Empirical Evidence of Nonlinear Effects of Monetary Policy Reaction Functions in a Developing Country

- Abstract
- The paper examines nonlinear effects of monetary policy reaction function using 1978-2015 annual sample with threshold autoregressive (TAR) and traditional models to find out how Bank of Ghana (BOG) reacts to achieve its primary goals when inflation rate deepens. Estimating linear functions to capture temporary monetary policy reaction functions to assess reactions of Central Banks' monetary policy, especially in developing countries, often suffer from serial correlation, heteroscedasticity and functional instability problems. We remedied these problems by using interest rate to minimize a quadratic nonlinear loss function to derive an asymmetric TAR model. We then identified logged price as the threshold variable, with one threshold value in a two inflation regimes from designated output and inflation threshold variables, and two threshold values in a three inflation regimes when exchange rate is included in the designated threshold variables. In all inflation regimes, the BOG responds to external account deficits, and in a low inflation regime, it responds to both inflation and output. In the moderate inflation regime, it responds to only output. In the high inflation regime, it responds to only inflation in the two inflation regimes, and to both output and depreciation in the three inflation regimes. Both Engle-Granger and asymmetric error correction estimates indicate that temporary deviations of interest rates from a long-run equilibrium are symmetrical with the speed of adjustment being fast in the former, and in the latter case, where the negative phase of deviations is persistent and seems to be temporarily asymmetrical. Furthermore, both threshold and Engle-Granger cointegration tests are supported by Johansen cointegration tests. Thus, the symmetric policy response results in both short term and long-run are consistent with the central bank's public stance of pursuing inflation targeting policy to reduce inflation, even though it is ineffective in moderate and high inflation regimes.

- Keywords: Nonlinearity effects, monetary policy, reaction functions, threshold autoregression, interest rates, inflation rates, economic growth, exchange rates, symmetry.
- JEL: E5, O1, C4

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Quadratic-loss function:

$$L_t = a_1(y_t – y*_t)^2 + a_2(p_t – p*_t)^2 + a_3(xr_t – xr*_t)^2 + a_4(ca – ca*_t)^2 + \varphi(r_t – r*_{t-1})^2 \qquad (1)$$

Reaction function:

$$r_t = b_1 y_{t-1} + b_2 p_{t-1} + b_3 xr_{t-1} + b_4 ca_{t-1} + u_t \qquad (2)$$

Estimated reaction function:

$$r_t = b_1 y_t + b_2 p_t + b_3 xr_t + b_4 ca_t + u_t \qquad (3)$$

Threshold regression equation 1:

$$r_t = (\alpha_1 y_t + \alpha_2 p_t + \alpha_3 xr_t) I(1)_t (p_{t-1} < k_1) + (\alpha_1' y_t + \alpha_2' p_t + \alpha_3' xr_t) I(2)_t (k_1 \leq p_{t-1}) + \alpha_4 ca_t + u_t \qquad (4a)$$

Threshold regression equation 2:

$$r_t = (\beta_1 y_t + \beta_2 p_t + \beta_3 xr_t)I(1)_t(p_{t-1} < k_1) + (\beta_1' y_t + \beta_2' p_t + \beta_3' xr_t)I(2)_t(k_1 \leq p_{t-1} < k_2)$$
$$+ (\beta_1'' y_t + \beta_2'' p_t + \beta_3'' xr_t)I(3)_t(k_2 \leq p_{t-1}) + \beta_4 ca_t + u_t' \quad (4b)$$

Engle-Granger Two-Stage Approach (TSA):

$$\Delta r_t = b_1 \Delta y_{t-1} + b_2 \Delta p_{t-1} + b_3 \Delta xr_{t-1} + b_4 \Delta ca_{t-1} - \lambda u_{t-1} \quad (5a)$$

$$\Delta u_t = \rho u_{t-1} + \varepsilon_t \quad (5b)$$

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

Assuming that our leading TAR model follows equations 4a, and the adjustment is asymmetric, then the TAR model will be expressed as

$$\Delta u_t = \rho_1 u_{t-1} + \varepsilon_t \text{ if } u_{t-1} \geq k_1 \text{ and } \rho_2 u_{t-1} + \varepsilon_t \qquad \text{if } u_{t-1} < k_1 \tag{6a}$$

Here, the sufficient condition for stationarity or convergence of u_t is $(\rho_1, \rho_2) \epsilon (-2, 0)$.

The adjustment process is formally re-written as

$$\Delta u_t = I_t.\rho_1.u_{t-1} + (1 - I_t).\rho_2.u_{t-1} + \varepsilon_t \tag{6b}$$

The Heaviside step or indicator function is

$$I_t = 1 \text{ if } u_{t-1} \geq k_1 \text{ or } 0 \text{ if } u_{t-1} < k_1 \tag{6c}$$

The error-correction behaviour of the adjustment for momentum-TAR (MTAR) is

$$\Delta u_t = M_t.\rho_1.u_{t-1} + (1 - M_t).\rho_2.u_{t-1} + \varepsilon_t \tag{6d}$$

where, the Heaviside step function is specified as

$$M_t = 1 \text{ if } \Delta u_{t-1} \geq k_1 \text{ or } 0 \text{ if } \Delta u_{t-1} < k_1 \tag{6e}$$

Adjustment in a three regime TAR model, where there are two threshold values such that $k_1 < k_2$, is expressed in error-correction form as

$$\Delta r_t = I(1)_t.\rho_1.u_{t-1} + I(2)_t.\rho_2.u_{t-1} + I(3)_t.\rho_3.u_{t-1} + \varepsilon_t \quad (7a)$$

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 (7b)

The M-TAR model of a three regimes threshold comprises of equations 7c and 7d.

The adjustment is expressed in error-correction form as

$$\Delta r_t = M(1)_t.\rho_1.u_{t-1} + M(2)_t.\rho_2.u_{t-1} + M(3)_t.\rho_3.u_{t-1} + \varepsilon_t \quad (7c)$$

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 (7d)

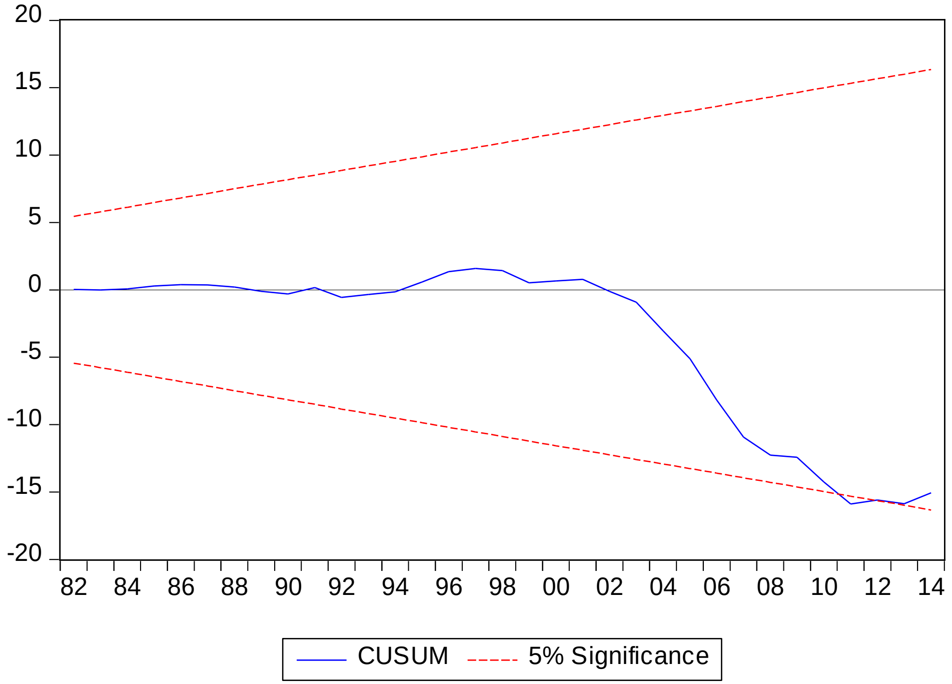
Table 1: Unit roots tests

	Level-form		First Difference-form	
Variables	ADF	ERS DF-GLS	ADF	ERS DF-GLS
	No intercept and trend	With intercept	No intercept and trend	With intercept
r	0.073 [2.631]	-2.070[2.631]	-6.975*[2.633]	-6.986*[2.633]
y	-2.767**[2.613]	0.295[2.613]		-4.255*[2.613]
xr	-3.561**[2.609]	-4.091**[2.609]		
p	-0.954[2.614]	-0.146[2.614]	-1.362[2.614]	-3.910**[2.613]
Δp	-1.362[2.614]	-3.910**[2.613]	-11.408*[2.614]	-10.276*[2.614]
ca	-0.437[2.610]	-1.019[2.610]	-8.132*[2.610]	-9.556*[2.609]
u	-7.015*[2.614]	-7.006*[2.614]		

Table 2: Linear regression and Nonlinear-regressions with interest rate (r_t) as a regressand

Variables	Slope coefficients		Variables	Slope coefficients		Variables	Slope coefficients	
1a: Linear (OLS Estimates)			1b: Non-linear (TR Estimates)			1c: Non-linear (TR Estimates)		
p_t	0.064	(0.25)	Threshold variables			Threshold variables		
y_t	0.118*	(0.00)		p_t (p_{t-1}) < 3.828(3.709)			p_{t-1} < 1.477	
xr_t	0.079	(0.55)	p_t	0.214*	(0.00)	p_t	0.201*	(0.00)
ca_t	-3.300*	(0.09)	y_t	0.127*	(0.00)	y_t	0.125*	(0.00)
				p_t (p_{t-1})≥ **3.828(3.709)**		xr_t	-0.044	(0.36)
1a': Linear (GMM Estimates)			p_t	0.747*	(0.00)		1.477 ≤ p_{t-1} <3.709	
p_t	0.070	(0.06)	y_t	-0.050	(0.42)	p_t	-0.116	(0.21)
y_t	0.110	(0.00)	Non-threshold variables			y_t	0.170*	(0.00)
xr_t	0.404	(0.23)	xr_t	-0.015	(0.83)	xr_t	0.196	(0.30)
ca_t	-4.173	(0.00)	ca_t	-2.561***	(0.06)		3.709 ≤ p_{t-1}	
						p_t	0.042	(0.84)
						y_t	0.089***	(0.07)
						xr_t	2.591*	(0.00)
						Non-threshold variables		
J-Stat.	6.438	(0.17)				ca_t	-2.980*	(0.00)
$\bar{R}^2$	-0.14			0.69			0.90	
DW	0.559			1.919			2.095	
Breusch-Godfrey Serial Correlation LM Tests								
F(1,32)	39.050*	(0.00)	F(1,30)	0.020	(0.89)	F(1,26)	0.172	(0.68)
Breusch-Pagan-Godfrey Heteroscedasticity LM Tests								
F(4,32)	1.638	(0.19)	F(6,30)	2.678*	(0.03)	F(10,26)	0.414	(0.93)
SBC	1.524		SBC	0.352		SBC	-0.254	

Figure 1a: Stability tests of monetary policy (MP) reaction function in a linear model



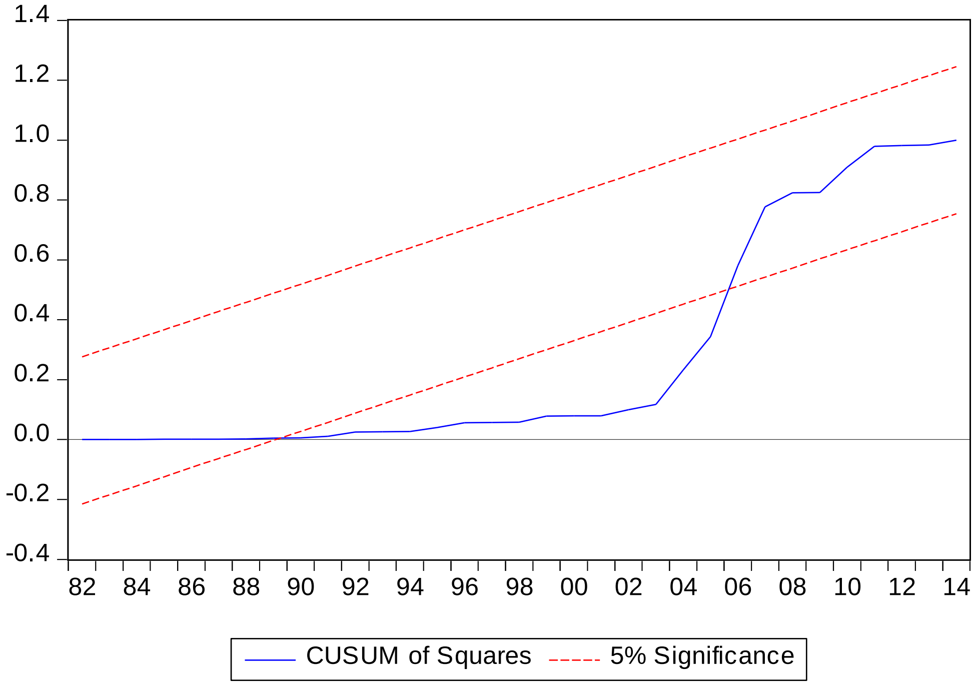


Figure 1b: Stability tests of MP reaction function in a nonlinear model with two inflation regimes

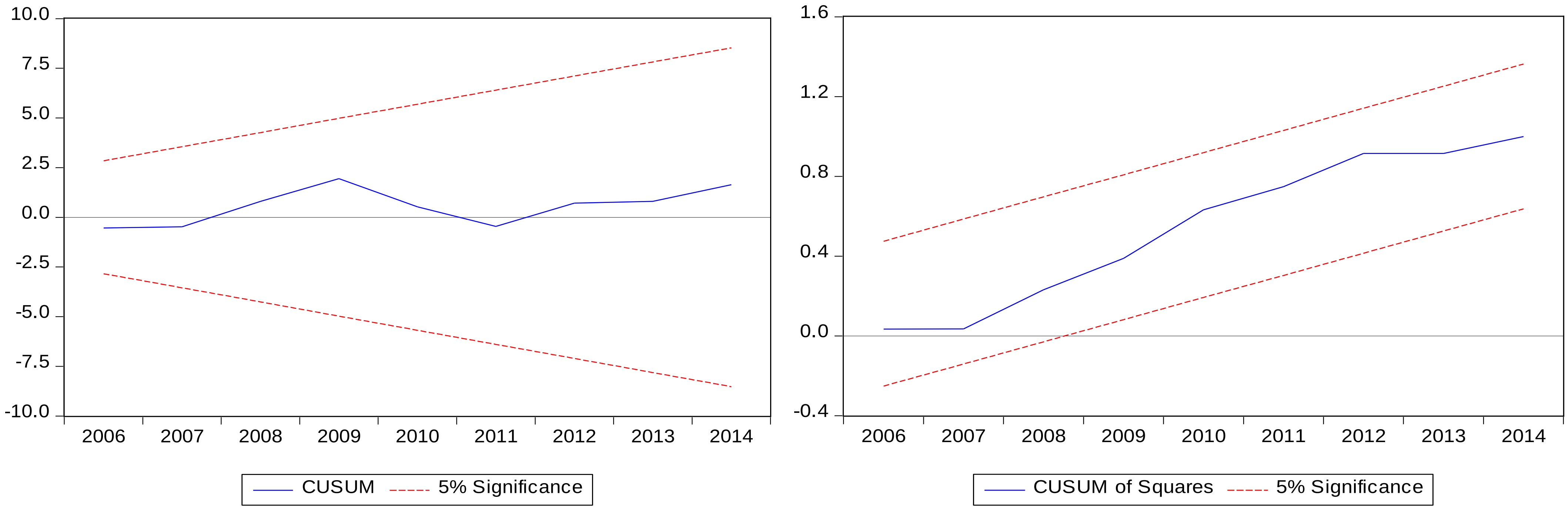
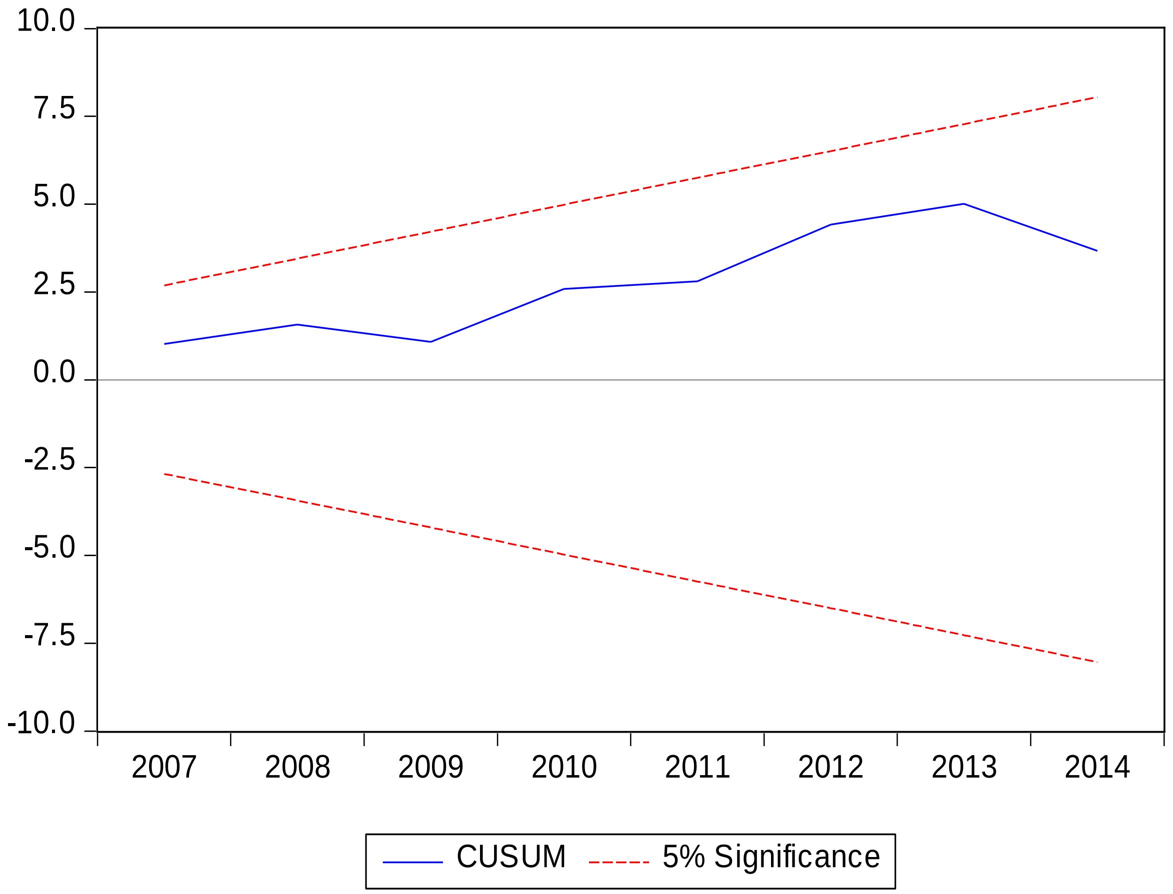


Figure 1c: Stability tests of MP reaction function in a nonlinear model with three inflation regimes



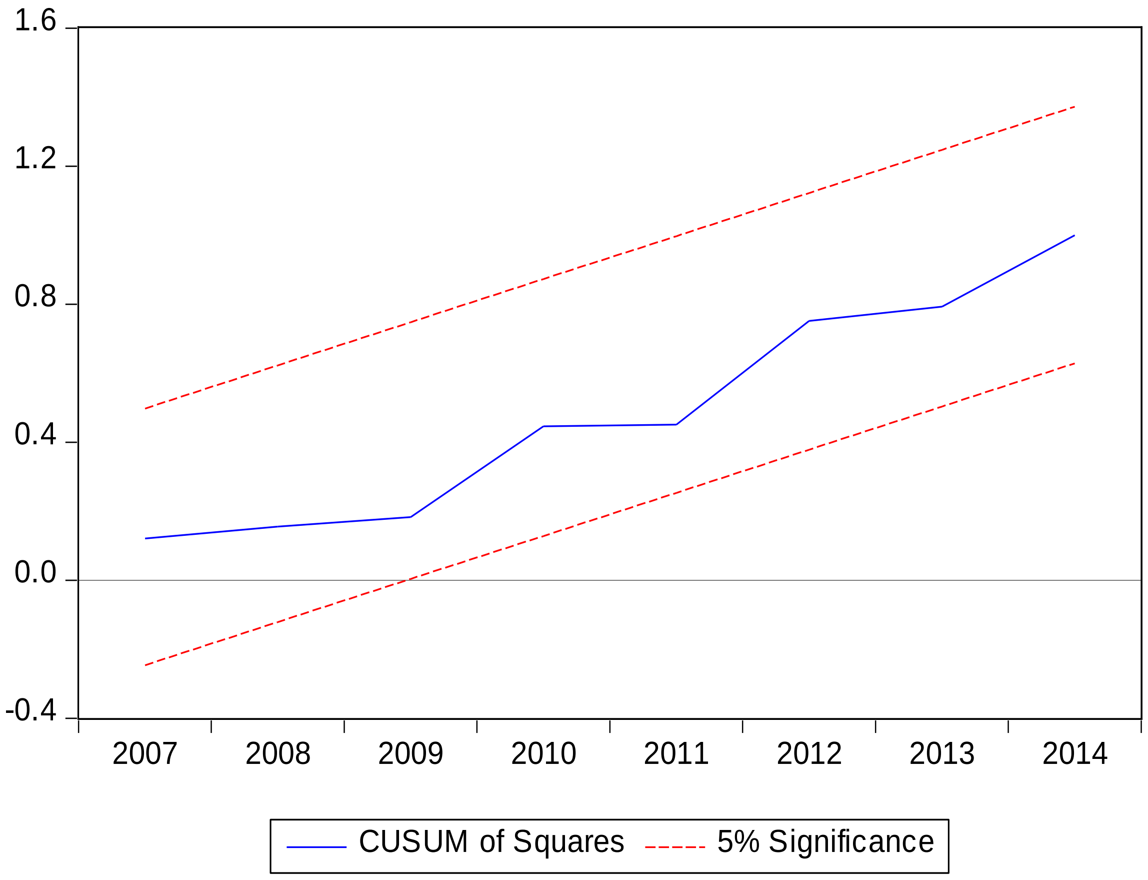


Table 3: Johansen’s maximum likelihood cointegration estimates with interest rate as a regressand

No. of CEs Hypothesized	Eigenvalue	Λ_{Trace}	P-values	Λ_{Max}	P-values
None	0.658	85.116*	0.00	37.539*	0.00
At most 1	0.499	47.577*	0.01	24.215**	0.05
At most 2	0.334	23.362	0.06	14.237	0.16
At most 3	0.194	9.125	0.16	7.559	0.20
At most 4	0.044	1.565	0.25	1.565	0.25
Cointegration equation 1	r = 0.189[1.45]p – 0.050[2.08]***y + 0.929[3.32]**xr – 13.136[3.01]**ca				

Table 4a: EG TSA, TAR and M-TAR estimates of interest rate in two inflation rate regimes

Parameter	EG-TSA	TAR	M-TAR
ρ_1	-0.651(0.00)	-0.334(0.25)	-0.337(0.26)
ρ_2	NA	-0.983*(0.00)	-0.144(0.49)
$\overline{R}^2$	0.30	0.27	0.02
DW	2.076	2.339	2.121
Breusch-Godfrey (BG) Serial Correlation LM Tests			
F(1,33)	0.100(0.75)	1.848(0.18)	0.315(0.58)
$X^2(1)$	0.000(1.00)	1.810(0.18)	0.225(0.63)
Breusch-Pagan-Godfrey (BPG) Heteroscedasticity LM Tests			
F(2,33)	2.252(0.12)	1.352(0.27)	0.039(0.96)
$X^2(2)$	4.324(0.11)	2.013(0.36)	0.084(0.96)
Wald-Test		$\rho_1 = \rho_2 = 0$	
Φ: F(2,34)[a], Φ(M): F(2,33)[b]		6.984*(0.00)	0.908(0.41)
$X^2(2)$		13.969*(0.00)	1.816(0.40)
Wald-Test		$\rho_1 = \rho_2$	
F(2,34)[a], F(2,33)[b]		1.625(0.11)	0.289(0.59)
$X^2(2)$		2.642(0.10)	0.289(0.59)
SBC	0.214	2.661	0.589

Table 4b: EG TSA, TAR and M-TAR estimates of interest rate in three inflation rate regimes

Parameter	EG-TSA[a]	TAR[b]	M-TAR
ρ_1	-0.995*(0.00)	-1.485**(0.02)	-0.802***(0.07)
ρ_2	NA	-0.890(0.11)	-0.444 (0.29)
ρ_3	NA	-1.185**(0.05)	-0.354(0.52)
$\bar{R}^2$	0.30	0.22	0.08
DW	2.147	1.950	2.010
Breusch-Godfrey Serial Correlation LM Tests			
$F(1,32)^a$, $(1, 31)^b$	0.405(0.53)	0.027(0.87)	0.015(0.90)
$X^2(1)$			
Breusch-Pagan-Godfrey Heteroscedasticity LM Tests			
$F(3, 32)$	1.081(0.37)	0.317(0.81)	0.348(0.79)
Wald-Test		$\rho_1 = \rho_2 = \rho_3 = 0$	
Φ: $F(2,32)^a$, $\Phi(M)$: $F(3,32)^b$		4.064*(0.01)	1.712(0.18)
$X^2(3)$		12.191* (0.01)	5.135 (0.16)
Wald-Test		$\rho_1 = \rho_2 = \rho_3$	
$F(2, 33)^a$, $F(2,32)^{b,c}$		0.254(0.78)	0.272 (0.76)
$X^2(2)$		0.509(0.77)	0.543(0.76)
SBC	0.284	0.395	0.508

Table 5: Error-correction estimates of interest rates regressand (Δr_t) during different inflation rates regimes

	Symmetric error-correction models		Asymmetric error-correction models	
Regressor	Two regimes	Three regimes	Two regimes	Three regimes
Δp_t	-0.348(0.21)	-0.285(0.32)	-0.356(0.19)	-0.362(0.23)
Δy_t	-0.601**(0.03)	-0.517***(0.06)	-0.612**(0.02)	-0.581*(0.05)
Δxr_t	-0.048(0.52)	-0.056(0.46)	-0.045(0.54)	-0.051(0.51)
Δca_t	0.008(0.71)	0.007(0.74)	0.010(0.65)	0.004(0.86)
Δr_{t-1}	-0.017(0.92)	-0.105(0.53)	-0.016(0.92)	-0.087(0.62)
μ_{t-1}	-0.629*(0.01)	-0.937**(0.02)		
μLIR_{t-1}			-0.275(0.38)	-1.320***(0.07)
μMIR_{t-1}				-0.477(0.44)
μHIR_{t-1}			-0.951*(0.00)	-1.115***(0.08)
$\bar{R}^2$	0.26	0.24	0.31	0.21
DW	2.160	1.930	2.496	1.896
Breusch-Godfrey Serial Correlation LM Tests				
$F(1,28)^a, F(2,26)^b$	0.610(0.44)	0.014(0.90)	2.919***(0.07)	0.054(0.82)
$X^2(2)$	0.734(0.39)	0.012(0.91)	6.403**(0.04)	0.035(0.85)
Breusch-Pagan-Godfrey Heteroscedasticity LM Tests				
F(6,28), F(7,27)	1.160(0.35)	0.809(0.57)	0.809(0.59)	0.731(0.66)
$X^2(6), X^2(8), X^2(2)$	4.889(0.56)	4.659(0.59)	2.981(0.89)	5.082(0.75)
Wald Test			$\mu LIR_{t-1} = \mu HIR_{t-1} = 0$	$\mu LIR_{t-1} = \mu MIR_{t-1} = \mu HIR_{t-1} = 0$
Φ: $F(2, 28)^a$, $\Phi(M)$:$F(3,27)^b$			5.193*(0.01)	2.262***(0.10)
$X^2(1)^a, X^2(2)^b$			10.385*(0.00)	6.786***(0.08)
Wald Test			$\mu LIR_{t-1} = \mu HIR_{t-1}$	$\mu LIR_{t-1} = \mu MIR_{t-1} = \mu HIR_{t-1}$
$F(1,28)^a, F(2, 27)^b$			2.942***(0.09)	0.449(0.61)
$X^2(1)^a, X^2(2)^b$			2.942***(0.08)	0.999(0.60)
SBC	0.579	0.606	0.580	0.773

Conclusion

The paper examines nonlinear effects of monetary policy reaction function using 1978-2015 annual sample with TAR and traditional models to find out how Bank of Ghana (BOG) reacts to achieve its primary goals when inflation rate deepens. Estimating linear functions to capture temporary monetary policy reaction functions which is routinely employed to assess reactions of Central Banks' monetary policy reaction functions yield inefficient results because of serial correlation, heteroscedasticity and functional instability problems. Consequently, policymakers cannot rely on such results to inform short-term policy.

Interest rate is used to minimize a quadratic nonlinear loss function to derive an asymmetric TAR model. Both Engle-Granger and asymmetric error correction estimates indicate that temporary deviations of interest rates from a long-run equilibrium are symmetrical. The speed of adjustment is faster in the former, even though in the latter case, the negative phase of deviations is persistent and seems to be temporarily asymmetrical. Furthermore, the symmetrical adjustment towards long-run equilibrium observed in both threshold and Engle-Granger cointegration tests, are supported by Johansen cointegration tests. Thus, the symmetric policy response results in both short term and long-run are consistent with the central bank's public stance of pursuing inflation targeting policy to reduce inflation, even though it is ineffective during high inflation period.