiosyncratic components specific to international trade, and oil prices. On the other hand, for the purposes of this research, linear and STR Error Correction Models (ECM) will be set out, as they reflect short-run and long-run effects on the data.

### 2.2.2 Modelling cycle

The nonlinear modelling procedure we carry out is partially based on that developed by Granger and Teräsvirta (1993) and Teräsvirta (1994, 1998), who reproduce the Box and Jenkins (1970) iterative methodology. First, we take into account the results of the cointegration study. For those countries where, at least, one cointegration relationship between the African RERs and the real oil prices is found, we determine the linear model that would describe the evolution of the exchange rates by Ordinary Least Squares (OLS). In cases where none of our two variables is exogenous, we also estimate an equation for the real oil prices. The models include regular differences of both variables and their lags, the error correction term obtained from the cointegration vector, and, if necessary, step dummy variables in differences.

Once the linear formulation is obtained, the linearity hypothesis is tested against a STR specification. In this vein, there is a well-established procedure by Teräsvirta (1994) and it is quite commonplace to account for it. However, several authors from the most recent empirical literature also claim that it is possible to develop valid nonlinear models that improve the fit of the linear ones without having to do the previous tests, as they are not always conclusive. Following this strand, the strategy is to carry out an extensive search of STR models by defining several combinations for $(\gamma, c, d)$ and the one offering the best statistical properties will be selected. The emphasis lies in the evaluation of the proposed model and any possible inadequacy will be unveiled at the validation stage (van Dijk *et al.*, 2002; Sensier *et al.*, 2002).

At this stage, we estimate the parameters of the STR models by nonlinear least squares, and proceed to evaluate their properties so as to verify whether they describe the behaviour of the variable in a satisfactory manner.[2]

Applying this nonlinear procedure we are able to answer the key question of whether the nonlinear specification better captures the evolution of the exchange rates dynamics more adequately than a linear formulation.

[2]The usual validation tests for dynamic models apply for STR specifications. Apart from these, the tests especially derived for STs by Eitrheim and Teräsvirta (1996) are also developed and applied.

# 3 Empirical Evidence

## 3.1 The data

We consider a sample of thirteen African countries, namely Burkina Faso, Cameroon, Ivory Coast, Kenya, Madagascar, Mauritius, Morocco, Nigeria, Rwanda, Senegal, Seychelles, South Africa and Togo. In this paper, data for Real Effective Exchange Rates (REER) is obtained from Bahmani-Oskooee and Gelan (2007), who obtain RER *vis-à-vis* the main trading partners, i.e. defined as the price of local currency in foreign currency for each of the aforementioned countries, weighted by trade volumes.[3] The real oil prices have been obtained by dividing the nominal oil price ($P(oil)_i$) by the corresponding consumer price Index (CPI) for each country($CPI_i$), both of which have been obtained from the International Monetary Fund's *International Financial Statistics* database. Our data span 1970Q1-2004Q4.

For the sake of brevity, Figures 1 - 4 only display the REER and Real Oil Prices for a sub-sample of the countries in our sample. In same cases, there appears to be a certain degree of co-movement between the two variables - suggesting a long-run relationship.

## 3.2 Long run analysis

To proceed with the cointegration analysis, we specify the unrestricted Vector Autoregression (VAR) models in terms of lag length and statistical properties of the residuals. The bivariate model is based on the log of the REER ($q_t$) and the log of the real oil price ($oil_t$). The primary aim here is to analyse whether $oil_t$ explains the long run path of $q_t$. Also, it has been necessary to include some dummy variables, and a shift restricted to the cointegration space given that some shocks did not cancel out in the cointegrating space.[4] The lag length for each VAR has been chosen by means of goodness of residual

[3]By using an effective exchange rate, we are implicitly considering competitiveness of each country with its main trading partners.

[4]see Appendix I.

tests specification. The baseline models were carefully checked for signs of misspecification using a variety of diagnostic tests, reported in Tables 1 and 2. We find that some normality and heteroskedasticity problems persist even after inclusion of the dummy variables. However, following Gonzalo (1994), the Johansen maximum likelihood estimation procedure is robust to normality and heteroskedasticity problems.

Given that we have two variables, there can be a maximum of one cointegrating vector.[5] Table 3 reports the results of the Johansen stationarity tests and suggest that for Madagascar, Mauritius, Rwanda, Senegal and South Africa it is not possible to reject the null of stationarity for at least one of the variables. Therefore, for these countries, we can conclude that there is no long run relationship between REER and real oil prices.

Testing for weak exogeneity of the REER, we find that for the case of Togo, Seychelles and Nigeria the null hypothesis cannot be rejected [$\chi^2(2) = 2.889$, $p - value = 0.236$; $\chi^2(1) = 2.341, p - value = 0.126$; $\chi^2(1) = 0.438, p - value = 0.508$ respectively]. This implies that these countries' REER will not adjust to a potential long-run relationship between $q_t$ and $oil_t$. Now, testing for the existence of a cointegrating relationship, table 4 reports results of Johansen's Trace test. The results imply that in all cases the null of a unique cointegrating relationship cannot be rejected, except for Ivory Coast where there is no evidence of cointegration.[6]

Once the cointegration rank has been determined, the next step in our analysis is to test the hypothesis of long-run exclusion of the variables. In the case of Morocco, the restricted constant is not significant ($\chi^2(1) = 2.218, p - value = 0.136$), i.e. the intercept in the data cancels out in the cointegration space.

The cointegrating relationships are reported in Table 5. We note that for Burkina Faso and Kenya, the sign of the parameter for the oil price ($oil_t$) is negative. This implies that a rise in oil prices leads to a depreciation in their currency in real terms, which

[5]A full rank would imply that both variables are stationary.

[6]The roots of the companion matrix corroborate these results. Test results are not reported here for the sake of brevity, but are available upon request.

increases competitiveness of these countries, but makes their imports more expensive. This may be due to the fact that these oil importing countries are heavily dependent on their trading partners for national consumption. However, the picture is different for oil producers Cameroon and Morocco, where an increase in oil prices appreciate the national currency in real terms. This suggests that for these two countries a rise in oil price increases the purchasing power of their currencies as oil is a source of income. The dummy variable for the case of Morocco captures the effect of a sudden depreciation of the national currency as a measure to improve competitiveness. For Burkina Faso and Cameroon, the respective dummy variables capture the effect of the 1994 Franc zone-wide devaluation of the CFAF by their Central Banks. Finally, the Central Bank of Kenya depreciated the shilling by 85% in the first nine months of 1993 which is captured by the variable $ds932$.

Figures 5-8 provide the graphical representation of the recursive Hansen and Johansen (1999) stability tests for the cointegration relationship. Bearing in mind that the graphical representations of the tests are during most of the sample under the critical level, which is one, we can say that the relationships identified in Table 5 are globally stable. In the case of Morocco some instability is evident during the first quarter of the sample, therefore we should consider these elasticities as average figures for the whole sample.[7]

## 3.3 Nonlinear dynamics

### 3.3.1 Detecting nonlinearities

The modelling procedure begins with the linear specification that describes the behaviour of the exchange rates for those countries where a cointegration relationship is found. Two equations, one for the exchange rate and the other for the oil price, are estimated in the cases where none of these variables are exogenous. The maximum lag order ($p$) of the variables is the one considered in the cointegration analysis (i.e. 2 in Burkina Faso,

[7] We subsequently show that the nonlinear models are globally stable in the four cases.

Cameroon and Morocco; 3 in Kenya). In addition to the first difference of (the logarithm of) REERs and real oil prices, we introduce the variation in the dummy variable and the error correction term at $t-1$. The constant term is also included in the cointegration relationship.

Linear models are estimated by OLS with all parameters initially introduced, but then we successively exclude those with the lowest $t$-values (the limit is 1.6). In Burkina Faso and Morocco, we find that the REERs and the real oil prices are not exogenous. Therefore, for these countries, we estimate one equation for each variable. The exogeneity of the real oil prices in Cameroon and Kenya leads to only one model for the exchange rates.[8] Upon obtaining the linear models, we then test whether there is evidence of the type of nonlinear behaviour generated by STRs.

It is worth pointing out at this point that the linearity test process consists of completing a sequence of auxiliary regressions. Owing to the fact that we have an adequate number of observations, we use the so-called *unconditional* approach. This approach is based on the notion that for each transition variable candidate, the transition lag $d$ is unknown. The transition variable is assumed to be the linear combination $\sum_{i=0,1}^{p} \upsilon_i s_{t-i}$, where $\upsilon' = (0...1...0)'$ is a selection vector with the only unit element corresponding to the transition lag.[9] The transition variables taken into account are the differences of (the logarithm of) REERs and real oil prices, and the error correction term. The transition lag $d$ goes from 0 or 1 to the maximum $p$ contemplated in each country. For increased flexibility, we permit the transition function to be either logistic or exponential, even in the case of the exchange rates (although the exponential function is deemed to be the most appropriate for this variable).

Table 6 presents the $p$-values of the linearity tests for the exchange rates and the oil prices. Rejection of linearity is somewhat stronger when dealing with the oil prices, as it

[8]For the sake of brevity, we do not report the final estimated models here, but they are available upon request.

[9]The reader is referred to Teräsvirta (1994, 1998) and van Dijk *et al.* 2002 for a more detailed discussion on the linearity tests procedure employed.

is detected in, at least, two of the three transition variable candidates and for both types of transition function. For Burkina Faso and Morocco, We find evidence of nonlinearities in both the exchange rates and the oil prices in the latter, but only regarding the oil prices in the former. For Cameroon and Kenya, the results are rather clear - the hypothesis of a linear behaviour of the exchange rates is generally rejected in the former, whilst it is never rejected in the latter. As the results are not conclusive for the whole set of countries, we follow the aforementioned strategy of an extensive search of STR models for the REERs and, where necessary, the real oil prices.

### 3.3.2 Nonlinear modelling

The starting point for the nonlinear specification is the estimated linear model. The extensive search of STR specifications results in a substantial number of models as we consider all the combinations of the distinct transition variables (for all the values of $d$), the different values of $\gamma$ and a location parameter $c$ in the neighborhood of the sample mean of the transition variable. As suggested by Teräsvirta (1994), the argument of the logistic (exponential) function is scaled through division by the standard error (variance) of the transition variable. The models are estimated by nonlinear least squares. Those specifications attaining parameter convergence are subjected to further refinement. Non-significant coefficients are removed to conserve degrees of freedom and cross-parameter restrictions are evaluated to gain efficiency. At this stage, we select the models offering the best properties, which are then validated by means of a battery of evaluation and diagnostic tests. The features of the estimated transition functions are also carefully examined.

Given the linear long-run relationship between exchange rates and oil prices, the empirical evidence suggests nonlinear behaviour in the short-run deviations of both variables from that equilibrium. We achieve valid STR-ECMs for the exchange rates in all four countries; and for the oil prices in only Burkina Faso and Morocco. The estimated models are reported in Table 7, together with some descriptive statistics and misspecification tests. The descriptive statistics presented are the residual standard error(s) and the variance ratio of the residuals from the nonlinear model and the linear specification ($s^2/s_L^2$). With regard to the misspecification tests, those employed are the test of no Autoregressive Conditional Heteroskedasticity (ARCH) with four lags and the three specific tests proposed by Eitrheim and Teräsvirta (1996).[10]

First, focusing on Burkina Faso and Morocco, these countries display variations in the exchange rates that depend on their own recent history and also react to deviations from their equilibrium path; the dynamics of the dummy variables are also present in the models. For oil prices, they vary according to their own past values and are also influenced by their deviations from the long-run state.

We find that the transition between regimes is an exponential one in the case of the exchange rates, which fits with the findings in the literature (see Michael *et al.* 1997, Taylor and Peel 2000). The most suitable transition variable is the error correction term, i.e. the deviations from the equilibrium path determine the nonlinear behaviour of the exchange rates in Burkina Faso; the variation of the oil prices are the source of nonlinearities in the case of Morocco.

Figure **??** presents the estimated transition functions. Most observations lie to the right of the location parameter, so that the function mimics a logistic one in both countries. Burkina Faso shows two extreme regimes associated with the deviations from the equilibrium, i.e. the inner regime for values of the error correction term reasonably close to zero; and the outer regime, covering the remaining (positive and negative) values. In Morocco the extreme regimes are related to null and large (positive and negative) oil prices growth. The asymmetric evolution is clearly observable in both countries; the higher the absolute deviations from the corresponding threshold, the more pronounced

[10]These include the test of residual serial independence against a tenth-order process (AUTO), the test of no remaining nonlinearity in the residuals (NL, computed for all the potential transition variables under the alternative, but only the one minimizing the $p$-value is displayed), and the test of parameter constancy that allows for monotonically changing parameters under the alternative (PC).

the reaction of the exchange rates.

Centering now on oil prices, their recent values generate nonlinearities in Burkina Faso, while in Morocco the cause is the variation in the exchange rates. In the first case, oil prices growth show different dynamics for negative (lower regime) and positive (upper regime) past variations. The variation range of the logistic function is not wide in practice; almost all its values are above 0.6, which restricts the flexibility in the dynamics of the variable. In Morocco, the transition between regimes is exponential; the greater the change in the exchange rates, the more severe the reaction of the price of oil.

According to the validation tests, there is no evidence of misspecification in the proposed ESTR models, so one may conclude that they are adequate. Moreover, the variance ratios indicate that the estimated nonlinear models for Burkina Faso and Morocco explain 5% and 9% of the residual variance of the linear regressions in the case of the exchange rates, and 23% and 15% regarding oil prices, respectively.

For Cameroon and Kenya, the dynamic structure of their exchange rates is quite similar to that of Burkina Faso and Morocco. The transition function is exponential and it is determined by the error correction term in both countries. The deviations from the long-run path therefore cause nonlinear effects on the exchange rates. As shown in Figure **??**, the observations display a rather equal distribution, giving rise to clear representations of an exponential function.

The exchange rates evolve more rapidly from one extreme regime to the other in Cameroon and Kenya than in Burkina Faso and Morocco. As a result of the nearly abrupt changes, the models behave like threshold specifications; this observation further strengthens the importance of employing STR models. Following the validation stage, there are no indications of misspecification in the models. According to the variance ratio, the STR model explains 9% of the residual variance of the linear regression in Cameroon and 8% in Kenya.

The key point we have found out is the nonlinear nature of both the exchange rate dynamics in all our countries and the oil prices in those where this variable is not exogenous. Remarkably, the relationship "exchange rates-oil prices" is not only mirrored in the dynamic structure of both variables in several countries, but notably in the transition variable.

In most cases, what is affecting the exchange rate dynamics is not so much the oil price growth but how important the degree of deviation of the former is from their equilibrium with the latter. We suggest the following explanation for this behaviour. In the framework of our analysis, a shock in the oil prices has two basic implications, i.e. an immediate oil price growth, and an alteration in the long-run relationship with the exchange rates. These two effects must be taken into account as their relevance, or weight, would differ across countries. In fact, our countries have a well-defined equilibrium relationship between the price of oil and the exchange rates. This causes a rise or a fall in the oil prices to have a stronger effect through the deviations from the long-run path, than through the movements of prices.

With regard to oil prices in Burkina Faso and Morocco, their most recent values and the exchange rate dynamics are the deciding factors in their nonlinear behaviour, respectively. The case of Morocco should be mentioned, as oil prices are driven by the variations in the exchange rates while the former are the source of nonlinearities of the latter. The "strenght" of this relationship might be related to the fact of being an oil producer, as there exists certain room for action over both variables; given that, deviations from the respective equilibria should not be so decisive in this country (as it mainly is in the others), which might explain that the error correction term never appears as a transition variable in Morocco.

# 4 Policy implications

Of the thirteen countries in our original sample, Burkina Faso, Cameroon, Ivory Coast, Senegal and Togo belong to the *Communauté Financière Africaine*, i.e. CFA Franc zone.[11] Focussing on this subset of countries for the time being, we highlight the following. Article 10 of the BEAC Constitution and Article 6 of the UEMOA Accord both provide for the freedom of capital flow across the zone.

First, our inability to find a long-run relationship between REER and real oil prices for Ivory Coast, Senegal and Togo suggest that oil price shocks will have different impacts, at least in the long run, in Burkina Faso and Cameroon. With policy coordination and fixed nominal exchange rate being foundations of the union, these heterogeneities we observe in long-run behaviour should pose significant difficulties for (monetary) policy formulation if price stability and provisions of the Constitution is adhered to. Differences in price effects *vis-à-vis* the unrestricted flow of capital across the zone is likely to skew money supply from some countries to the detriment of economic growth.

Second, with Burkina Faso and Cameroon demonstrating different signs in their respective cointegrating relationships, the ability of the policymakers to maintain the peg is again challenged. A common (oil price) shock provides a depreciating (appreciating) effect for the Burkina Faso (Cameroon) CFA Franc. On the one hand, the "reverse" effect observed in the case of Cameroon could be attributed to less dependence on imported oil than her major trading partners.[12] On the other hand, the effect observed in Burkina Faso demonstrates the significant dependence on imported oil. In order to maintain the peg, uniform monetary policy needs to be augmented with country-specific measures, which may include increasing government intervention in energy regulation, or

[11] Technically, Cameroon is somewhat distinct in this subset of countries, as it is under the jurisdiction of a separate central bank, (the BEAC), while the remaining (West African, or UMOA) countries fall under the control of a separate central bank, the BCEAO.

[12] Although Cameroon is not a world level exporter of oil, it is considered one of Africa's main oil producers and exported (imported) 108,800 (50,750) barrels/day at 2005 estimates. Proved oil reserves are 98 million barrels at 2008 estimates.(*Source*: CIA World Factbook).

even planned transfer of funds, as required.

Regarding Kenya and Morocco, the significant role played by the manufacturing sector in Kenya's economy is well known, and is widely touted as the regional hub for trade and finance in East Africa.[13] In the light of this and the fact that Kenya is a net importer of oil, our finding that positive real oil price shocks lead to depreciation in the Kenyan shilling is expected. The appreciation observed in the Moroccan dirham following a positive shock in real oil price suggests limited dependence on imported oil than her major trading partners.[14] In both of these countries the more flexible exchange rate regimes allow for better chance of improving competitiveness through nominal adjustment.

Last, for Burkina Faso, Cameroon, Kenya and Morocco, where we find evidence of a long-run relationship, the nonlinear behaviour we uncover for exchange rates dynamics provides support for some policy intervention, if price stability is important. The effects generated by more-pronounced real oil price shocks should elicit a more rapid and tailored response compared to less-pronounced ones.

# 5 Conclusions

As volatility in oil prices continue to dominate global energy markets, and as governments and countries grapple with achieving some stability in real exchange rates, the need for evidence on how this volatility impacts on the latter becomes crucial. Aiming to contribute to studies determining the sources of shocks to real exchange rates, we have analysed in this paper, the role of oil prices as a long-run determinant of real exchange rates in a sample of African countries.

Whether or not real exchange rates depend in the long-run on real oil prices has

[13] According to Kenya's Export Promotion Council (EPC), the manufacturing sector contributed 10.5% to the country's GDP in 2005, an increase of 0.6% over the previous year. We also note that, as of 2006, Kenya had no proven oil reserves.

[14] Although Morocco is currently a net importer of oil, the proven oil reserves, as of 2008, are estimated as 100 million barrels (*Source*: CIA World Factbook).

important implications for exchange rate modelling. If shocks that affect real exchange rates have permanent effects on the variable and there is no evidence of a long-run relationship, then effectiveness of policy measures aimed at returning the real exchange rate to its equilibrium will be limited or, at best, temporary. However, if real exchange rates are indeed driven by oil prices, then countries lose or gain competitiveness (albeit, with a time lag) depending on the direction of the shock. To this end, foreign exchange rate policy authorities should be better equipped to stabilise the real value of the currency given that a measurable relation has been established between the long-run values of both variables. Precisely, by monitoring real oil prices, it should be possible to predict the existence of real shocks that affect the real exchange rate.

Using cointegration techniques and allowing for nonlinear dynamics, we find that real oil prices and real exchange rates are indeed cointegrated in some African countries, but not in others. A number of conclusions follow from our results. First, in Burkina Faso, Cameroon, Morocco and Kenya, where this evidence of cointegration exists, the important role the price of oil plays in real exchange rate determination is established. Second, the effects of oil prices shocks on the evolution of the real exchange rates in each of these four countries is different, which highlights the fact that oil plays a different role for each of them. This may be due to the different economic structures of these economies, i.e. whether the country is net exporter or importer of oil. Finally, our results also suggest that adoption of more flexible exchange rates would allow them to improve their international competitiveness.

# Appendix I

The following dummy variables have been included in the VAR models in order to capture the presence of socio-political events and devaluations that have affected the variables.

Burkina Faso, Cameroon, Ivory Coast, Nigeria, Senegal and Togo: ds941

Kenya: $ds932$

Madagascar: $ds862$

Mauritius: $ds794$

Morocco: $ds852$

Rwanda: $ds952$

Seychelles: $ds851$

South Africa: $ds853$

where $dsxxy = 1$ from 19xx:y to the end of the sample and 0 otherwise. This shift variables are restricted to the cointegration space ad appear in the dynamics in first differences.

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**Figure 1: Real Effective Exchange Rates and Real Oil Prices for Cameroon**

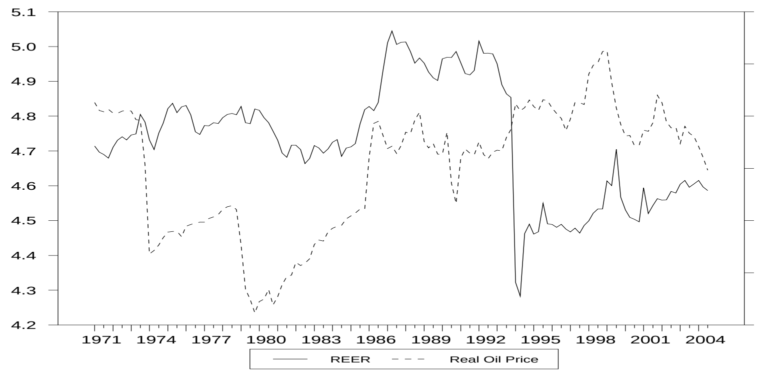



**Figure 2: Real Effective Exchange Rates and Real Oil Prices for Ivory Coast**

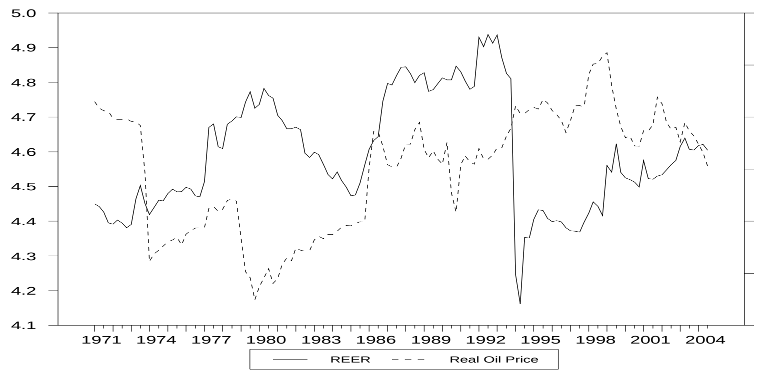



**Figure 3: Real Effective Exchange Rates and Real Oil Prices for Kenya**

Figure 4: Real Effective Exchange Rates and Real Oil Prices for Seychelles

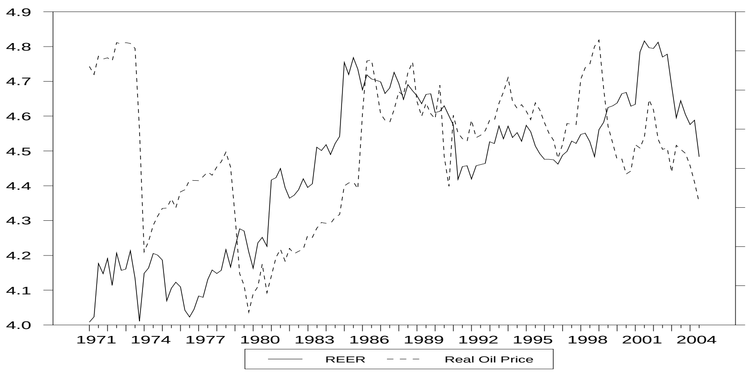



Figure 5: Structural stability tests for Burkina Faso

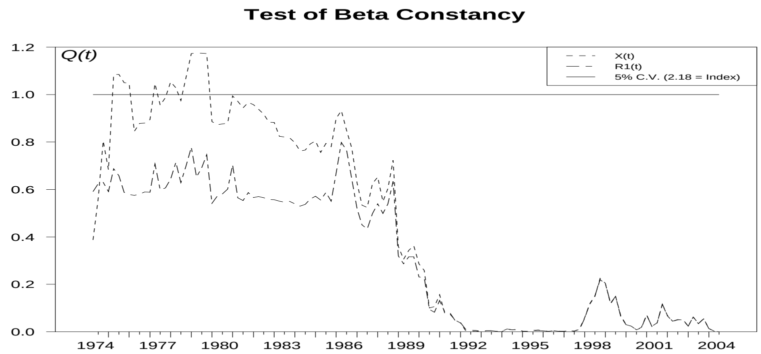
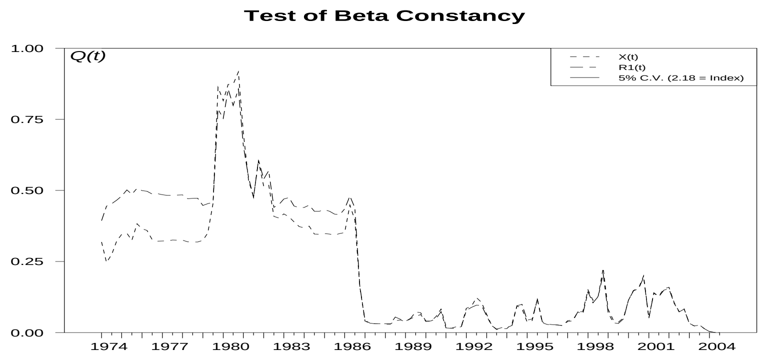
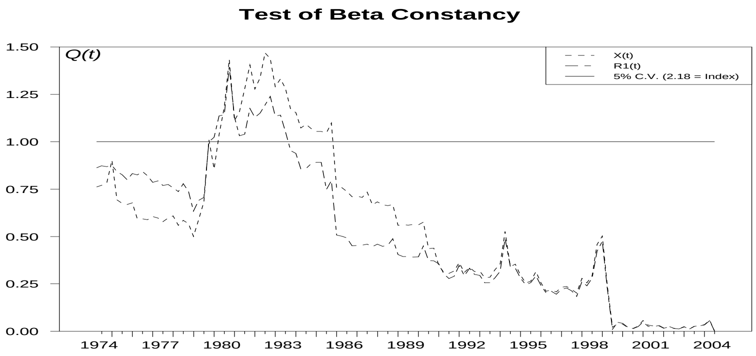


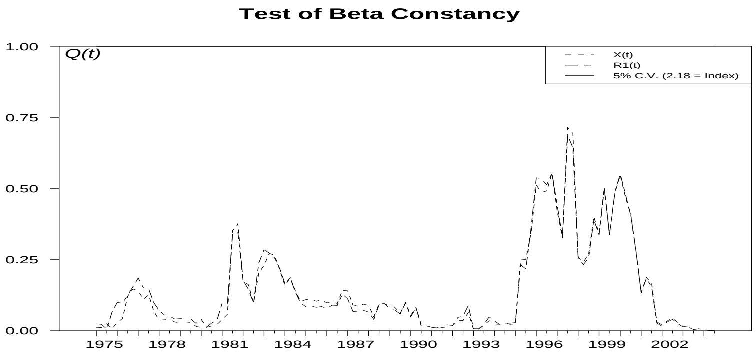

Figure 6: Structural stability tests for Cameroon



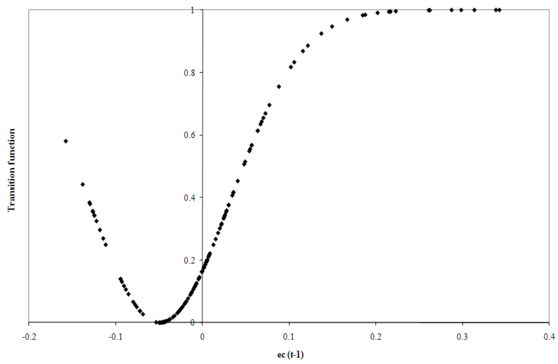
## Figure 7: Structural stability tests for Morocco



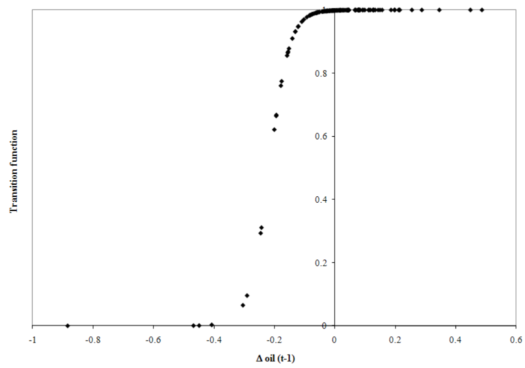

## Figure 8: Structural stability tests for Kenya



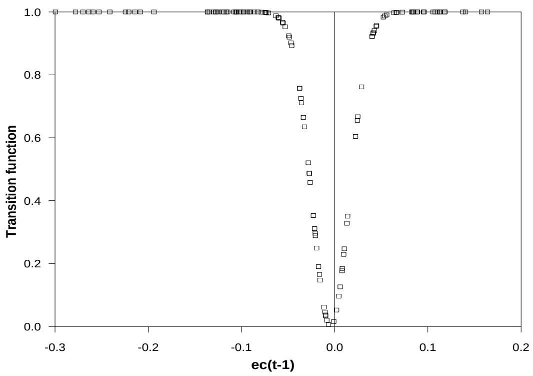
## Figure 9: Estimated STAR functions



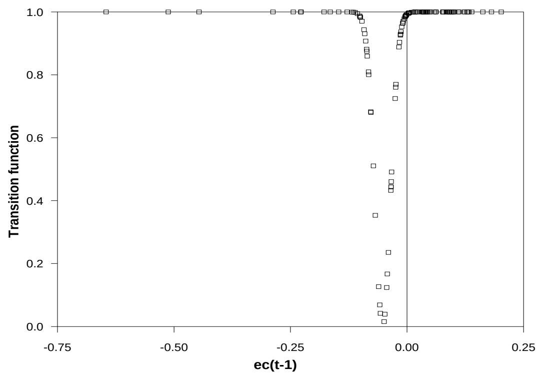

(a) Burkina Faso, REER



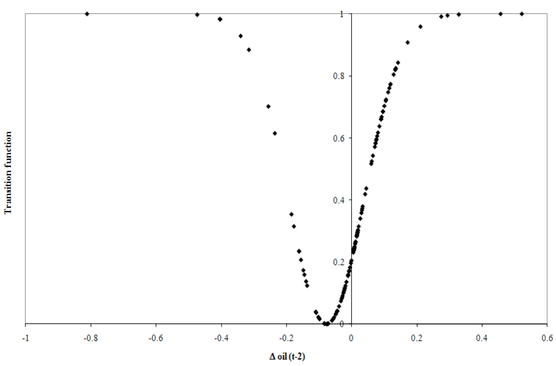

(b) Burkina Faso, Oil Prices



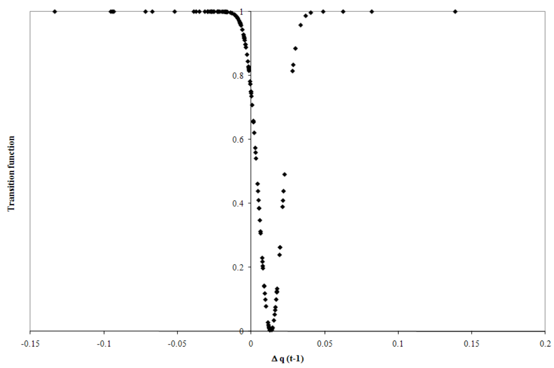

(c) Cameroon




(d) Kenya




(e) Morocco, REER




(f) Morocco, Oil Prices

**Table 1: Univariate misspecification tests**

| Country/VAR(p) | Variable | ARCH | Normality | Skewness | Kurotsis |
|---|---|---|---|---|---|
| Burkina Faso | $\Delta q_t$ | 12.316 [0.002] | 23.877 [0.000] | 1.052 | 4.651 |
| VAR(2) | $\Delta oil_t$ | 3.246 [0.197] | 47.940 [0.000] | -0.797 | 7.969 |
| Côte d'Ivoire | $\Delta q_t$ | 0.023 [0.989] | 36.036 [0.000] | 1.494 | 7.295 |
| VAR(2) | $\Delta oil_t$ | 4.994 [0.082] | 59.720 [0.000] | -0.836 | 8.849 |
| Cameroon | $\Delta q_t$ | 3.766 [0.152] | 33.200 [0.000] | 0.419 | 6.099 |
| VAR(2) | $\Delta oil_t$ | 6.007 [0.050] | 57.978 [0.000] | -0.968 | 9.287 |
| Kenya | $\Delta q_t$ | 0.506 [0.918] | 33.335 [0.000] | -1.474 | 9.161 |
| VAR(3) | $\Delta oil_t$ | 6.518 [0.089] | 48.812 [0.000] | -1.099 | 9.261 |
| Madagascar | $\Delta q_t$ | 0.501 [0.778] | 64.641 [0.000] | -2.548 | 17.353 |
| VAR(2) | $\Delta oil_t$ | 2.907 [0.234] | 59.530 [0.000] | -0.972 | 9.404 |
| Mauritius | $\Delta q_t$ | 0.246 [0.884] | 3.327 [0.189] | -0.291 | 3.495 |
| VAR(2) | $\Delta oil_t$ | 3.588 [0.166] | 49.461 [0.000] | -0.786 | 8.030 |
| Morocco | $\Delta q_t$ | 10.276 [0.006] | 108.990 [0.000] | -0.201 | 9.818 |
| VAR(2) | $\Delta oil_t$ | 3.450 [0.178] | 39.693 [0.000] | -0.904 | 7.779 |
| Nigeria | $\Delta q_t$ | 8.989 [0.011] | 5.890 [0.053] | 0.226 | 3.857 |
| VAR(2) | $\Delta oil_t$ | 1.792 [0.408] | 37.479 [0.000] | -0.951 | 7.776 |
| Rwanda | $\Delta q_t$ | 14.591 [0.001] | 120.872 [0.000] | 0.298 | 10.527 |
| VAR(2) | $\Delta oil_t$ | 5.891 [0.053] | 36.426 [0.000] | -1.090 | 8.208 |
| South Africa | $\Delta q_t$ | 21.844 [0.000] | 119.999 [0.000] | -0.272 | 10.444 |
| VAR(2) | $\Delta oil_t$ | 2.934 [0.231] | 43.981 [0.000] | -1.178 | 9.228 |
| Senegal | $\Delta q_t$ | 1.296 [0.523] | 20.051 [0.000] | 1.040 | 5.076 |
| VAR(2) | $\Delta oil_t$ | 3.708 [0.157] | 62.761 [0.000] | -0.883 | 9.222 |
| Seychelles | $\Delta q_t$ | 4.030 [0.776] | 18.325 [0.000] | 0.082 | 4.869 |
| VAR(7) | $\Delta oil_t$ | 7.856 [0.346] | 13.754 [0.001] | -0.598 | 4.911 |
| Togo | $\Delta q_t$ | 18.504 [0.018] | 21.754 [0.000] | 0.371 | 5.318 |
| VAR(8) | $\Delta oil_t$ | 3.285 [0.915] | 32.580 [0.000] | -0.748 | 6.837 |

*Note*: P-values are reported in brackets.

## Table 2: Multivariate misspecification tests

| | | | |
|---|---|---|---|
| Burkina Faso | **Tests for Autocorrelation:** | Ljung-Box(33): | $\chi^2(124) = 194.766[0.000]$ |
| | | LM(1): | $\chi^2(4) = 2.106[0.716]$ |
| | | LM(2): | $\chi^2(4) = 15.122[0.004]$ |
| | **Test for Normality:** | | $\chi^2(4) = 79.286[0.000]$ |
| | **Test for ARCH:** | LM(1): | $\chi^2(9) = 29.309[0.001]$ |
| | | LM(2): | $\chi^2(18) = 30.088[0.037]$ |
| Côte d'Ivoire | **Tests for Autocorrelation:** | Ljung-Box(33): | $\chi^2(124) = 127.207[0.404]$ |
| | | LM(1): | $\chi^2(4) = 4.097[0.393]$ |
| | | LM(2): | $\chi^2(4) = 4.472[0.346]$ |
| | **Test for Normality:** | | $\chi^2(4) = 101.732[0.000]$ |
| | **Test for ARCH:** | LM(1): | $\chi^2(9) = 12.130[0.206]$ |
| | | LM(2): | $\chi^2(18) = 19.149[0.383]$ |
| Cameroon | **Tests for Autocorrelation:** | Ljung-Box(33): | $\chi^2(124) = 131.694[0.301]$ |
| | | LM(1): | $\chi^2(4) = 4.202[0.379]$ |
| | | LM(2): | $\chi^2(4) = 7.002[0.136]$ |
| | **Test for Normality:** | | $\chi^2(4) = 91.717[0.000]$ |
| | **Test for ARCH:** | LM(1): | $\chi^2(9) = 13.718[0.133]$ |
| | | LM(2): | $\chi^2(18) = 19.180[0.381]$ |
| Kenya | **Tests for Autocorrelation:** | Ljung-Box(33): | $\chi^2(124) = 132.964[0.197]$ |
| | | LM(1): | $\chi^2(4) = 4.392[0.356]$ |
| | | LM(2): | $\chi^2(4) = 3.187[0.527]$ |
| | **Test for Normality:** | | $\chi^2(4) = 82.666[0.000]$ |
| | **Test for ARCH:** | LM(1): | $\chi^2(9) = 6.848[0.653]$ |
| | | LM(2): | $\chi^2(18) = 13.906[0.735]$ |
| Madagascar | **Tests for Autocorrelation:** | Ljung-Box(33): | $\chi^2(124) = 135.511[0.226]$ |
| | | LM(1): | $\chi^2(4) = 1.758[0.780]$ |
| | | LM(2): | $\chi^2(4) = 2.787[0.594]$ |
| | **Test for Normality:** | | $\chi^2(4) = 128.118[0.000]$ |
| | **Test for ARCH:** | LM(1): | $\chi^2(9) = 15.913[0.069]$ |
| | | LM(2): | $\chi^2(18) = 17.815[0.468]$ |
| Mauritius | **Tests for Autocorrelation:** | Ljung-Box(33): | $\chi^2(124) = 152.272[0.043]$ |
| | | LM(1): | $\chi^2(4) = 5.767[0.217]$ |
| | | LM(2): | $\chi^2(4) = 9.318[0.054]$ |
| | **Test for Normality:** | | $\chi^2(4) = 45.676[0.000]$ |
| | **Test for ARCH:** | LM(1): | $\chi^2(9) = 10.993[0.276]$ |
| | | LM(2): | $\chi^2(18) = 13.902[0.735]$ |
| Morocco | **Tests for Autocorrelation:** | Ljung-Box(33): | $\chi^2(124) = 140.269[0.151]$ |
| | | LM(1): | $\chi^2(4) = 7.009[0.135]$ |
| | | LM(2): | $\chi^2(4) = 7.259[0.123]$ |
| | **Test for Normality:** | | $\chi^2(4) = 152.581[0.000]$ |
| | **Test for ARCH:** | LM(1): | $\chi^2(9) = 34.286[0.000]$ |
| | | LM(2): | $\chi^2(18) = 45.456[0.000]$ |
| Nigeria | **Tests for Autocorrelation:** | Ljung-Box(33): | $\chi^2(124) = 164.117[0.009]$ |
| | | LM(1): | $\chi^2(4) = 5.655[0.226]$ |
| | | LM(2): | $\chi^2(4) = 4.494[0.343]$ |
| | **Test for Normality:** | | $\chi^2(4) = 51.677[0.000]$ |
| | **Test for ARCH:** | LM(1): | $\chi^2(9) = 10.640[0.301]$ |
| | | LM(2): | $\chi^2(18) = 22.905[0.194]$ |
| Rwanda | **Tests for Autocorrelation:** | Ljung-Box(33): | $\chi^2(124) = 96.886[0.966]$ |
| | | LM(1): | $\chi^2(4) = 3.645[0.456]$ |
| | | LM(2): | $\chi^2(4) = 3.279[0.512]$ |
| | **Test for Normality:** | | $\chi^2(4) = 156.937[0.000]$ |
| | **Test for ARCH:** | LM(1): | $\chi^2(9) = 55.114[0.000]$ |
| | | LM(2): | $\chi^2(18) = 63.939[0.000]$ |
| South Africa | **Tests for Autocorrelation:** | Ljung-Box(33): | $\chi^2(124) = 126.490[0.421]$ |
| | | LM(1): | $\chi^2(4) = 8.117[0.087]$ |
| | | LM(2): | $\chi^2(4) = 5.826[0.213]$ |
| | **Test for Normality:** | | $\chi^2(4) = 161.593[0.000]$ |
| | **Test for ARCH:** | LM(1): | $\chi^2(9) = 29.215[0.001]$ |
| | | LM(2): | $\chi^2(18) = 36.733[0.006]$ |
| Senegal | **Tests for Autocorrelation:** | Ljung-Box(33): | $\chi^2(124) = 110.683[0.798]$ |
| | | LM(1): | $\chi^2(4) = 4.528[0.339]$ |
| | | LM(2): | $\chi^2(4) = 5.723[0.221]$ |
| | **Test for Normality:** | | $\chi^2(4) = 88.475[0.000]$ |
| | **Test for ARCH:** | LM(1): | $\chi^2(9) = 5.130[0.823]$ |
| | | LM(2): | $\chi^2(18) = 13.886[0.736]$ |
| Seychelles | **Tests for Autocorrelation:** | Ljung-Box(33): | $\chi^2(100) = 81.299[0.914]$ |
| | | LM(1): | $\chi^2(4) = 3.498[0.478]$ |
| | | LM(2): | $\chi^2(4) = 3.576[0.466]$ |
| | **Test for Normality:** | | $\chi^2(4) = 32.083[0.000]$ |
| | **Test for ARCH:** | LM(1): | $\chi^2(9) = 27.282[0.001]$ |
| | | LM(2): | $\chi^2(18) = 28.511[0.055]$ |
| Togo | **Tests for Autocorrelation:** | Ljung-Box(33): | $\chi^2(92) = 95.779[0.373]$ |
| | | LM(1): | $\chi^2(4) = 8.208[0.084]$ |
| | | LM(2): | $\chi^2(4) = 4.456[0.348]$ |
| | **Test for Normality:** | | $\chi^2(4) = 61.371[0.000]$ |
| | **Test for ARCH:** | LM(1): | $\chi^2(9) = 23.414[0.005]$ |
| | | LM(2): | $\chi^2(18) = 39.516[0.002]$ |

*Note*: P-values are reported in brackets.

**Table 3: Tests for stationarity**

| Country | $q_t$ | $oil_t$ |
|---|---|---|
| Burkina Faso | 3.697 [0.054] | 10.149 [0.001] |
| Cameroon | 8.226 [0.004] | 11.118 [0.001] |
| Côte d'Ivoire | 4.735 [0.030] | 3.225 [0.073] |
| Kenya | 35.872 [0.000] | 2.564 [0.109] |
| Madagascar | 1.234 [0.267] | 20.623 [0.000] |
| Mauritius | 1.749 [0.186] | 0.824 [0.364] |
| Morocco | 11.086 [0.001] | 2.425 [0.119] |
| Nigeria | 14.679 [0.000] | 3.923 [0.048] |
| Rwanda | 0.274 [0.601] | 0.337 [0.562] |
| Senegal | 1.094 [0.296] | 6.875 [0.009] |
| Seychelles | 14.622 [0.000] | 3.582 [0.058] |
| South Africa | 2.145 [0.143] | 0.306 [0.580] |
| Togo | 18.328 [0.000] | 9.903 [0.002] |

*Note*: P-values are reported in brackets.

**Table 4: Trace test for the cointegration rank**

| Country | p-r | r | Eig.Value | Trace | Trace* | Frac95 | P-Value | P-Value* |
|---|---|---|---|---|---|---|---|---|
| Burnika Faso | 2 | 0 | 0.137 | 27.901 | 27.197 | 26.378 | 0.032 | 0.039 |
| | 1 | 1 | 0.061 | 8.331 | 7.984 | 12.822 | 0.256 | 0.285 |
| Cameroon | 2 | 0 | 0.139 | 25.238 | 24.563 | 27.134 | 0.082 | 0.098 |
| | 1 | 1 | 0.039 | 5.264 | 5.053 | 13.020 | 0.532 | 0.558 |
| Côte d'Ivoire | 2 | 0 | 0.098 | 18.354 | 17.860 | 27.134 | 0.368 | 0.400 |
| | 1 | 1 | 0.034 | 4.622 | 4.313 | 13.020 | 0.613 | 0.653 |
| Kenya | 2 | 0 | 0.252 | 39.671 | 38.322 | 27.015 | 0.001 | 0.001 |
| | 1 | 1 | 0.010 | 1.327 | 1.297 | 12.983 | 0.976 | 0.977 |
| Morocco | 2 | 0 | 0.137 | 27.901 | 27.197 | 26.378 | 0.032 | 0.039 |
| | 1 | 1 | 0.061 | 8.331 | 7.984 | 12.822 | 0.256 | 0.285 |
| Seychelles | 2 | 0 | 0.149 | 26.488 | 26.488 | 26.387 | 0.049 | 0.049 |
| | 1 | 1 | 0.044 | 5.808 | 5.808 | 12.827 | 0.526 | 0.526 |

*Note*: The symbol * represents bartlett corrections.

**Table 5: Identified cointegrated vectors**

| | |
|---|---|
| Burkina Faso | $q_t = \underset{(90.987)}{5.131} - \underset{(-2.300)}{0.108}\, oil_t - \underset{(-7.667)}{0.387}\, ds941$ |
| Cameroon | $q_t = \underset{(104.469)}{4.721} + \underset{(3.161)}{0.151} oil_t - \underset{(-5.958)}{0.373}\, ds941$ |
| Morocco | $q_t = \underset{(6.167)}{7.064} oil_t - \underset{(-3.237)}{6.160}\, ds852$ |
| Kenya | $q_t = \underset{(145.852)}{4.344} - \underset{(-3.029)}{0.104}\, oil_t + \underset{(5.441)}{0.427} ds932$ |

*Note:* t-statistics are reported in parenthesis.

**Table 6: Linearity tests against smooth transition regression (p-values)**

| | Transition Variables | | | | | |
|---|---|---|---|---|---|---|
| | $\Delta q_t$ | | $\Delta oil_t$ | | $ec_{t-1}$ | |
| Country-variable | LSTR | ESTR | LSTR | ESTR | LSTR | ESTR |
| Burkina Faso - $q_t$ | 0.2988 | 0.2145 | 0.8564 | 0.7777 | 0.3962 | 0.6080 |
| Burkina Faso - $oil_t$ | 0.1402 | 0.3764 | 0.0001 | 0.000002 | 0.0005 | 0.0002 |
| Cameroon - $q_t$ | 0.0439 | 0.0027 | 0.1879 | 0.1053 | 0.0068 | 0.0335 |
| Kenya - $q_t$ | 0.2550 | 0.4381 | 0.8834 | 0.9925 | 0.3527 | 0.6768 |
| Morocco - $q_t$ | 0.0093 | 0.0015 | 0.0054 | 0.0430 | 0.0093 | 0.0058 |
| Morocco - $oil_t$ | 0.0581 | 0.0814 | 0.0343 | 0.0107 | 0.0231 | 0.0103 |

# Table 7: Estimated STR models

BURKINA FASO

Real effective exchange rates

$$\Delta q_t = \underset{(0.09)}{0.22}\Delta q_{t-1} - \underset{(0.09)}{0.17}ec_{t-1} - \underset{(0.04)}{0.42}\Delta ds9401 + \left(-\underset{(0.17)}{0.33}\Delta q_{t-1} - \underset{(0.16)}{0.64}\Delta q_{t-2} + \underset{(0.09)}{0.17}ec_{t-1}\right) \times \left[1 - exp\left\{-\underset{(0.40)}{0.76} \times 97.56\left(ec_{t-1} + \underset{(0.02)}{0.05}\right)^2\right\}\right] + u_t$$

s=0.04; $s^2/s_L^2 = 0.95$; ARCH=3.07 (0.02); AUTO=1.87 (0.06); NL=1.39 (0.15); PC=1.17 (0.31)

BURKINA FASO

Real oil prices

$$\Delta oil_t = \underset{(0.13)}{0.55}\Delta oil_{t-1} - \underset{(0.31)}{1.42}\Delta oil_{t-2} - \underset{(0.61)}{3.47}ec_{t-1} + \left(-\underset{(0.17)}{0.44}\Delta oil_{t-1} + \underset{(0.32)}{1.38}\Delta oil_{t-2} + \underset{(0.63)}{3.15}ec_{t-1}\right) \times \left[1 + exp\left\{-\underset{(2.74)}{4.86} \times 6.25\left(\Delta oil_{t-1} + \underset{(0.03)}{0.22}\right)\right\}\right]^{-1} + u_t$$

s=0.13; $s^2/s_L^2 = 0.73$; ARCH=0.32 (0.87); AUTO=1.17 (0.32); NL=1.59 (0.07); PC=0.57 (0.88)

CAMEROON

Real effective exchange rates

$$\Delta q_t = \underset{(0.19)}{0.44}\Delta q_{t-1} + \underset{(0.21)}{0.31}\Delta q_{t-2} - \underset{(0.03)}{0.10}ec_{t-1} - \underset{(0.03)}{0.54}\Delta ds9401 + \left(-\underset{(0.19)}{0.44}\Delta q_{t-1} - \underset{(0.21)}{0.54}\Delta q_{t-2}\right) \times \left[1 - exp\left\{-\underset{(12.68)}{12.71} \times 101.17\left(ec_{t-1} + \underset{(0.01)}{0.004}\right)^2\right\}\right] + u_t$$

s=0.03; $s^2/s_L^2 = 0.91$; ARCH=2.54 (0.04); AUTO=1.73 (0.08); NL=1.31 (0.19); PC=1.43 (0.14)

KENYA

Real effective exchange rates

$$\Delta q_t = -\underset{(0.29)}{0.40}\Delta q_{t-2} - \underset{(0.46)}{1.18}ec_{t-1} - -\underset{(0.05)}{0.22}\Delta ds9302 + \left(\underset{(0.30)}{0.61}\Delta q_{t-2} + \underset{(0.46)}{0.96}ec_{t-1}\right) \times \left[1 - exp\left\{-\underset{(34.90)}{44.23} \times 70.20\left(ec_{t-1} + \underset{(0.005)}{0.05}\right)^2\right\}\right] + u_t$$

s=0.05; $s^2/s_L^2 = 0.92$; ARCH=0.19 (0.94); AUTO=0.99 (0.46); NL=1.40 (0.12); PC=0.52 (0.95)

MOROCCO

Real effective exchange rates

$$\Delta q_t = \underset{(0.23)}{0.34}\Delta q_{t-1} - \underset{(0.001)}{0.002}ec_{t-1} - \underset{(0.03)}{0.09}\Delta ds8502 + \left(-\underset{(0.34)}{1.01}\Delta q_{t-1} + \underset{(0.001)}{0.002}ec_{t-1}\right) \times \left[1 - exp\left\{-\underset{(0.78)}{0.88} \times 43.31\left(\Delta oil_{t-2} + \underset{(0.02)}{0.08}\right)^2\right\}\right] + u_t$$

s=0.03; $s^2/s_L^2 = 0.91$; ARCH=0.62 (0.64); AUTO=1.80 (0.07); NL=1.68 (0.05); PC=1.46 (0.14)

MOROCCO

Real oil prices

$$\Delta oil_t = \underset{(0.16)}{0.58}\Delta oil_{t-1} + \underset{(0.01)}{0.06}ec_{t-1} + \left(-\underset{(0.21)}{0.45}\Delta oil_{t-1} - \underset{(0.01)}{0.06}ec_{t-1}\right) \times \left[1 - exp\left\{-\underset{(4.28)}{7.96} \times 968.05\left(\Delta qt - 1 - \underset{(0.002)}{0.01}\right)^2\right\}\right] + u_t$$

s=0.13; $s^2/s_L^2 = 0.85$; ARCH=0.72 (0.58); AUTO=1.82 (0.07); NL=1.64 (0.06); PC=1.40 (0.16)

*Notes*: $\Delta q_t$ stands for the REER in first differences; $\Delta oil_t$ for the oil price in first differences; $ec_t$ for the error correction term; $\Delta dx$ for the variation of the step dummy variable at time x. Values under regression coefficients are standard errors of the estimates; $s$ is the residual standard error; $s^2/s_L^2$ is the variance ratio of the residuals from the nonlinear model and the best linear regression; ARCH is the statistic of no ARCH based on four lags; AUTO is the test for residual autocorrelation of order 10; NL is the test for no remaining nonlinearity; PC is a parameter constancy test. Numbers in parentheses after values of ARCH, AUTO, NL and PC are p-values.