Asymmetries in Yield Curves: Some Empirical Evidence from Ghana

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Abstract

We analyze the co-movements of the monetary policy rates (MPR) and the treasury bill rates (TBR) in Ghana over the period January 2007 to July 2016 using three nonlinear econometric techniques. We find the MPR and the TBR to be cointegrated with threshold adjustments. Positive deviations from the long-term equilibrium due to increases in the MPR or decreases in the TBR are corrected at 0.3% monthly. Negative deviations from the long-term equilibrium due to decreases in the MPR or increases in TBR are corrected at 8.8% monthly. Our results show bidirectional causal flow between MPR and TBR. We also find positive deviations in the TBR to be corrected at 0.34% monthly, while negative deviations are corrected at 8.6% monthly, in the short term. Thus, the TBR responds faster to negative than positive deviations. These findings are broadly consistent with the inflation-targeting framework of the Bank of Ghana.

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1 - Introduction

In the finance and economics literature, one of the most widely studied concepts is the yield curve. The yield curve is a graph that demonstrates the theoretical and empirical relationships between interest rates and their maturities (see Taylor, 1992; Malkiel, 2015; Iyke, 2017). The yield curve serves useful purposes in decision-making. First, the yield curve serves as a crucial leading indicator for business cycle forecasting. Inverted yield curves are known to signal potential recessions (see Estrella and Hardouvelis, 1991; Estrella and Mishkin, 1997). Some studies even argue that yield curves offer superior forecast of the economy than large-scale computer-based models (see Harvey, 1988; 1991; 1993; Bernanke; 1990; Chen, 1991). Second, yield curves can also provide superior indicators of monetary policy than monetary growth rates (see McCallum, 1983; Bernanke and Blinder, 1989; Piazzesi, 2010). Third, most investors utilize yield curves to forecast interest rates, bond prices, and to manage investment portfolios. Aling and Hassan (2012), for example, observe that short-term interest rates, in particular, are essential in the valuation of interest rate derivatives.

Despite its immense importance, the yield curve remains one of the least studied concepts on developing countries (see Iyke, 2017). If we narrow our scope to the Ghanaian context, yield curves have barely received research attention. The only existing study on yield curves in Ghana is that of Dzigbede and Ofori (2004), which forecasts real interest rates using yield curves in linear settings. Given that Ghana is one of the developing countries that has persistent inflation, depreciation, and excessive economic underperformance problems in recent memory, the lack of theoretical and empirical insight into crucial concepts such as the yield curves of the country raises serious policy questions. For instance, how do policymakers of this country predict economic downturns? How do investors and players in the financial industry evaluate assets? This paper contributes to the literature by investigating the nature of yield curves in Ghana within an asymmetric setting. In particular, we investigate whether short- and long-term interest rates are cointegrated. Then, we analyze the direction of causal flow between the interest rates. In some sense, our paper explores the expectation theory of yield curves, which posits a strong relationship between short- and long-term interest rates. We restrict our sample to the period January 2007 to July 2016. This period covers the inflation-targeting regime, when the Bank of Ghana (BOG) officially introduced forward-looking monetary policies. During this period, the BOG has reacted to prevailing market conditions – which includes the behaviour of treasury bill rates (TBR) – by adjusting the monetary policy rate (MPR). Therefore, short- and long-term interest rates are more likely to exhibit strong co-movement under this regime than under any other regime. Moreover, the behaviour of the yield curves during the inflation-targeting regime may influence future decisions of investors and policymakers than the previous regimes. These factors make it all the more important for us to consider this study period.

This paper differs from the existing studies in two ways. First, we explore both nonlinear cointegration and causality between interest rates with different maturities. Second, we do so using a data set for a developing economy. The econometric techniques that we utilize are efficient and are found to fit data on macroeconomic variables such as interest rates well. These econometric techniques are: Kapetanios *et al.* (2003) nonlinear unit root test; Enders and Siklos (2001) threshold cointegration test; and asymmetric error correction model with threshold adjustments documented in Granger and Lee (1989), Balke and Fomby (1997), and Enders and Granger (1998).

The remaining sections of this paper are organized as follows. In the next section, we review the literature. Then, in section 3, we discuss our methodology and the data. In section 4, we report and discuss our results. In the final section, we present the concluding remarks.

2 - The literature

2.1 The theoretical literature

The theoretical literature on yield curves – the expectation theory, in particular – implicates a steady-state relationship between interest rates (see, for example, Vasicek, 1977; Richard, 1978; Cox *et al.*, 1985; Hall *et al.*, 1992; Bekaert and Hodrick, 2001; Malkiel, 2015). On the basis of the expectation theory of yield curves, interest rates are supposed to co-move over time (see Sarno *et al.*, 2007).

The expectation theory posits that the yield on long-term financial instruments are an average of the yield of short-term financial instruments during the holding period (or the life) of the long-term financial instruments. The latent assumption is that investors are risk-neutral; hence investors would not pay a premium to lock in a long-term interest rate (see Meiselman, 1962; McFayden *et al.*, 1991; Arize *et al.*, 2002; Sarno *et al.*, 2007). Given these assumptions and supposing that long-term financial instruments are infinitely held, the expectation theory of yield curves relates interest rates on long-term financial instruments to the expected interest rates on short-term financial instruments as

$$R_t^n = 1 - \omega \sum_{j=0}^{\infty} \omega^j E_t\left(r_{t+j}\right) \qquad (1)$$

where R_t is the long-term interest rate at time t, r_{t+j} is the short-term interest rate at time $t+j$, E_t is the expected value notation, $\omega = \frac{1}{1+\bar{R}}$, $\bar{R}$ is the mean long-term interest rate, $E_t\left(r_{t+j}\right)$ is the present value of the future short-term interest rate, and $j = 0, 1, \dots, \infty$.

According to the expectation theory, the long-term and the short-term interest rates share steady-state relationships (see Shiller, 1979; MacDonald and Speight, 1988; McFayden *et al.*, 1991). This is in contrast with the segmented market theory which contends that the long-term and the short-term interest rate are not related. That is, the demand and supply in the markets for short-term and long-term instruments is determined independently (see Van Home, 1978; McEnally, 1983). Following the expectation theory, *Eq.* (1) imposes some form of cointegrating relationship between R and r. Our paper tests this hypothesized cointegrating relationship.

2.2 The empirical literature

The cointegrating relationship between interest rates has remained under-examined in the empirical literature, judging from the important policy implications of such a relationship. Yet, the available ones have conflicting conclusions on the relationship between interest rates.

In their single-country studies, Stock and Watson (1988), MacDonald and Speight (1988), McFadyen *et al.* (1991), Hall *et al.* (1992), Wallace and Warner (1993), Mandeno and Giles (1995), Enders and Siklos (2001), Della Corte *et al.* (2008), and Dube and Zhou (2013) find cointegrating relationship between interest rates to exist. Similarly, Arize *et al.* (2002) find the evidence in support of the cointegrating relationship between interest rates in their multi-country study. These empirical findings lend strong support for the expectation theory of yield curves, which suggests that interest rates co-move closely.

Other studies find no evidence of cointegrating relationship between interest rates. Such studies are Taylor (1992), Mustafa and Rahman (1995), Bekaert and Hodrick (2001), Clarida *et al.* (2006), and Sarno *et al.* (2007). The evidence of no cointegrating relationship between interest rates is in line with the segmented-market theory, which argues that interest rates are unrelated (see McFayden *et al.*, 1991; Arize *et al.*, 2002).

In spite of the fact that the existing empirical studies are remarkably conflicting, they appear to concentrate on just developed countries.[1] As noted earlier in this paper, yield curves offer important policy understanding of the state of an economy. For example, should the expectation theory be supported, it would imply that central banks can exert some influence on the long-term interest rates using instruments from the short-term market (see Arize *et al.*, 2002). That is, the central banks can execute monetary policy near the short end of the maturity spectrum (see McFayden *et al.*, 1991). Our paper takes the scant nature of the literature on developing countries into consideration by re-examining the relationship between interest rates for a developing country, Ghana.

3 - Methodology

3.1 The model

Our empirical model stems from the implications of the expectation theory of yield curves. A simple representation of *Eq.* (1) can be formulated, following MacDonald and Speight (1988), McFayden *et al.* (1991), Mustafa and Rahman (1995), Arize *et al.* (2002), and Sarno *et al.* (2007) as

$$R_t - \Omega_0 - \Omega_1 r_t = \mu_t \quad (2)$$

where R_t denotes the long-term interest rate; r_t denotes the short-term interest rate; Ω_0 and Ω_1 are vectors of coefficients; and μ_t denotes a random disturbance term. The rest of the paper attempts to establish that μ_t is integrated of order zero, I(0), and to provide the appropriate empirical representation of *Eq.* (2).

3.1 Asymmetric cointegration test

Interest rates are known to contain unit roots (see Rose, 1988; Stock and Watson, 1988; Taylor *et al.*, 2001). So, we examine the existence of unit

[1] The only available studies which consider a developing country are those of Arize *et al.* (2002), and Dube and Zhou (2013).

roots in the interest rates using the Dickey-Fuller Generalized Least Squares (DF-GLS) and the Ng-Perron tests. We determine the optimal lags in the augmented Dickey-Fuller regressions of these tests using the Modified Akaike Information Criterion (MAIC). The drawback of these tests is that they assume linearity in the data-generating process of the series under consideration. However, if the characteristic mean-reverting process exhibits nonlinearities or asymmetries, then these unit roots tests would frequently fail to reject the null hypothesis of unit root (see Kapetanios *et al.*, 2003). To overcome this problem, we utilize the Kapetanios-Shin-Snell (KSS) test developed by Kapetanios *et al.* (2003). These tests are well documented in the literature. Thus, we do not discuss them here due to space consideration.

If the interest rates are found to contain unit roots, it is possible that they can co-move in the long run (see Engle and Granger, 1987). So, we test the possibilities of co-movements or cointegration in the interest rates using two linear cointegration techniques: (i) the Johansen technique proposed by Johansen (1988), Johansen and Juselius (1990), and Johansen (1991; 1995); and (ii) the Engle-Granger two-step technique developed by Engle and Granger (1987).[2] As with the classical unit root tests, these linear cointegration tests assume that the underlying variables co-move in a linear fashion. However, most macroeconomic variables including interest rates have been found to co-move nonlinearly or asymmetrically over the business cycle. For example, Granger and Lee (1989) found that sales, production, and inventories in the U.S. exhibit asymmetric adjustment toward a long-run multi-cointegrating relationship. To provide robust verification of potential cointegrating relationship between the interest rates, we use the asymmetric cointegration test develop in Enders and Siklos (2001).

This asymmetric cointegration technique assumes two-regime threshold and is a simple extension of the Engle-Granger two-step technique. Enders and Siklos (2001) propose the following specification of the asymmetric adjustment mechanism

$$\Delta\hat{\mu}_t = \psi_1 I_t \hat{\mu}_{t-1} + \psi_2 (1 - I_t)\hat{\mu}_{t-1} + \sum_{i=1}^{q} \phi_i \Delta\hat{\mu}_{t-i} + \epsilon_t \tag{3}$$

$$I_t = 1 \text{ if } \hat{\mu}_{t-1} \geq \tau, 0 \text{ otherwise} \tag{4a}$$

Or

$$I_t = 1 \text{ if } \Delta\hat{\mu}_{t-1} \geq \tau, 0 \text{ otherwise} \tag{4b}$$

[2] These are well documented tests in the literature. Due to space limitation, we do not discuss them here.

where I_t is the Heaviside indicator, ψ_1, ψ_2 and ϕ_i are the coefficients, q is the number of lags, and τ is the threshold value. To determine q, which accounts for the order of autocorrelated residuals, Enders and Siklos (2001) suggest we use the AIC and the BIC.

The Heaviside indicator, I_t, can be specified in two ways. First, (3) and (4a) referred as the Threshold Autoregression (TAR) model; and second, (3) and (4b) referred as the Momentum Threshold Autoregression (MTAR) model. The TAR model accounts for potential nonlinear "deep" movements in the residual, whereas the MTAR model accounts for potential "steep" variability in the residual (see Enders and Granger, 1998; Enders and Siklos, 2001). The existence of "negative deepness" ($|\psi_1| \leq |\psi_2|$) implies increases are persistent, and decreases move faster to equilibrium. The MTAR model offer valuable insight when the adjustment mechanism exhibits great momentum in one direction, as opposed to the other (see Enders and Granger, 1998).

The threshold value, τ, can be specified in two ways, for the TAR and MTAR models. We can set τ to zero (i.e. $\tau = 0$), leaving the names of the models intact. Or we can determine the threshold value from the data by utilizing the search method proposed by Chan (1993). Should we determine the threshold value with the search method, the resulting models become the consistent TAR and MTAR models.[3] To determine the threshold value using Chan's (1993) search method, we follow specific steps. We first sort the threshold variable, $\hat{\mu}_{t-1}$ for TAR, and $\Delta\hat{\mu}_{t-1}$ for MTAR, in ascending order. Then, we determine the potential threshold values. Enders (2004) recommends that the threshold value should lie between the minimum and the maximum values of the threshold variable. In practice, we must discard the lowest and highest 15% of the threshold values during the search, to allow for sufficient observations on either side of the sample. Finally, the values of the threshold variable that fall within the middle 70% band are used as potential threshold values to estimate the consistent TAR and MTAR models.

This discussion suggests that the asymmetric cointegration test is based on four models: (i) TAR with $\tau = 0$; (ii) consistent TAR with estimated τ; (iii) MTAR with $\tau = 0$; and (iv) consistent MTAR with estimated τ.[4] The

[3] Chan (1993), indeed, demonstrates that the threshold value is superconsistent if it results from the minimum sum of squared errors of the fitted model after searching over the potential threshold values (see also Enders and Siklos, 2001).

[4] See Sun (2011) and Iyke (2017) for similar discussion.

model which best fits the dataset is the one with the minimum AIC and BIC (see Enders and Siklos, 2001). After obtaining the best model, we can test for asymmetric cointegrating relationships in the interest rates using two tests. First, the null hypothesis, $H_0: \psi_1 = \psi_2 = 0$, of no cointegration against the alternative of cointegration with TAR or MTAR adjustment scheme. This is a non-standard *F*-test with test statistic Φ and critical values reported in Enders and Siklos (2001). Second, the null hypothesis, $H_0: \psi_1 = \psi_2$, of linear equilibrium adjustment scheme against a nonlinear adjustment scheme alternative. This test follows a standard *F*-distribution.

3.2 Nonlinear error correction estimation

If we establish asymmetric cointegrating relationships in the interest rates or the yield curves, there is theoretical justification to fit an error correction model in the spirit of the Engle-Granger representation theorem (see Engle and Granger, 1987). In this paper, we use the asymmetric error correction model discussed in Granger and Lee (1989), Balke and Fomby (1997), and Enders and Granger (1998) to fit the interest rates. This model accounts for threshold effects and asymmetric dynamics in the underlying series of the form:

$$\Delta y_t = \eta_{11} + \varpi_{11}^{+} E_{t-1}^{+} + \varpi_{12}^{-} E_{t-1}^{-} + \sum_{j=1}^{J} \varphi_{j1}^{+} \Delta y_{t-j}^{+} + \sum_{j=1}^{J} \varphi_{j2}^{-} \Delta y_{t-j}^{-} + \sum_{j=1}^{J} \Theta_{j1}^{+} \Delta x_{t-j}^{+} + \sum_{j=1}^{J} \Theta_{j2}^{-} \Delta x_{t-j}^{-} + v_{t1} \qquad (5a)$$

$$\Delta x_t = \eta_{21} + \varpi_{21}^{+} E_{t-1}^{+} + \varpi_{22}^{-} E_{t-1}^{-} + \sum_{j=1}^{J} \varphi_{j3}^{+} \Delta y_{t-j}^{+} + \sum_{j=1}^{J} \varphi_{j4}^{-} \Delta y_{t-j}^{-} + \sum_{j=1}^{J} \Theta_{j3}^{+} \Delta x_{t-j}^{+} + \sum_{j=1}^{J} \Theta_{j4}^{-} \Delta x_{t-j}^{-} + v_{t2} \qquad (5b)$$

where Δy_t and Δx_t are the first difference of the interest rates, η, ϖ, φ, and Θ are coefficients to be estimated, J is the number of lags to be included, t is the time subscript, and v denotes the white-noise error term. The choice of J, the number of lags, is determined by the AIC and the BIC. The lagged first difference interest rates, Δy_{t-j} and Δx_{t-j}, are decomposed into positive and negative components. The error correction terms E_{t-1} are also decomposed into positive and negative components such that $E_{t-1}^{+} = I_t \hat{\mu}_{t-1}$ and $E_{t-1}^{-} = (1 - I_t)\hat{\mu}_{t-1}$ following the threshold cointegration specifications in (4), (5a), and (5b). This decomposition ensures that asymmetric shocks (both negative and positive), and threshold effects are incorporated into the error correction model (see Sun, 2011; Iyke, 2017). ϖ_{11} and ϖ_{12} would be positive, and ϖ_{21} and ϖ_{22} negative, if y_t drives the cointegrating relationship. The reverse holds, if x_t drives the cointegrating relationship.

We can investigate the existence of Granger causality by setting: (i) $\varphi_{j1}^{+} = \varphi_{j2}^{-} = 0$, y_t does not cause itself or $\Theta_{j1}^{+} = \Theta_{j2}^{-} = 0$, x_t does not cause y_t; and (ii) $\Theta_{j3}^{+} = \Theta_{j4}^{-} = 0$, x_t does not cause itself or $\varphi_{j3}^{+} = \varphi_{j4}^{-} = 0$, y_t does not cause x_t. Next, we can also test the existence of distributed lag asymmetric effect by setting $\varphi_{11}^{+} = \varphi_{12}^{-}$ to test the hypothesis that at first lag, y_t has symmetric effect on itself; the process is replicated for each lag and for $\Theta_{j1}^{+} = \Theta_{j2}^{-}$ to examine the asymmetric effect of x_t on y_t at the jth lag. In addition, we can test for the cumulative symmetric effect of y_t on itself by setting $\sum_{j=1}^{J} \varphi_{j1}^{+} = \sum_{j=1}^{J} \varphi_{j2}^{-}$; the cumulative symmetric effect of x_t on y_t by setting $\sum_{j=1}^{J} \Theta_{j1}^{+} = \sum_{j=1}^{J} \Theta_{j2}^{-}$; the cumulative symmetric effect of y_t on x_t by setting $\sum_{j=1}^{J} \varphi_{j3}^{+} = \sum_{j=1}^{J} \varphi_{j4}^{-}$; and the cumulative symmetric effect of x_t on itself by setting $\sum_{j=1}^{J} \Theta_{j3}^{+} = \sum_{j=1}^{J} \Theta_{j4}^{-}$. Finally, we can test for asymmetric equilibrium path by setting $\varpi_{11} = \varpi_{12}$ for (5a) and $\varpi_{21} = \varpi_{22}$ for (5b).

3.3 Data

The data on the two interest rates are extracted from the Bank of Ghana's Monetary Time Series Data, available on the bank's website. We supplement missing data points for some of the months using data from the International Financial Statistics (IFS) database compiled by the IMF. We extract the monetary policy rate (MPR), and the yield on one-year government bonds (TBR) for our empirical analysis. Our choice of the Monetary Time Series Data and the IFS Data is informed by the originality of these datasets. The sample period spans January 2007 to July 2016. This period covers the Bank of Ghana's (BOG) inflation-targeting framework. The restricted sample size makes sense for two reasons. First, the techniques we use are able to account for not more than two thresholds or regimes. Second, it is more likely that the behaviour of interest rates in the current regime, the inflation-targeting regime, would be of interest to investors and policymakers than the three previous regimes.[5]

4 – Results

4.1 Summary statistics of monetary policy rate and treasury bill rate

Table 1 displays the key statistics of the Bank of Ghana's monetary policy rate (MPR) and the returns on one-year treasury bills (TBR) in Ghana. On the average, the MPR has been lower than the TBR over the sample period (i.e. January 2007 to July 2016). The MPR averaged approximately 16.83%, while the TBR averaged approximately 18.04% over the sample period. The TBR has been approximately 1.21% higher, on the average, than the MPR during this period. This appears to be consistent with the theory because lenders are known to demand higher interest on long-term loans due to their associated higher risks (Campbell and Viceira, 2001; Ross *et al.*, 2012). The theory suggests that long-term debt instruments command higher interest rates due to two main reasons. First, there is a higher probability that interest rates would increase within a longer period than within a shorter period. This likely increase in interest rates exerts negative impact on bond prices. Second, long-term bonds generally have longer maturities than short-term bonds. Thus, a given change in interest rate would have greater impact on long-term bonds than on short-term bonds (Campbell and Viceira, 2001; Ross *et al.*, 2012).

The maximum MPR recorded over the sample period is 26.00% which occurred between 11/30/2015 and 7/31/2016. The short-term interest rate (MPR) has been very high during this period, perhaps reflecting the unfavourable economic conditions in the country in recent times. The maximum TBR is 25.82% which occurred somewhere around 10/31/2014 and 12/31/2014 (see Figure 1). The high TBR during this period could be attributed to the growing government debt and souring consumer prices during this period. For example, inflation has increased about 0.5% each month from January 2014 to December 2016 (see International Financial Statistics). This incremental rate of inflation – which reduces the returns from investment – may have dissuaded investors from investing in treasury bills (TB), hence exerting upward pressure on the TBR. Government debt to GDP,

[5] For detailed classification of the monetary policy regimes in Ghana, the reader may refer to Bawumia (2010).

which was 55.64 in 2013, increased to 67.60 by the end of 2014 – an increase of about 11.96%.[6] This perhaps signaled to TB investors that the government may not be able to honour its debt obligations. Therefore, the TBR may have increased to compensate the risk-loving investors. The minimum MPR recorded during the sample period is 12.50% which occurred between 1/31/2007 and 10/31/2007, and between 7/31/2011 and 1/31/2012. For the TBR, the minimum over the sample period is 9.05% which occurred on 10/31/2011, about four years after crude oil was discovered in the country. Not surprisingly, the country began to receive huge inflows of capital from crude oil and natural gas production during 2011. This suggests that the government was not under pressure to raise funds from the sale of treasury bills, reflecting in the low returns on this debt instrument.

[6] See http://www.tradingeconomics.com/ghana/government-debt-to-gdp for this data.

Table 1: Descriptive Statistics of Monetary Policy Rate and Treasury Bill Rate

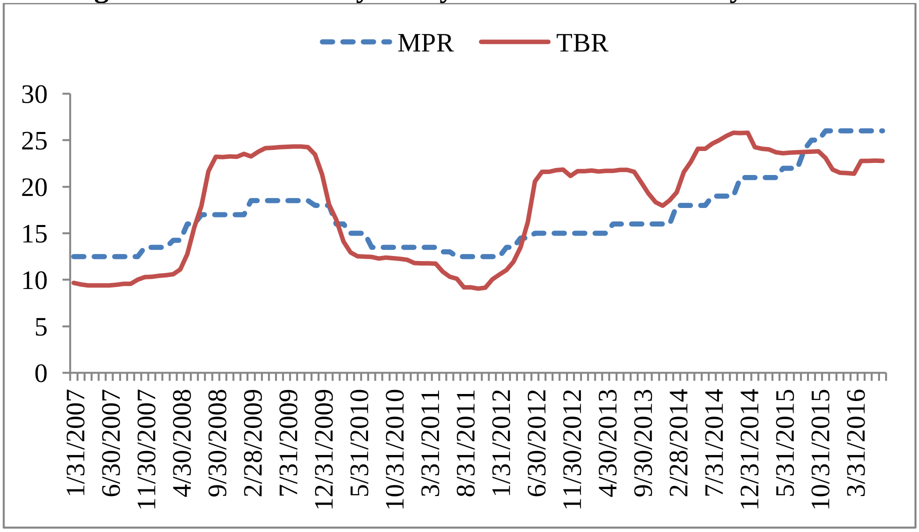
Statistic	Monetary Policy Rate	Treasury Bill Rate
Mean	16.830	18.044
Median	16	21.405
Maximum	26	25.818
Minimum	12.500	9.050
Std. Dev.	3.959	5.875
Skewness	1.008	-0.344
Kurtosis	3.169	1.416
Jarque-Bera	19.647	14.295
Probability	0.000	0.000
Sum	1935.500	2075.018
Sum Sq. Dev.	1786.818	3934.721
Observations	115	115

Note: Std. Dev. and Sum Sq. Dev. denote standard deviation and sum of squared deviations, respectively.

Figure 1 shows the yield curves for the two interest rates in Ghana from January 2007 to July 2016. These curves are sometimes known as the term structure of interest rates (Estrella and Mishkin, 1997; Malkiel, 2015; Iyke, 2017). A careful inspection suggests that these yield curves are inverted between 1/31/2007 and 1/31/2012. The fact that these curves are inverted is because the MPR exceeded the TBR at some point. Towards the late-2000s, the government of Ghana shifted the economy steadily from a controlled regime to a more market-friendly regime. The central bank implemented interest rate policies that reflected the economic conditions prevailing in the economy at the time. In fact, the inflation-targeting framework was successfully implemented in 2007. Perhaps, the increase in the MPR during 2007 may have tightened economic conditions to the extent that investors were unable to save more for investment purposes, thereby forcing the TBR upwards between 2008 and 2009 (see Figure 1). For a prolong period (i.e.

between 5/31/2012 and 7/31/2015), the TBR was successively higher than the MPR. The figure shows clearly that the two interest rates are strongly correlated over time. In the next sections, we provide formal examination of this phenomenon. In particular, we examine whether there is a particular "force" which tends to pull these series closer to each other.

Figure 1: The Monetary Policy Rate and the Treasury Bill Rate



Source: Plotted by author using data from the Bank of Ghana's Monetary Time Series Data.

4.2 Results of cointegration tests

We examine the possibilities of unit roots in the two interest rates, namely: MPR and TBR, using the DF-GLS, Ng-Perron, and KSS tests and find them to be first difference stationary (see Table A.1 in Appendix). So, we proceed to investigate the potential cointegrating relationship between the interest rates using linear and nonlinear cointegration tests. Table 2 reports the results of the Johansen test. The maximum eigen value statistic (λ_{max}) is reported at the upper panel, while the trace statistic (λ_{trace}) is reported at the lower panel. The Johansen test suggests that the evidence of cointegrating relationship between the MPR and the TBR is weak at the conventional level of significance using the trace and the maximum eigen value statistics (see Table 2). In panel [1] of Table 3, we report the results of the Engle-Granger two-step test. The statistic of this residual unit root test ψ is -0.027 which is significant at 10% level. Thus, the Engle-Granger two-step test confirms that the two interest rates are cointegrated at 10% level of significance. These two tests (i.e. Engle-Granger two-step and Johansen tests) report weak evidence of cointegration. This is particularly not surprising because these two tests assume that the MPR and the TBR are cointegrated in a linear fashion, which may be untrue. Therefore, we implement the nonlinear cointegration test advanced by Enders and Siklos (2001) to account for any potential nonlinearity in the relationship between the MPR and the TBR.

Table 2: Results of Johansen Cointegration Test

Test	Specification	Lag	Statistic	Critical Value		
				10%	5%	1%
Johansen λ_{max}						
r=1	Trend	4	1.704	10.49	12.25	16.26
r=0	Trend	4	18.702*	16.85	18.96	23.65
r=1	Constant	4	2.495	7.52	9.24	12.97
r=0	Constant	4	12.095	13.75	15.67	20.20
r=1	None	4	0.008	6.50	8.18	11.65
r=0	None	4	14.637*	12.91	14.90	19.19
Johansen λ_{trace}						
r≤1	Trend	4	12.704**	10.49	12.25	16.26
r=0	Trend	4	13.406	22.76	25.32	30.45
r≤1	Constant	4	2.495	7.52	9.24	12.97
r=0	Constant	4	21.589**	17.85	19.96	24.60
r≤1	None	4	0.008	6.50	8.18	11.65
r=0	None	4	11.645	15.66	17.95	23.52

Note: r is the number of cointegrating vectors; * and ** denote significance 10% and 5%, respectively.

The results for the nonlinear or asymmetric cointegration test are reported in Table 3. Panels [2] to [5] show the four models that we discussed earlier. The optimal lag determined by the AIC and the BIC for the analysis is 4. We first estimate the TAR model with $\tau = 0$ and report the results in Panel [2] of Table 3. The point estimates of $\psi_1 = -0.011$ and $\psi_2 = -0.075$ indicates that there is convergence. Also, $\Phi = 7.132$ is greater than the critical value at 5% (i.e. 6.280). Thus, the null hypothesis of no cointegration between the monetary policy rate (MPR) and the yield on long-term government bonds (TBR) can be rejected. The adjustment mechanism is asymmetric because the p-value of 0.000 under the *F*-statistic is smaller than 0.010 (see Panel [2]). The results of the MTAR version for $\tau = 0$ are reported in Panel [4]. The point estimates of $\psi_1 = -0.047$ and $\psi_2 = -0.038$ implies that there is convergence. Also, $\Phi = 8.492$ is greater than the critical value at 1% (i.e. 8.460). This means we can reject the null hypothesis of no cointegration between MPR and TBR. The adjustment process to equilibrium is asymmetric, since the p-value of 0.000 under the *F*-statistic is smaller than 0.010.

Next, Panels [3] and [5] display the results for the TAR and MTAR models with unknown τ. Chan's (1993) search method is deployed to determine the best threshold. The consistent threshold for the TAR model is 0.076; whereas the consistent threshold for the MTAR model is –0.023. The point estimates of $\psi_1 = -0.003$ and $\psi_2 = -0.088$ for the consistent TAR model imply that there is convergence. These estimates suggest that the speed of adjustment is faster for negative than for positive deviations. Moreover, $\Phi = 8.667$ is greater than the critical value near 5% level (i.e. 7.410), suggesting that we can reject the null hypothesis of no cointegration between MPR and TBR. The adjustment scheme is asymmetric, since the p-value of 0.013 computed under the *F*-statistic is smaller than 0.050 (see Panel [3]). The point estimates of $\psi_1 = -0.054$ and $\psi_2 = -0.013$ for the MTAR suggests that there is convergence. That aside, $\Phi = 10.728$ is greater than the critical value near 1% level (i.e. 8.910), suggesting that we can reject the null hypothesis of no cointegration between the MPR and the TBR. The adjustment scheme is also asymmetric, since the p-value of 0.005 computed under the *F*-statistic is smaller than 0.010 (see Panel [5]).

As discussed earlier, the appropriate model to proceed with is the one which yields the smallest AIC and BIC. From our analysis, the consistent TAR model yields the smallest AIC and BIC. Hence, the consistent TAR model with asymmetric equilibrium adjustment characterizes the observe nature of interest rate co-movements in Ghana. Generally, the evidence of cointegration between the interest rates confirms the expectation hypothesis of yield curves. Focusing on the consistent TAR with threshold $\tau = 0.076$, we find that positive deviations from the long-term equilibrium due to increases in the MPR or decreases in TBR ($\Delta\hat{\mu}_{t-1} \geq 0.076$) are corrected at 0.3% per month. Negative deviations from the long-term equilibrium due to decreases in the MPR or increases in the TBR ($\Delta\hat{\mu}_{t-1} < 0.076$) are corrected at 8.8%

per month (see Panel [3]). It is evident that negative deviations are corrected faster than positive deviation.

Table: Results of Engle-Granger and Threshold Cointegration Tests

Item	[1]	[2]	[3]	[4]	[5]
	Engle-Granger	TAR	Consistent TAR	MTAR	Consistent MTAR
Lag	__	4	4	4	4
Threshold	__	0	0.076	0	-0.023
ψ_1	-0.027*	-0.011**	-0.003***	-0.047***	-0.054*
	(1.684)	(-2.213)	(-3.057)	(-2.917)	(-1.659)
ψ_2	__	-0.075*	-0.088*	-0.038*	-0.013**
	__	(-1.846)	(-1.679)	(-1.722)	(-2.146)
Total observations	115	115	115	115	115
Cointegration obs.	113	102	102	102	102
Diagnostics					
AIC	-345.910	-367.524	-368.728	-366.069	-366.609
BIC	-336.708	-328.15	-329.353	-326.695	-327.234
Hypotheses					
$\Phi(H_0: \psi_1 = \psi_2 = 0)$	__	7.132**	8.667**	8.492***	10.728***
CV(1%)	__	8.820	9.880	8.460	8.910
CV(5%)	__	6.280	7.410	6.200	6.560
$F(H_0: \psi_1 = \psi_2)$	__	10.289***	6.348**	14.024***	8.491***
p-value	__	0.000	0.013	0.000	0.005

Note:

a) $\psi_1 = \psi_2$ for the Engle-Granger cointegration test, so that we report only $\psi_1 = \psi$.

b) Φ is the threshold cointegration test whose critical values are reported from Tables 1 and 5 of Enders and Siklos (2001).

c) F denotes the test of asymmetric adjustment to equilibrium.
d) t-statistics are reported in the parentheses.
e) *, ** and *** denote significance at 10%, 5% and 1%, respectively.

4.3 Results of the asymmetric error correction model

The model that best fit the observed characteristics of the yield curves in Ghana is the consistent TAR model (see Section 4.2). Since the MPR and the TBR are cointegrated with asymmetric adjustment, we proceed by fitting the corresponding error correction model. Based on the AIC and BIC, the optimal lag deemed sufficient for fitting the asymmetric error correction model is four. The asymmetric error correction model is reported as *Eqs*. (6a) and (6b). Note that x_t and y_t denote, respectively TBR and MPR. We find seven parameters to be significant in the MPR equation at the conventional levels (i.e. Θ_1^+, Θ_1^-, Θ_4^-, φ_1^+, φ_1^-, $\varpi^+$and ϖ^-). In the TBR equation, however, we find only four parameters to be significant (i.e. Θ_1^-, φ_2^- ϖ^+, and ϖ^-). The R^2 reported for the MPR and TBR equations, respectively, are 0.673 and 0.233, suggesting that the MPR equation is better specified than the TBR equation (see Table 4).

$$\Delta y_t = \underset{[-2.161]**}{-0.001} \underset{[-1.551]*}{-0.023E_{t-1}^+} \underset{[2.187]**}{+0.076E_{t-1}^-} \underset{[2.547]**}{+0.388\Delta y_0^+} \underset{[2.714]***}{+0.714\Delta y_0^-} \underset{[5.755]***}{+0.739\Delta x_0^+} \underset{[3.388]***}{+0.593\Delta x_0^-} \underset{[-2.945]***}{-0.535\Delta y_3^-} \tag{6a}$$

$$\Delta x_t = \underset{[2.348]**}{0.014} \underset{[-2.027]**}{-0.003E_{t-1}^+} \underset{[-3.119]***}{-0.086E_{t-1}^-} \underset{[-2.069]**}{-0.016\Delta y_1^-} \underset{[2.656]***}{+0.389\Delta y_0^-} \tag{6b}$$

Notes: *, ** and *** denote, respectively significance at 10%, 5% and 1%. Δ is the first difference operator.

In the next few lines, we consider a series of hypotheses. H_{01} and H_{02} are the hypotheses for Granger causality between the MPR and the TBR. The *F*-statistic of 1.857 under H_{01} with a *p*-value of 0.080 suggests a causal flow from the MPR to the TBR. Similarly, the *F*-statistic of 2.054 under H_{02} with a *p*-value of 0.050 suggests a causal flow from the TBR to the MPR. Also, the MPR is influenced by its lags but the TBR is not. These results indicate bidirectional causal flow between the monetary policy rate (MPR) and the returns on treasury bills in Ghana. This evidence also implies that the TBR has strong influence on the MPR during the study period, which is consistent with the forward-looking monetary policy pursued by Bank of Ghana under the inflation-targeting framework and some existing studies. In particular, our results are consistent with the liquidity premium theory which argues that the long-term interest rates exert causal influence on the short-term rates (see McFayden *et al.*, 1991). The Bank of Ghana's Monetary Policy Committee convenes regularly to set the MPR in direct response to changing economic conditions of which the returns on one-year treasury bills form part. The returns on treasury bills, however, are influenced by market forces of which the Bank of Ghana has no influence, in principle. This evidence is similar to the evidence found for other central banks which pursue similar policies (see Enders and Siklos, 2001; Naraidoo and Paya, 2012).

The remaining hypotheses concern asymmetric effects. H_{03} and H_{04} are hypotheses for distributed lag asymmetric effect. We find evidence of distributed lag asymmetric effect for both the MPR and the TBR at the conventional levels. H_{05} and H_{06} are hypotheses of cumulative lag asymmetric effect. The F-statistic of 4.352 for the TBR equation implies that cumulative lag effects from the MPR are asymmetric on the TBR. The F-statistic of 4.557 for the MPR equation suggests that cumulative lag effects from the TBR are asymmetric on the MPR at conventional levels as well. However, own cumulative lag effects are symmetric for both variables. Finally, H_{07} is the hypothesis for asymmetric adjustment to equilibrium effect. The F-statistic for the TBR equation is 3.811 with a p-value of 0.042, suggesting that the equilibrium adjustment path is asymmetric. Moreover, the F-statistic for the MPR equation is 7.438 with a p-value of 0.000, suggesting that the equilibrium adjustment path is asymmetric. The implication is that, in the short term, positive deviations in the TBR are corrected at 0.34% monthly, whereas negative deviations are corrected at 8.60% monthly. Thus, the TBR responds faster to negative than positive deviations.

Table 4: Results of Nonlinear Causality Test

Item	MPR		TBR	
	Estimate	t-statistic	Estimate	t-statistic
R^2	0.673	_	0.233	_
$H_{01}: \Theta_i^+ = \Theta_i^- = 0$ for all lags	10.672***	[0.000]	1.857*	[0.080]
$H_{02}: \varphi_i^+ = \varphi_i^- = 0$ for all lags	2.054**	[0.048]	0.721	[0.670]
$H_{03}: \Theta_2^+ = \Theta_2^-$	8.019***	[0.000]	0.005	[0.940]
$H_{04}: \varphi_4^+ = \varphi_4^-$	0.004	[0.950]	4.450**	[0.038]
$H_{05}: \sum_i^4 \Theta_i^+ = \sum_i^4 \Theta_i^-$	2.736	[0.100]	4.352**	[0.040]
$H_{06}: \sum_i^4 \varphi_i^+ = \sum_i^4 \varphi_i^-$	4.557**	[0.034]	0.036	[0.850]
$H_{07}: \varpi^+ = \varpi^-$	7.438***	[0.000]	3.811**	[0.042]

Note:
a) H_{01} and H_{02} are tests for Granger Causality.
b) H_{03} and H_{04} are tests for distributed lag asymmetric effect.
c) H_{05} and H_{06} are tests for cumulative asymmetric effect.
d) H_{07} is the test for asymmetric adjustment to equilibrium effect.
e) *, ** and *** denote significance at 10%, 5% and 1%, respectively.
f) P-values are in the parentheses.

5 - Concluding remarks

In this paper, we examine the nature of the yield curves in Ghana using three nonlinear econometric techniques that have been found to fit data on macroeconomic variables such as interest rates well. These techniques are: Kapetanios et al. (2003) nonlinear unit root test; Enders and Siklos (2001) threshold cointegration test; and asymmetric error correction model with threshold adjustments documented in Granger and Lee (1989), Balke and Fomby (1997), and Enders and Granger (1998). We proceed by analyzing the stationary properties of the Bank of Ghana's monetary policy rate (MPR) and the treasury bill rate (TBR) and find them to be first difference stationary. We, then, examine whether the MPR and the TBR are cointegrated and find them to be cointegrated with threshold adjustments, which is in line with the expectation theory of yield curves. In particular, we find positive deviations from the long-term equilibrium due to increases in the MPR or decreases in the TBR to be corrected at 0.3% monthly. Negative deviations from the long-term equilibrium due to decreases in the MPR or increases in TBR are corrected at 8.8% monthly. Since the MPR and the TBR are cointegrated with threshold adjustments, we estimate an asymmetric error correction model and test for causality between these series. Our results show causal flows in both directions between the MPR and the TBR. The causal flow from the TBR to the MPR is stronger statistically, suggesting that the TBR has strong influence on the MPR during the study period. This evidence appears to be consistent with the forward-looking monetary policy pursued by Bank of Ghana under the inflation-targeting framework and some existing studies, as well as the liquidity premium theory. We also find that, in the short term, positive deviations in the TBR are corrected at 0.34% monthly, while negative deviations are corrected at 8.60% monthly – meaning that the TBR responds faster to negative than positive deviations. These findings offer another channel through which the monetary authority may pursue its policies. The knowledge that the long-term rate influences the short-term rate means that the monetary authority can set its repo rate by not only considering the level of inflation and unemployment as it does under its inflation-targeting framework, but also by considering the yield on long-term government bonds. In other words, the BOG can execute monetary policy near the short end of the maturity spectrum. It is clear from our results that models of yield curves should incorporate nonlinearities. This may also extend to bond pricing models in general. To the market participants, our results provide an additional source of information about the future level of the short-term interest rate. Specifically, since our results are consistent with the liquidity premium theory, the spread between the long-term rate and the short-term rate would be useful in determining the future level of the short-term rate, and thereby informing their portfolio allocation decisions. The limitation of this study is that it does not forecast the future path of the MPR and the TBR which may be useful for investors. Future studies may consider using time varying regressions to forecast these interest rates. It may also be empirically useful for future studies to consider the behaviour of the yield curves under different monetary regimes in Ghana.

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Appendix

Table A.1: Results for the Linear and Nonlinear Unit Root Tests

Tests	MPR Level	MPR Difference	TBR Level	TBR Difference
DF-GLS [Drift]	1.356	-5.739***	-1.443	-3.842***
DF-GLS [Trend]	-0.815	-5.936***	-2.153	-3.949***
Ng-Perron [Drift]	1.871	-34.466***	-4.994	-23.248***
Ng-Perron [Trend]	-2.064	-35.973***	-10.410	-24.234***
KSS	0.458	NA	0.255	NA

Note: NA denotes non-applicable. The critical values for KSS are compared to Table 1 [Case 1] in Kapetanios *et al.* (2003, p. 364). *** denotes significance at 1% level, respectively.