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Unfolding the Monetary Policy Rule in Ghana:
Quantile-Based Evidence within Time-Frequency Framework

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Abstract

In this paper, we unfold the historical behaviour of monetary authority in Ghana by estimating the policy rule using the standard quantile regression techniques within wavelet multiscale framework. The results generally suggest an overriding bias towards positive inflation gap across time-scales and quantiles. This is an indication of asymmetric (nonlinear) monetary policy reaction function for Ghana. A policy preference for inflation stabilization is clearly conspicuous in the medium-to-long run, consistent with the medium–to-long term policy objective of price stability in Ghana. Our empirical results thus convey important implications for monetary policy implementation and outcomes in Ghana.

Key Words: *Price Stability, Policy Rule, Inertia, Quantile Regression, Wavelet, Multiscale, Time-Frequency.*

JEL: C11, C22, C32, E42, E43, E52, E58, F41.

Disclaimer: The views in this article are those of the authors and do not in any way represent that of affiliated institutions.

1. Introduction

Ghanaian economy, like other small-open developing nation, is often thumped by large domestic and external aggregate demand and supply-side shocks[1]. These shocks have reflected in high and persistent consumer price inflation (CPI), placing Ghana among the sub-Saharan African economies with the highest inflation over the years. The persistent and high inflation in Ghana despite over decades of practicing inflation targeting begs fundamental question of how the Bank of Ghana (henceforth, BOG) has responded to aggregate demand and supply shocks over the years.

The objective of this study to re-examine the historical behaviour of BOG by estimating the monetary policy function. Even though the literature on MPRF is not new, it remains topical as most studies have estimated the latter using standard estimation techniques that focus mainly on the conditional mean of policy interest rate. Notable studies including Taylor (1993), Clarida et al (2000), Surico (2002, 2007) and de Sa and Portugal (2015) for the USA; Nelson, (2000) for the UK; Dolado et al (2005) for Germany, France, Spain and US; Takáts (2012) for selected emerging and developed economies; Naraido and Raputsoane (2010) for South Africa, among others. However, these conditional mean estimates may provide a partial picture of policy response to aggregate demand and supply shocks in an economy especially if the dynamic links for policy interest rate against inflation and output gaps differ at the tails. Consequently, fewer number of empirical studies on MPRF have applied quantile regression techniques to examine the dynamic response of interest rate to inflation and output gaps at the entire conditional distribution of policy interest rate.

Chevapatrakul and Paez-Farrell (2014) employed versions of quantile regressions (2SQR and Bootstrapping Quantile regression) to estimate monetary policy rule for three small open economies including Australia, Canada and New Zealand. The study spans the beginning of inflation targeting for each economy (i.e. June 1991 for Australia and New Zealand, and January 1993 for Canada) to the end of December 2007. They find evidence of asymmetric interest rate response for all the three economies. Specifically, they find that monetary policy across the selected countries react more aggressively to inflation when interest rate are high than when they are low. Besides, more weight is placed on positive deviations of inflation from its target than negative deviations. On the contrary, the interest rate response to output gap is largely symmetric and small across the selected economies.

Using real-time data, Wolters (2012) employed standard and inverse quantile regression techniques (IVQR proposed by Chernozhukov and Hansen, 2005) to estimate MPRF for the US Federal Reserve over the period 1969Q4 – 2005Q4. The study unveils clear evidence of nonlinear relationship between the interest rate, inflation, output gap and the lagged interest rate. The study also detects significantly high interest rate smoothing by the US Fed for the sample period. More so, the study found policy parameters to fluctuate significantly and systematically over the conditional distribution of the Fed fund rate.

[1] More often than not, the acute inflationary pressures have principally been linked to the perennial fiscal excesses (especially during election cycles) accompanied by monetary accommodation and continuous exchange rate vulnerability with attendant repercussions on domestic utility, petroleum and transport prices as well as imported inflation.

Chevapatrakul, Kim and Mizen (2009) employ two-stage quantile regression to estimate the MPRF for the US and Japan based on respective data span October 1979 – September 2005 and May-1979 – January 1999. They find that both countries upheld the Taylor principle and also respond aggressively to inflation at the higher quantiles. In general, they also find evidence of more aggressive policy response to inflation in Japan compared to the USA. Yet, they find no detectable evidence of increasing aggression when approaching the zero lower bound in both countries.

The study however differs strikingly and therefore offers cogent contributions to the literature by utilizing quantile regression techniques within time-frequency (i.e. multiscale) framework. First, our application of multiscale framework along with Frequentist quantile regression techniques is uniquely different from most previous works that have applied conditional mean estimation techniques (including Taylor, 1993, 1999; CGG, 2000; Nelson, 2000, de Sa and Portugal, 2015; etc.)[2] or even from those studies that have employed quantile regression techniques at time-domain (such as Chevapatrakul et al., 2009; Wolters, 2012; and Chevapatrakul and Paez-Farrell, 2014, etc.). These foregone studies concentrated solely on time-domain analysis (only two time scales) and offer virtually no information about the frequency at which the macroeconomic interactions occur[3]. To the best of our knowledge, our study is thus among the bourgeoning studies (notably Akosah et al., 2020) that analyse MPRF using Quantile techniques with multi-scale inferences. Second, the application of a more innovative technique like Maximal Overlap Discrete Wavelet Transform (MODWT)[4] with Debauches least asymmetric filter of length (LA8) to obtain wavelet time-scale coefficients for the analysis of MPRF at the short, medium and longer time horizons is a contribution worth mentioning.

Section 2 provides the empirical methodology and dataset used for the analysis; Section 3 presents the empirical results and inferences, while Section 4 concludes and offers policy suggestions.

2. Empirical Methodology and Data

The conventional generalized linear models fit a single conditional mean regression curve to the mean part of the response distribution in a bid to establishing a relationship between response variable and its predictors. In a situation whereby several sets of changes exist in the distribution of the response variable, the conditional mean regression model may fail to display the entire relationship between the response variable and its predictors. In view of this limitation, Keonker and Bassets in the 1970s introduced quantile regression (QR) techniques as an alternative approach to the conventional conditional mean regression model. Given a set of predictors, the QR method

[2] It is worthwhile to note however that such studies essentially provide an incomplete account of MPRF, exactly when the parameters diverge over the entire conditional distribution of interest rate (see Wolters, 2012). In view of this limitation with conditional mean estimation, a fewer numbers of researches such as have employed versions of frequentist quantile regressions to examine MPRF in order to explore policy dynamics across the entire conditional distribution of policy interest rate.

[3] It is well acknowledged that monetary authority may simultaneously operate at more than two timescales (see, Aguiar-Conraria, et al., 2008, 2012; Gallegati, et al, 2015).

[4] See Section 2 for the overriding advantages of MODWT over DWT.

allows for several regression curves to be fitted through many parts of the distribution of a response variable.

Consider T observations $\{i_t\}_{t=1,..,T}$ on the monetary policy interest rate conditional on the inflation deviation from target (π_t^d), output gap ($\tilde{y}_t$) and other relevant predictors ($z_{i,t}$). In this study, the $z_{i,t}$ variable comprises exchange rate and/or the interaction terms, as discussed above. The conditional α^{th} quantile function of i_t given i_{t-1}, π_{t+p}^d, $\tilde{y}_{t+p}$ and $z_{i,t}$, represented by $\Gamma_\alpha(i_t|i_{t-1},\pi_{t+p}^d,\tilde{y}_{t+p},z_{i,t})$, is defined as

$$\int_{-\infty}^{\Pi_\tau(i_t|i_{t-1},\tilde{\pi}_{t+p},\tilde{y}_{t+p},x_{i,t}),} g_{i_t|i_{t-1},\tilde{\pi}_{t+p},\tilde{y}_{t+p},x_{i,t}}(i_t|i_{t-1},\tilde{\pi}_{t+p},\tilde{y}_{t+p},x_{i,t}) = \tau, \tag{1}$$

Where $g_{i_t|i_{t-1},\tilde{\pi}_{t+p},\tilde{y}_{t+p},z_{i,t}}(i_t|i_{t-1},\tilde{\pi}_{t+p},\tilde{y}_{t+p},x_{i,t})$ is the conditional quantile function (density) of the response variable, i_t, at time t given i_{t-1}, $\tilde{\pi}_{t+p}$, $\tilde{y}_{t+p}$ and $z_{i,t}$; $\tau \in [0,1]$. When $\tau = 0.5$, equation (1) is simply the conditional median function of i_t given $\tilde{\pi}_{t+p},\tilde{y}_{t+p}$ and $x_{i,t}$. The parameters φ_τ β_τ, θ_τ and γ_τ are allowed to vary with α and they measure the degree of responsiveness of i_t (the policy interest rate) to i_{t-1}, $\tilde{\pi}_{t+p}$, $\tilde{y}_{t+p}$ and $x_{i,t}$ respectively when i_t is located at the τth quantile of the conditional distribution. For a fixed value of α, the parameters φ_τ, β_τ, θ_τ and γ_τ are estimated through minimization:

$$\min_{\varphi_\tau,\beta_\tau,\theta_\tau,\gamma_\tau} \sum_{t=1}^{T} \rho_\tau\left((w_j)i_t - \left[\omega_\tau + \varphi_\tau(w_j)i_{t-1} + \gamma_\tau(w_j)x_{i,t} + \beta_\tau(w_j)\tilde{\pi}_{t+p|t} + \theta_\tau(w_j)\tilde{y}_{t+p|t}\right]\right) \tag{2}$$

Where w_j for $(j = 1, 2, 3)$ is similarly defined as the wavelet decomposed time scale series based on MODWT with asymmetric filter (LA8). So for QR analysis based on the level dataset, $w_j = 1$ which disappears from equation 8. The loss function $\rho_\tau(\varepsilon)$ is defined as

$$p_\tau(\varepsilon) = \varepsilon\left[\tau - I_{(\varepsilon\leq 0)}\right] \tag{3}$$

and the model's residuals, $I_{(\varepsilon\leq 0)}$, are formulated as an indicator function taking two values:

$$I_{(\varepsilon\leq 0)} = \begin{cases} 1 & for\ \varepsilon \leq 0 \\ 0 & otherwise \end{cases} \tag{4}$$

According to Keonker and Hallock (2001), $\rho_\tau(\varepsilon)$ effectively imposes different weight on positive and negative residuals and when $\tau = 0.5$ it is the median estimator.

However, the one-step quantile regression in equation (2) assumes there is no endogeneity problem. That is, the explanatory variables i_{t-1}, $\tilde{\pi}_{t+p}$, $\tilde{y}_{t+p}$ and $x_{i,t}$ are not correlated with the error term ε_t. The inclusion of forward inflation rates in equation (2) also introduces endogeneity problem (see, Chevapatrakul et al., 2009, 2014), which biases the corresponding quantile estimators $\hat{\beta}_\tau$, $\hat{\theta}_\tau$ and $\hat{\gamma}_\tau$ (Kim and Muller, 2008). To overcome this biasedness we use two approaches. First, we apply residual (error) bootstrapping techniques espoused by Buchinsky (1995) to generate standard errors and covariances of the one-stage quantile estimates that are robust to heteroscedasticity and autocorrelation of unknown forms. For each bootstrap block, the variables are drawn randomly from the whole sample after a sufficiently large bootstrap replications, M.

Second, we apply the two-stage quantile regression (2SQR) methodology proposed by Kim and Muller (2008), Powell (1983) and Amemiya (1982). In this approach, we initially regress inflation and output gap on a set of instruments and generate fitted values, $\check{\pi}_t$ and $\check{y}_t$ respectively.

Next, policy interest rate (i_t) is then regressed on the fitted values generated for both inflation and output gap from the first step using quantile regression technique; $i_t = g(\breve{\pi}_t, \breve{y}_t)$.[5] Due to the fact that the explanatory variables in the two-stage quantile regression are forecasted from the first-stage GMM estimation instead of the true values, the standard errors of the estimates may also be biased. In order to attain accurate standard errors, similar bootstrapping technique is applied on the standard residuals of the estimates obtained from the second-stage quantile regression. In this case, we first generate at random from the residuals, $\hat{\varepsilon}_i(\tau)$, and the predictor variables (Γ_i) by resampling separately with replacement where $\Gamma_i = (\breve{\pi}_t, \breve{y}_t)$. We use the p-vector of resampled residuals, ε^*, $p\ x\ q$ matrix of independent resampled variables, Γ^* and estimated coefficient to determine the dependent variable as; $i^* = \Gamma^* \hat{\varphi}(\tau) + \varepsilon^*$. Similarly, bootstrap estimates of $\varphi(\tau)$ are finally computed using i^* and Γ^* after a sufficiently large bootstrap replications, M. In this study, we set M to 100000.

We employ quarterly dataset spanning the period 2001Q1-2017Q4[6] to estimate of monetary policy reaction function (MPRF) for Ghana. The choice of the variables is purely based on the literature on MPRF. The variables are the monetary policy interest rate (MPR), inflation gap, output gap, nominal bilateral exchange rate gap. Official monetary policy rate (MPR) is used as the nominal interest rate. All variables are seasonally adjusted and are in logarithmic terms, except MPR. As prerequisite in this study, we compute gaps as deviations from the interested variables (mainly CPI inflation output and exchange rate) from a certain policy desired level of following the literature. Particularly, inflation gap is defined as a deviation of CPI inflation from official inflation target of 8%. However, for the period where the target was not explicit (especially for the 2001-2007), the target was computed as a linear trend of the actual CPI inflation using the Hodrick-Prescott (HP) filter. The output gap is computed as the difference between the actual real GDP and its trend (or potential) level, with the latter generated using band pass (BP) filter based on fixed length (Baxter-King) symmetric filter with low and upper durations of 6 and 32 quarters respectively.

For the multiscale analysis of MPRF, we apply Maximal Overlap Discrete Wavelet Transforms (MODWT)[7] with Debauchies least asymmetric filter of length 8 (LA8) to decompose each macro-data into wavelet coefficients at different time scales[8]. In this study, the highest decomposition level, j, is given by $j = \log_2(68) = 6$, thus 6 maximum levels. Knowing the ideal

[5]Kim and Muller (2004) show that the slope coefficients are unbiased while the intercept is biased. Consequently, we do not discuss the intercept in this study.

[6] The choice of the sample size is to cover both the transition (IT lite) and the full inflation targeting (IT) regimes from 2002 as well as easily availability of quarterly data. However, the inclusion of one-year (2001Q1-Q4) preceding the adoption of IT lite is just to ensure that the introduction of lagged variables (especially with respective to the instruments) still maintains a sizeable data sample for the estimation. Nevertheless, our empirical results show that the inclusion or otherwise of one-year dataset preceding the IT adoption does not affect the results.

[7] MODWT denotes a modified version of discrete wavelet transform. Our preference for the MODWT is based on the fact that it can handle any sample size T and its variance estimator is asymptotically more efficient than that of the DWT and hence more suitable when calculating wavelet correlations. In addition, the MODWT is not affected by the arrival of new information. Also, the MODWT is invariant to circularly shifting time series and has the multi-resolution detail and smooth coefficients that are linked with zero phase filter, two properties that do not hold for DWT (see, Dar et al, 2014).

[8]See Percival and Walden (2000) and Daubechies (1992) for detailed readings on MODWT and its competitive advantages over the conventional Discrete Wavelet Transform (DWT) as well as wavelet filters.

band-pass filters' nature of MODWT, with band-pass from the periodicity interval $[2^{-(j+1)}, 2^{-j})$ for $j = 1,..., J$, and through inverting the periodicity range, it is deduced that the associated time periods should be taken as $(2^{j}, 2^{j+1}]$ time units (Whitcher *et al*. 2000). Therefore, the following respective periods are deemed to be associated with the desired wavelet coefficients of scale $\psi_j = 1, \ldots, 6$: 2~4 quarters (6months – 1year), 4~8 quarters (1-2 year scale), 8~16 quarters (2-4 year scale), 16~32 quarters (4-8 year scale), 32~64 quarters (8-16 year scale), 64~128 quarters (16-32 year scale), etc. Due to small sample datasets, we however chose to examine MPRF for Ghana at the first three time-scales to proxy for short-, medium-, and long run interaction of policy interest rate and macroeconomic variables.

3. Empirical Results and Inferences

3.1 Preliminary Analysis: Evidence of Asymmetric Quantile Slope

We begin quantile analysis by comparing the estimates at the first and third quartile with the median specification to ascertain any evidence of symmetric or asymmetric policy reaction function for Ghana. This is done by performing the Newey and Powell (1987) test of conditional symmetry as well as the Koenker and Bassett (1982) test for slope equality[9].

Table A1 at Appendix A presents the results for Newey and Powell joint test of conditional symmetry and Koenker and Bassett (1982) test for slope equality based on both aggregated and segregated dataset. It can be concluded that the slope coefficients are not constant across quantiles for both datasets, as the respective computed Wald statistics reject the null of symmetry across quantiles. This provides ample evidence of a departure from symmetric to asymmetric policy reaction function for BOG. Consistently, the results from the Koenker and Bassett (1982) test, exhibited in Panel B of the table, also unveil favourable evidence of changing slope coefficients across quantiles. Precisely, the computed Wald statistic also rejects the null of equal slope coefficients across quantiles (at least at 5% significant level) which suggests that the conditional mean estimates may not provide the full picture of policy reaction to inflation and output gap, especially at the tails.

Having detected clear evidence of asymmetry, we proceed to examine the quantile process estimates at both time and multiscale domains. Due to the small sample size, this paper focuses on the estimated posterior means for seven (7) quantiles including 30th, 40th 50th, 60th, 75th, 80th and 90th. In this case, we proxy the lower quartile effects with the 30th and 40th quantiles. We then report quantile process estimates at both levels (i.e. time-domain) and wavelet time-scales (i.e. multiscale domain) dataset, the latter generated using MODWT with Debauchies' asymmetric filter of length 8 (LA8).

3.2 One-Stage Frequentist Quantile (FQ) Estimates at Time Domain

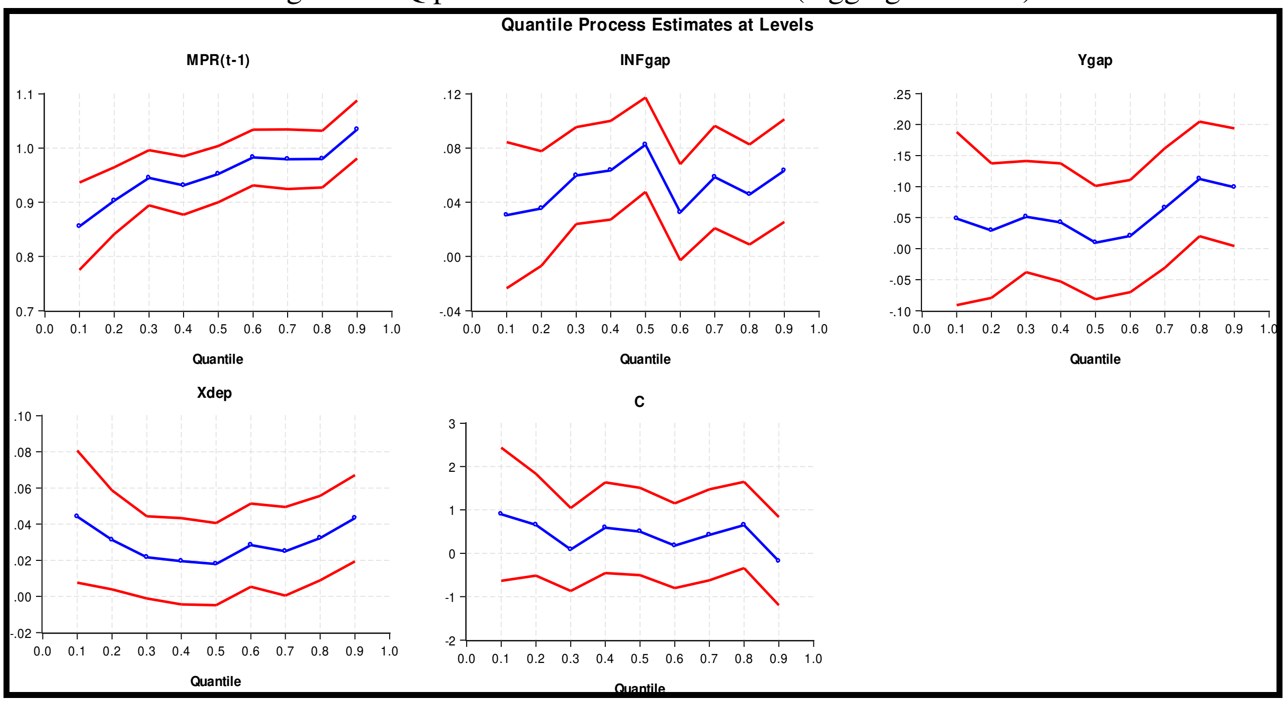
3.2.1 *Linear Rule Estimates at Time Domain*

Figure 1 presents the FQ process estimates for monetary policy rule based on the level aggregated dataset (i.e. linear Taylor rule). Notably, the FQ process estimates differ significantly over the conditional distribution of policy interest rate, surmising a nonlinear BOG policy rule. The FQ

[9]For brevity, interested readers are kindly referred to Newey and Powell (1987); Koenker and Bassett (1982), Akosah et al., (2020) for detailed exposition of both methods.

estimates in the figure show that the process coefficients for the lagged policy interest rate are positive and statistically different from zero across all quantiles. In terms of magnitude, the interest rate persistence increases from 0.94 at the lower (30th) decile to 0.98 at the 60th quartile and further up to 1.03 at the extreme upper (90th) decile quantile, indicating a monotonically increasing policy inertia for Ghana. The high interest rate inertia across all quantiles also reveals a backward-looking monetary policy rule, in line with Akosah et al. (2020). However, the observed changing magnitudes of policy inertia across quantiles reinforce the claim that the standard regression based on the conditional mean does not adequately provide the dynamic behaviour of MPRF at the extremes.

Figure 1: FQ process Estimates at Levels (Aggregated Data)



Note: Model satisfies stability and normality assumptions with respective p-values of 0.5093 and 0.4027. INFGAP is inflation gap; YGAP is output gap and Xdep denote changes in log nominal exchange (+ = depreciation; - = appreciation)

Further analysis of the Figure shows that the process coefficients of output gap are positive but statistically indifferent from zero across all quantiles, except at the extreme upper quantiles (80th and 90th deciles) where they become positive and significant. This implies that output gap (overall business cycle) tends to have a general weak influence on changes in monetary policy interest rate, especially below 80th quantiles at levels. However, Figure A1 at Appendix A clearly illustrates a positive and statistical significance process coefficient for lagged output gap at the lower quartile (30th) and the upper quartiles (60th, 70th and 80th deciles). Thus, monetary authority responds contemporaneously to aggregate demand pressures when policy interest rate is at the extreme upper quantiles but have a have delayed reaction to aggregate demand pressures when interest rate is below extreme upper quantiles. The significant policy response to output gap at different quantiles indicates policy pursuit of flexible inflation targeting (IT) regime over the sample period.

On the other hand, the process coefficients for inflation gap at the aggregated data level (see Figure 1) are also positive and statistically significant across quantiles. The magnitudes of policy response are however small when compared with the Taylor principle. Yet, divergent policy response remains as the coefficients rise from the lower to median quantile (50^{th}) and generally decline thereafter at extreme upper decile quantiles. This observation illustrates an apparent significant contemporaneous influence of inflation dynamics on policy interest rate across quantiles.

In addition, we also identify comparable positive effect of nominal exchange rate (depreciation) on monetary policy rate and this is statistically significant across all quantiles, except at the 40^{th} and 50^{th} decile quantiles. The effects of exchange rate on monetary policy rate for the level aggregated dataset are estimated to be in the range of 0.017 and 0.044. This suggests quantile-specific dependence of monetary policy rate on nominal exchange rate in Ghana, as the effects are somewhat larger at the tails. In addition, the lack of statistical significance of the process coefficients for nominal exchange rate at the 40^{th} and 50^{th} decile quantiles also reinforces that an application of the conditional mean estimation techniques may not detect these extreme dynamic influence of the former on policy interest rate in Ghana.

3.2.2 *Nonlinear Rule Estimates at Time-Domain*

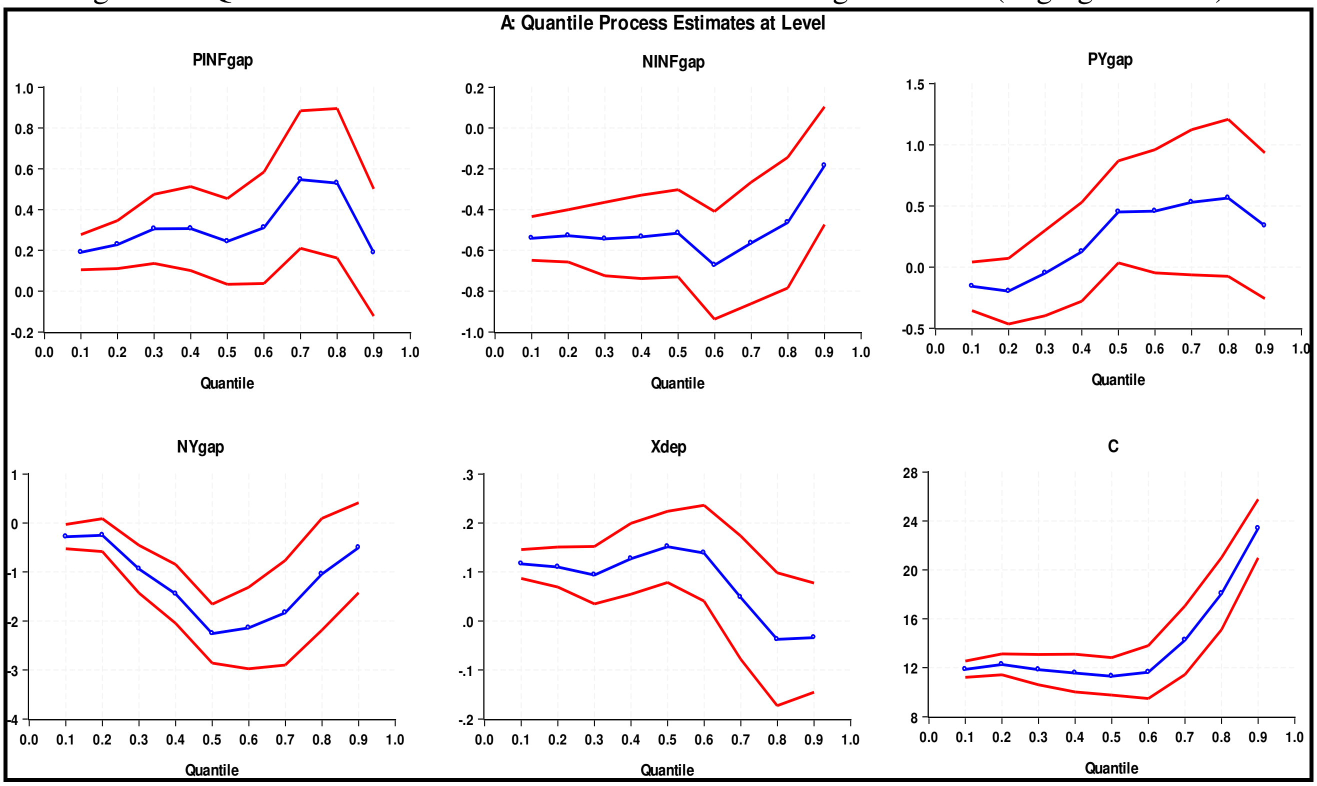
We now turn to the segregated dataset to explore possible nonlinear policy dynamics in Ghana at time-domain. Figures 2 and 3 display the time-domain FQ estimates for monetary policy rule based on segregated data without and with lagged interest rate respectively. The figures remit significant monetary policy dynamics that are hardly discernible from the aggregated dataset. Notably, Figure 2 clearly lends support to high interest rate smoothing in Ghana. However, the estimates without the interest rate smoothing parameter clearly illustrate increasing importance of both inflation and output gaps in policy decision making process although the model missed a couple of diagnostics tests. Nevertheless, not only does the inclusion of the smoothing parameter dampen the weights and significance of the other predictor variables, it also alters the signs of some variables across quantiles (see Figure 3). This suggests that although policy rules with an interest rate smoothing term show a high fit in general, the estimation results could be misleading (see Wolters, 2012).

Notwithstanding, some salient observations are detected for the predictor variable that are worth noting. Nonlinear policy reactions to negative and positive inflation and output gap are clearly discernible from both figures. Specifically, the process estimates illustrates that BOG has diverse responses to positive and negative output gap across all quantiles. Both figures show a general weak policy response to economic expansion (positive output gap) across quantiles, except at the 60^{th} and 70^{th} deciles (see Figure 2). The direction of policy response to economic expansion also differ as negative process coefficients are observed from the lower to median quartiles, but they assume positive signs between 60^{th} and 90^{th} deciles.

However, mixed outcome is observed for the policy parameter for economic recession from both figures. While Figure 2 reveals a general negative and significant policy response to economic recession (except at the extreme upper quartiles), Figure 3 rather unveils a general positive but insignificant policy parameter for the latter.

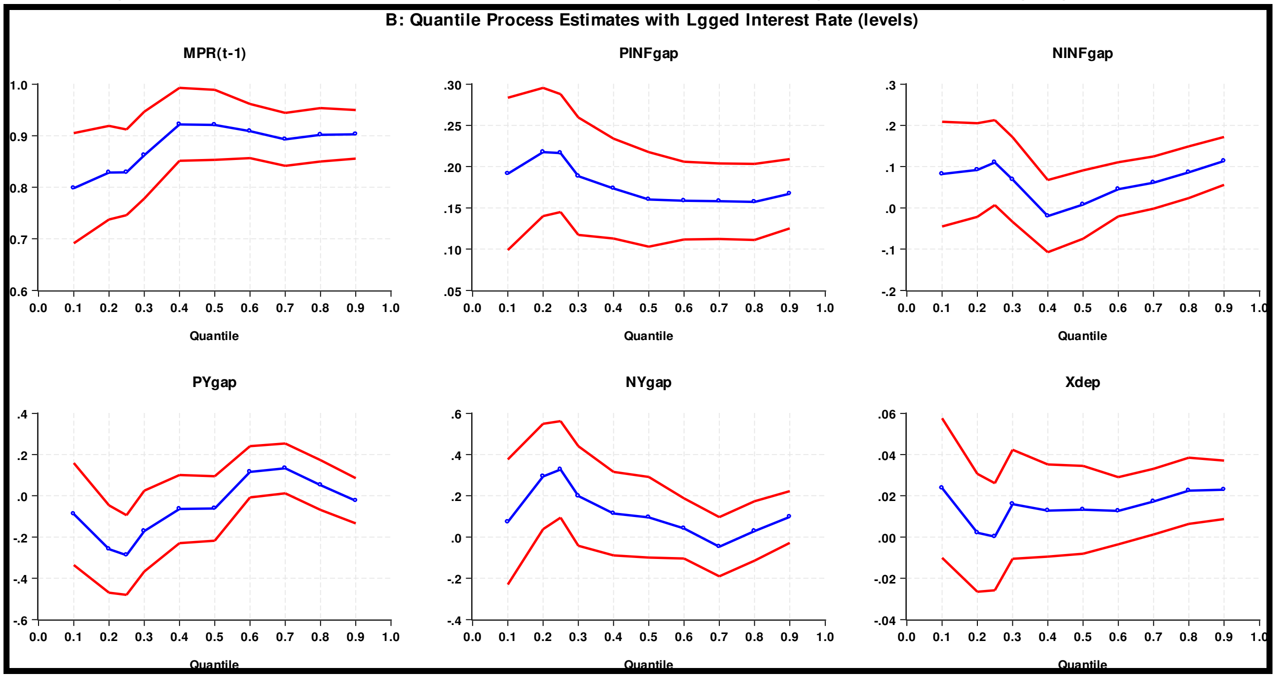
Similar nonlinear responses to positive and negative inflation gap are observed in both figures. On one hand, BOG response to positive inflation gap is generally positive and significant across quantiles. On the other hand, the policy response to negative inflation gap is however mixed from both figures. While Figure 2 illustrates a general insignificant positive policy response to negative inflation gap, Figure 3 shows a significant negative policy responses to below-target inflation across all quantiles. Similar to the aggregate data, both figures indicate that the policy relevance of exchange rate remains quantile-dependent.

Figure 2: FQ Process Estimates at Levels without Smoothing Parameter (Segregated Data)



Note: This model excluding the lagged interest rate. It satisfies both stability and normality assumptions with respective p-values of 0.5812 and 0.2617 but fails serial correlation test based on both correlogram of residuals and squared residual up to 28 lags. PINFGAP is positive inflation gap; NINFGAP is negative inflation gap; PYGAP is positive output gap; NYGAP is negative output gap and Xdep denote changes in log nominal exchange (+ = depreciation; - = appreciation)

Figure 3: FQ Process Estimates at Levels with Smoothing Parameter (Segregated Data)



Note: This model includes lagged policy interest rate. It satisfies stability and normality assumptions with respective p-values of 0.4213 and 0.1418 and the Q-statistics for both Correlogram of Residuals and Squared Residuals could not reject the null of no serial correlation up to lag 28. PINFGAP is positive inflation gap; NINFGAP is negative inflation gap; PYGAP is positive output gap; NYGAP is negative output gap and Xdep denote changes in log nominal exchange (+ = depreciation; - = appreciation)

3.2 Wavelet Multiscale (Time-Frequency Domain) Quantile Estimates

Due to the fact that level analysis may potential conceal policy dynamic at the frequency domain, we proceed to examine MPRF at multiscale for robustness. In addition, since the segregated data tends to unveil salient policy dynamics, this section focuses on the latter only for the purpose of brevity. In detail, Figure 4 (A, B & C) presents the FQ process coefficients at different time scales (for short-, medium- & long-run respectively) based on the segregated data, while Figure B1 at Appendix B displays similar time-scale estimates using the aggregated data. The time-scale results in both figures largely contradict the findings from the level data for all the predictor variables. Particularly, both figures illustrates lack of significant evidence of interest rate inertia at the shorter time-scale across all quantiles as the process coefficients for the smoothing parameter are negative but statistically insignificant across quantiles (except at 30th decile). Nonetheless, policy inertia becomes more obvious at the medium and longer time horizons although the magnitude is relatively smaller than that reported from the time-domain (level) analysis.

Figures 4A-C rather reveal varying policy parameters for difference phase of economic cycles (boom or downturn) across quantiles and time-scale. On one hand, the estimates (in Figure 4A-B) illustrate a general easing policy stance during economic downturn but the corresponding 95% CIs suggest insignificant policy reaction at the shorter and medium time-scales. The policy parameter for negative output gap is however significant in the longer time scale for quantiles beyond 70th decile (see Figure 4C). This connotes policy aggression in curtailing economic recession is more apparent in the long run, particularly at the upper tail, indicating a flexible IT framework in Ghana.

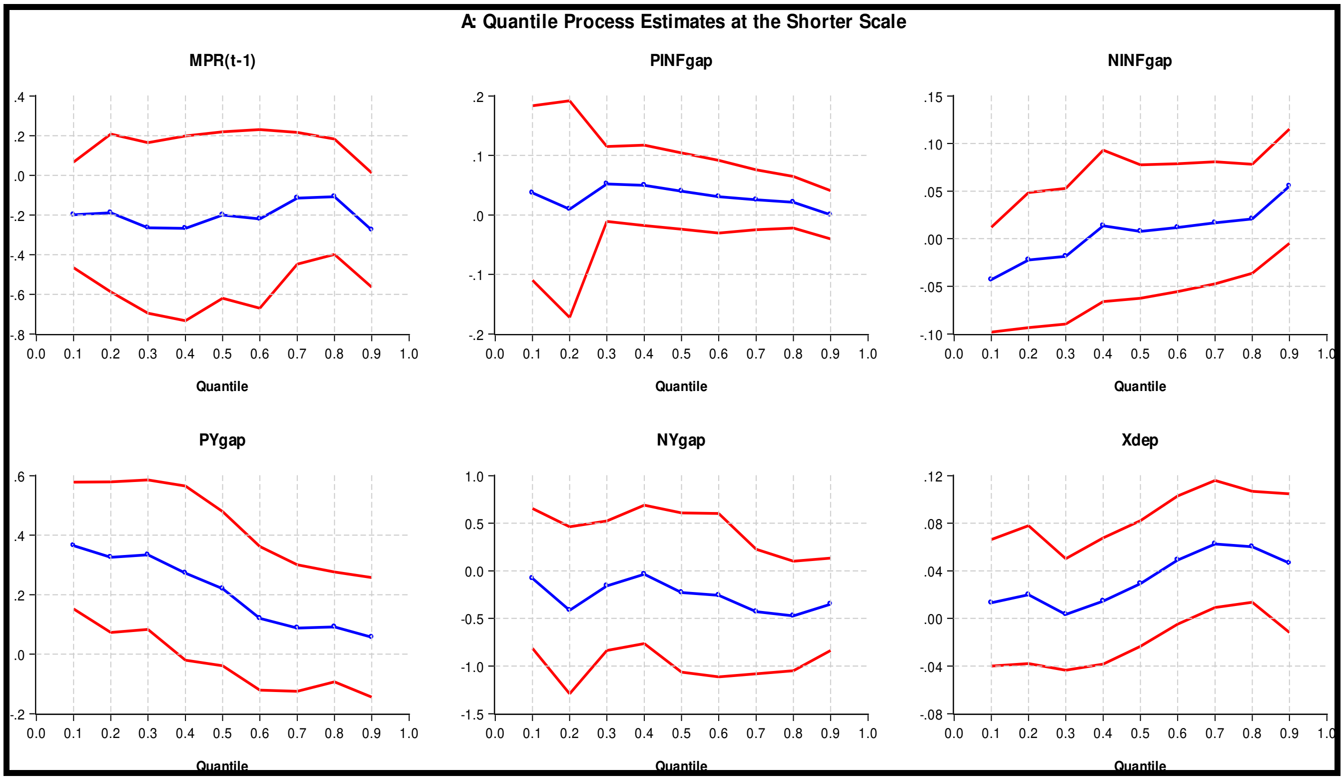
On the other hand, policy reaction to economic booms (positive output gap) is generally positive across time-scales and quantiles, which is intuitively consistent with economic theory. Nevertheless, analogous asymmetric policy response is clearly noticeable across time-scale and quantile, as policy aggression in dampening aggregate demand pressures is noticed at the lower tails of the shorter time-scale (see Figure 4A). Yet, a parallel aggressive policy response to economic expansion is apparent (see Figure 4B-C) only at the extreme upper tails in the medium (at 90th decile) and longer ($\geq$ 70th decile) time-scales. Nonetheless, we uncover unveil greater magnitude of policy response (in absolute terms) to output gap during economic recession than during economic expansion (Figures 4A-C). This contrasting policy response to downturn and boom cycles may intuitively be linked to the predominant and lingering supply-side shocks (such as frequent adjustments in domestic ex-pump, utilities and transport prices, and recurrent acute exchange rate depreciation, etc.) which adversely affect domestic economic activities in Ghana. Conceivably, these lingering supply-side shocks somewhat compel the BOG to adopt a precautionary demand for expansions, by desiring a positive than a negative output gap at a given inflation level.

Furthermore, we detect similar nonlinear policy response to different trajectory of inflation deviation from target (or trend). Specifically, policy response to negative inflation gap (disinflationary period) diverges across quantiles and time-scales, though generally insignificant. The response is negative and statistically significant from the 60th decile upward at the longer time-scale, surmising upper tail effect. In contrast, although policy reaction to positive inflation gap is generally positive, the degree and the level of statistical significance increase with time-scales. Precisely, we find apparently low and broadly insignificant policy response to positive inflation gap at the shorter time-scale across quantiles (see Figure 4A) with a range of [0.0002 0.0521]. The range of responses however increase to [0.0822 0.1543] and [0.1477 0.3575] in the medium and longer time-scales respectively, and are all statistically significant across quantiles. By inference, policy activism increases in the long run and particularly at the lower tails when inflationary pressures become highly persistent.

There is also a vivid evident of a monotonically decreasing trends in the magnitude of response to above-target inflation (i.e. positive gap) from lower (30th decile) to extreme upper (90th decile) quantiles across time-scales. The observed positive inflation bias reinforces that BOG has precautionary demand for price stability, especially in the medium- to long-run, in a quest to building policy credibility.

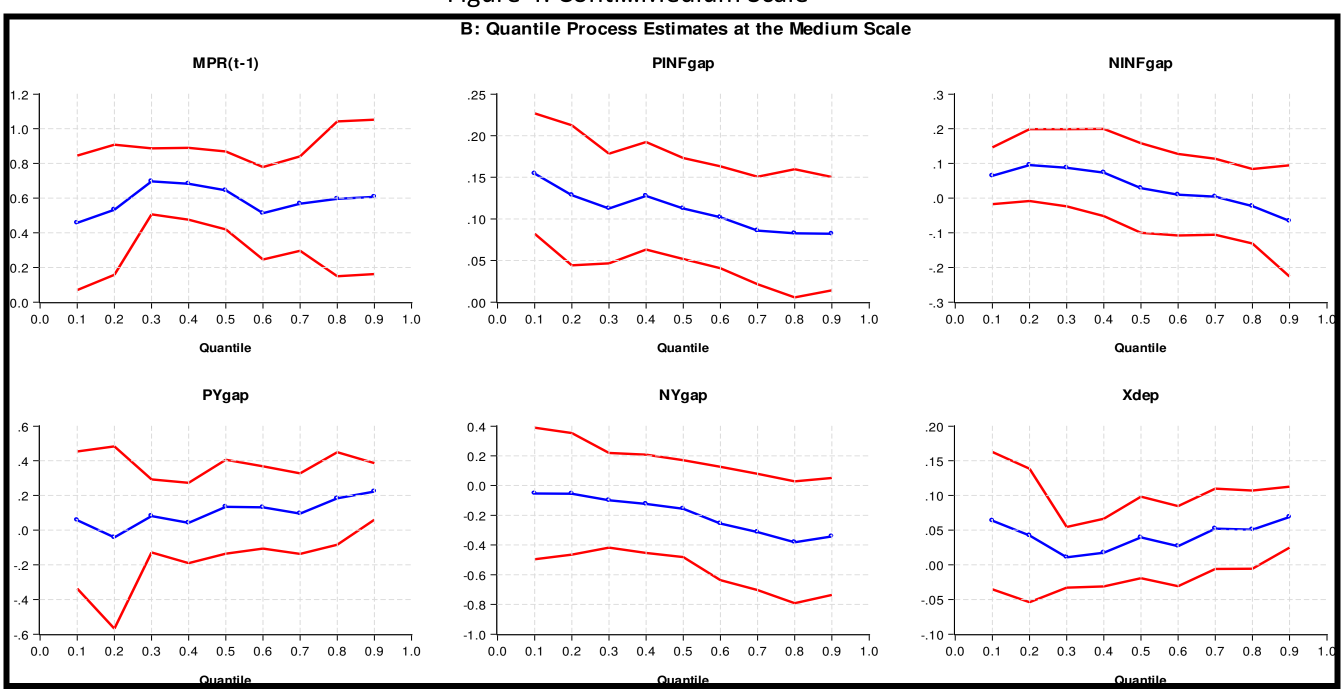
Another important observation is that policy response to exchange rate dynamics is positive and statistically significant at the upper quartiles across all time-scales. While the short run policy response to exchange rate is statistically significant at the 70th and 80th decile quantiles, significant policy reactions are only visualized at the 90th and 70th deciles in the medium and longer time-scales respectively. This strongly emphasises the earlier finding of tailed exchange rate effect on policy interest rate in Ghana.

Figure 4: Quantile Process Estimates at Wavelet Time-Scales (Decomposed Data)



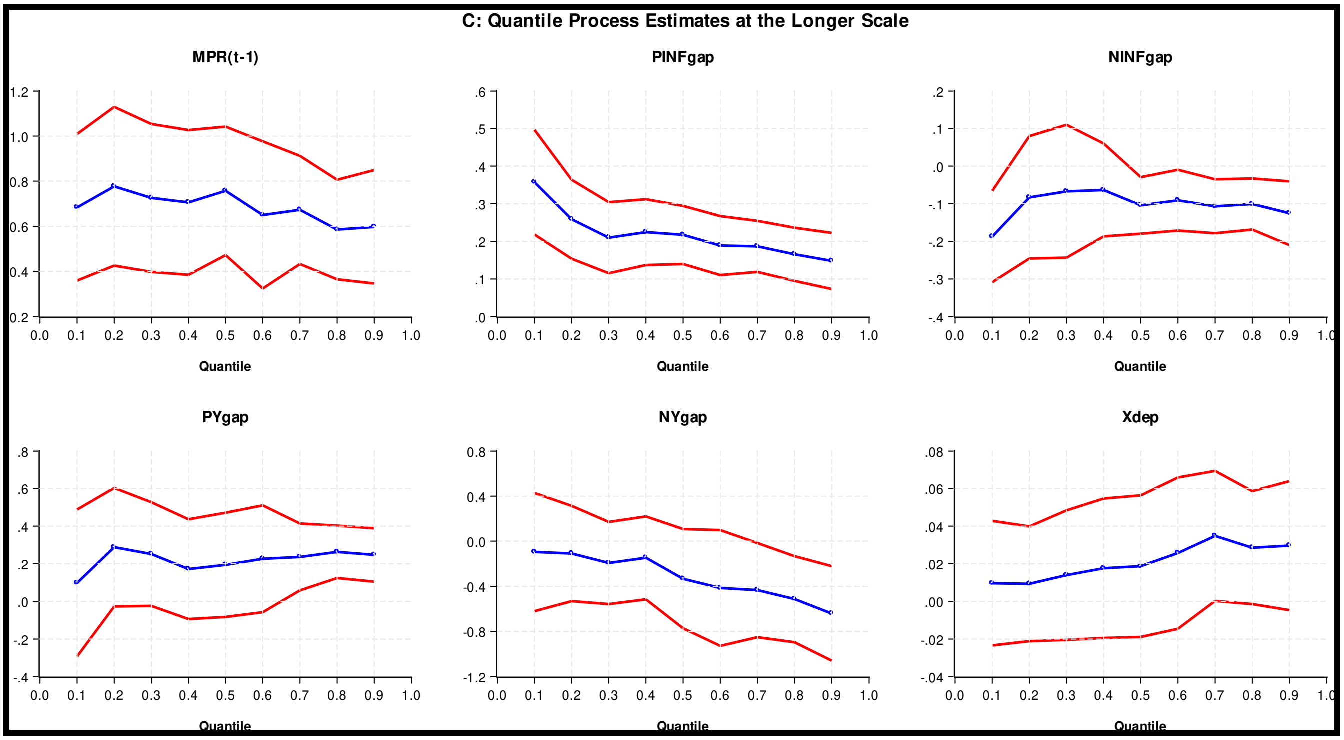
Note: Model satisfies stability and normality assumptions with respective p-values of 0.8598 and 0.7324. PINFGAP is positive inflation gap; NINFGAP is negative inflation gap; PYGAP is positive output gap; NYGAP is negative output gap and Xdep denote changes in log nominal exchange (+ = depreciation; - = appreciation)

Figure 4: Conti…Medium Scale



Note: Model satisfies stability and normality assumptions with respective p-values of 0.3047 and 0.1648. PINFGAP is positive inflation gap; NINFGAP is negative inflation gap; PYGAP is positive output gap; NYGAP is negative output gap and Xdep denote changes in log nominal exchange (+ = depreciation; - = appreciation)

Figure 4: Conti…Longer Scale



Note: Model satisfies stability and normality assumptions with respective p-values of 0.9621 and 0.1325. PINFGAP is positive inflation gap; NINFGAP is negative inflation gap; PYGAP is positive output gap; NYGAP is negative output gap and Xdep denote changes in log nominal exchange (+ = depreciation; - = appreciation)

3.3 Robustness: Two Stage Frequentist Quantile Estimates

For robustness, we validate the preceding results by re-estimating the policy reaction function using two stage quantile regression for BOG monetary policy rule, in line with Chevapatrakul et al (2009, 2014). As afore-mentioned, we first regress inflation and output gap on a set of instruments and generate fitted values. Second, policy interest rate is then regressed on the fitted values generated for both inflation and output gap from the first step using quantile regression technique. Unlike Chevapatrakul et al (2009, 2014) that applied OLS to generate the fitted values for inflation and output gap, we however employ GMM which is more robust than the latter technique (see Table C1 at Appendix C). Based on similar residual bootstrapping technique with 100000 repetitions to obtain asymptotic covariance matrix of the estimates, Figures C2 and C3 at Appendix C present the two-stage Frequentist quantile (2SFQR) estimates for the aggregated and segregated datasets respectively with smoothing parameter. Notwithstanding, it is however apparent from the figures that the empirical results from 2SFQR do not differ significantly from the preceding one-stage approach. In view of this, the analysis based on the one-stage quantile regression is robust for economic inference.

4. Conclusion

Ghana's inflation has remained persistently high amid large internal and external aggregate demand and supply-side shocks. Consequently, this study empirically examines the monetary policy reaction function for Ghana at both time- and wavelet multiscale-spectrums. We employ versions of Frequentist quantile regressions to fit an augmented Taylor rule which incorporate nominal exchange rate in order to account for small-open economy characteristics of Ghana.

The results unveil nonlinear (asymmetric) monetary policy rule for Ghana, as policy responses to inflation and output gap vary considerably along the conditional interest rate distribution and time scales (short, medium and long run). The observed quantile-dependent policy rule also surmises that the conditional mean estimate may inadequately reflect the full policy dynamics at the tails of interest rate distribution. There is high policy inertia, although this is both quantile and time-scale dependent. Policy response to inflation gap is generally positive and significant, but the magnitude is very low when compared to the level prescribed by the Taylor Principle, epitomizing a general passive reaction to macroeconomic shocks using policy interest rate. Nonetheless, the results exhibit overriding bias towards positive inflation gap, indicating BOG's quest for maintaining price stability. Then again, policy aggression to output (in absolute terms) during recession (negative gap) generally outweighs that of expansion (positive gap), across quantiles and time-scales (especially medium-to-long run horizons). However, policy preference for output stabilization becomes paramount especially at the medium to longer time-scales via easing policy stance during economic downturn. Another key finding is that exchange rate has some influence on policy interest rate, although this exhibits quantile and time-scale dependence.

Our empirical findings reveal important policy implications. Exchange rate stability remains paramount for BOG to rein in inflation. This, together with effective communication strategies, is critical to anchor inflation and inflation expectations, and hence, boosts central bank's credibility. Capacity building of BOG forecasting team is equally pivotal to enhance the determination of the state of the economy at the time of policy decision-making. This is expected to improve information flow, inure well-informed policy decision and ultimately moderate policy inertia. There is also the need for continuous harmonisation of monetary and fiscal policies to address structural bottlenecks in order to hasten the financial and real sector response to policy action.

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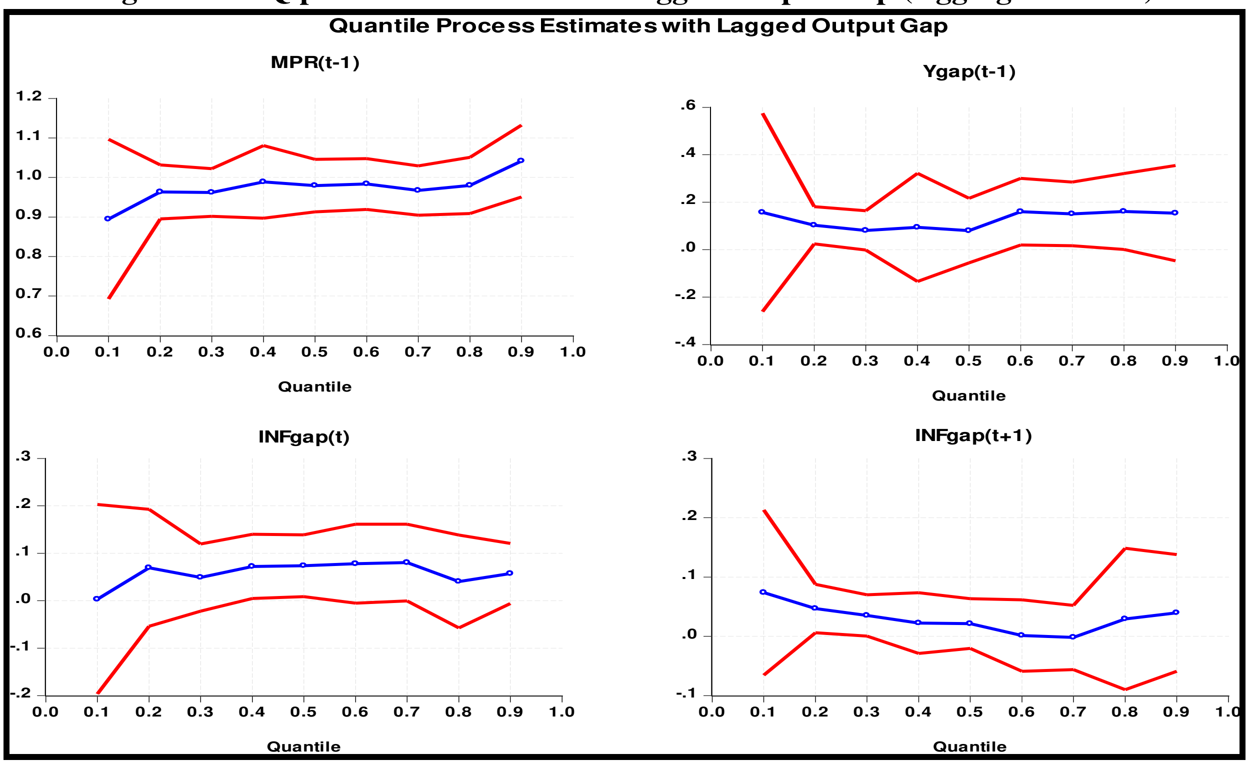
Appendix A

Table A1: Tests for Symmetry and Quantile Slope Equality

Panel A: Newell and Powell (1987) Joint Test for Symmetric Policy Reaction Function		
	Aggregated Data	**Segregated Data**
	Chi-Sq. Statistic [Prob]	***Chi-Sq. Statistic [Prob]***
Wald Test	10.552[0.0144]**	13.425[0.0038]*
Restriction: b(tau) + b(1-tau) - 2*b(0.5) = 0		
Panel B: Quantile Slope Equality Tests		
Wald Test	18.750[0.0009]*	26.839[0.0008]*
Restriction: b(tau_h) - b(tau_k) = 0		

Note: *&** denote 1% & 5% significant levels respectively.

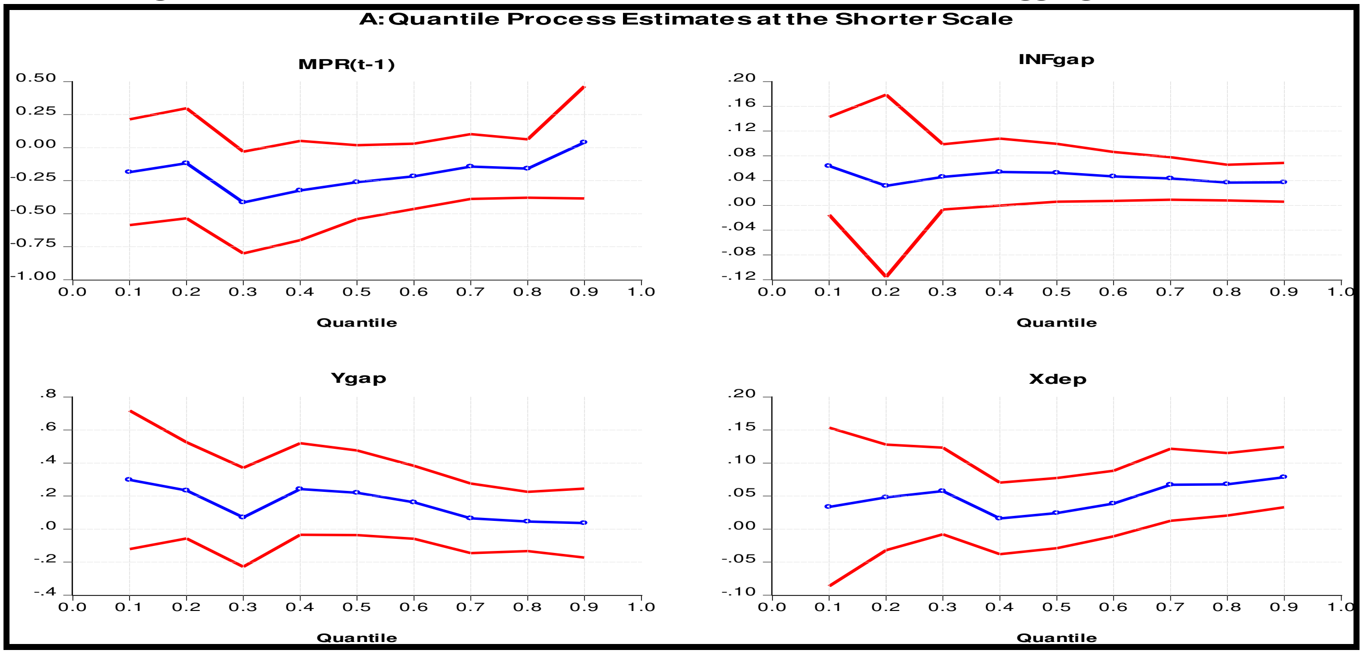
Figure A1. FQ process Estimates with Lagged Output Gap (Aggregated Data)



Note: Model satisfies stability and normality assumptions with respective p-values of 0.2303 and 0.3152. While the policy response to current inflation gap is insignificant the lower quartiles (10th -30th deciles) and extreme upper quartile (80th), that of the expected inflation gap is significant at the 20th and 30th deciles.

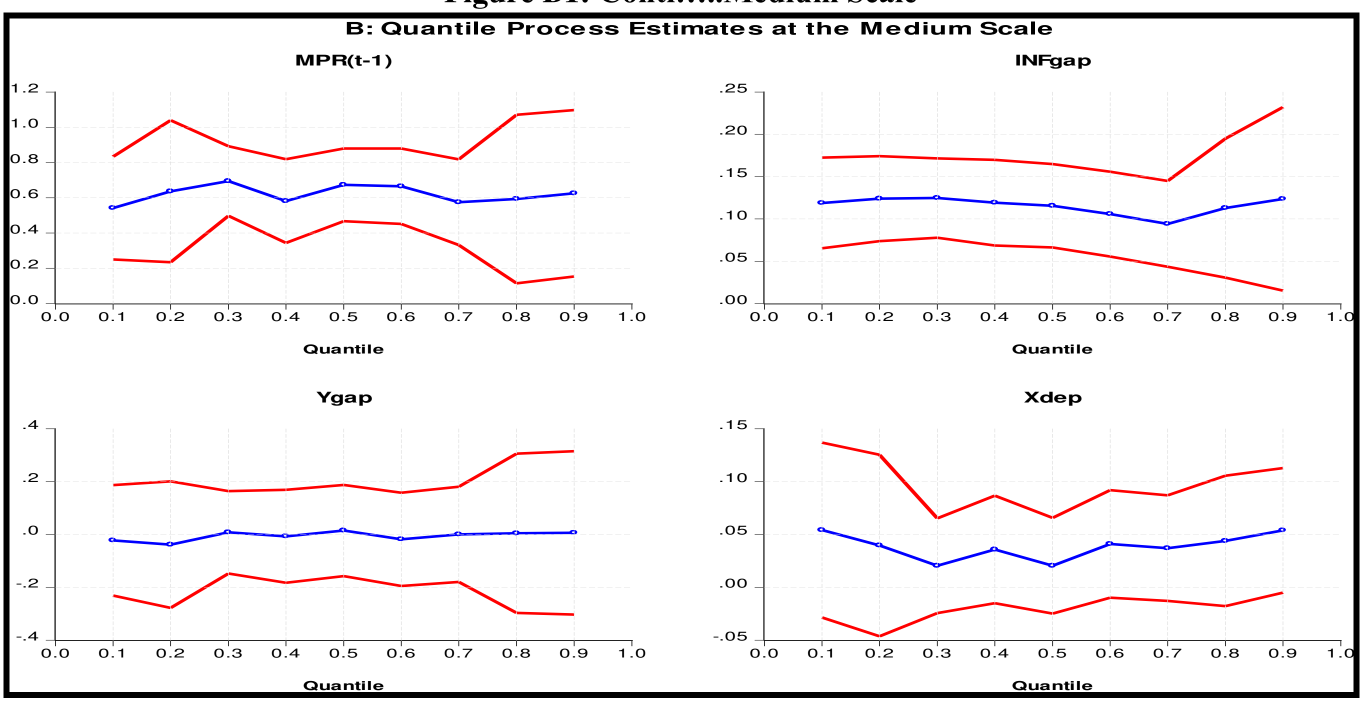
Appendix B

Figure B1. Quantile Process Estimates at Wavelet Time-Scales (Aggregated Data)



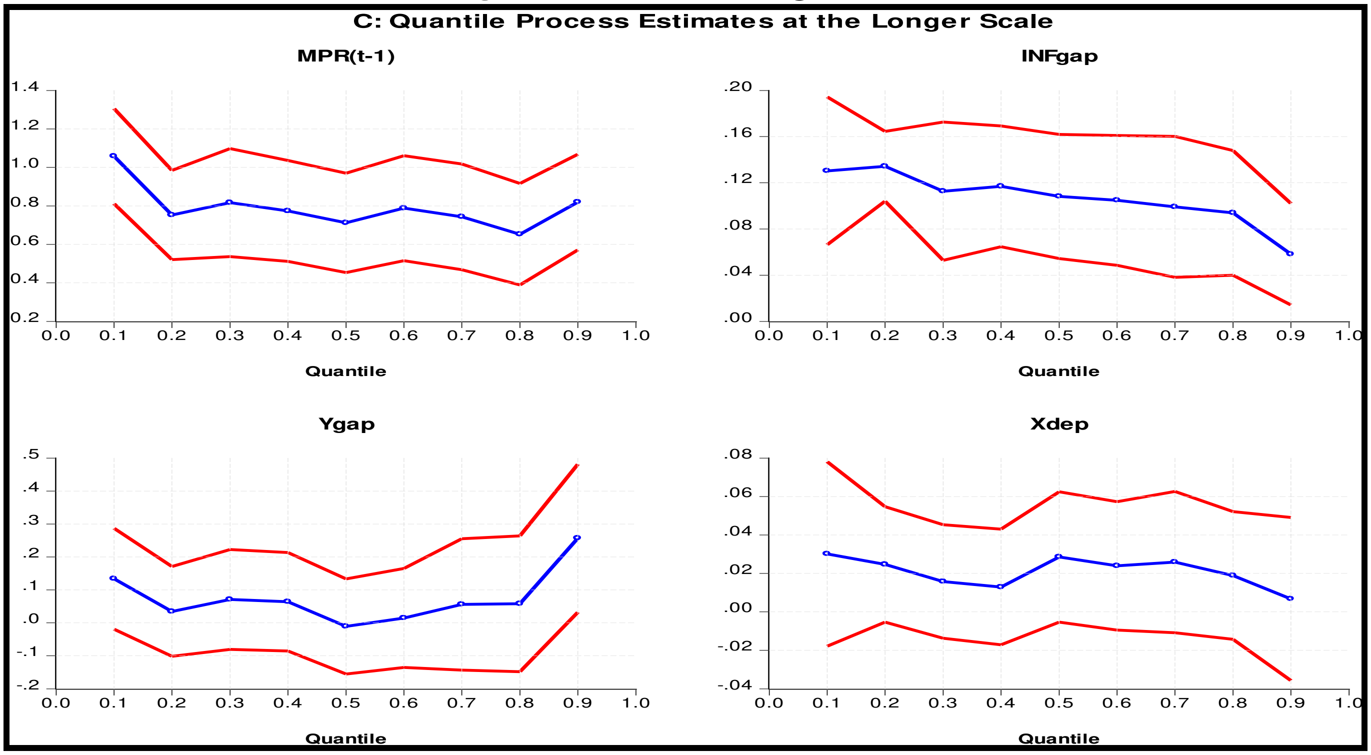
Note: Model satisfies stability and normality assumptions with respective p-values of 0.2855 and 0.5324. MPR is monetary policy interest rate; INFGAP is inflation gap; YGAP is output gap; and Xdep denote changes in log nominal exchange (+ = depreciation; - = appreciation); _hat denotes fitted values of the variable.

Figure B1: Conti…..Medium Scale



Note: Model satisfies stability and normality assumptions with respective p-values of 0.2403 and 0.1741; MPR is monetary policy interest rate; INFGAP is inflation gap; YGAP is output gap; Xdep denote changes in log nominal exchange (+ = depreciation; - = appreciation); _hat denotes fitted values of the variable.

Figure B1: Conti…..Longer Scale



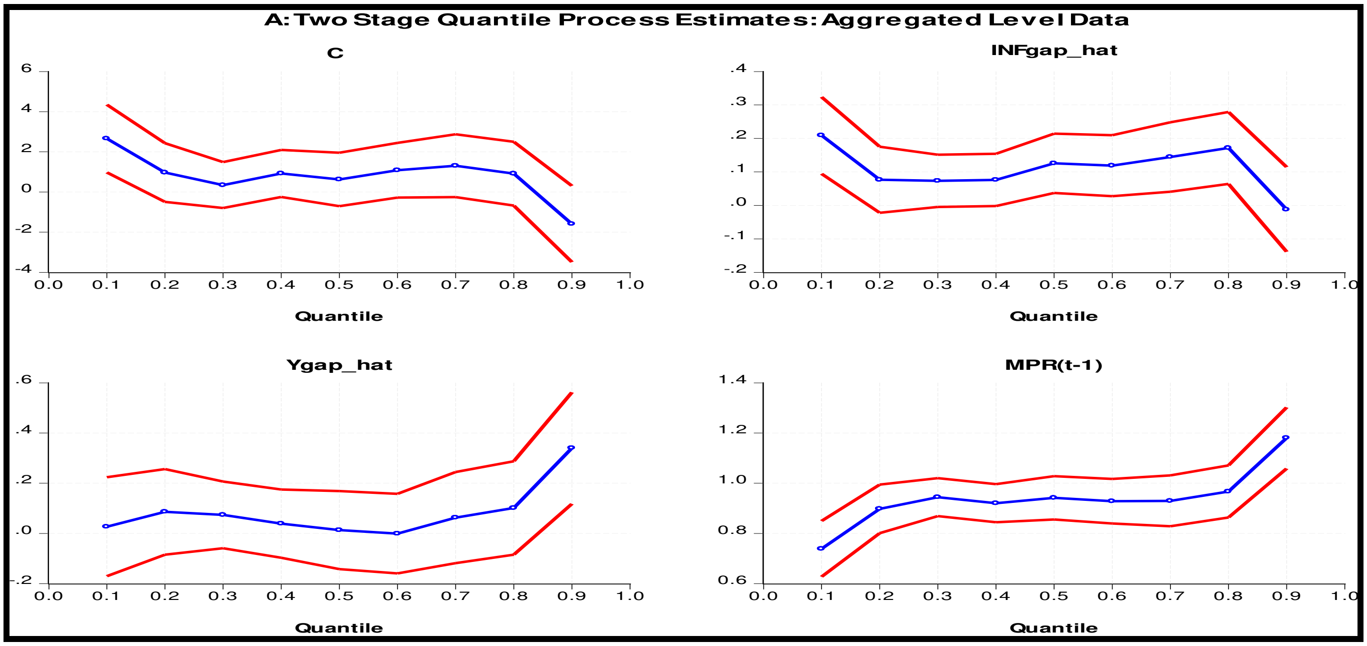
Note: Model satisfies stability and normality assumptions with respective p-values of 0.1640 and 0.5458. MPR is monetary policy interest rate; INFGAP is inflation gap; YGAP is output gap; Xdep denote changes in log nominal exchange (+ = depreciation; - = appreciation); _hat denotes fitted values of the variable.

Appendix C

Table C1: Model Selection for Two Stage FQR Estimates

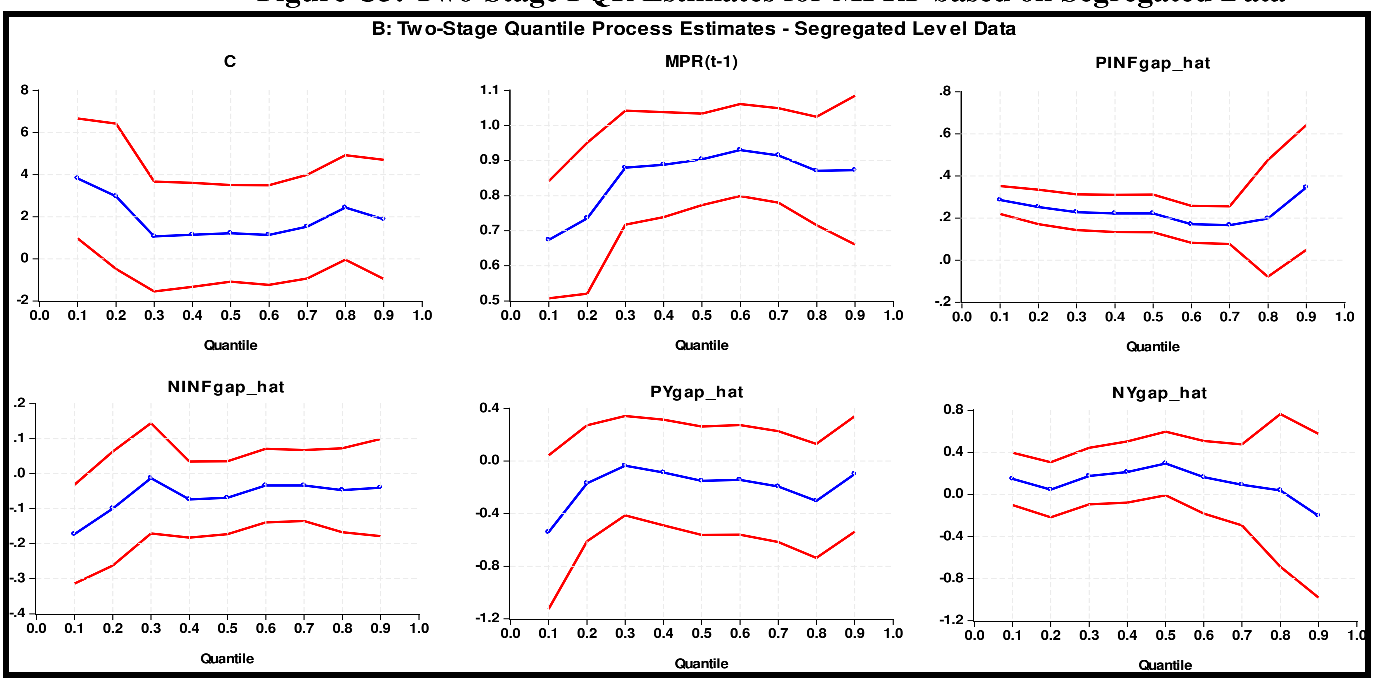
	5th		25th		50th		75th		90th	
C	10.781	0.972	13.280	0.366	14.796	0.626	16.755	1.194	18.522	-1.593
	[21.84]*	[0.79]	[25.39]*	[0.57]	[28.02]*	[0.92]	[23.29]*	[1.43]	[19.72]*	[-1.64]
INF_{gap_hat}	0.877	0.205	0.678	0.071	0.701	0.126	0.793	0.150	0.852	-0.012
	[8.49]*	[2.52]**	[6.62]*	[1.64]	[6.65]*	[2.77]*	[5.64]*	[2.70]*	[4.49]*	[-0.19]
Y_{gap_hat}	-1.287	0.146	-0.934	0.073	-0.904	0.013	-1.391	0.060	-1.158	0.340
	[-7.42]*	[1.02]	[-5.34]*	[0.99]	[-5.05]*	[0.16]	[-5.79]*	[0.61]	[-3.59]*	[3.00]*
MPR_{t-1}		0.821		0.943		0.942		0.940		1.180
		[10.47]*		[22.49]*		[21.43]*		[17.40]*		[18.99]*
	Model Diagnostics									
Adj. R-squared	0.151	0.615	0.278	0.732	0.343	0.774	0.386	0.802	0.328	0.792
Prob(Quasi-LR stat)	{0.019}**	{0.000}*	{0.000}*	{0.000}*	{0.000}*	{0.000}*	{0.000}*	{0.000}*	{0.000}*	{0.000}*
S.E. of regression	4.962	2.155	3.726	1.217	3.110	1.117	3.690	1.255	4.961	1.974
Normality	{0.008}*	{0.000}*	{0.002}*	{0.000}*	{0.001}*	{0.001}*	{0.032}**	{0.003}*	{0.003}*	{0.000}*
Stability	{0.079}***	{0.185}	{0.103}	{0.481}	{0.486}	{0.715}	{0.028}**	{0.519}	{0.251}	{0.526}
Correlogram of Residuals	Reject Ho	Accept Ho	Reject Ho	Accept Ho	Reject Ho	Accept Ho	Reject Ho	Accept Ho	Reject Ho	Accept Ho
Squared Residuals	Reject Ho	Accept Ho	Reject Ho	Reject Ho (3)	Reject Ho (2-5)	Accept Ho	Accept Ho	Accept Ho	Reject Ho (1-5)	Accept Ho

Figure C2: Two-Stage FQR Estimates for MPRF based on Aggregated Data



Note: Model satisfies stability and normality assumptions with respective p-values of 0.3917 and 0.0842; INFGAP is inflation gap; YGAP is output gap; MPR is monetary policy interest rate; _hat denotes fitted values of the variable.

Figure C3: Two-Stage FQR Estimates for MPRF based on Segregated Data



Note: Model satisfies stability and normality assumptions with respective p-values of 0.7820 and 0.1871. Also, the Q-statistics for both Correlogram of Residuals and Squared Residuals could not reject the null of no serial correlation up to lag 28. PINFGAP is positive inflation gap; NINFGAP is negative inflation gap; PYGAP is positive output gap; NYGAP is negative output gap and Xdep denote changes in log nominal exchange (+ = depreciation; - = appreciation); MPR is monetary policy interest rate; _hat denotes fitted values of the variable.