Monetary Policy Reaction Functions of the TICKs: A Quantile Regression Approach*

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Abstract

The purpose of this study is to investigate how the four nations of Taiwan, India, China and Korea (i.e., the TICKs member states) set interest rates in the context of policy reaction functions. It adds to the previous literature in that the empirical estimates are conducted not only at the central mean of interest rate, but we also take into account the response of interest rate to inflation, output and exchange rate at various points on the conditional distribution of interest rates, hence offering the possibility to test predictions of greater or lesser aggression at different bounds of interest rate. Our results indicate the tendency of a milder response to inflation at low interest rates and greater response at higher quantiles of interest rates, where inflation is presumably higher than desired for China and South Korea and hence offers evidence for non-linearity. While the response to inflation over the quantiles is significant for India, yet the Taylor principle is less likely to hold. For Taiwan, the results imply that another instrument is employed to deal with its official managed floating currency.

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1. Introduction

On January 28, 2017, the Financial Times reported that the BRIC is being replaced by TICKs. More specifically, two commodity-centric countries, Brazil and Russia, are replaced by two tech-heavy countries, Korea and Taiwan. Even though TICKs are firstly introduced for investment purposes with emphasis on their industry-level edges, it would be also useful to investigate the monetary policy of these countries. TICKs countries share some common characteristics. First, all of four countries are located in Asia and have IT industries as their engines of economic growth. Second, one of the major monetary objectives of these economies is price stability. Third, these countries have achieved relatively high and stable economic growths in the past decade.

However, there are some differences in these countries. Table 1 reports economic growth rates and inflation rates of TICKs countries. First, they are at different stages of development and have different economic scales as shown by differences in real GDP growth, per capita GDP and nominal GDP in Table 1. For example, regarding the economic scales, nominal GDP growth rates between 1980 and 2016 are 3,581% (from $304 billion to $11,181 billion) for China, 1,096% (from $189 billion to $2,260 billion) for India, 2,071% (from $65 billion to $1,411 billion) for Korea, and 1,155% (from $42 billion to 530 billion) for Taiwan. Second, those countries show different inflation rates. For example, average inflation rates between 2010 and 2016 are 2.8% for China, 8.3% for India, 1.9% for Korea, and 1.1% for Taiwan.

Table 1: Economic growth rates and inflation rates of TICKs countries

Category	Year	China	India	Korea	Taiwan
Real GDP growth rate (Average, %)	1980-1989	9.8	5.8	8.8	8.3
	1990-1999	9.9	5.7	7.1	6.6
	2000-2009	10.3	6.9	4.7	3.8
	2010-2016	8.1	7.2	3.5	3.6
Per capita GDP (Nominal US dollars)	1980	311	271	1,735	2,362
	1990	343	379	6,501	8,167
	2000	953	451	12,155	14,923
	2010	4,536	1,356	22,296	19,291
	2016	8,088	1,703	27,942	22,520
Nominal GDP (Billion US dollars)	1980	304	189	65	42
	1990	410	330	279	167
	2000	1,210	475	562	331
	2010	6,082	1,669	1,095	446
	2016	11,181	2,260	1,411	530
Inflation rate (Average, %)	1980-1989	8.0	8.8	8.4	4.6
	1990-1999	7.8	9.5	5.7	2.9
	2000-2009	1.9	5.6	3.1	1.0
	2010-2016	2.8	8.3	1.9	1.1

Source: IHS DataInsight-Web.

There are also differences in the monetary policy objectives in these countries. For example, Central Bank of the Republic of China (Taiwan) appears to emphasize the stability of exchange rate (external value of the currency) while Reserve Bank of India seems to emphasize the economic growth. Therefore, it would be interesting to see how central banks in TICKs countries react to different macroeconomic conditions using Taylor-type rule. The current inflation targets for central banks in TICKs countries are: China around 3.00%, India 4.00%±2%, Korea 2.00%±0.5% and Taiwan 2.00%.[1]

[1] For the inflation target for China, see http://www.centralbanknews.info/p/inflation-targets.html.

The most common form of monetary policy reaction functions typically assume that interest rates relate linearly to the gap between actual and desired values of inflation and output (see e.g. Taylor, 1993, Clarida et al., 2000, and Swamy et al., 2005). Nonlinear policy rules emerge from either asymmetric central bank preferences (e.g. Nobay and Peel, 2003, and Cukierman and Muscatelli, 2008) or a nonlinear (convex) aggregate supply or Phillips curve (e.g. Dolado et al., 2005), or still when central banks follow the opportunistic approach to disinflation (Aksoy et al., 2006). Dolado et al. (2004) discuss a model, which comprises both asymmetric central bank preferences and a nonlinear Phillips curve. Another strand of the monetary policy literature, dynamic stochastic general equilibrium models (see e.g. Smets and Wouters, 2003) make use of linear policy reaction function.

Empirical studies on nonlinear monetary policy reaction functions abound in the literature for both developed and developing countries. For instance, Moura and de Carvalho (2010) investigated the existence of non-linear policy responses in developing Latin American countries and found some tentative evidence in support. However most of these studies have focussed on estimates only at the central mean of the policy rate with recent few exceptions that offer quantile regression method to generate estimates of the response to inflation at each of the points (quantiles) of the interest rate distribution. For instance, Chevapatrukul et al. (2009) employed quantile regression to Taylor rules for Japan and the USA. They found that inflation has a larger effect on higher quantiles of interest rates (where inflation is presumably higher than desired) than at lower quantiles of interest rates (where inflation is likely relatively low) contrary to the greater aggression to inflation that they expected to find as interest rates reach low levels as the lower bound is approached. Miles and Schreyer (2012) apply quantile regression to Taylor estimations for four South East Asian economies, viz., Indonesia, Korea, Malaysia, and

Thailand. They found that monetary policy in all four economies are nonlinear with hump-shaped response to inflation across quantiles. They attribute their results to the desire from these economies to limit exchange rate appreciation, as all four countries depend heavily on exports.

The TICKs member states in our sample might have varied monetary policy stances. For instance, the People's Bank of China does not have an obvious operational target that can be used as a main indicator of its policy stance, together with Taiwan. However, Wang and Handa (2007) find that, during the period 1993 to 2003, the People's Bank of China followed a Taylor-type rule for the interest rate to target inflation and output. Burdekin and Siklos (2008) model post-1990 monetary policy with an augmented McCallum-type rule and show that the monetary authority responds to both the output gap and the exchange rate. Zhang (2009) finds that the interest rate (price) rule is likely to be more effective in macroeconomic management. Chang and Chien (2017) assume a Taylor rule for the central bank of Taiwan post 1980's and showed that the real exchange rate matters on top of output and inflation. In India, Singh and Kalirajan (2006) assessment of monetary policy reaction functions suggest that monetary policy addresses multiple objectives of achieving and managing sustained growth, while ensuring macroeconomic stability. Taylor rules for Korea over the period since inflation targets were adopted in 1998 and there have been empirical studies by Eichengreen (2004) and Aizenman et al. (2008) that have reported that the Bank of Korea targeted lagged changes in the real exchange rate, current output and expected inflation over a 12-month horizon.

Keeping these in mind, the main crux of this study is to investigate how Taiwan, India, China and South Korea set interest rates in the context of Taylor-type rule models. A significant point of departure from previous studies on these economies is that the empirical estimates are conducted not only at the central mean of interest rate, but we also take into account the response of interest rate to inflation, output and exchange rate at various points on the conditional distribution of interest rates. This allows us to test predictions of nonlinearity in terms of the response of the central banks at different bounds of interest rate. Our results indicate the tendency of a milder response to inflation at low interest rates and greater response at higher quantiles of interest rates, where inflation is presumably higher than desired for China and South Korea and hence offers evidence for non-linearity. For India, the Taylor principle is less likely to hold across the different quantiles. For Taiwan, the results imply that another operational target might be used as a main indicator of its policy stance.

2. Methodology and Data

2.1. Econometric Methodology: The Interest Rate Rule –Estimation using Quantile Regression Methodology

Clarida et al. (1998; 2000) measure monetary policy by the short-term interest rate. This allows the central bank to choose the level of the interest rate from period to period and conduct policy. They end up with the following modified forward-type of monetary rule:

$$i_t = (1-\rho)\left[\alpha + \beta\pi_{t+k|t} + \gamma y_t\right] + \rho i_{t-1} + \varepsilon_t \qquad (1)$$

where ε_t is a policy shock, y_t is the output gap, $\pi_{t+k|t}$ is a k-period-ahead inflation forecast, and $0 \leq \rho \leq 1$ is the degree of interest rate smoothing. However, in our case, all interest rate time series appear to be near to unit root processes and estimates of ρ are very close to unity. It is well known that values of ρ in the vicinity of unity cause parameter estimates to diverge

(Chevapatrakul et al.; 2009).[2] To solve this problem, we follow Chevapatrakul et al. (2009) and we adopt Taylor's original rule specified by

$$i_t = \alpha + \beta\pi_{t+k|t} + \gamma y_t + \varepsilon_t. \quad (2)$$

For the purpose of this study, equation (2) can be modified and extended to capture the reaction of monetary policy to exchange rate movement:

$$i_t = \alpha + \beta\pi_{t+k|t} + \gamma y_t + \theta ER_t + \varepsilon_t, \quad (3)$$

where ER_t is the exchange rate return against the US dollar.

The standard approach of estimating a forward-looking Taylor rule, is to estimate the model parameters at the mean by GMM due to endogeneity, with a limited number of lagged variables included in the instrument set. However, parameter estimation at the mean of the interest rate distribution conditional on inflation and output gap is an incomplete description of monetary policy reactions. Specifically, several authors have shown that monetary policy reactions are not uniform over the conditional distribution of the interest rate. Wolters (2012) uses quantile regressions to estimate parameters over the whole conditional distribution of the federal funds rate and finds significant and systematic variations of parameters over the conditional interest rate distribution. Furthermore, Chevapatrakul et al. (2009) estimate the response of interest rates to inflation and the output gap at various quantiles on the conditional distribution of interest rates and show that there is no detectable evidence of increasing aggression toward inflation as interest rates reach low quantiles.

[2] Unit root test results are available from the authors upon request.

Several quantile estimation and inference methods that account for endogeneity are recently proposed in the literature. Chernozhukov and Hansen (2013) review quantile models with endogeneity and briefly review the literature on estimation and inference. Specifically, the authors review the main three quantile modeling frameworks: the inverse quantile regressions (IVQR) methodology developed by Chernozhukov and Hansen (2005, 2006, 2008), the local quantile treatment effects with binary treatment and instrument approach of Abadie, Angrist, and Imbens (2002), and the instrumental variables quantile regression in triangular systems (see, e.g., Imbens and Newey (2009), Chesher (2003), Koenker and Ma (2006), and Lee (2007)). The three approaches are not nested in general. The approach of Abadie, Angrist, and Imbens (2002) is not suitable for estimating the interest rate rule (equation (2)) since it requires both a binary endogenous variable and a binary instrument. Chernozhukov and Hansen (2013) argue that the key difference of the other two approaches is the conditions that allow identification. Specifically, the methodology of Chernozhukov and Hansen (2005, 2006, 2008) uses an unrestricted reduced form but imposes restrictions on the structural equation. On the other hand, the instrumental variables quantile regression in triangular systems approach requires monotonicity of the reduce form disturbance. However, Torgovitsky (2012) shows that under certain conditions the two approaches can be made compatible.

However, Lee (2016) argues that conventional quantile regression (QR) econometric techniques are not valid when regressors are highly persistent. Lee (2016) developed quantile econometric methods for robust inference in the presence of persistent and endogenous regressors. Specifically, Lee (2009) develops a new QR methodology (called IVX-QR) which corrects size distortions arising from regressors' persistence by adopting the IVX filtering method proposed by Magdalinos and Phillips (2009). In this paper, we use the IVX-QR methodology of Lee

(2016) in order to account of the endogeneity end persistence of monetary rule given in equation (3).

The IVX-QR approach

Recently, Lee (2016) developed quantile econometric methods for inference and prediction allowing for persistent and endogenous regressors. It is known that conventional quantile regression methods are invalid when predictors are highly persistent, such as in the case of monetary policy rules, whereby both interest rate and inflation are highly persistent. Hence Lee (2016) method adequately deals with these drawbacks. Consider a simple predictive model in mean:

$$\Upsilon_t = \delta_0 + \delta_1^{'}\mathcal{X}_t + u_{0t}, \quad (4)$$

with $E(u_{0t}/I_t) = 0$, where $\mathcal{X}_t$ is a mx1 vector of regressors, δ_1 is a mx1 vector of parameters, and I_t is the natural filtration. Now consider a linear QR model. Given the natural filtration I_t, the predictive QR model is

$$\Upsilon_t = Q_{\Upsilon_t}(\tau/I_t) + u_{0t\tau} = \delta_{0,\tau} + \delta_{1,\tau}^{'}\mathcal{X}_t + u_{0t\tau}, \quad (5)$$

where $Q_{\Upsilon_t}(\tau/I_t)$ is the conditional quantile of Υ_t such that $P\left(\Upsilon_t \leq Q_{\Upsilon_t}(\tau/I_t)/I_t\right) = \tau \in (0,1)$. Model (5) analyzes other quantile predictability as well as the median of Υ_t. This feature is well suited to the analysis of financial asset returns.

We further assume that the regressors follow an autoregressive form:

$$\mathcal{X}_t = R_n\mathcal{X}_{t-1} + u_{xt}, \quad (6)$$

where $R_n = I_K + \frac{C}{n^{\alpha}}$, for some $\alpha > 0$. In this specification, the pair (α, C) represents persistence of the regressors. Lee (2016) shows that in the case of persistent (local to unity or unit root) regressors, the limit distribution of the ordinary QR slope coefficient estimator is nonstandard and nonpivotal. Specifically, the t-ratio becomes:

$$t_{\hat{\delta}_{1,\tau}} = \frac{\hat{\delta}_{1,\tau} - \delta_{1,\tau}}{SE(\hat{\delta}_{1,\tau})} \sim [1 - \lambda(\tau)]^{0.5} \, Z + \lambda(\tau) \, \eta(C), \tag{7}$$

Where Z and $\eta(C)$ stand for standard normal distribution and nonstationary statistics, respectively, and $\lambda(\tau) = -Corr(1(u_{0t\tau} < 0) u_{xt})$. The first term of the asymptotic distribution in equation (7) corresponds to standard inference, while the second term, $\lambda(\tau) \, \eta(C)$, introduces nonstandard distortions. Clearly, the magnitude of nonstandard distortions depends firstly, on the degree of persistence through the nonstationary distortion component $\eta(C)$ and secondly, on the endogeneity of regressors through the QR endogeneity component $\lambda(\tau)$.

It is convenient to transform the model (4) to remove the intercept term:

$$\Upsilon_{t\tau} = \delta_{1,\tau}^{'} \mathcal{X}_t + u_{0t\tau}, \tag{8}$$

where $\Upsilon_{t\tau} = \Upsilon_t - \hat{\delta}_{0,\tau}^{QR}(\tau) = \Upsilon_t - \delta_{0,\tau} + O_p\left(n^{-1/2}\right)$ is the zero-intercept QR dependent variable, and n is the sample size. This is analogous to the demeaning process in the predictive mean regression in preparation for tests of the slope coefficient. Lee (2016) adopts the IVX filtering technique of Magdalinos and Phillips (2009) to correct the asymptotic distribution (equation (7)) for the nonstandard distortion. The main idea of IVX filtering is to filter $\mathcal{X}_t$ to generate $\tilde{\mathcal{Z}}_t$ with mild persistence – intermediate between first differencing and the use of levels data. In particular,

$$\tilde{\mathcal{Z}}_t = R_{n\mathcal{Z}} \tilde{\mathcal{Z}}_{t-1} + \Delta \mathcal{X}_t, \quad R_{n\mathcal{Z}} = I_K + \frac{C_{\mathcal{Z}}}{n^{\psi}}, \tag{9}$$

where $\psi \in (0,1)$, $C_{\mathcal{Z}} = c_{\mathcal{Z}} I_k$, $c_{\mathcal{Z}} < 0$, $\tilde{\mathcal{Z}}_0 = 0$. The parameters $\psi \in (0,1)$ and $c_{\mathcal{Z}} < 0$ are specified by the researcher.[3]

Lee (2016) proposed new IVX-QR methods that are based on the use of IVX filtered instruments $\tilde{\mathcal{Z}}_t$. The IVX-QR estimator $\hat{\delta}_{1,\tau}$ for $\delta_{1,\tau}$ is defined as

$$\hat{\delta}_{1,\tau}^{IVXQR} = arg \underbrace{\inf}_{\beta_1} \left(\sum_{t=1}^{n} m_t(\delta_1)\right)' \left(\sum_{t=1}^{n} m_t(\delta_1)\right), \tag{10}$$

where $m_t(\delta_1) = \tilde{\mathcal{Z}}_{t-1} \left(\tau - 1\left(\Upsilon_{t,\tau} \leq \delta_1' \mathcal{X}_t\right)\right)$.

Considering that the null hypothesis of interest in predictive regression is of the form $H_0\colon \delta_{1,\tau} = 0$, Lee (2016) proposed a computationally attractive testing procedure. Based on the fact that $\tilde{\mathcal{Z}}_t$ and $\mathcal{X}_t$ are “close” to each other, the author uses ordinary QR regressions on $\tilde{\mathcal{Z}}_t$ to test $H_0\colon \delta_{1,\tau} = 0$.

Specifically, consider the simple QR regression

$$\hat{\phi}_{1,\tau}^{IVXQR} = arg \underbrace{\min}_{\phi_1} \left(\sum_{t=1}^{n} \rho_t\left(\Upsilon_{t\tau} - \phi_1' \tilde{\mathcal{Z}}_t\right)\right), \tag{11}$$

where $\rho_t(v) = v(\tau - 1(v < 0))$ is the asymmetric QR loss function.

Then, it can be shown that under $H_0\colon \delta_{1,\tau} = 0$,

$$\widehat{f_{u_{ot}}(0)} \left(\tau(1-\tau)\right)^{-1} \left(\hat{\phi}_{1,\tau}^{IVXQR} - \delta_{1,\tau}\right)' \left(\tilde{Z}' \tilde{Z}\right) \left(\hat{\phi}_{1,\tau}^{IVXQR} - \delta_{1,\tau}\right) \to \chi^2(K), \tag{12}$$

[3] Lee (2016) discusses in detail the proper choice of (c_Z,ψ) and suggests a practical rule.

where $\tilde{Z}'\tilde{Z} = \sum_{t=2}^{n} \tilde{\mathcal{Z}}_t \tilde{\mathcal{Z}}_t'$.

2.2 Data

We use data for the 1994:M1 to 2016:M2 period for the four economies: Taiwan, India, China and South Korea (TICKs). The choice is partly driven by period over which the respective Central Banks have been operating and is also partly driven by data availability at the time of writing this paper. Data on the policy rate, consumer price index used to compute the month-on-month inflation rate, industrial production used to create the measure of output-gap based on the Hodrick-Prescott filter (with a penalty of 14400), the US dollar-based exchange rates (used to compute the month-on-month growth rate of the exchange rates), are all derived from the IHS DataInsight-Web.

The evolution of interest rates, inflation, output gap and exchange rate returns over the period of study are shown in Figures A1 to A4 in the Appendix of the paper, and the corresponding interest rates histograms are shown in Figures A5 to A8. One discernible pattern is that the distributions have heavy masses in the upper tail, i.e., the distribution is positively skewed with excess kurtosis (to the extent that the normality is rejected at the highest level of significance based on the Jarque-Bera test).[4] Our results based on the quantile regressions tend to confirm such patterns for the reaction of the interest rate to inflation rates, in the sense, that stronger responses are observed at higher quantiles.

[4] Complete details of which are available upon request from the authors.

3. Empirical analysis

3.1 Estimates at the Central Conditional Mean

To fix ideas, Table 2 reports GMM estimates of the Taylor rule equation (3) over the data window, i.e., 1994:M1 to 2016:M2. Inflation, output gap and exchange rate growth are instrumented using appropriately chosen lags of these variables. The set of instruments are determined by choosing lags that are sufficiently long to avoid correlation with the error term. We use the *J*-test (Hansen; 1982) for the validity of overidentifying restrictions for each set of chosen instruments.

Table 2: GMM estimation of the monetary rule at the conditional mean

	Taiwan	India	China	Korea
β	0.1513	0.6099	0.3499	6.1605**
γ	0.0434	0.1412	0.3166**	-0.0155
θ	-0.2361	-0.0850	0.6935***	-0.3895
J statistic	3.0420***	7.6238***	15.3589**	10.0968***

Notes: Estimated monetary rule: $i_t = \alpha + \beta\pi_{t+12} + \gamma y_t + \theta ER_t + \varepsilon_t$. *, **, *** denote statistical significance at 10%, 5% and 1%, respectively. J-statistic refers to Hansen's (1982) test for overidentifying restrictions. The set of instruments includes a constant, 1-4 lagged values of inflation, the output gap and exchange rate growth rate.

The specification for equation (3) allows for a forward-looking rate of inflation 12 months ahead, k=12 for inflation, a contemporary output gap, and contemporaneous exchange rate growth. (The dependence of these countries' monetary policy on current rather than expected output gap agrees with general consensus (as for example, Miles and Schreyer's (2016) study of Asian economies, and that in the Euro area wide model of Dieppe et al., (2004)). *, **, *** denote statistical significance at 10%, 5% and 1%, respectively. Our results show that the set of instruments includes a constant, 1-4 lagged values of inflation, the output gap and exchange rate growth rate. In all cases and except for South Korea, the inflation (β) effect is statistically insignificant and China seems to respond to both the output gap (γ) and exchange rate (θ). The inflation effect β is much higher than one for South Korea, satisfying the "Taylor principle" that inflation increases trigger an increase in the real interest rate. This result echoes Miles and Schreyer (2012) results for South Korea to some extent and Jawadi et al. (2014) results for the response of the Bank of China to the exchange rate.

3.2 The Taylor Rule at Various Quantiles

Table 3 reports the estimated coefficients at each quantile using Lee (2016) IVX-QR for the countries over the data window which runs from 1994:M1 to 2016:M2 and we use an equation with the same set of instruments and the same forward-looking horizon as reported above in Section 3.1. The coefficient on the inflation rate variable for China is significantly different from zero at the upper end of the range, more precisely from the 80th to the 95th quantile. The response is greater than unity, supporting the Taylor principle. The responsiveness of the interest rate toward inflation at the upper end of the distribution of interest rate, i.e., at the relatively higher levels of interest rates (and possibly inflation as well) suggests that the Bank of China responded more aggressively to inflation and hence shows evidence of a deflation bias to monetary policy. South Korea, on the other hand, seems to respond to inflation rate at all quantiles except at the very end of the 95th quantile and is above unity at every point from the 20th quantile, hence supporting the Taylor principle. In fact, the response to inflation is greater than 1.50 at many points of the interest rate distribution and generally increases across quantiles. The response of the Reserve Bank of India to inflation rate, though positive, does not seem to adhere to the Taylor principle. As for Taiwan, its managed floating currency regime for the New Taiwanese

Table 3: Monetary rule using IVX-QR estimation

Country	Parameters	Quantiles										
		Q=5	Q= 10	Q=20	Q=30	Q=40	Q=50	Q=60	Q=70	Q=80	Q=90	Q=95
Taiwan	β	0.0460	0.0768	0.0926	-0.0221	-0.0394	-0.0832	-0.0196	0.0025	0.1260	-0.0595	0.1822
	γ	0.0082	0.0082	0.0086	0.0139	0.0239	0.0346	-0.0164	0.0155	-0.0581	0.0214	0.0133
	θ	-0.0421	-0.0700	-0.0802	-0.1233	-0.1664	-0.1958	0.0004	-0.0706	-0.1712	-0.1332	0.0160
India	β	0.0652	0.1885	0.1668	0.1389	0.5281***	0.6423***	0.7291***	0.6975***	0.6189**	0.7609**	0.2140
	γ	-0.0805**	-0.0565	0.0001	0.0134	0.0501*	0.0517**	0.0359**	0.0376*	0.0368	0.0450	0.1559**
	θ	0.0305	0.0175	0.0134	0.0146	0.0113	0.0038	-0.0100	-0.0092	-0.487	-0.0049	-0.0034
China	β	-0.0000	0.0000	-0.3418***	-0.3255***	-0.3740***	-0.1077	-0.3044	-0.2097	1.6050*	1.7964***	1.1094**
	γ	0.0000	-0.0000	0.0636*	0.0549	0.0773*	0.0437	0.1097*	0.1477*	-0.1508	-0.2233***	-0.0022
	θ	0.0000	0.0000	0.0565	0.0916*	0.0650	0.0215	0.1363*	0.3731***	-0.4349***	-0.2152*	-0.0176
Korea	β	0.5507*	0.7704**	1.0915***	2.7796***	1.9947***	1.8898***	2.8011***	3.0393***	4.3835**	3.1741**	1.7956
	γ	0.0082	0.0010	-0.0007	-0.0222	-0.0165	-0.0316	-0.1126	-0.1707	0.7594	0.6120***	0.3943***
	θ	0.0036	-0.0071	0.0054	0.2483***	0.1726***	0.1690***	0.4863***	0.5720**	1.5644**	0.7305**	0.1727*

Notes: Estimated monetary rule: $i_t = \alpha + \beta\pi_{t+12} + \gamma y_t + \theta ER_t + \varepsilon_t$. *, **, *** denote statistical significance at 10%, 5% and 1%, respectively.

Dollar, together with tepid economic growth in the last few years reinforces the argument that the Central Bank is preoccupied mainly in keeping the currency rate once it gets out of range. The general echo for the TICKs member states is, however, a milder response to inflation at low interest rates and this may reflect the general sentiment of aversion towards deflation especially post financial crisis period of 2007. Many central banks worldwide including the Fed have warned of this danger in public testimony, viz., the zero lower bound for interest rate that has been in practice in many developed economies. The general display of 'hump-shaped' response to inflation across the quantiles, i.e., policy becomes tighter, going from lower to higher quantiles, reaches a peak, and then becomes looser as found in for instance Miles and Schreyer (2012) for Asian emerging market economies likely arising from a desire to limit exchange rate appreciation echoes in this study to some extent.

The response to output gaps for China and India is variable over the quantiles and of a smaller magnitude from the figure that Taylor proposed. For South Korea, there is rather strong response to the output gap when inflation and interest rate are high with the output response being insignificant at low inflation and interest rates. One could possibly argue that the Bank of Korea places high importance on inflationary pressures of output during periods of rising inflation. Taiwan does not respond to the output gap at any quantile.

With respect to the impact of the exchange rate on policy, the results indicate that China does raise the interest rate at the 60th and 70th quantiles in response to yuan depreciation where inflation is likely to be higher. The Bank of Korea does take account of the exchange rate at almost all interest rate quantiles and India and Taiwan do not respond to their currencies value at all. Again, the results of McCauley (2006) should be kept in mind, in the sense that a failure to find significance of the exchange rate on the interest rate movements may simply mean that another instrument is employed to deal with the currency value. A strong possibility would be foreign currency reserves especially for China and Taiwan, with Aizenman et al. (2011) discussing the role that currency reserves play in Asian emerging economies seeking to limit exchange rate movements.

4. Robustness analysis

We assess the sensitivity of our findings firstly, using different model specification secondly, using different inflation horizon, and thirdly repeating the analysis using quarterly data. An important part of the paper is that the central banks in our study take the exchange rate into account when setting interest rates as generally found for the case of China and South Korea. To assess the usefulness of the exchange rate variable, we estimate the model without including the exchange rate in Table 4. We find that the qualitative robustness of the quantile estimates does not change that much with respect to the response of the monetary authorities vis-a-vis the inflation rates for China, India and South Korea while still maintaining insignificant responses for Taiwan. The results with the shorter horizon for inflation at one-month ahead in Table 5 shows the robustness of the quantile estimates for inflation and somewhat different estimates for output and exchange rate. Hence, we can conclude that inflation has a noticeable larger effect on higher quantiles of interest rates (where inflation is presumably higher than desired) than at lower quantiles of interest rates (where inflation is likely relatively low). This is especially true for China and South Korea, as found in Section 4, the Taylor principle is usually adhered to.

Table 6 reports the results calculated using quarterly data. In this case, output gap was obtained from quarterly GDP. The coefficient on the inflation rate variable for China is significantly different from zero and greater than unity at the upper end of the range, more precisely from the

Table 4: Monetary rule using IVX-QR estimation

Country	Parameters	Quantiles										
		Q=5	Q= 10	Q=20	Q=30	Q=40	Q=50	Q=60	Q=70	Q=80	Q=90	Q=95
Taiwan	β	0.0342	-0.0088	0.0452	-0.0249	-0.0622	-0.0071	-0.0161	0.0210	0.2258	0.2530	0.1909
	γ	0.0105	0.0045	0.0067	0.0120	0.0209	0.0307	-0.0182	0.0203	-0.0457	0.0220	0.0278
India	β	0.1634	0.1520	0.1898	0.1535	0.5310***	0.6455***	0.7376***	0.6995***	0.5242***	0.7791**	0.1494
	γ	-0.1173***	-0.0590	-0.0122	-0.0048	0.1085*	0.1422**	0.1400**	0.1262*	0.0577	0.1883*	0.1848**
China	β	0.0001	-0.0001	-0.3749***	-0.3715***	-0.4300***	-0.1248	-0.4051**	-0.3257	1.6758*	1.2146***	1.0113**
	γ	0.0001	0.0001	0.0346	0.0430	0.0598*	0.0370	0.0917**	0.2143***	0.2270	0.2033**	0.1411
Korea	β	0.4637	0.8031**	1.1929***	2.4650***	2.4596***	2.0641***	2.7778***	3.4868***	5.3421*	1.2428	-0.8338
	γ	0.0277	0.0026	0.0066	0.0233	0.0363	0.0485	0.0801	0.0457	-0.1731	-0.3311***	-0.4328***

Notes: Estimated monetary rule: $i_t = \alpha + \beta\pi_{t+12} + \gamma y_t + \varepsilon_t$. *, **, *** denote statistical significance at 10%, 5% and 1%, respectively.

Table 5: Monetary rule using IVX-QR estimation

Country	Parameters	Quantiles										
		Q=5	Q= 10	Q=20	Q=30	Q=40	Q=50	Q=60	Q=70	Q=80	Q=90	Q=95
Taiwan	β	0.0151	-0.0162	0.0564	0.0187	0.2075	0.0584	0.0591	0.2609	0.2868	0.2984	0.2788
	γ	0.0088	0.0121	0.0052	0.0109	0.0080	0.0262	0.0289	0.0593	-0.0172	0.0093	0.0040
	θ	-0.0393	-0.0451	-0.0511	0.0706	-0.1247*	-0.2480**	-0.0551	-0.0343	-0.1504	-0.0779	-0.0273
India	β	0.0774	0.2326**	0.2554*	0.3665**	0.5345***	0.5215***	0.6433***	0.6764***	1.0851***	1.4165	1.1477
	γ	-0.1432***	-0.0519	-0.0578	-0.0098	0.0161	0.0413	0.0416*	0.0426*	-0.0105	-0.0729	-0.0285**
	θ	0.0648	0.0210	0.0281	0.0214	-0.0069	-0.0217	-0.0020	0.0022	-0.0112	-0.0035	-0.0100
China	β	-0.0000	-0.0000	-0.0800	-0.1540	-0.1346	-0.1078	-0.2349	0.3537	1.7299***	1.9164***	1.8547***
	γ	0.0000	0.0000	0.479	0.0793**	0.0621	0.0325	0.0678	0.0549	-0.0506	-0.1675	-0.2047**
	θ	0.0000	0.0000	0.0582	0.0793	0.1124*	0.0206	0.0415	0.1862***	-0.3327**	-0.4922***	-0.4205***
Korea	β	1.8871***	1.5051***	1.6866***	2.1073***	2.4962***	2.2082***	2.9915***	2.9158***	7.4939***	5.7674***	3.7814***
	γ)	-0.0168	-0.0032	-0.0146	-0.0352	-0.0179	0.0100	-0.0159	-0.0451	0.5170	1.2285***	1.4204***
	θ	0.0888***	-0.0052	-0.0058	0.0859*	0.2607***	0.1752***	0.2974**	0.1628	-1.1607	0.0419	0.0500

Notes: Estimated monetary rule: $i_t = \alpha + \beta\pi_{t+1} + \gamma y_t + \theta ER_t + \varepsilon_t$. *, **, *** denote statistical significance at 10%, 5% and 1%, respectively.

Table 6: Monetary rule using IVX-QR estimation and quarterly data

Country	Parameters	Quantiles										
		Q=5	Q= 10	Q=20	Q=30	Q=40	Q=50	Q=60	Q=70	Q=80	Q=90	Q=95
Taiwan	β	0.0525	0.1243	0.0034	0.0416	-0.0142	-0.0891	0.2805	1.0443	-0.1893	0.3901	-0.0428
	γ	0.0336	0.0488	0.0762	0.1142*	0.1544*	0.1585	0.1537	-0.0172	0.1048	-0.1614*	0.1765
	θ	-0.0382	-0.0421	-0.0130	-0.0964	-0.1146	-0.0758	-0.2061	0.0117	-0.2502	-0.0917*	-0.2374*
India	β	0.1375	0.2875**	0.5298***	0.6242***	0.6558***	0.6533***	0.7977***	0.9666***	0.9189***	0.5443***	0.1509
	γ	-0.1549**	-0.1672**	-0.0341	0.0086	0.0288	0.0302	0.0242	0.0080	0.0225	0.3296***	0.6133***
	θ	-0.0146	0.0025	0.0009	-0.0068	-0.0041	-0.0074	-0.0172	-0.0024	-0.0049	-0.0403	0.0006
China	β	-0.0000	-0.1694*	-0.2717***	-0.3138***	-0.0826	-0.1201	-0.3436***	-0.2852**	-0.2787	1.6692***	1.0538***
	γ	0.0000	0.1956	0.6179***	0.4413***	0.3618***	0.3757***	0.5108***	0.6578***	1.3355**	-1.1950***	-0.0824***
	θ	0.0000	-0.0087	0.0219	0.0021	-0.0020	0.0047	0.0498	0.0711	0.2050	-0.1387*	-0.0137**
Korea	β	0.1390	0.7956***	1.1495***	-0.1796	0.0131	1.0131***	1.4735***	0.7715	2.7320	2.3369**	-1.2028*
	γ	0.1142*	0.0219	-0.0496***	0.1743	0.1724	-0.0020	-0.1338*	0.0912	0.1470	0.5196	-1.7739*
	θ	-0.0223	-0.0011	0.0059	-0.0191	-0.0211	-0.0001	-0.0064	-0.0088	0.2960	0.0853***	-0.2250*

Notes: Estimated monetary rule: $i_t = \alpha + \beta\pi_{t+4} + \gamma y_t + \theta ER_t + \varepsilon_t$. *, **, *** denote *statistical significance at 10%, 5% and 1%, respectively.*

90th quantile. In the case of South Korea on the other hand interest rate seems to positively respond to inflation rate at a sequence of quantiles, from the 10th to the 90th. Specifically, the response appears to be greater the unity, except the response at the 10th quantile. The response of the Reserve Bank of India to inflation rate, though positive, does not seem to adhere to the Taylor principle. As for Taiwan, we do not observe any statistically significant reaction of interest rate to inflation.

The response to output gaps for China and India is variable over the quantiles and of a smaller magnitude from the figure that Taylor proposed. For Taiwan and South Korea, there is no statistically significant (at least at 5% level) response of interest rate to output gap at any quantile. In the case of India, we observe significant reaction of interest rate to output gap only at the tails of the interest rate distribution. Specifically, interest rate response negatively at the 5th and 10th quantiles, and positively at the 90th and 95th quantiles. Lastly, for China, our results suggest statistically significant response to output gap most quantiles, from the 10th to the 90th. For South Korea, there is rather strong response to the output gap when inflation and interest rate are high with the output response being insignificant at low inflation and interest rates. One could possibly argue that the Bank of Korea places high importance on inflationary pressures of output during periods of rising inflation. Taiwan does not respond to the output gap at any quantile.

With respect to the impact of the exchange rate on policy, our results indicate statistically significant effects only at the right tail of the interest rate distribution. Specifically, at the 5% significance level, interest rate response positively to exchange rate in the cases of India (90th and 95th quantiles) and South Korea (90th quantile). For China and Taiwan, there is rather weak (only at the 10% significance level) negative response to exchange rate at 90th and 95th quantiles.

In general, our results are qualitatively similar for the countries whether we use monthly or quarterly data.

5. Conclusions

This paper provides findings that support non-linearities in central bank responses to policy determinants in the emerging economies of China, India and South Korea. Interestingly, for China and India, there is no response of interest rate at the mean. While all these three central banks respond significantly to inflation at a number of quantiles, yet the magnitude of the response varies widely, not just across the countries but also across the quantiles within each country. The exception is Taiwan which does not respond to inflation at all quantiles and this could be due to Taiwan's adoption of monetary targeting of M2 growth. Though it is interesting to note that a constant money supply growth rule, i.e., a Friedman rule has been found to have the same implication as a Taylor rule. These results clearly show that relying on linear models to investigate monetary policy reaction functions might be misleading for these emerging economies.

Estimating the response of interest rates to its determinants not only at various quantiles on the conditional distribution of interest rates but also at the various quantiles of its determinants is what we intend to address in future research.

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Appendix:

Figure A1. Plot of Interest Rates of TICKs:

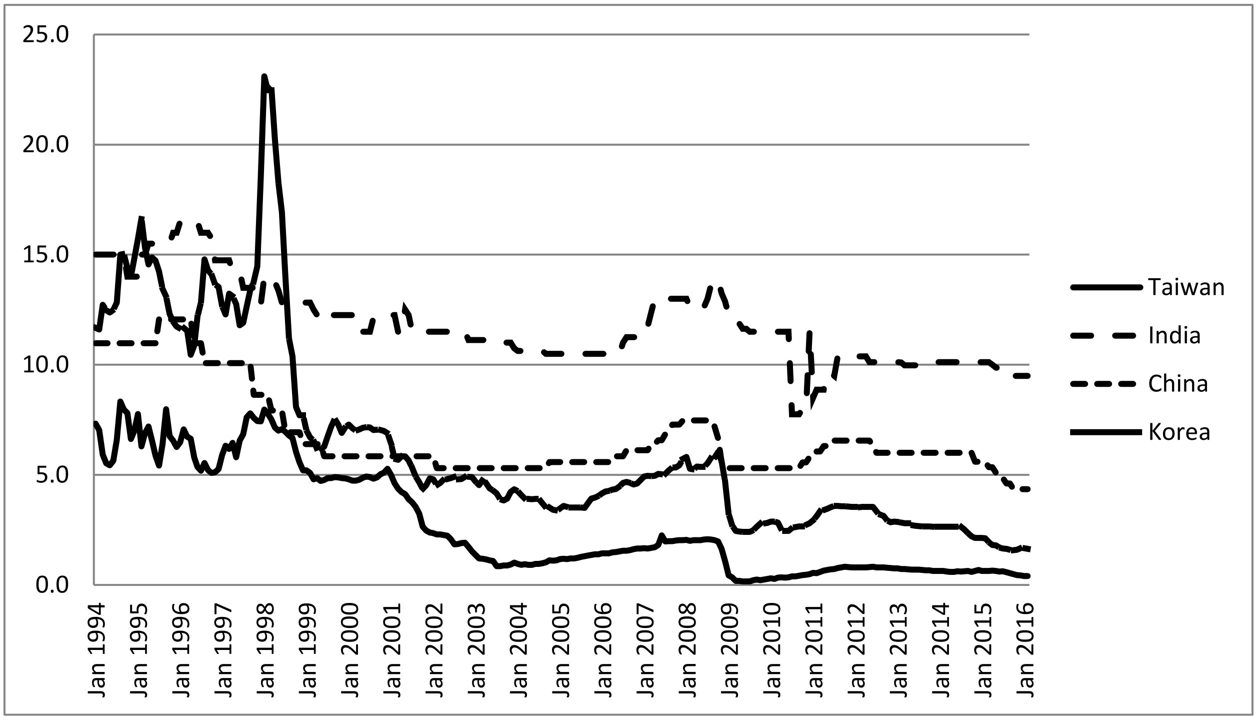

Figure A2. Plot of Inflation Rates of TICKs:

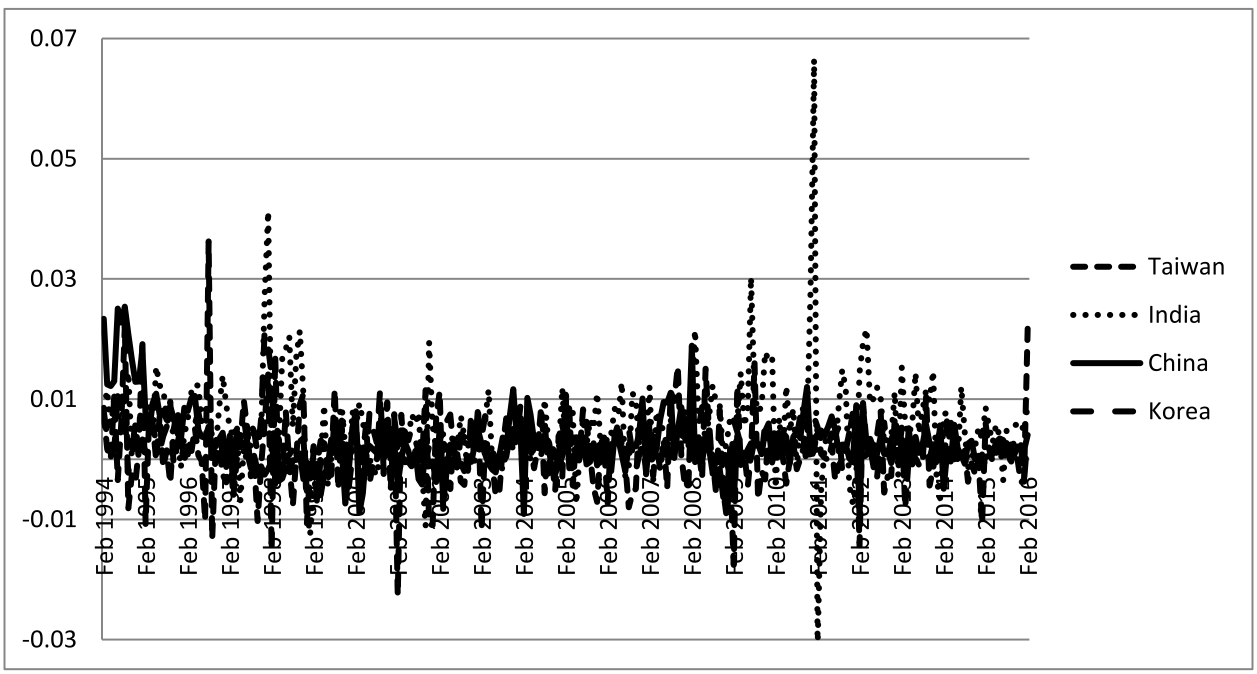

Figure A3. Plot of Output Gap of TICKs:

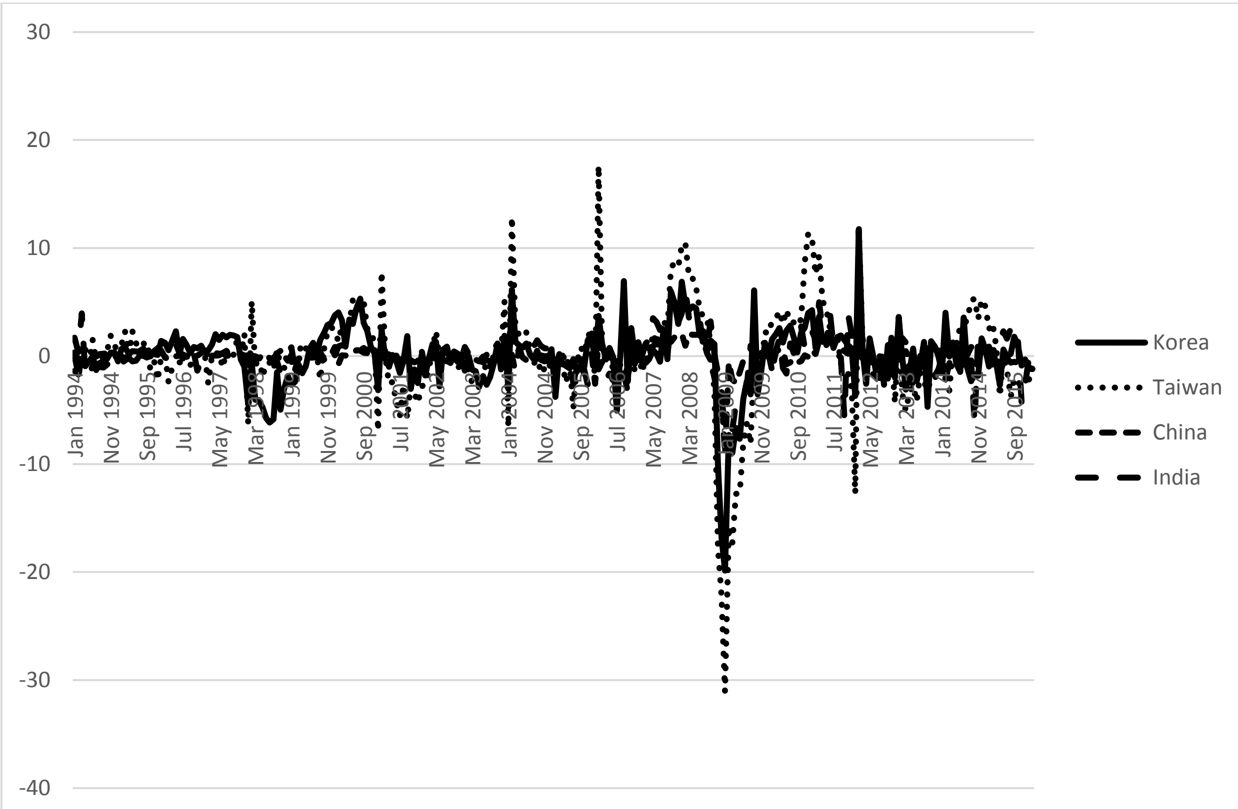

Figure A4. Plot of Dollar-Based Exchange Rate Returns of TICKs:

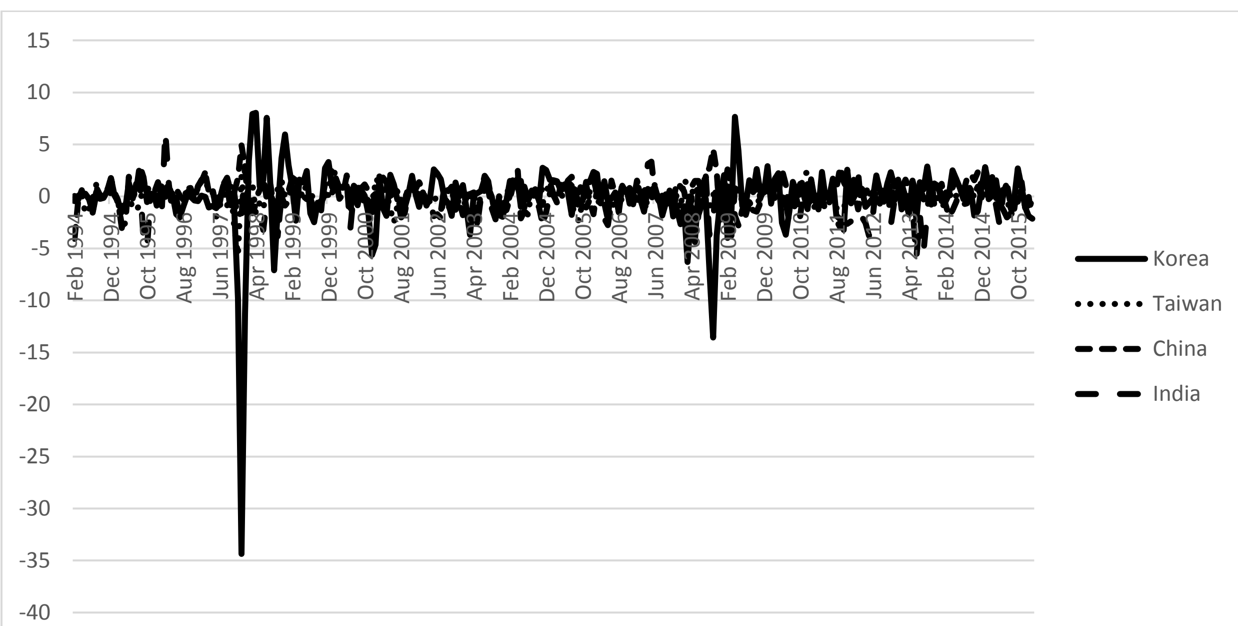

Figure A5. Histogram of Interest Rate for Taiwan:

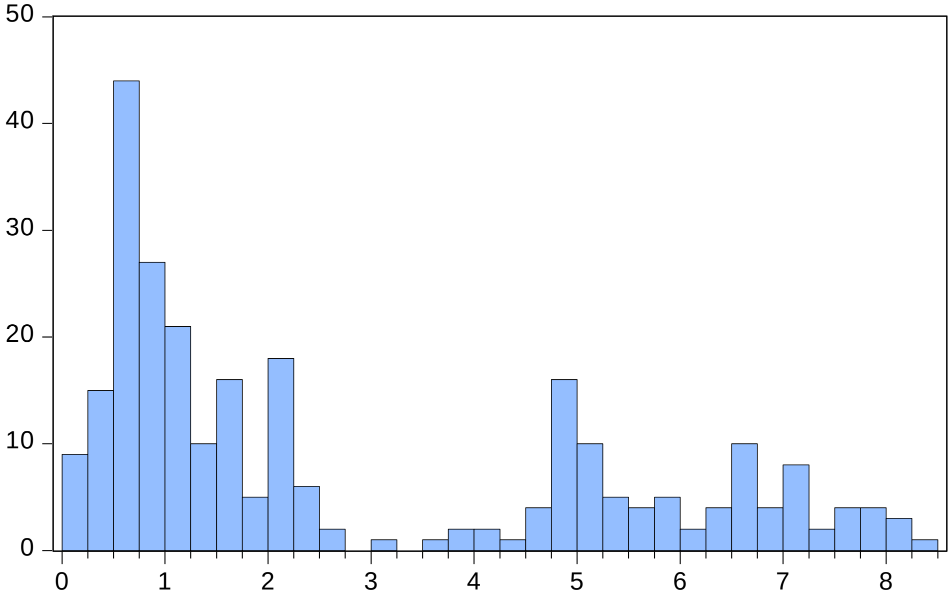

Figure A6. Histogram of Interest Rate for India:

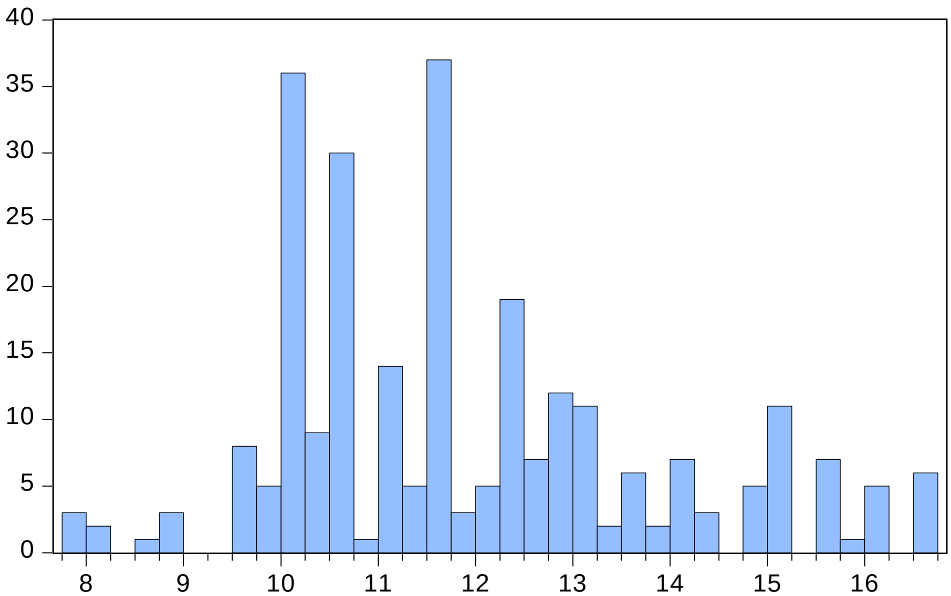

Figure A7. Histogram of Interest Rate for China:

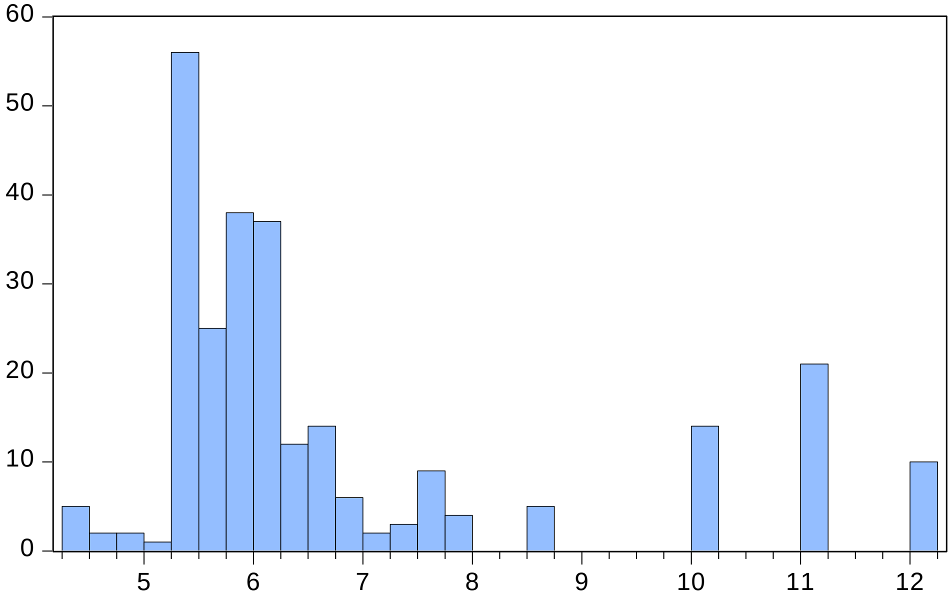

Figure A8. Histogram of Interest Rate for Korea: