Information Contents of Term Structure of Interest Rates and Inflation Rates in a Developing Country

Abstract:

Term structure of interest rates, inflation rates and their information contents are investigated in a developing country by using different measures of inflation rates and default-free Treasury instruments of different maturities. Results from high frequency monthly data in 1990:01, before the inception of monetary policy committee in 2002, when the Bank of Ghana adopted inflation targeting as its policy goal to 2017:02, show that the country's yield curve is asymmetrical. Error-correction adjustments of discrepancies from the long-run equilibrium are slow at low and high rates, and faster at intermediate rates. Short-term interest rates, monetary policy rates, expected forward rates, interest rates spread and risk premium explain the country's long-term rates. Only short term 91-Day Treasury Bills and monetary policy rates contain the information required to predict the country's inflation rates, with the latter being more effective. Consequently, monetary authorities can effectively use those rates to curb the country's inflation rates.

Keywords: Monetary policy rates; Treasury Bills rates; inflation rates; asymmetric adjustments

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1.0: Introduction

Early studies of the term structure of interest rates or yield curves hardly employed stationary series. Consequently, both short-term and long-run interest rates employed were not ensured to be stationarized in conducting regression analysis of the term structure of interest rates. See Fama (1975), Carlson (1977), Mankiw (1986), Nelson and Siegel (1987), Mishkin (1990), Campbell and Shiller (1991), Koedijk and Kool (1995), Chapman and Pearson (2001), Tabak (2004) and Ghartey (2005). However, since the inception of the concept of cointegration developed by Granger (1983), and Engle and Granger (1987, 1991), it has become a precursor test of economic variables, most of which are non-stationary (Nelson and Plosser, 1982) in empirical studies. Once economic variables have been found to be cointegrated, they can be expressed as error-correction representations (ECR) to study short-term and long-run dynamics of equations of interest.

An alternative to the use of ECR to study short-term and long-run dynamics of economic variables is autoregressive distributed lagged (ADL) models, which can be used to determine whether variables of equations of interest should be specified in either a level or first difference-form or as an ECR in ADL bounds testing. See Pesaran, et al. (2001). Knowing that an estimated ADL model in a bounds testing has an F- statistic which lies either before the bounds or beyond the bounds or within the bounds, instructs the modeller to use either a level form or first difference form or an ECR, respectively, to model the ADL process. However, it should be noted that using either the ADL bounds testing approach or ECR to determine cointegration properties of variables, is applicable to only linear models with symmetric adjustments (Engle and Granger, 1987; Pesaran, et al., 2001). Neither the ADL bounds testing approach nor the ECR model addresses or resolves nonlinear cointegration or nonlinear models or nonlinear adjustments from short-term deviation to long-run equilibrium. See Engle and Granger (1987), Balke and Fomby (1997), Enders and Granger (1998), Schorderet (2001), and Granger and Yoon (2002).

Considering that most econometric models are nonlinear or have nonlinear cointegration or exhibit nonlinear adjustment when displaced from long-run equilibrium, serial correlation, heteroscedasticity, and functional-form instability problems associated with estimating the standard cointegration in the term structure of interest rates, are resolved in this study by addressing such nonlinearities. See Balke and Fomby (1997) for threshold cointegration, Schorderet (2001) and Granger and Yoon (2002) for short-term and long-run asymmetric adjustments, and Enders and Granger (1998), and Enders and Siklos (2001) for nonlinear adjustments towards long-run equilibrium or attractor.

Since cointegration exists when economic variables either share common stochastic trends or respond to common shocks, the problem associated with estimating cointegration of the term structure of interest rates may emanate from the fact that the long-run and short-term interest rates do not share common trends or respond to linear combination of stochastic shocks. It is therefore important that instead of using estimation techniques which assume a linear cointegration and adjustments between/among variables of interest, we use the threshold regression technique which addresses nonlinear relationship between short-term and long-run interest rates in the term structure of interest rates. See Balke and Fomby (1997) and Enders and Siklos (2001). Threshold regression analysis and cointegration will allow us to separate high interest rate regimes from low and moderate regimes, and address nonlinear adjustments towards long-run equilibrium or attractor (Enders and Granger, 1998; Enders and Siklos, 2001).

Finally, considering that central banks or monetary authorities tend to pay more attention to increasing interest rates because of its effect on higher prices or inflation and depreciation of the national currencies, we have resolved the lack of information between prices/inflation and the term structure of interest rates in previous studies by differentiating the responsiveness of components of the term structure of interest rates to components of prices during business expansion, when prices are rising, from the situation of business contractions, when prices are declining (see Schorderet, 2001; Granger and Yoon, 2002, Shin et al., 2011). Thus, the study also employs asymmetric ECR to determine the nonlinear adjustment of common shocks among components of interest rates in the term structure and components of prices.

Following the introduction, the nonlinear models employed in the study are developed in section 2. It is followed by a discussion of empirical results in section 3. The study is concluded with a summary of the findings and policy implications derived in section 4.

2.0: Nonlinear Models

Empirical studies of the information contents in the term structure of interest rates and inflation have often yielded results which suffer from serial correlation, heteroscedasticity and functional-form instabilities problems. Consequently, results of past studies on the term structure of interest rates fail to observe cointegration between the term structure of interest rates and prices and/or inflation. Since most past studies on the term structure of interest rates are mostly specified in linear forms, and their adjustments from short-term to long-run equilibrium are also specified in linear forms by using the Engle and Granger's two stage approach (EG TSA) model, we have resolved the linearity bias in such studies, by using nonlinear regression analysis and nonlinear cointegration models to study the term structure of interest rate and price/inflation.

Thus, we have estimated both linear and nonlinear or threshold regression models. We have also employed linear cointegration in the form of Johansen, and attempted to resolve the nonlinearity problem by using threshold cointegration and asymmetric cointegration (see Engle and Granger, 1987; Enders and Siklos, 2002; Granger and Yoon, 2002). We have also used asymmetric adjustments to address the dynamics of short-term deviations to long-run equilibrium. The threshold model and nonlinear adjustments are developed in section 2.1, and the nonlinear asymmetric cointegration and adjustments are developed in section 2.2.

2.1: Threshold Model

Estimated cointegration or long-run equilibrium relationship function is

$$r1y_t = b_1r91d_t + b_2f1_t + b_3mpr_t + b_4rsp_t + c + u_t \tag{1a}$$

Associated threshold regression equation is

$$\begin{aligned} r1y_t = {} & (\beta_1 r91d_t + \beta_2 f1_t + \beta_3 mpr_t + \beta_4 rsp_{t-1})I(1)_t(r91d_{t-1}<k_1) + (\beta_1' rd91_t + \beta_2' f1_t + \beta_3' mpr_t \\ & + \beta_4' rsp_{t-1})I(2)_t(k_1 \leq r91d_{t-1}< k_2) + (\beta_1'' r91d_t + \beta_2'' f1_t + \beta_3'' mpr_t + \beta_3'' rsp_{t-1})I(3)_t(k_2 \leq r91d_{t-1}) \\ & + c + u_t' \end{aligned} \tag{1b}$$

Engle-Granger Two-Stage Approach (TSA):

$$\Delta r1y_t = b_1\Delta r91d_t + b_2\Delta f1_t + b_3\Delta mpr_t + b_4\Delta rsp_{t-1} - \lambda u_{t-1} \tag{2a}$$

where, 91-day Treasury Bills Rate (TBR) is r91d, rr91d is real r91d, 1-year TBR is r1y, 91-day or a quarter forecast of r91d based on the expectation hypothesis is f1, Bank of Ghana's monetary policy rate is mpr, rmpr is real mpr, year on year inflation rate is π yy, non-food inflation rate is π nf, the spread between r1y and r91d is rsp, the spread between π yy and π yy (-3) is π spy, p is overall consumer price index (CPI), $\hat{u}_t$ is the estimated residual ($u_t = r1y_t - b_1r91d_t - b_2f1_t - b_3mpr_t - b_4rsp_{t-1} - c$) from equation 1a, and corresponding threshold residual is obtained from equation 1b.

The lagged augmentations have been reduced to only unity because of under-sized sample problem. I is an indication function. The error-correction term in equation 2a is λ; it is stable if $\lambda \in [-1, 0]$. There is instantaneous adjustment when λ is -1, and no adjustment when λ is zero. Significance of λ indicates that variables in equation 1a are cointegrated, and the size of λ measures the speed of adjustment when displaced from long-run equilibrium. See Table 2 and notes in Table 1.

Alternative expression for testing the Engle and Granger (1987) TSA error-correction model in equation 2a is to express the adjustment as follows:

$$\Delta u_t = \rho u_{t-1} + \varepsilon_t \tag{2b}$$

where, $\rho \in (-2, 0)$ and $\varepsilon_t \sim N(0, \sigma^2)$ and is iid or has white noise innovation. Thus, if the $|\rho| < 1$ or $\rho \in (-2, 0)$ then the adjustment towards long-run equilibrium is stationary or linear and symmetrical or convergent.

In a three regime threshold autoregressive (TAR) model, where there are two threshold values such that $k_1 < k_2$, representing three threshold regimes, if indeed our leading TAR model follows equation 1b, then the (a)symmetric adjustment of the TAR model will be expressed in error-correction form as

$$\Delta r1y_t = I(1)_t.\rho_1.u_{t-1} + I(2)_t.\rho_2.u_{t-1} + I(3)_t.\rho_3.u_{t-1} + \varepsilon_t \qquad (3a)$$

where,

$I(1)_t = 1$ if $u_{t-1} < k_1$ and 0 if otherwise

$I(2)_t = 1$ if $k_1 \leq u_{t-1} < k_2$ and 0 if otherwise

and $I(3)_t = 1$ if $u_{t-1} \geq k_2$ and 0 if otherwise (3b)

Here, equation 3a is stationary when $-2 < (\rho_1, \rho_2, \rho_3) < 0$, random-walk when $\rho_1 = \rho_2 = \rho_3 = 0$, and reduces to equation 2b when $\rho_1 = \rho_2 = \rho_3 = \rho$. The Heaviside step functions I(1), I(2) and I(3) in equation 3b and equation 3a constitute the TAR equation.

The momentum (M)-TAR model of a three regimes threshold will comprise of equations 3c and 3d[1]. Its (a)symmetric adjustment is expressed in error-correction form as

$$\Delta r1y_t = M(1)_t.\rho_1.u_{t-1} + M(2)_t.\rho_2.u_{t-1} + M(3)_t.\rho_3.u_{t-1} + \varepsilon_t \qquad (3c)$$

where, the Heaviside step functions are

$M(1)_t = 1$ if $\Delta u_{t-1} < k_1$ and 0 if otherwise

$M(2)_t = 1$ if $k_1 \leq \Delta u_{t-1} < k_2$ and 0 if otherwise

and $M(3)_t = 1$ if $\Delta u_{t-1} \geq k_2$ and 0 if otherwise (3d)

Equation 3c replaces equation 3a so that the TAR model which comprises of equations 3c and 3d constitute a momentum-TAR (M-TAR) model. In such a situation, the adjustment is asymmetrical to the extent that the series show more 'momentum' in one direction than the other. Thus, if $|\rho_1| < |\rho_2| < |\rho_3|$, then the M-TAR model exhibits less decay when Δu_{t-1} is above the threshold value k_1, and relatively more decay when Δu_{t-1} is below k_1. It also means that increase in Δu_{t-1} results in persistent adjustment, whereas a reduction in Δu_{t-1} results in the system reverting towards its long-run equilibrium or attractor. The M-TAR

[1] Ghartey (2017) estimated both models with two and three threshold values. See also Enders and Granger (1998).

can be used to capture ‘steepness’, where according to Sichel (1993, p.225), steepness refers to the cycle in which contractions tend to be steeper than expansions, while ‘deepness’ refers to a cycle where troughs are further below the trend line than peaks are above it.

A series of F-statistics tests are used to determine cointegration, and whether adjustments are symmetrical or asymmetrical. In the case of two threshold values which means three regimes, we employ the Φ or F-statistic to test H_0: $\rho_1 = \rho_2 = \rho_3 = 0$. If the null hypothesis is not rejected, then the adjustment is random walk, but if it is rejected, then there is a threshold cointegration. We then proceed to test whether the adjustment is symmetrical or asymmetrical by testing the F-statistic for H_0: $\rho_1 = \rho_2 = \rho_3$. If we fail to reject the null hypothesis of equal parameter restriction, then the adjustment is symmetrical. If we reject the null hypothesis, which means that we accept the H_1: $\rho_1 \neq \rho_2 \neq \rho_3$, then the adjustment is asymmetrical.

Thus, we first determine the threshold variable and its associated values for the term structure of interest rates, and from then on proceed to determine whether there is a threshold cointegration, and if so whether the adjustment towards long-run equilibrium is symmetrical or asymmetrical. We therefore establish that a nonlinear or threshold model can exhibit a symmetrical or asymmetrical adjustment towards a long-run equilibrium. According to Balke and Fomby (1997, p.628): “... the standard tests for detecting cointegration in linear time series are also capable of detecting threshold cointegration.”

2.2: Nonlinear Asymmetric Cointegration

Since we could not find any relationship among the term structure of interest rates and prices/inflation, we decided to explore the relationship among the term structure of interest rates and rising and falling prices. The reason being that responsiveness of interest rates to rising and falling prices, and vice versa are different, as prices tend to rise rather quickly but fall sluggishly or even remain the same. The associated long-run asymmetric regression equation is

$$r91d_t = \beta^+ p^+_t + \beta^- p^-_t + w_t \tag{4a}$$

$$\Delta p_t = v_t \tag{4b}$$

where, $r91d_t$ and p_t are I(1) variables.

The variable p_t is decomposed as

$$p_t = p_0 + p^+_t + p^-_t$$

where, $p^+_t = \sum_{i=1}^{n} \Delta p^+_i = \sum_{i=1}^{n} \max(\Delta p_i, 0)$ and $p^-_t = \sum_{i=1}^{n} \Delta p^-_i = \sum_{i=1}^{n} \min(\Delta p_i, 0)$, and

$$r91d^{+}_{t} = \sum_{i=1}^{n} \Delta r91d^{+}_{i} = \sum_{i=1}^{n} \max(\Delta r91d_i, 0) \text{ and } r91d^{-}_{t} = \sum_{i=1}^{n} \Delta r91d^{-}_{i} = \sum_{i=1}^{n} \min(\Delta r91d_i, 0)$$

Thus, p^{+}_{t} ($r91d^{+}_{t}$) is a partial sum of processes of positive changes, and p^{-}_{t} ($r91d^{-}_{t}$) is a partial sum of processes of negative changes. See Schorderet (2001), Granger and Yoon (2002), and Shin et al. (2011). Variables $r91d_t$ and p_t are 'asymmetrically cointegrated' if their partial sum components is z_t, and is stationary or integrated at degree zero I(0), such that their linear combinations can be expressed as

$$z_t = \beta_0^{+} r91d^{+}_{t} + \beta_0^{-} r91d^{-}_{t} + \beta_1^{+} p^{+}_{t} + \beta_1^{-} p^{-}_{t} \tag{4c}$$

Equation (4c) with z_t as a regressand is linearly cointegrated if $\beta_0^{+} = \beta_0^{-}$ and $\beta_1^{+} = \beta_1^{-}$, under the assumption that z_t is an iid process with a zero mean and finite constant variance ($E(w_t) = 0$, and $V(w_t) = \sigma^2 < \infty$) which are identically and independently distributed (iid).

Equation 4a is expressed as a nonlinear autoregressive distributed lag (NADL) model with orders p' and q' -- NADL (p', q') model -- as follows:

$$r91d_t = \sum_{i=0}^{p'} \alpha_i r91d_{t-i} + \sum_{i=0}^{q'} \lambda_i^{+\prime} p^{+}_{t-i} + \sum_{i=0}^{q'} \lambda_i^{-\prime} p^{-}_{t-i} + \varepsilon_t \tag{5a}$$

where p_t is our exogenous variable defined above, α is the autoregressive parameter, λ_i^{+} and λ_i^{-} are the asymmetric distributed lag parameters, and ε is the error term which exhibits iid process with zero mean and constant finite variance.

Although p can be decomposed around any estimated non-zero calculated threshold value, we have decomposed it into p^{+} and p^{-} around a threshold value of zero. Thus, expansion or increase in p (or inflation) is denoted by p^{+} and contraction or decrease in p (or deflation) is denoted by p^{-}.

Equation 5a can be re-written as

$$\Delta r91d_t = \rho r91d_{t-1} + \lambda^{+} p^{+}_{t-1} + \lambda^{-} p^{-}_{t-1} + \sum_{i=1}^{p'-1} \partial_i \Delta r91d_{t-i} + \sum_{i=0}^{q'-1} \lambda_i^{+\prime} \Delta p^{+}_{t-i} + \sum_{i=0}^{q'-1} \lambda_i^{-\prime} \Delta p^{-}_{t-i} + \varepsilon_t \tag{5b}$$

Its nonlinear long-run equation is equation 4a, and its associated nonlinear error-correction term is

$$\xi_t = r91d_t - \beta^{+} p^{+}_{t} - \beta^{-} p^{-}_{t}$$

The nonlinear error-correction form of equation 5b is re-written as

$$\Delta r91d_t = \rho \xi_{t-1} + \lambda^{+} p^{+}_{t-1} + \lambda^{-} p^{-}_{t-1} + \sum_{i=1}^{p'-1} \partial_i \Delta r91d_{t-i} + \sum_{i=0}^{q'-1} \lambda_i^{+\prime} \Delta p^{+}_{t-i} + \sum_{i=0}^{q'-1} \lambda_i^{-\prime} \Delta p^{-}_{t-i} + \varepsilon_t \tag{5c}$$

where $\rho = \sum_{i=1}^{p'} \alpha_i - 1$, and $\partial_j = -\sum_{j=i+1}^{p'} \alpha_j \;\; \forall$ j = 1, … , p'-1, with $\beta^+ = -\frac{\lambda^+}{\rho}$ and $\beta^- = -\frac{\lambda^-}{\rho}$ as the corresponding long-run asymmetric parameters, and λ^+ and λ^- are the short-term asymmetric parameters.

In a large sample data, the optimal lag-length is chosen from AIC and SBC. Generally, serial correlation is corrected by using an appropriate lag-length criteria. However, because our study is faced with under-sized sample problem, we impose a unit lag as the optimal lag-length.

Additionally, misspecification originating from weak endogeneity associated with nonstationary regressors, will be corrected by using the NADL error-correction model (ECM), which is estimated by the standard ordinary least squares (OLS) estimator, and the fully modified Phillips and Hansen maximum likelihood estimator (FMOLS), in cases where there are serial correlation and heteroscedasticity problem. See Phillips and Hansen (1990), Pesaran and Shin (1998), and Pesaran et al. (2001).

We use the unit lag as the optimum lag-length in our NADL model because of undersized sample problem, although we often arrive at it from a maximum lag-length of two. We also employ long-run or reaction asymmetry, and short-term and/or impact asymmetry to study the dynamic effect, and reaction of the monetary policy principle on the term structure of interest rates and inflation in Ghana, a developing country. See Borenstein et al. (1997), Apergis and Miller (2006), Shin et al. (2011), Schorderet (2001) and Granger and Yoon (2002).

Finally, secondary data for the study is sourced from Bank of Ghana's website. Monthly data for food consumer price index (CPI), non-food CPI, overall CPI and non-food inflation (π_{nf}) range from 1990:01 to 2016:09; year-on-year inflation (π_{yy}) and 91-day Treasury Bills rates (r91d) range from 1990:01 to 2017:02; exchange rates (xr) range from 1990:01 to 2017:04, monetary policy rates (mpr) range from 1990:07 to 2017:04, and 1-year Treasury Bills rates (r1y) range from 2006:12 to 2017:02.

3.0: Discussions of Empirical Results

3.1: Term Structure of Interest Rates

Stationarity results from augmented Dickey-Fuller (ADF) test, and Elliott-Rothenberg-Scott (ERS) Dickey-Fuller (DF) Generalized Least Squares (GLS) test reported in Table 1, show that in both cases of level form without intercept and trend, and with intercept, all variables except inflation spread (π sp) are stationary in their first difference form. Only inflation spread is stationary at the level form. The spread (rsp) between r1y and r91d is stationary at its level form for the case without intercept and trend. All components or partial sum processes of (positive or negative) changes in prices (p^+ or p^-), real Treasury Bills rates ($rr91d^+$ or $rr91d^-$) or real monetary policy rates ($rmpr^+$ or $rmpr^-$) are stationary in level form for both cases of without

Table 1: Unit Roots Tests

Variables	Level-form		First Difference-form	
	No intercept and trend	With intercept	No intercept and trend	With trend
	ADF, k = 1	ERS DF-GLS, k = 1	ADF, k=1	ERS DF-GLS, k = 1
r91d	-0.440 [2.57]	-1.994 [2.57]	-10.637 [2.57]	-10.595 [2.57]
r1y	0.309 [2.58]	-1.311 [2.58]	-15.553 [2.58]	-3.275 [2.58]
f1	-0.618 [2.58]	-1.875 [2.58]	-19.688 [2.58]	-19.556 [2.58]
mpr	-0.254 [2.57]	-0.938 [2.57]	-9.226 [2.57]	-9.226 [2.57]
π yy	-0.882 [2.57]	-1.299 [2.57]	-13.648 [2.57]	-6.421 [2.57]
π nf	-0.600 [2.57]	-1.668 [2.57]	-17.199 [2.57]	-7.582 [2.57]
rsp	-2.671 [2.57]	-0.839 [2.58]		-3.084 [2.58]
π sp	-6.913 [2.57]	-6.288 [2.57]		
p	1.698 [2.57]	0.986 [2.57]	-16.963 [2.57]	-9.409 [2.57]
p^-	-17.728 [2.57]	-17.749 [2.57]		
p^+	-4.594[2.57]	-2.233 [2.57]		-6.44 [2.57]
rr91d	-0.251 [2.57]	0.373 [2.57]	-15.250 [2.57]	-14.106 [2.57]
$rr91d^-$	-6.626 (2.57}	-7.734 [2.57]		
$rr91d^+$	-16.114 [2.57]	-16.267 [2.57]		
rmpr	-0.118 [2.57]	0.636 [2.57]	-17.057 [2.57]	-17.113 [2.57]
$rmpr^-$	-6.866 [2.57]	-7.386 [2.57]		
$rmpr^+$	-10.501 [2.57]	-10.583[2.57]		

Note: All variables are expressed in logarithmic form. 91-day treasury bill rate is r91d, rr91d is real r91d, 1-year treasury bill rate is r1y, 91-day or a quarter forecast of r91d based on the expectation hypothesis is f1, Bank of Ghana's monetary policy rate is mpr, rmpr is real mpr, year on year inflation rate is π yy, non-food inflation rate is π nf, the spread between r1y and r91d is rsp, the spread between π yy and π yy (-3) is π spy, p is overall consumer price index (CPI), and augmented lag-length is k. Absolute values of t-ratios are reported in square brackets. Augmented Dickey-Fuller is ADF and ERS is Elliott-Rothenberg-Scott Generalized Least Squares. Time is supressed in defining the variables, although all variables are measured at current period. Data employed in the study span 1990:01 to 2017:02.

Table 2: Linear and Threshold Regressions of the Term Structure of Interest Rates

Linear Regressions with r1y dependent variable			Threshold Regressions with r1y dependent variable		
Variables	Coefficients	Prob. Values	Variables	Coefficients	Prob. Values
r91d	0.660	0.00	r91d(-1) < 3.125, N = 66		
f1	0.088	0.10	r91d	0.416	0.00
mpr	0.136	0.00	f1	0.411	0.00
rsp(-1)	0.374	0.00	mpr	0.101	0.01
c	0.329	0.00	rsp(-1)	0.470	0.00
			3.125 ≤ r91d(-1) < 3.181, N = 21		
			r91d	-0.626	0.00
			f1	1.924	0.00
			mpr	-0.423	0.00

			rsp(-1)	-0.743	0.00
			$3.181 \leq$ r91d(-1), N = 35		
			r91d	0.747	0.00
			f1	0.014	0.72
			mpr	0.183	0.01
			rsp(-1)	0.702	0.00
Non-threshold Variable			c	0.183	0.02
$\overline{R}^2$	0.92		0.97		
DW	2.167		1.893		
F-Stat	331.43	0.00	364.75		0.00
BG $\chi^2_{SC}(1)$	2.967	0.06	0.589		0.47
BPG $\chi^2_H(4/12)^a$	8.701	0.06	14.701		0.26
AIC	-3.294		-3.294		
SBC	-2.995		-2.995		
Stability	Very Unstable			Very Stable	

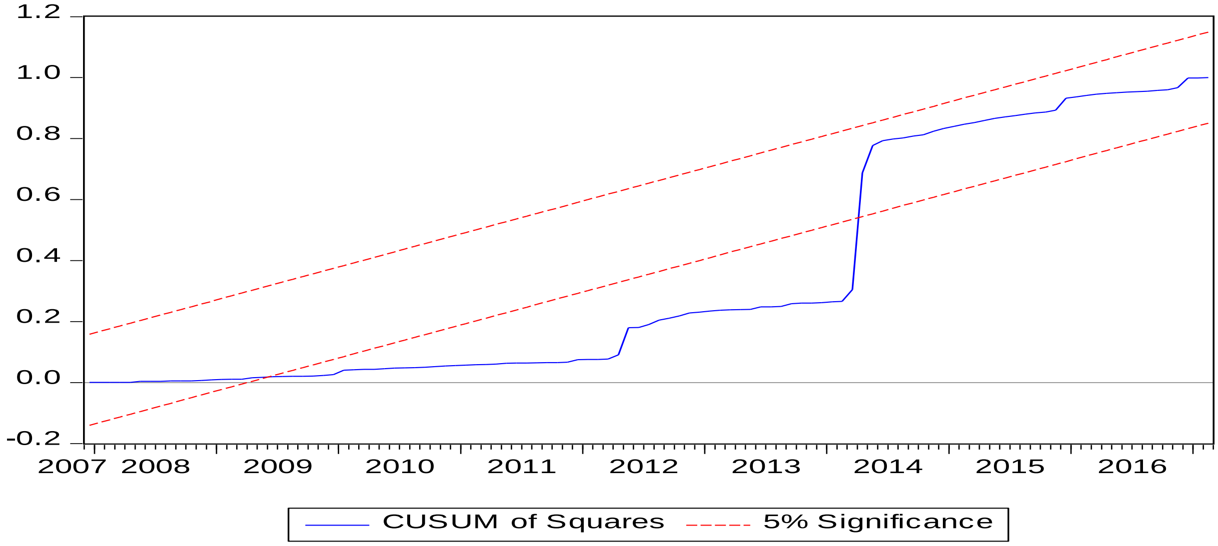
Notes: N is number of included observations after adjustments, c is intercept term or risk premium, $\overline{R}^2$ is adjusted coefficient of determination, DW is Durbin-Watson statistic, F-stat is F-statistic, BG $\chi^2_{SC}(1)$ is Breusch-Godfrey's serial correlation LM test, BPG $\chi^2_H(4/12)^a$ Breusch-Pagan-Godfrey's heteroscedasticity test, a denotes that figures in parenthesis are degrees of freedom for linear and threshold regressions, respectively, and rsp(-1) is a unit lag of rsp. Functional form stability is measured by cumulative sum (CUSUM) and CUSUM of squares (CUSUMSQ). See also Table 1 and Figures 1 and 2.

Table 3: EG TSA, TAR and M-TAR Cointegration Estimates of the Term Structure of Interest Rates

Parameter	EG-TSA[a]	TAR[b]	M-TAR
ρ_1	-0.948*(0.00)	-0.749(0.00)	-0.568(0.00)
ρ_2	NA	-1.205(0.00)	-1.899(0.00)
ρ_3	NA	-0.715(0.00)	-1.000(0.00)
$\overline{R}^2$	0.47	0.49	0.77
DW	1.989	2..038	2.163
Breusch-Godfrey Serial Correlation LM Tests			
$\chi^2(1)$, $\chi^2(1)^a$, $\chi^2(1)^b$	0.000(0.98)	1.432(0.23)	0.832(0.36)
Breusch-Pagan-Godfrey Heteroscedasticity LM Tests			
$\chi^2(1)$, $\chi^2(3)^a$, $\chi^2(3)$	1.010 (0.31)	1.827 (0.60)	5.541 (0.14)
Wald-Test		$\rho_1 = \rho_2 = \rho_3 = 0$	
Φ: $F(3,118)^a$, $\Phi(M)$: $F(3,117)^b$		39.849 (0.00)	139.524 (0.00)
$\chi^2(3)$		119.548 (0.00)	418.572 (0.00)
Wald-Test		$\rho_1 = \rho_2 = \rho_3 = \rho$	
$F(2, 118)^a$, $F(2,117)^b$		3.380 (0.03)	38.569 (0.00)
$\chi^2(2)$		6.761 (0.03)	77.138 (0.00)
AIC	-3.488	-3.511	-2.542
SBC	-3.465	-3.442	-2.473

Notes: Threshold auto-regression is TAR and momentum-TAR is M-TAR; superscripts a, b of F-tests denote F-tests of TAR and M-TAR estimates, respectively. P-values are reported in parentheses. Φ and $\Phi(M)$ are TAR and M-TAR statistics, respectively, for H_0: $\rho_1 = \rho_2 = \rho_3 = 0$. EG TSA denotes Engle and Granger two step approach (EG-TSA), and NA denotes non applicable.

Figure 1: Linear Regression



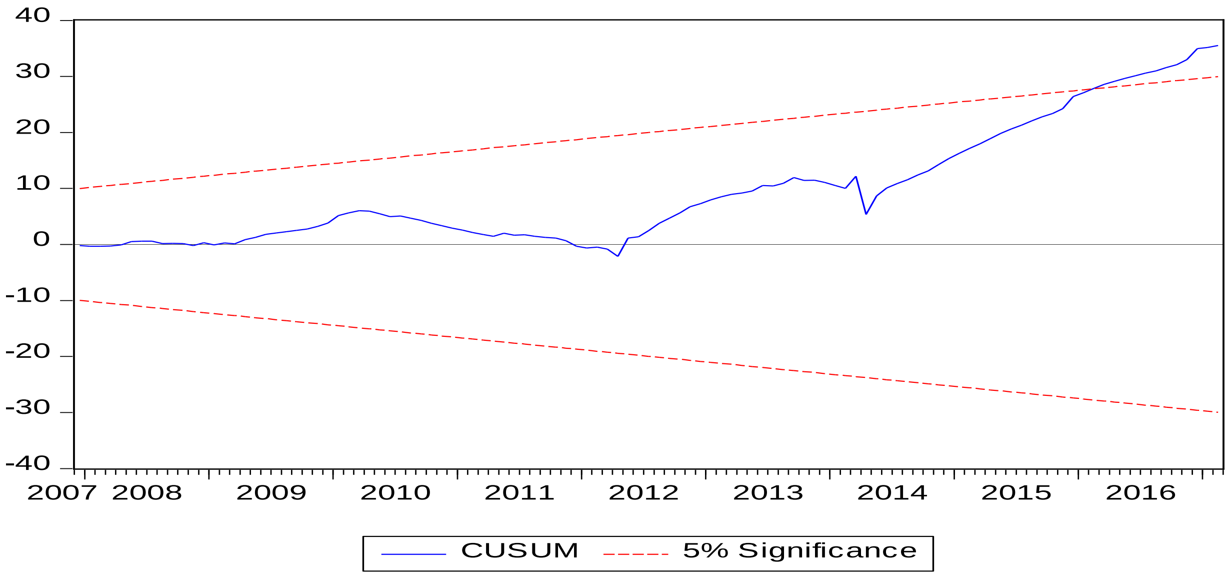
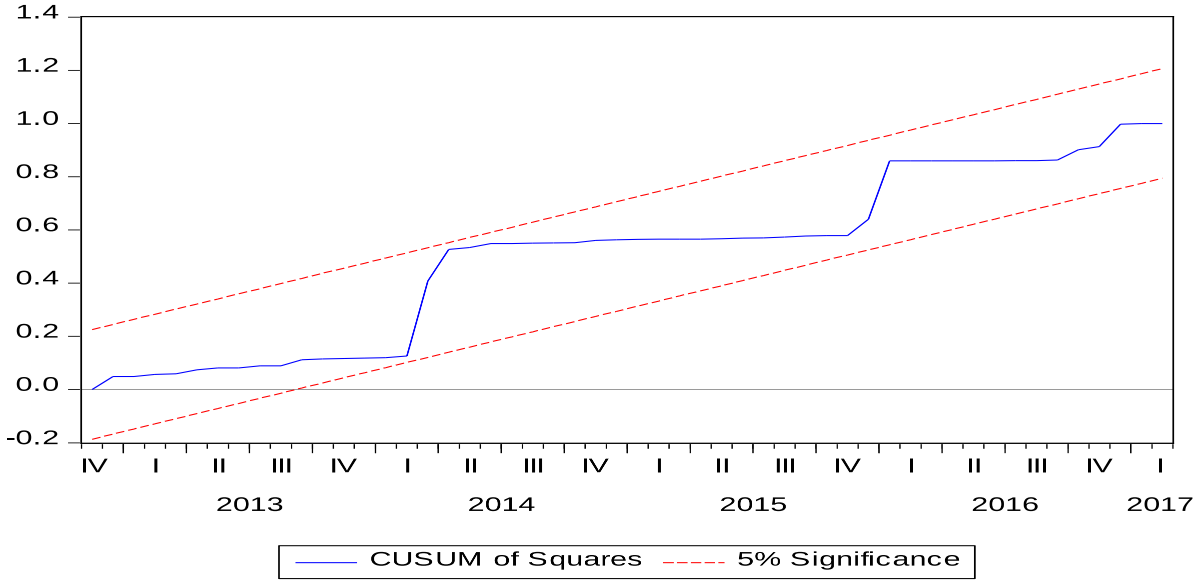


Figure 2: Threshold Regression



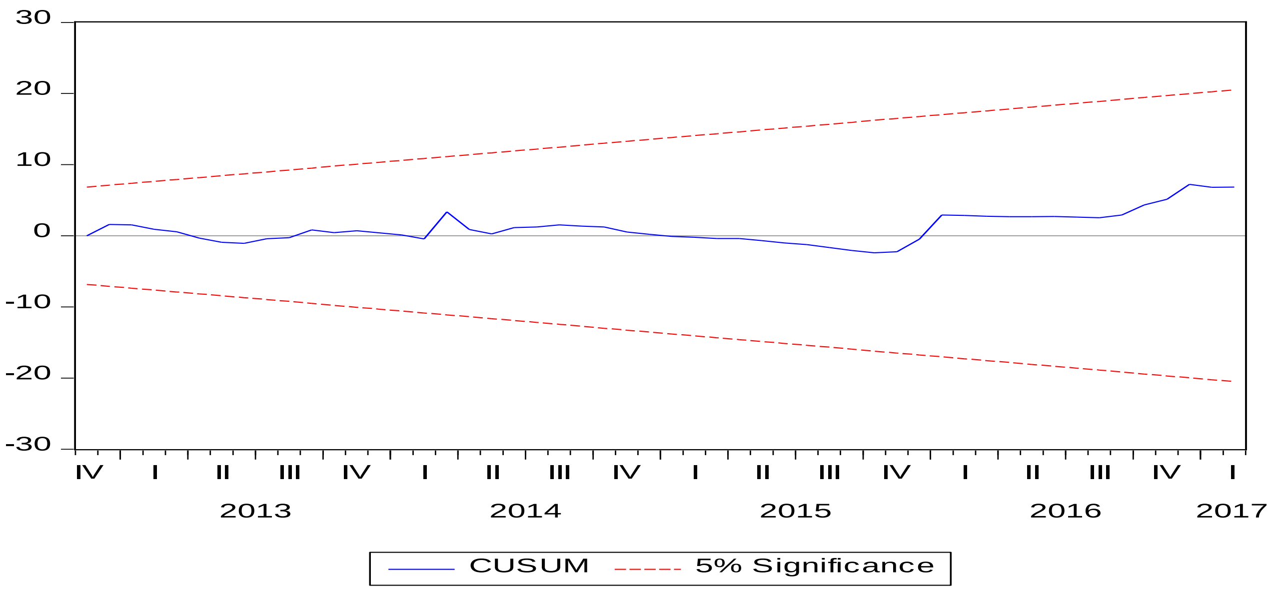


Table 4: Multivariate Cointegration Tests from Johansen's MLE (Non-trended Case)

Model 1a: p, rmpr, rr91d					
	H_0: r = 0	H_0: r ≤ 1	H_0: r ≤ 2	H_0: r ≤ 3	H_0: r ≤ 4
Trace	23.928 (0.10)	7.740 (0.26)	0.022 (0.90)		
λ-Max	16.188 (0.19)	7.718 (0.19)	0.022(0.90)		
Model 1b: p, $rmpr^-$, $rmpr^+$, $rr91d^-$, $rr91d^+$					
	H_0: r = 0	H_0: r ≤ 1	H_0: r ≤ 2	H_0: r ≤ 3	H_0: r ≤ 4
Trace	414.433 (0.00)	264.454(0.00)	139.485 (0.00)	57.988 (0.00)	1.964 (0.19)
λ-Max	149.978 (0.00)	124.969 (0.00)	81.498 (0.00)	56.023 (0.00)	1.964 (0.19)
Model 2a: p, rmpr					
	H_0: r = 0	H_0: r ≤ 1	H_0: r ≤ 2	H_0: r ≤ 3	H_0: r ≤ 4
Trace	9.580 (0.14)	0.052 (0.85)			
λ-Max	9.528 (0.10)	0.053 (0.85)			
Model 2b: p, $rmpr^-$, $rmpr^+$					
	H_0: r = 0	H_0: r ≤ 1	H_0: r ≤ 2	H_0: r ≤ 3	H_0: r ≤ 4
Trace	207.057 (0.00)	78.315 (0.00)	2.062 (0.18)		
λ-Max	128.742 (0.00)	76.252 (0.00)	2.063 (0.18)		
Model 3a: p, rr91d					
	H_0: r = 0	H_0: r ≤ 1	H_0: r ≤ 2	H_0: r ≤ 3	H_0: r ≤ 4
0.91	8.965 (0.17)	0.026 (0.89)			
λ-Max	8.939 (0.12)	0.026 (0.89)			
Model 3b: p, $rr91d^-$, $rr91d^+$					
	H_0: r = 0	H_0: r ≤ 1	H_0: r ≤ 2	H_0: r ≤ 3	H_0: r ≤ 4
Trace	154.602 (0.00)	70.513 (0.00)	2.210 (0.16)		
λ-Max	84.088 (0.00)	68.303 (0.00)	2.20 (0.16)		

Notes: Numbers in parentheses are probability-values at the 0.05 significance levels computed by MacKinnon-Haug-Michelis (1999). The trace and λ-max tests are eigenvalues computed from the strong form of cointegration proposed by Johansen covering the period 1990:10-2016:09. MLE denotes maximum likelihood estimates. See Table 1.

Table 5: Estimates of Crouching Error-Correction Models, and Non-Linear ADL Estimates

5.1: Crouching Error-Correction Models Estimates

$$\Delta\pi yy = 0.300(0.03)\Delta mpr^-(-1) + 0.579(0.00)\,\Delta mpr^- + 0.295(0.03)\,\Delta mpr^+(-1) + 0.566(0.00)\,\Delta mpr^+$$
$$- 0.063(0.53)\,\Delta r91d^- + 0.222(0.02)\Delta r91d^-(-1) - 0.062(0.53)\,\Delta r91d^+$$
$$+ 0.218(0.02)\Delta r91d^+(-1) - 0.046(0.00)\xi(-1) - 0.004(0.46) \quad (6a)$$

$\overline{R}^2$ = 0.13, DW = 1.598, AIC = -4.598, SBC = -4.905, BG $\chi_{SC}^2(1)$LM = 13.973(0.00),

BPG $\chi_H^2(8)$LM = 13.244(0.15), $WT_{SR}\,\chi^2(2)$ = 4.574(0.10), AIC = -2.013, SBC = -1.894,

Method = FMOLS

5.2: Nonlinear ADL (NADL) Estimates

$$\Delta p = -0.118(0.00)rmpr^{-} + 0.127(0.00)rmpr^{-}(-2) - 0.518(0.00)rmpr^{+} + 0.229(0.00)rmpr^{+}(-1)$$
$$+ 0.083(0.00)rr91d^{-} - 0.380(0.00)rr91d^{+} + 0.271(0.00)rr91d^{+}(-1) - 0.002(0.05)p(-1)$$
$$+ 0.527(0.00)\Delta p(-1) + 0.021(0.00) \qquad (6b)$$

$\overline{R}^2 = 0.91$, DW = 2.073, AIC = -4.608, SBC = -4.488, BG $\chi_{SC}^2(1)$LM = 2.096(0.15),

BPG $\chi_H^2(9)$LM = 110.072(0.00), $WT_{SR}\chi^2(2)$ = 57.616(0.00), $WT_{LR}\ \chi^2(2)$ = 3.894(0.14),

Method = FMOLS

5.3: Long-run and Short-term Asymmetric Monetary Policy Principle (MPP) Reaction Estimates

$$rr91d^{+} = 0.563(0.00)p^{+} - 1.041(0.00)p^{-} \qquad (7a)$$

$\overline{R}^2 = 0.81$, DW = 1.044, AIC = -3.681, SBC = -3.657, BG $\chi_{SC}^2(1)$LM = 66.248(0.00),

BPG $\chi_H^2(9)$LM = 0.589(0.74), $WT_{SR}\ \chi^2(1)$ = 105.07(0.00), Method = FMOLS

$$\Delta rr91d^{+} = 0.006(0.74)\Delta p^{+} - 1.030(0.00)\Delta p^{-} - 0.387(0.00)\xi_{t-1} \qquad (7b)$$

$\overline{R}^2 = 0.95$, DW = 2.046, AIC = -3.974, SBC = -3.938, BG $\chi_{SC}^2(1)$LM = 0.000(1.00),

BPG $\chi_H^2(3)$LM = 83.746(0.00), $WT_{SR}\ \chi^2(1)$ = 1866.577(0.00), Method = FMOLS

$$rmpr^{+} = 0.260(0.00)p^{+} - 1.000(0.00)p^{-} \qquad (8a)$$

$\overline{R}^2 = 0.89$, DW = 1.887, AIC = -4.329, SBC = -4.305, BG $\chi_{SC}^2(1)$LM = 0.000(1.00),

BPG $\chi_H^2(2)$LM = 1.417(0.49), $WT_{SR}\ \chi^2(1)$ = 273.348(0.00), Method = OLS

$$\Delta rmpr^{+} = -0.002(0.91)\Delta p^{+} - 0.999(0.00)\Delta p^{-} - 0.927(0.00)\xi_{t-1} \qquad (8b)$$

$\overline{R}^2 = 0.97$, DW = 2.013, AIC = -4.351, SBC = -4.315, BG $\chi_{SC}^2(1)$LM = 0.000(1.00),

BPG $\chi_H^2(3)$LM = 1.652(0.65), $WT_{SR}\ \chi^2(1)$ = 1943.789(0.00), Method = FMOLS

where $WT_{SR}\ \chi^2(1)$ is the short-term Wald Test of the $H_0 : \beta^{+} = \beta^{-}$ which is the short-term test of symmetry, and $WT_{LR}\ \chi^2(2)$ is the long-run Wald Test of the $H_0 : \beta^{+} = \beta^{-} = \lambda$ which is the long-run and short-term symmetry. LM denotes Lagrange multiplier. Probability-values are reported in parentheses, although for χ^2 tests we also have degrees of freedom reported in parentheses.

5.4: Estimates of Effects of Nonlinear MPP on Rising Prices or Inflation

$$p^+ = 0.024(0.27)rmpr^+ - 0.399(0.00)rmpr^- \quad (9a)$$

$DW = 0.87$, $AIC = -5.282$, $SBC = -5.259$, $WT_{SR}\ \chi^2(1) = 7.585(0.00)$, Method = FMOLS

$$\Delta p^+ = -0.042(0.01)\Delta rmpr^+ - 0.814(0.00)\Delta rmpr^- - 0.529(0.00)\xi_{t-1} \quad (9b)$$

$\overline{R}^2 = 0.84$, $DW = 3.005$, $AIC = -3.574$, $SBC = -3.538$, Method = OLS

$$p^+ = -0.045(0.04)r91d^+ - 0.275(0.00)r91d^- \quad (10a)$$

$DW = 0.620$, $AIC = -5.115$, $SBC = -5.092$, $WT_{SR}\ \chi^2(1) = 51.290(0.00)$, Method = FMOLS

$$\Delta p^+ = -0.009(0.54)\Delta r91d^+ - 0.821(0.00)\Delta r91d^- - 0.708(0.00)\xi_{t-1} + 0.001 \quad (10b)$$

$\overline{R}^2 = 0.83$, $DW = 2.757$, $AIC = -3.530$, $SBC = -3.494$, Method = FMOLS

$$p^+ = 0.039(0.08)rxr^+ - 0.861(0.00)rxr^- \quad (11a)$$

$DW = 0.820$, $AIC = -5.317$, $SBC = -5.293$, $WT_{SR}\chi^2(1) = 100.522(0.00)$ Method = FMOLS intercept and trends, and with intercept, with the exception of p^+ which is stationary for the case with intercept in first difference form. The absolute values reported in the square brackets in Table 1 are the critical values at the 0.01 significant levels.

In Table 2, results of both linear and threshold regressions of the term structure of interest rates using r1y as the regressand are reported. The least squares result show a highly significant coefficients at 0.01 significant levels for the regressors, except f1 which is significant at 0.10 levels. Although the coefficient of determination ($\overline{R}^2$) shows that the regressors explain more than 90 percent of changes in the r1y, with Durbin-Watson (DW) of 2.16 indicating the absence of serial correlation, the Breusch-Godfrey (BG) serial correlation test indicate a serial correlation problem at 0.05 significant levels. Furthermore, the Breausch-Pagan-Godfrey (BPG) heteroscedasticity test also reveals a heretoscedasticity problem at 0.01 significant levels. Functional forms of the model are also unstable, judging by both the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) of residuals as shown in Figure 1.

Threshold regression results reported in the same Table 2, show an improved results on the linear regression results. There is one threshold variable which is r91d, with two threshold values (3.125, and 3.181), covering three interest rate regimes, which are r91d(-1) $<$ 3.125, 3.125 $\leq$ r91d(-1) $<$ 3.181 and 3.181 $<$ r91d(-1); and they represent low, moderate and high interest rate regimes, respectively. The $\overline{R}^2$ is 97 percent, and both BG serial correlation test and BPG heteroscedasticity test are insignificant, indicating a complete absence of serial correlation and heteroscedasticity problems. Furthermore, both CUSUM and CUSUMSQ are within their 0.05 significant bands, which indicate very stable functional forms.

In all three regimes, all the explanatory variables are significant at 0.01 levels, with the exception of f1, the forecasted variable of r91d based on the expectation hypothesis, which is insignificant during the high interest rate regime. A unit increase in r91d causes r1y to increase by 41.6 percent during low interest regime, and 74.7 percent during a high interest rate regime, and reduces the one year TBR by 62.6 percent during moderate interest rate regime. In fact, a unit increase in f1, mpr and rsp(-1) causes 0.41, 0.10 and 0.47, respective increase in r1y during low interest rate regime, and 0.01, 0.18 and 0.70, respective increase in r1y during high interest rate regime. However, apart from a unit increase in f1 increasing r1y by 192 percent during moderate interest rate regime, the same increase in mpr and rsp(-1) results in r1y decreasing by 0.42 and 0.74, respectively, during the same regime. In all three interest rate regimes, risk premium drives the long-run one-year TBRs.

Cointegration estimates of EG TSA, TAR and M-TAR are reported in Table 3. There are no serial correlation or heteroscedasticity problems in all three estimates, as both BG serial correlation and BPG heteroscedasticity tests are insignificant. The coefficient of ρ_1 in the EG TSA is -0.948 and significant at

0.01 levels. This means that deviations from long-run equilibrium adjust symmetrically to it at the speed of nearly 95 percent.

The estimated coefficients of the parameters of the TAR model in Table 3, (ρ_1, ρ_2, ρ_3) ϵ (-2, 0), and their Wald test of zero restriction is rejected at 0.01 significant levels, which confirms threshold cointegration. Additionally, the Wald test of equal restriction is rejected at 0.01 significant levels, which shows that deviations from long-run equilibrium adjusts asymmetrically to it. Similar results are obtained for the M-TAR estimates, although the absence of serial correlation occurs at 0.05 significant levels, and the coefficients of ρ_2 and ρ_3 are greater than those of the TAR model. The Wald test of zero restriction is rejected at 0.01 significant levels which indicates momentum threshold cointegration. The Wald test of equal restriction is rejected at 0.01 significant levels, which shows asymmetric adjustment towards long-run equilibrium after displacement from it. Thus, adjustment of threshold regression of the term structure of interest rates from the long-run equilibrium is asymmetric, although the results are appears to be independent of prices and inflation.

3.2: Price and Inflation Content of the Term Structure of Interest Rates

To find price and inflation content of the term structure of interest rates, we narrowed our investigation to examine the cointegration among p, rmpr and rr91d. Considering that most linear cointegration and linear adjustments tend to be too restrictive to the point that they fail to unravel nonlinear cointegration and nonlinear adjustment, we examine the price (p), real monetary policy rate (rmpr), and real 91-day TBR (rr91d) from both perspective of linear cointegration, and nonlinear cointegration. The three variables of interest are sufficient to provide us information on the price/inflation content of the term structure of interest rates, and policy effectiveness of the Taylor ‘or monetary policy’ principle.

Johansen’s multivariate cointegration results reported in Table 4 show no cointegration among the variables (p, rmpr, rr91d) in Model 1a, (p, rmpr) in Model 2a, and (p, rr91d) in Model 3a, judging by both trace and maximum eigen value (λ-max) tests. This suggest that there is no long-run equilibrium relation among or between price and either interest rates. However, when we decompose rmpr and rr91d into components of partial sum process of positive and negative changes, we find long-run equilibrium relationship among the variables in Model 1b, and between the variables in both Models 2b and 3b as judged by their respective trace and λ-max tests which are rejected at 0.01 significant levels. According to Stock and Watson (1988) and Granger and Yoon (2001), cointegration occurs when variables which share a common trend eliminates those trend by their linear combinations. Decomposing real interest rates produces variables that share common trends with prices, as those variables now share a common response to specific positive or negative shocks together.

In Table 5, we further explore the information content between the term structure of interest rates and prices or inflation by estimating an error-correction model associated with such hidden cointegration among them in equation (6a) (see Granger and Yoon, 2001; Shin et al., 2011). We also employed nonlinear ADL model to achieve the same goal in equation (6b) (Pesaran and Shin, 1999; Shin et al. 2011). Crouching or hidden error-correction estimates of equation (6a) reported in Table 5.1 show cointegration among year-on-year inflation (π yy) and the components of monetary policy rates and the Treasury Bills rates, although the speed of adjustment of 4.6 percent, which is significant at 0.01 significant levels, is very slow. There is impact asymmetry as the Wald test (WT_{SR}) of H_0 of impact symmetric adjustment is rejected at 0.10 significant levels.

The NADL estimates reported in equation 6b show that actual inflation is explained by components of rmpr and rr91d. With the exception of lagged prices which is significant at 0.05 levels, all the regressors are significant at 0.01 levels. The Wald test rejects the H_0 of short-term symmetric adjustment at 0.01 significant levels, although Wald test of both long-run and short-term symmetry (WT_{LR}) is not rejected. Thus, there is asymmetric adjustments among inflation and components of rmpr and rr91d in the short-term, although the adjustment between short-term and long-run is symmetrical. Thus, in both equations 6a and b of Table 5, inflation is explained by components of partial sum processes of positive and negative changes in real interest rates (rmpr and rr91d).

To examine the effect of components of prices on components of real interest rates, we estimated the monetary policy principle (MPP) reaction in equations 7a – 8b of Table 5.3. Results show that inflation (p^+) drives both $rr91d^+$ and $rmpr^+$ whereas deflation (p^-) reduces both variables. The elasticities of the effect of rising prices on both real interest rates components are much smaller than what is prescribed by the Taylor principle (or MPP), as a solution to curb destabilizing inflation. Wald tests reject symmetric adjustment in the short-term in both equations. There is cointegration among both components of real interest rates and price, although the speed of adjustment of 38.7 percent in the estimated equation (7b) is far smaller than that of 92.7 percent in the estimated equation (8b).

Finally, effects of nonlinear components of real interest rates on rising prices or inflation reported in equations 9a-10b of Table 5.4, also show an increase in the real interest rate component ($rmpr^+$) driving rising prices although statistically insignificant, while the same increase in the real interest rate component ($rr91d^+$) reduces prices. Both equations are cointegrated, as their respective error-correction terms are significant at 0.01 levels, although the speed of adjustment of rising prices explained by components of rmpr is 52.9 percent, whereas that of components of rr91d is 70.8 percent, as shown in equations 9b and 10b. Thus, the rmpr components are much slower than the components of rr91d judging by the magnitudes of their respective error-correction terms.

Effective policy instrument for reducing p^+ is by increasing the $rmpr^-$, but its magnitude of 39.9 percent, which is greater than the magnitude of 27.5 percent of the $rr91d^-$, is by far weaker, as compared with the magnitude of 86.1 percent which results from increasing rxr^-. This, depicts that appreciation of the national currency, is the most effective instrument for reducing rising price/inflation in the country.

4. Conclusion

Stationarity tests show all real and nominal variables are stationary in their first difference forms. However, the spread between one year and 91-day TBRs, actual inflation spread and the components of positive and negative changes in real 91-day TBR, real mpr and prices are integrated at degree zero.

Linear regression result has serial correlation, heteroscedasticty, and functional form instability problems. Threshold regression result resolves these problems, and selects lagged 91-day TBR as the threshold variable, with three threshold values representing low, moderate and high interest rate regimes. The one-year TBR is positively driven by 91-day TBR, monetary policy rate, expectation forecast of the 91-day TBR, and the spread between one-year and 91-day TBR, during low and high interest rates regimes, although the effects are high for the 91-day TBR, and the lagged spread between one-year and 91-day TBRs. The effect of expectation forecast of the 91-day TBR is much stronger, although it is insignificant statistically, and both 91-day TBR and monetary policy rate are negative during the moderate interest rate regime. In all interest rate regimes, the one-year TBR is driven by a risk premium, and the yield curve is nonlinear in the country. The EG-TSA cointegration estimate shows that the error-correction term of the term structure of interest rates is about 95 percent, which is very fast. This means the adjustment is linear and symmetrical. However, threshold cointegration of both TAR and M-TAR show that adjustment to the long-run equilibrium is asymmetrical.

It appears that there is no price effect in the country's term structure of interest rates. Johansen cointegration test of price, 91-day TBR and monetary policy rate does not reveal any long-run equilibrium relation among them. However, decomposing the variables into components of positive and negative changes show cointegration among price and components of both interest rates, and between price and each component of interest rate. Estimates of crouching error-correction model show a short-term asymmetrical adjustment towards long-run equilibrium, whereas estimates of the nonlinear ADL model show both short-term and long-run asymmetrical adjustments toward the long-run equilibrium. Further, estimates of effects of nonlinear real interest rates on rising prices or inflation also confirm nonlinear cointegration. In the long-run, between the two real interest rates, reducing the real monetary policy rate has stronger effect in reducing inflation than reducing the real 91-day TBR. However, both effects are by far weaker in comparison to exchange rate appreciation, in reducing rising prices or inflation in the country.

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