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Barendra Kumar Bhoi, Abhishek Kumar and Prashant Mehul Parab

Indira Gandhi Institute of Development Research, Mumbai
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Abstract

This paper evaluates the rule-based interest rate policy for India since 2000 Q1, which has become more relevant in the flexible inflation targeting (FIT) regime. Based on the results of the reduced form Taylor-rule, we observed two episodes of possible policy errors since 2001. First, in the aftermath of the global financial crisis, RBI brought down the repo rate much below the level warranted by the Taylor rule that fueled inflation. Moreover, monetary policy tightening, followed thereafter, from March 2009 to June 2011 was insufficient in controlling prices. Second, despite favorable supply shocks, the repo rate was above the rule-based policy rate from June 2013 to March 2016, leading to a very high real interest rate. In the post-crisis period, we observed a significant increase in the interest rate persistence, which could be attributed to RBI's reluctance to cut policy rate despite the softening of inflation, leading to the growth slowdown. Our results suggest that the optimal policy rate ranges from 4% to 5% for the last quarter of 2018. The actual repo rate at 6.5% in December 2018 was 150 to 250 basis points above the optimal rate. The RBI has reduced the repo rate by 135 basis points during February-October 2019. As the negative output gap has widened and the inflation outlook remains benign in the medium-term, there is scope to cut the repo rate further.

Keywords: Optimal Monetary Policy, Flexible Inflation Targeting, Taylor Rule, Growth Slowdown

JEL Classification: E47, E52, E58

The corresponding author is B.K.Bhoi (barendrakumar@igidr.ac.in).

[1] Barendra Kumar Bhoi is a Visiting Fellow and Abhishek Kumar and Prashant Mehul Parab are Ph.D. Scholars at Indira Gandhi Institute of Development Research (IGIDR). Views expressed in this article are exclusively those of the authors.

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I. Introduction

There is a broad consensus in the literature that monetary policy is neutral to growth in the long-run. However, monetary policy is non-neutral to both growth and inflation in the short-run mainly due to wage-price rigidity. The trade-off between growth and inflation is a complex process, which varies widely across countries. Ever since the growth-inflation trade-off was introduced in the literature by A. W. Phillips (1958), many economists undertook critical empirical research on the topic around the world. The original Phillips curve has been augmented in several ways over time to capture the behaviour of firms. Similarly, the aggregate demand curve is modified to incorporate household expectations, i.e., the inter-temporal substitution of work and leisure, subject to budget constraints. Within the constraints of aggregate demand and supply curves, central banks pursuing rule-based monetary policy, proposed by Taylor (1993), have been reasonably successful in achieving their objectives. During the last three decades, a large body of literature has emerged on optimal monetary policy coinciding with inflation targeting as a monetary policy framework since the early 1980s. The theoretical support to the optimum monetary policy has been provided by the New Keynesian School of economists (Clarida *et al.,* 1999; Woodford, 2003).

The optimal monetary policy is presumed to ensure maximum social welfare. More specifically, social welfare can be maximized if actual output converges to the potential level of output together with a low rate of inflation, which is perceived as price stability consistent with the natural rate of growth or in some sense a desirable inflation target for the society. Departures from the potential output (output gap) and/or from the desired inflation target (inflation gap) are suboptimal outcomes having implications for social welfare.

The objectives of this paper are two-fold: a) to study whether monetary policy pursued by the Reserve Bank of India (RBI) since 2000 has been rule-based; and b) to estimate optimum policy rule for India by simulating a small macro model of new Keynesian tradition (Clarida *et al*., 1999, Svensson, 1997, 2000). Globally, many economists, through country-specific empirical studies, have offered precise conclusions on the optimal interest rate that is useful to policymakers. As India has recently switched over to flexible inflation targeting, it has become important to undertake such studies for providing evidence of optimal rate to the Monetary Policy Committee (MPC) - the highest decision-making body on repo rate at RBI.

Although there has been a regime shift from the multiple indicator approach (MIA) (from 1998 to 2014) to the flexible inflation targeting (FIT) since 2015, price stability has been a major objective of monetary policy in both regimes. None of these regimes completely ignores the growth objective. While price stability, measured in terms of annual variation in the new consumer price index (CPI) within the range of 4±2%, has been accepted as the overriding objective of monetary policy under FIT, relative weights, assigned to growth and price stability (in terms of WPI inflation) under MIA, were based on circumstances. Moreover, the repo rate gradually emerged as the dominant monetary policy instrument under MIA with an emphasis on quantity indicators (reserve money, broad money) waning. Under FIT, while money supply has become endogenous, modulated largely by liquidity management by RBI on a day-to-day basis, MPC has been empowered to decide the policy repo rate regularly. The formulation of monetary policy, operating procedure, nominal anchor, accountability are clearly defined and transparently followed under FIT as against considerable ambiguity under the previous regime. While two regimes are materially different in many respects, they have at least one thing in common i.e., repo rate as a policy instrument, developed in the earlier regime, and unequivocally followed in the current regime.

Repo rate was introduced in India under an interim liquidity adjustment facility in April 1999. The full-fledged liquidity adjustment facility (LAF) commenced in June 2000. Therefore, our study relates to the period from 2000Q1 to 2018Q4 to have a common thread of monetary policy signaling in India through the repo rate. During this period, the weighted average call money rate (WACMR) was monitored intensively, which has finally emerged as the operating target of monetary policy in India in the new regime.

We assume WACMR as an effective policy rate throughout the period of study although it was initially more volatile in the earlier regime.

The scheme of the paper is as follows. Section 2 provides a brief overview of the literature relating to the optimal monetary policy. Section 3 sets out the analytical framework and methodology of the study. Section 4 analyses the results of reduced form aggregate demand (IS curve) and aggregate supply curves (new Keynesian Phillips curve (NKPC)). This section also attempts to estimate a reduced form Taylor-rule type reaction function fitted to the historical data to study whether RBI's interest rate policy followed during these years conformed to the rule-based monetary policy. While reduced form estimates of IS and NKPC could provide deep parameters, optimality could not be established in the data-driven Taylor rule type reaction function. Hence, in Section 5, optimum nominal interest rates are estimated for India using Taylor rule type monetary policy reaction function by minimizing the central bank loss function under alternative weights assigned to respective parameters subject to constraints imposed by the IS and NKPC, estimated in the earlier section. Section 6 reflects on the findings of the study and their policy implications besides concluding observations.

II. Optimal Monetary Policy: A Brief Review

Friedman's rule of k% growth in money supply (k equals the real GDP growth rate) was in vogue in advanced economies for some time as optimal monetary policy rule in the mid-1970s. However, the monetary targeting framework failed to deliver in achieving monetary policy objectives for obvious reasons[2] and interest rate became the key monetary policy instrument in most parts of the world in the deregulated environment since the early 1980s. The debate on rule-based vs. discretion-based monetary policy began with the seminal article by Kydland and Prescott (1977). There were several contributions by Taylor (1979, 1993) who favored a rule-based monetary policy over discretion. In his 1993 article, Taylor devised a rule (known as Taylor rule) for setting

[2] Reasons include: a) parameter instability of the money demand function, b) predictive failure, c) financial innovations d) deregulation, e) openness, f) misspecification etc.

the nominal interest rate based on inflation and output gaps, which worked reasonably well for the US economy. According to him, policy rates based on 'policy rules have major advantages over discretion in improving economic performance' (1993). Rule-based monetary policy studied by Ball (1999), Svensson (1999), and Rudebusch and Svensson (1999) are examples of backward-looking models, where inflation and output gaps depend on their own past values.

Carrying this idea forward, Clarida *et al.* (1999), in their article, 'The Science of Monetary Policy: A New Keynesian Perspective', provided a comprehensive analysis on optimal monetary policy that was forward-looking, which indicated a set of rules on how to conduct optimal monetary policy. In the case of the Phillips curve estimation, inflation emerges not only from output gaps but also from expected future inflation. Moreover, the shock to inflation emerging from the error term is either expectational or cost-push in nature. Similarly, in the case of the IS curve, the output gap is a function of not only the real interest rate but also the expected future output gap. The central bank can systematically influence the real interest rate by manipulating the nominal interest rate as prices are sticky in the short-run. An increase in the nominal interest rate may control inflation but raise the real interest rate and thereby harm growth. This phenomenon is popularly known as the sacrifice ratio - inverse of the coefficient of the output gap (Hetzel, 2000). Through Taylor rule, an optimal solution is arrived at by minimizing losses to the society arising out of both inflation and output gaps.

Woodford (1999) models an optimal monetary policy for the US by adding an inertial component of interest rate to the Taylor rule, which measures persistence. If the persistence is large, monetary policy is seen to be less closely following the Taylor rule and *vice versa*. Woodford (2001) arrives at similar conclusions. An interest rate rule with inertia should be adjusted gradually to the arrival of new information as aggregate demand is affected equally by current as well as future short term interest rates.

Hetzel (2000) models the usefulness of the Taylor rule for conducting monetary policy in the US economy and discovers that the US economy had fared well in controlling inflation since 1980. He suggests that the Taylor rule is a good guide for monetary policymakers when implemented in activist models with cost-push shocks. Erceg *et al*. (2000) model optimal monetary policy using a dynamic stochastic general equilibrium (DSGE) framework with staggered wage and price contracts (Calvo, 1983). Strict inflation targeting is found to generate large welfare losses while simple rules work nearly as well as the optimal monetary policy rule.

As an extension to their 1999 paper, Clarida *et al.* (2001) apply the rules formulated earlier to a small open economy, where the economy is a price-taker. They found that the working of monetary policy for a small open economy is *isomorphic* to the closed economy setting. They assert that a small open economy with a complete exchange rate pass-through and the floating exchange rate should target the domestic inflation rate. Specifying a suitable model for open economies, Corsetti *et al.* (2010) propose a unified framework for the conduct of optimal monetary policy. Consideration of tradeoffs between domestic and international price gaps and elasticity of imports to fluctuations in the exchange rate becomes crucial while formulating optimal monetary policy. Policymakers shift their focus from domestic inflation (measured using GDP deflator) to CPI inflation and real exchange rate stabilization.

In India, research relating to the optimal monetary policy is relatively nascent. Mishra and Mishra (2012) and Patra *et al.* (2017) have tried to model optimal monetary policy for India by estimating reduced form IS and new Keynesian Phillips curves through instrument variable generalized method of moments (IV-GMM) technique. Mishra and Mishra (2012), by using monthly data, found that simple Taylor-type monetary rules are unsuitable in stabilizing the economy. By comparing different cases of strict and flexible inflation targeting with CPI and WPI inflation, they suggest that 'flexible domestic inflation targeting seems a better alternative from an overall macro stabilization perspective in India'. According to Patra *et al.* (2017), 'an optimal policy rule with the ratio of weight on output gap to inflation gap higher than in the standard Taylor rule and a flexible inflation targeting framework turns out to be welfare-maximizing for India'. Their findings suggest that 'while a policy rate in the range of 6.25 - 6.70 appears to be best suited under macroeconomic situation prevailing during 2015-16, rates lower than 6.25% would lie outside the policy efficiency frontier'. Situations have changed a lot since then with the CPI inflation rate softening below the medium-term target of 4%. A negative output gap persists for a long time. Hence, the optimum rate may be different now than it was at the commencement of FIT. Moreover, the period of both the studies predates the actual implementation of FIT in India. If the central banks dynamically optimize rates in response to varying output gaps and inflation expectations, there is a need to study what would be the optimal rate going forward.

III. Framework and Methodology

We estimate a simple New Keynesian macroeconomic model for India using the Generalized Method of Moments (GMM) technique in lines of Clarida *et al.* (1999). Reduced form equations of aggregate demand and aggregate supply are estimated, which embody the features of micro-foundations. The period of study relates to 2000Q1 to 2018Q4. Besides estimation for the full sample, we have carried out estimation for two sub-samples: a) the pre-crisis period i.e., from 2000Q1 to 2007Q4, and the post-crisis period from 2009Q1 to 2018Q4. The detailed specification of the model is given below.

Aggregate Demand:

A reduced-form dynamic IS-curve is estimated for India that resembles the IS-curve derived from micro-foundations. This is essentially a typical inter-temporal demand function used in new Keynesian macro models. The IS curve is written as:

$$y_t = \alpha_y + \delta_1 y_{t-1} + \delta_2 RR_t + \delta_3 G7GR_{t-1} + \delta_4 DD_t + \varepsilon_{yt} \quad (1)$$

Where 'y_t' is the output gap estimated using a combination of filters such that the limitation of a single filter is surmounted (Bhoi *et al*. 2017). Unlike Clarida *et al.* (1999), we use a backward-looking IS-curve as it is well suited to the Indian scenario (Patra *et al*., 2017). 'δ_1' displays the persistence parameter relating to the output gap and 'δ_2' captures the impact of real interest rate (RR) on the output gap. We define RR as an effective policy rate minus inflation $(r_t - \pi_t)$[3] The aggregate demand equation (IS-curve) is augmented by external demand in the form of lagged real GDP growth of G7 countries. G7 growth was found to provide better results than other competing variables such as OECD or the US growth rates. We incorporate an exogenous domestic demand shock (DD) represented by the ratio of Gross Fiscal Deficit to GDP. A priori, we expect values of δ_1, δ_3, and δ_4 to be positive and δ_2 negative. A smooth process of monetary policy transmission *via* the interest rate channel to the output gap depends on the size and significance of δ_2. $'\varepsilon_{yt}'$ is the residual demand shock.

Aggregate Supply:

We estimate a hybrid New Keynesian Phillips Curve (NKPC) for the Indian economy. It differs from the standard forward-looking Phillips curve in the sense that it models persistence in inflation, a crucial factor especially relevant for an emerging economy like India. Hence, we incorporate both backward and forward-looking behavior of inflation which partly surmounts the Lucas critique and partly exhibits some aspects of adaptive expectation. We augment the NKPC with a change in the exchange rate and an exogenous supply shock in the form of rainfall variability. The model is written as:

$$\pi_t = \alpha_\pi + \beta_1 \pi_{t-1} + \beta_2 E_t \pi_{t+1} + \beta_3 y_t + \beta_4 \Delta NEER_t + \beta_5 SS_t + \varepsilon_{\pi t} \qquad (2)$$

Where $'\beta_1'$ displays intrinsic persistence of inflation and β_2 captures expectation-based persistence. The output gap (y_t) is expected to impact inflation positively. NEER is the trade-weighted nominal effective exchange rate which is modeled in the form of a year-on-year growth rate. ‘SS’ is the supply shock defined as the deviation of rainfall from the long-period average. Based on the theory, one would expect β_1, β_2, and β_3 to be positive and β_4 and β_5 negative. A higher nominal effective exchange rate implies appreciation and that should decrease inflation through exchange rate pass-through. Higher rainfall should lead to higher agricultural production, thus decreasing headline/food inflation.

[3] $(r_t - \pi_{t+1})$ also gives similar results.

Monetary Policy rule:

We also evaluate the reduced form monetary policy rule given by equation (3).

$$r_t = \gamma_0 + \gamma_1 r_{t-1} + \gamma_2 \pi_t + \gamma_3 y_t \qquad (3)$$

In case of the optimal policy, coefficients of the above equation $(\gamma_i \;\; i = 1,2.3)$ are obtained by minimizing the following central bank loss function given by (4), subject to deep parameters obtained from IS and NKPC:

$$L = \omega_1 var(\pi) + \omega_2 var(y) + \omega_3 var(r) \qquad (4)$$

Data and Methodology:

Global Financial Crisis (GFC) seemed to have inflicted a sudden break in the dataset. The government also came out of the fiscal discipline following GFC. Therefore, we analyze pre- and post-crisis periods by splitting the sample around the GFC and also for the entire sample period. The pre-crisis period relates to 2000Q1 to 2007Q4. As WACMR was unusually volatile in 2008, it is excluded from the post-crisis period, which spans from 2009Q1 to 2018Q4. The full sample includes 2008 with smoothing of WACMR for 2008. Quarterly data, used in the study, are taken from RBI publications and Federal Reserve Economic Database for the period 2000Q1 to 2018Q4. New CPI Combined (CPI-C) series is used to estimate inflation unlike WPI inflation in the earlier regime. The new CPI series is backcast using CPI for Industrial Workers (CPI-IW) at the aggregate level as weights of disaggregate components of CPI-C and CPI-IW are similar (Goyal, 2015; Goyal and Parab, 2019). As mentioned earlier, the output gap is estimated using a composite filter in lines of Bhoi *et al.* (2017). Detailed definition of variables used in the study is given in Appendix I. All the series having seasonality are adjusted using the Census X-13 algorithm. Reduced-form IS, Phillips curve, and Taylor rule are estimated using the Generalized Method of Moments (GMM) framework. It helps in addressing the endogeneity issue with the use of appropriate instruments. Expected inflation is assumed to be equal to actual one period ahead inflation and expectation error based on rational expectation hypothesis[4]. Since one-period-ahead inflation is endogenous, we use lag instruments for it. Instruments used in each equation are indicated below the respective tables.

Tests are conducted for weak instruments, over-identification, and under-identification. The first stage F test is required for testing the relevance of instruments; rejection implies that instruments are relevant. Sanderson-Windmeijer (SW) test for under-identification is used; rejection implies no under-identification. Hansen J test is for the validity of instruments when the number of instruments is more than the number of endogenous variables; the null hypothesis is that over-identification is valid. Anderson-Rubin (AR) test has joint null of exogeneity of instruments and insignificance of coefficients of endogenous variables. Since lag instruments are likely to be exogenous; rejection of null implies that the coefficients of endogenous variables are significant. It is also robust identification in case of weak instruments. We report this because in a few cases, the first stage F value is less than the rule of thumb value 10.

IV. Analysis of Empirical Results

Results of the reduced form IS curve, presented in Table 1, indicate that the output gap is inversely related to the real interest rate. The coefficient of the real interest rate, which was small and insignificant in the pre-crisis period, became relatively large and significant at one percent level in the post-crisis period. This shows that policymakers can influence the output gap by systematically changing the real interest rate. In the post-crisis period, an increase of real interest rate by one per cent (100 basis points) reduces the output gap by 0.14% in the short-run and around 0.44% in the long-run. The result is also valid for the full sample. Similarly, the positive impact of the G7 output growth on the domestic output gap was small and insignificant in the pre-crisis period, but turned highly positive and significant in the post-crisis period. For the full sample, G7 growth is significant at the 5% level. India may benefit to the tune of about 0.6% in the medium-term if G7 growth increases by 1%. The global recovery is therefore critical in

[4] The error in the Phillips curve consists of expectation error; we call the composite error supply shock in this paper.

improving the domestic growth outlook. India's recent growth slowdown may therefore be partly explained by sluggishness in global growth. The impact of domestic demand shock (by way of change in GFD-GDP ratio) on the output gap has declined drastically from the pre-crisis period to the post-crisis period. If fiscal stimulus cannot impact the output gap in a big way, it may add to aggregate demand which may push up prices. For the full sample period, as it is still large and significant, fiscal discipline may be beneficial and complementary to monetary policy in managing aggregate demand and thereby stabilising prices. The persistence of the output gap seems to have declined considerably from 0.9 in the pre-crisis period to 0.7 in the post-crisis period, implying a relatively quicker convergence of actual output to the potential in response to a shock. However, it remains at an elevated level of 0.8 for the full sample period, which may be due to the existence of supply bottlenecks and structural rigidities. Overall, the demand curve seems to have steepened as the economy has become more sensitive to changes in the real interest rate and less responsive to fiscal stimulus.

Results of the reduced form Phillips curve (Table 2) reveal that inflation persistence (coefficient of lagged inflation) has gone up modestly from the pre-crisis period to the post-crisis period implying price stickiness or staggered pricing (Calvo, 1983). This is called intrinsic persistence in the literature. If intrinsic persistence is high, inflation becomes less sensitive to movement in the output gap. Interestingly, the persistence of inflation emerging from forward-looking inflation expectation has improved considerably from the pre-crisis period (0.26) to the post-crisis period (0.44) although it is lower than the intrinsic persistence. People seem to have started forming expectations based on CPI inflation instead of WPI inflation earlier. This augurs well for the monetary authority to anchor inflation expectations under FIT. The output gap, supply shock like rainfall, nominal exchange rate are also expected to explain inflationary pressure in a small open economy like India. One would expect the impact of these variables to be small in the Indian case. We got the right sign for rainfall and NEER, which are small but significant. The impact of NEER on inflation seems to have fallen in the post-crisis period due to weak pass through. The impact of the output gap - the major determinant of a Phillips curve - on inflation has fallen from 0.16 in the pre-crisis period to 0.06 in the post-crisis period. This implies a weaker relationship between the output gap and inflation in India. In other words, the aggregate supply curve has become flat. India's inflation dynamic is dominated by supply shocks.

Table 1: Estimate of Aggregate Demand (IS Curve)
(Dependent Variable: Output gap)

Variable	Full sample	Pre-crisis	Post-crisis
C	0.87***	1.00***	-0.09
	(0.01)	(0.00)	(0.64)
y_{t-1}	0.75***	0.90***	0.68***
	(0.00)	(0.00)	(0.00)
$G7GR_{t-1}$	0.15**	0.01	0.25***
	(0.02)	(0.92)	(0.00)
RR_t	-0.14***	-0.01	-0.14***
	(0.00)	(0.67)	(0.00)
DD (GFD/GDP)	0.24***	0.19***	0.05*
	(0.00)	(0.00)	(0.06)
Adjusted R-squared	0.73	0.75	0.78
Ljung-Box Q	0.04**	0.24	0.62
First Stage F (p-value)	0.00***	0.06*	0.00***
AR Wald Test (p-value)	0.00***	0.00***	0.00***
Sanderson-Windmeijer (SW) (p-value)	0.00***	0.00***	0.00***
Hansen J (p-value)	0.23	0.25	0.44

***Source**:* Authors' Estimates
Notes: Level of significance - ***, **, * - 1%, 5% and 10%, p-values given in the parentheses.
Instruments: $y(-2\ to\ -4)$, $G7GR(-2\ to\ -4)$, $\Delta REER(-1\ to\ -4)$, $RR(-1\ to\ -4)$, $rnfcgr(-1\ to\ -4)$, $inv\_gap(-1\ to\ -4)$, $DD(-1\ to\ -4)$.

Table 2: New Keynesian Phillips Curve
(Dependent Variable: CPI Inflation)

Variable	Full sample	Pre-crisis	Post-crisis
C	0.12	0.98***	0.05
	(0.29)	(0.00)	(0.62)
π_{t-1}	0.56***	0.52***	0.54***
	(0.00)	(0.00)	(0.00)
π_{t+1}	0.41***	0.26***	0.44***
	(0.00)	(0.00)	(0.00)
y_t	0.06***	0.16***	0.06***
	(0.01)	(0.00)	(0.00)
SS (rainfall)	-0.02***	-0.01***	-0.01**
	(0.00)	(0.00)	(0.02)
ΔNEER	-0.03***	-0.08***	-0.01**
	(0.00)	(0.00)	(0.04)
Sacrifice Ratio	7.49	3.00	7.50
Adj-R-Squared	0.92	0.73	0.91
Ljung-Box Q (p value)	0.05**	0.27	0.08*
First stage F (π_{t+1}) (p value)	0.00***	0.00***	0.00***
First stage F (y_t) (p value)	0.00***	0.00***	0.00***
AR Wald (p value)	0.00***	0.00***	0.00***
Sanderson-Windmeijer (SW) (π_{t+1}) (p value)	0.00***	0.00***	0.00***
Sanderson-Windmeijer (SW) (y_t) (p value)	0.00***	0.00***	0.00***
Hansen J (p value)	0.63	0.36	0.44

***Source**:* Authors' Estimates
Notes: Level of significance - ***, **, * - 1%, 5% and 10%, p-values given in the parentheses.
Instruments: $y(-1\ to\ -4),\ nfcgr(-1\ to\ -4),\ \Delta NEER(-1\ to\ -4),\ G7GR(-1\ to\ -4),\ RR(-1\ to\ -4), ffr(-1\ to\ -4),\ \pi^{food}(-1\ to\ -4)$.

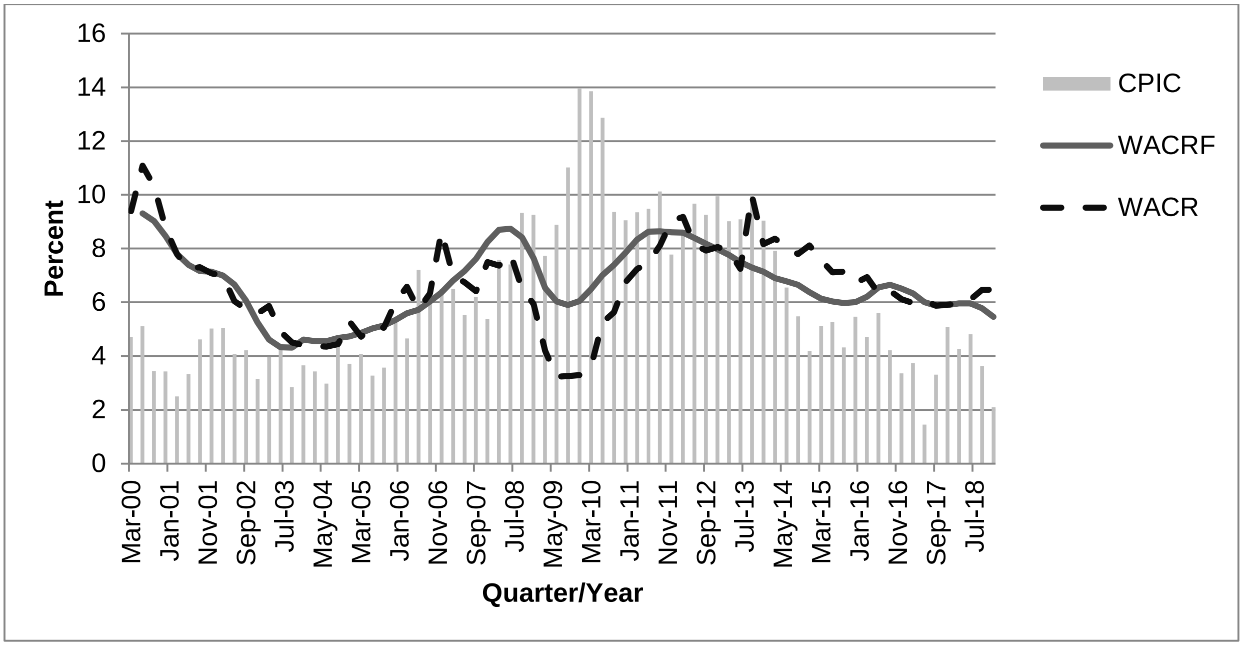
To study whether RBI's interest rate policy was close to the rule-based nominal interest rate derived from a Taylor-rule type reaction function, we estimated a standard Taylor rule for India with weighted average call money rate as the effective policy rate, which depends on its own lag (persistence or interest rate smoothing), output gap and inflation gap (Table 3). If the Taylor rule is followed more closely, then there would be a marked decrease in persistence and *vice versa*. The result shows a significant rise in persistence from the pre-crisis period (0.68) to the post-crisis period (0.92). Central banks do interest-rate smoothing, but a very high degree of persistence of the effective policy rate *prima facie* indicates that Taylor rule is less closely followed in India. Taylor rule-based WACMR and actual WACMR are plotted together with CPI inflation (Figure 1). While actual WACMR was broadly close to estimates in the pre-crisis period (except from November 2006 to July 2007), divergence was glaring in the post-crisis period, particularly from November 2008 to December 2011. The actual WACMR was persistently below the estimated one implying a more accommodative monetary policy during this period leading to a very low real rate (Figure 2). This resulted in sustained high inflation. The actual WACMR was consistently higher than estimates from June 2013 to March 2016 (Figure 1) - a period marked by unusual tightness, which might have led to a large sacrifice of output after a lag. This was also the period of very high real interest rate (Figure 2) that led to the growth slowdown. These evidences suggest that the interest rate policy was not optimal. We shall study this aspect in the next section. A possible departure may be due to inappropriate weights assigned to inflation and output gaps.

Table 3: Monetary Policy Reaction Function (Taylor Rule)
(Dependent Variable: WACMR)

Variable	Full sample	Pre-crisis	Post-crisis
C	1.02*** (0.00)	1.85*** (0.00)	0.48*** (0.00)
r_{t-1}	0.83*** (0.00)	0.68*** (0.00)	0.92*** (0.00)
y^{gap}	0.17*** (0.00)	0.10*** (0.00)	0.23*** (0.00)
π^{gap}	0.03* (0.08)	0.13** (0.02)	0.03** (0.03)
Adjusted R-squared	0.78	0.67	0.83
Ljung-Box Q (p value)	0.06*	0.31	0.11
First stage F (y^{gap}) (p-value)	0.00***	0.00***	0.00***
First stage F (π^{gap}) (p-value)	0.00***	0.00***	0.00***
AR Wald test (p-value)	0.00***	0.00***	0.00***
Sanderson-Windmeijer (SW) (y^{gap}) (p-value)	0.00***	0.00***	0.00***
Sanderson-Windmeijer (SW) (π^{gap}) (p-value)	0.00***	0.00***	0.00***
Hansen J (p-value)	0.67	0.44	0.43

***Source**:* Authors' Estimates
Notes: Level of significance - ***, **, * - 1%, 5% and 10%, p-values given in the parentheses
Instruments: $r(-2\ to\ -4), y(-1\ to\ -4),\ \pi^{gap}(-1\ to\ -4),\ \Delta NEER(-1\ to\ -4),\ YIELD_{gap}(-1\ to\ -4), inv\_gap(-1\ to\ -4)$.

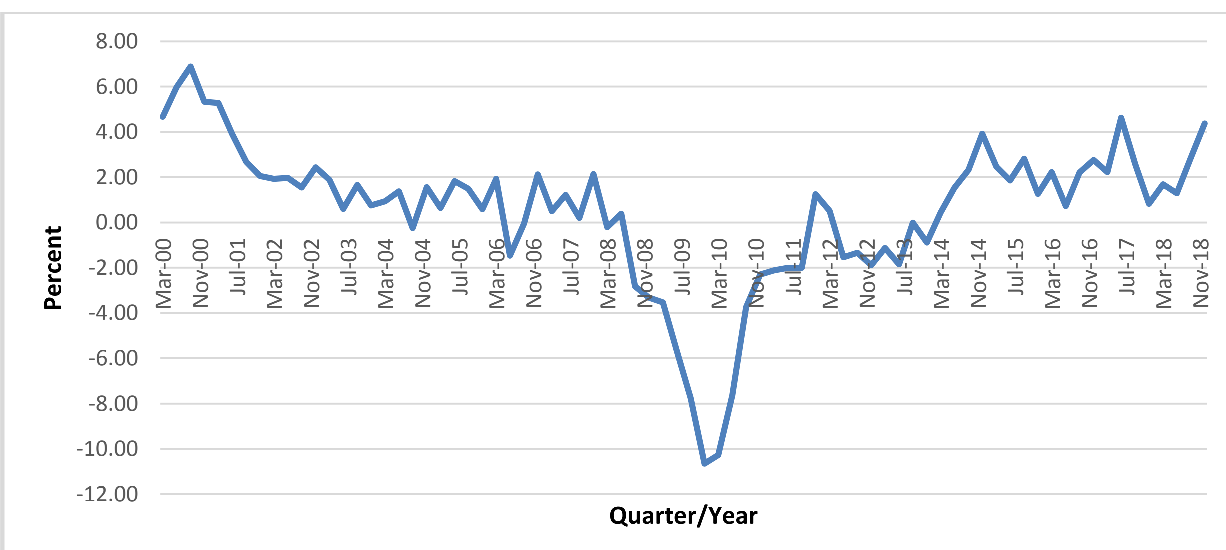
Figure 1: CPI Inflation and Actual vs. Predicted WACMR



Source: RBI DBIE, Authors' Estimates

Notes: CPIC represents consumer price inflation, WACR is weighted average call money rate and WACRF is the predicted value of WACR from reduced-form estimates.

Figure 2: Real Interest Rate



Source: RBI DBIE, Authors' Estimates

***Notes**:* The real interest rate is the difference between the Weighted Average Call Money Rate and CPI Inflation

V. Estimation of Optimal Interest Rate

V.1 Determinacy of Reduced Form Estimates

There are mainly two concerns for our reduced form estimates. The first concern is of determinacy and the second is whether monetary policy has been optimal. Determinacy is very crucial as in the case of indeterminacy there could be a price puzzle (Sims, 1980). The price puzzle implies that prices will rise in case of an increase in interest rate. This has been studied extensively in the context of new Keynesian models (Lubik and Schorfheide, 2003). When inflation is forward-looking, indeterminacy implies that the inflation process can be explosive and cannot be determined by the interest rate rule. Therefore, first we will check whether our reduced-form estimates give determinate Taylor rule or not.

The system of equations with IS-curve, Phillips curve, and Taylor rule given by equations (1), (2), and (3) can be written as:

$$BE_t z_{t+1} = Az_t + F\theta_t$$

Where z_t =$[\hat{y}_{t-1}, \hat{\pi}_t, \hat{\pi}_{t-1}, \hat{r}_{t-1}]$. θ_t includes all exogenous variables of the model and F is the conforming matrix consisting of the coefficient of exogenous variables. These exogenous variables are assumed to be stationary and they do not have any direct influence on determinacy. Matrices A and B are given below:

$$B = \begin{bmatrix} 1 & \beta_2 & 0 & -\beta_3 \\ \delta_3 & \delta_2 & -1 & 0 \\ -\gamma_3 & 0 & -\gamma_2 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix} \qquad A = \begin{bmatrix} \beta_1 & 0 & 0 & 0 \\ 0 & 0 & -\delta_1 & 0 \\ 0 & 0 & 0 & \gamma_1 \\ 0 & 1 & 0 & 0 \end{bmatrix}$$

If B is not singular (this is not singular in our case), then we can write the above system as:

$$E_t z_{t+1} = B^{-1}Az_t + B^{-1}F\theta_t$$

$E_t z_{t+1} = C z_t + D\theta_t$

Matrix C has four eigenvalues. Since in z_t there are three predetermined variables, only one eigenvalue of C should be outside the unit circle for determinacy (Blanchard and Kahn, 1980). For a textbook treatment of this, see Woodford (2003).

Table 4: Eigenvalue Test for Determinacy of Reduced Form Taylor Rule

Eigenvalue	Post-Crisis	Pre-Crisis	Full Sample
1	1.26	3.20	1.57
2	0.70	0.89	0.74
3	0.91	0.61	0.84
4	0.91	0.69	0.84

As we can see from Table 4, the reduced form Taylor rule was determinate in all three cases. Therefore, we can say that the inflation process was bounded and was being determined by the interest rate. But that does not mean that the interest rate has been optimal during this period. Now, we explore the optimality of the reduced form Taylor rule.

V.2 Optimal Monetary Policy

Reduced form coefficients of IS and Phillips curves for the post-crisis period are used to find optimal weights for the Taylor rule. The objective function given above by equation (4) is minimized every period for a given value of ω_1, ω_2, ω_3 to find weights of γ_1, γ_2, and γ_3. This gives us the optimal reaction function of the central bank and could be very different from the reduced form reaction function. Once we have the weights of the optimal reaction function the optimal rate is obtained. Taylor rule can be written in the expanded format:

$$r_t - r = \gamma_1(r_{t-1} - r) + \gamma_2\pi_t + \gamma_3 y_t \quad (5)$$

'r' is the mean value of interest rate in our sample (we also use two alternative values for r). We can write the above as:

$$r_t = \gamma_0 + \gamma_1 r_{t-1} + \gamma_2\pi_t + \gamma_3 y_t \quad (6)$$

Where $\gamma_0 = r - \gamma_1 r$.

Table 5: Optimized Coefficient of Taylor Rule and Optimal Interest Rate

ω_1	ω_2	ω_3	γ_1	γ_2	γ_3	r_1*	r_2*	r_3*
1.00	0.50	0.10	0.57	1.33	0.70	4.28	4.32	3.90
1.00	0.25	0.10	0.57	1.36	0.49	4.34	4.38	3.97
1.00	0.00	0.10	0.57	1.43	0.26	4.36	4.40	3.98
1.00	0.50	0.15	0.58	1.08	0.55	4.71	4.75	4.34
1.00	0.25	0.15	0.59	1.09	0.39	4.77	4.81	4.40
1.00	0.00	0.15	0.58	1.12	0.23	4.80	4.85	4.44
1.00	0.50	0.20	0.59	0.93	0.46	4.97	5.01	4.61
1.00	0.25	0.20	0.60	0.93	0.34	5.02	5.06	4.66
1.00	0.00	0.20	0.60	0.95	0.21	5.06	5.10	4.70

***Notes*:** r_i* $i = 1,2,3$ are optimal rates in the last quarter of 2018 in alternative scenarios.

The optimal rate is calculated from the estimated coefficient of the Taylor rule obtained from optimization of the objective function. We need an estimated coefficient and value of r to obtain a value of γ_0. Once we have γ_0, then the predicted optimal rate is calculated using $Eq(5,6)$. Three values of r are used, the full sample mean ($r = 6.63\%$) that gives r_1*. If we use the post-crisis sample mean ($r = 6.72\%$) that gives r_2*. Another possibility is to use $r = 5.75\%$, which is the sum of 4% inflation target and long-term real interest rate of 1.75% that gives the predicted optimal rate r_3*[5].

As we can see from the optimal weights given in Table 5, the reduced form weights are nowhere close to optimal weights[6]. Therefore, we can say that the reaction function of the Reserve Bank of India has not been optimal. As we can see from the above table, keeping ω_1 and ω_3 constant, if we decrease the weight attached to the

[5] In this paper, we are assuming 1.75% as a constant natural rate of interest. Behera *et al.* (2017) suggest 1.8% as the upper bound of the natural real rate of interest. Ideally one should allow the natural rate of interest to be dependent on the economic activity. For our purpose, the constant real interest rate bodes well because with the deteriorating growth scenario, the real rate would have been well below 1.75% and therefore, the actual nominal rate would have been lower than the one reported in this paper.

[6] These weights are relative to weight on inflation (ω_1) which has weight 1. ω_2 =0.5 implies that the output gap gets 50% importance in interest rate setting in comparison to the inflation gap.

output gap (ω_2), the central bank becomes less and less flexible and the weight on the output gap (γ_3) in reaction function decreases. Keeping ω_1 and ω_2 constant, if we increase the weight attached to the variance of interest rate (ω_3), then the weight attached to inflation gap (γ_2) and output gap (γ_3) in reaction function decreases. In the case of strict inflation targeting ($\omega_1 = 1, \omega_2 = 0$) and weight attached to the variance of interest rate ($\omega_3 = 0.1$), the optimal interest rate in the last quarter of 2018 comes out to be 4.36%. Whereas if we increase the weight attached to the variance of interest rate ($\omega_3 = 0.2$), the optimal interest rate in the last quarter of 2018 comes out to be 5.06%. The actual rate in the last quarter of 2018 was higher than the optimal rate. This implies that the Reserve Bank of India kept the interest rate higher than the optimal rate. Goyal and Kumar (2017, 2018, and 2019) provide evidence that the Reserve Bank of India has overreacted to inflation and kept rates higher for a longer period that contributed to the current slowdown in the economy. If we use the post-sample mean as r, then the optimal rate is slightly higher because of the higher value of the post-sample mean. If the long-run nominal interest rate is assumed as the sum of the inflation target and long-run real interest rate and a normative r (5.75%) is used, then the optimal rate is found to be lower than the previous case.

V.3 Impulse Response from Model with Optimal Reaction Function

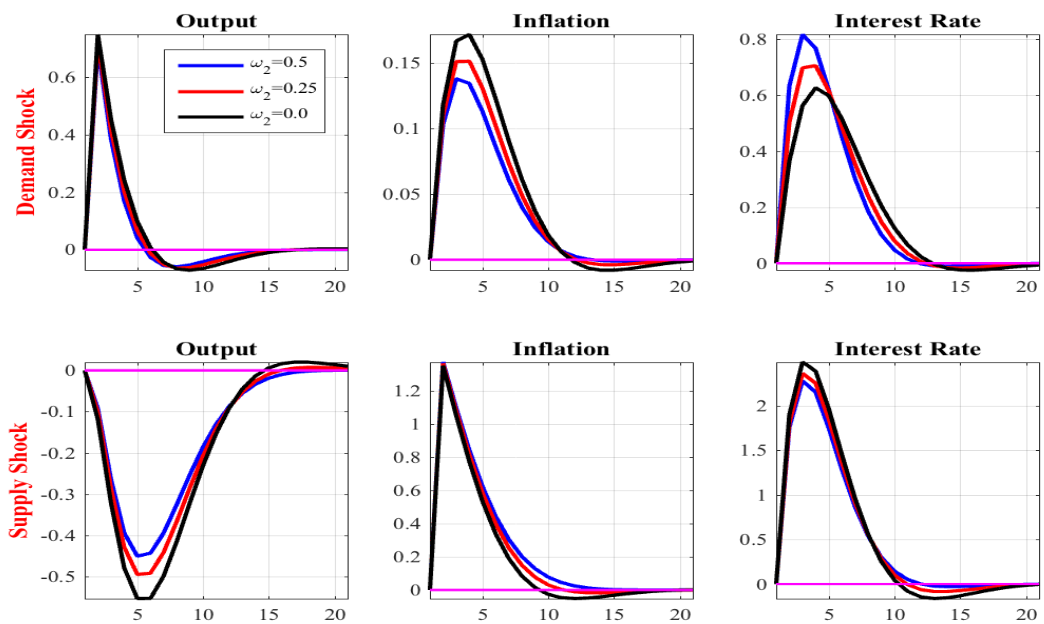
Figures 3, 4, and 5 give simulated impulse response[7] from the model with optimal reaction function. As we can see from these figures, demand shock increases output, inflation, and interest rate. Supply shock decreases output and increases inflation and interest rate. These impulse responses are as expected based on theory. In all these three figures, we can see that when the weight attached to output gap ω_2 is higher, then the loss in output is lower and that is because when the output gap has higher weights then the increase in the interest rate due to adverse supply shocks are lower. This suggests that higher weight on output gap leads to a less undesirable effect on output in case of adverse supply shocks and therefore, a more flexible inflation targeting regime

[7] These impulse responses are obtained by simulating the new Keynesian model. We use the reduced form parameters/variances for IS and NKPC and optimal reaction function obtained from optimization.

(higher ω_2) is favorable in a country like India where supply shocks are the major determinant of inflation using new Keynesian models (Goyal and Kumar, 2017).

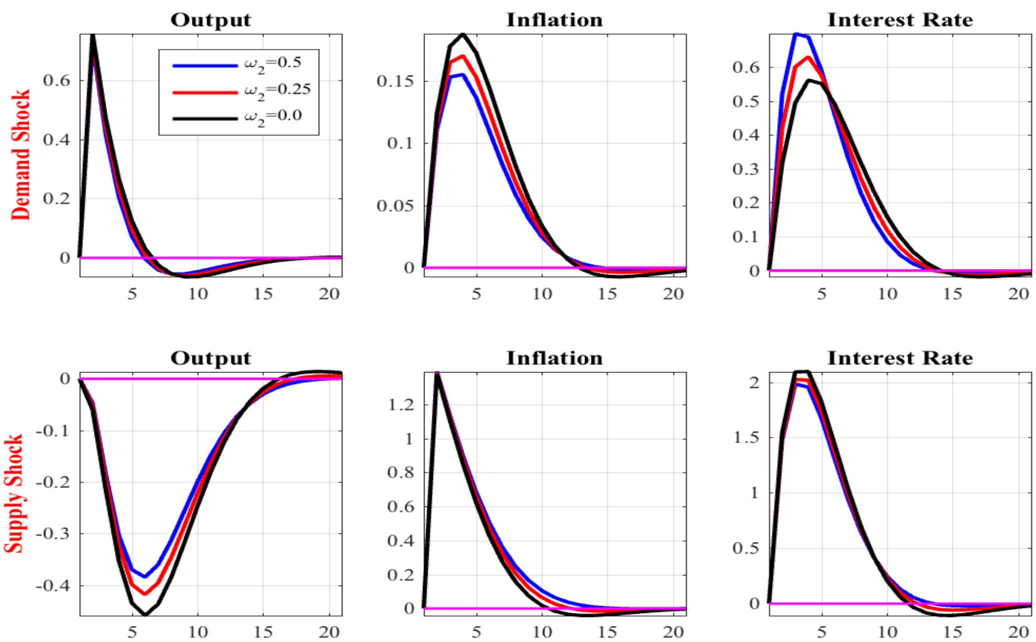
As we increase the weight on the variance of interest rate and move along figures 3 to 5, we can see that response of interest rate due to both demand and supply shocks decrease. This is expected as the central bank is now more concerned about the variability of the interest rate. This leads to a lesser loss in output due to an adverse supply shock because the response of the central bank is slightly muted due to higher weight on the variance of the interest rate.

Figure 3: Simulated Impulse Response from models with optimal monetary policy with different ω_2.



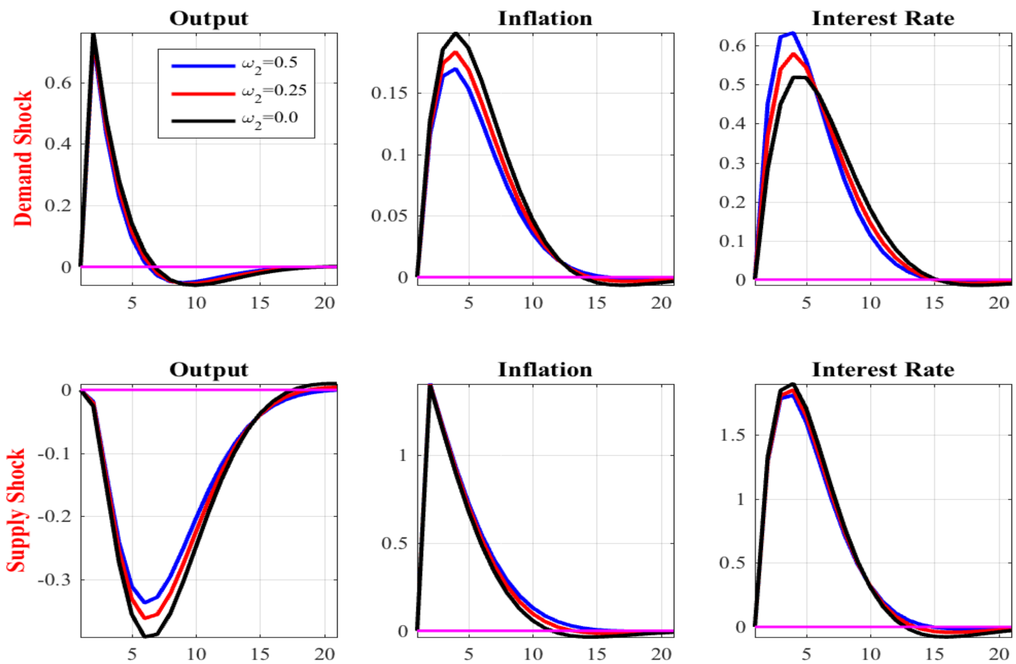
Notes: In all cases the value of $\omega_1 = 1$ and $\omega_3 = 0.1$

Figure 4: Simulated Impulse Response from models with optimal monetary policy with different ω_2.



Notes: In all cases the value of $\omega_1 = 1$ and $\omega_3 = 0.15$

Figure 5: Simulated Impulse Response from models with optimal monetary policy with different ω_2.



Notes: In all cases the value of $\omega_1 = 1$ and $\omega_3 = 0.20$

VI. Policy Implications and Concluding Observations

An optimal monetary policy under commitment may be too demanding and may turn out to be restrictive. Therefore, central banks typically revisit the optimal policy rate continuously based on evolving growth and inflation outlook besides interest rate smoothing (Clarida *et al.,* 1999). In fact, rules without commitment provide a fair degree of discretion to the policymakers. The exact magnitude of change in the policy rate and the appropriate time to announce the same continue to remain a prerogative of the monetary policy committee (MPC). While exercising this discretion, the MPC may commit policy errors by continuously deviating from the rule-based optimal policy rate. Continuous deviations from the optimal path adversely impact growth and inflation in many countries (Taylor 1993, 2012; Kahn, 2010). The policy mistakes may arise due to several reasons. First, models may not be in a position to accurately predict the underlying causes of a rapidly changing outlook on inflation and growth. Second, sources of a shock to the economy may be misjudged. While supply shocks need to be accommodated as these shocks are temporary, demand shocks responsible for inflation should be offset (Clarida *et al.,* 1999). Third, the MPC takes decision on a real-time basis, which may turn out to be erroneous if data are revised significantly at a later date. Fourth, as monetary policy is forward-looking, policy rate based on optimization is obscured if the time horizon is changed.

Indian inflation dynamics are dominated by supply shocks (Goyal *et al.,* 2017). Moreover, inflation persistence is very high in India. Nevertheless, the inflation outcome was close to the desired level when actual WACMR converged with the rule-based interest rate. Since 2000, we observed at least two episodes of possible monetary policy errors going by the reduced form Taylor rule-based nominal interest rate. The first one relates to the period immediately after the GFC, when the monetary policy became highly accommodative. This together with profligate fiscal policy flared up aggregate demand in the economy leading to an increase in inflationary pressures. As this episode was characterized by demand shock, there was a need to fully offset aggregate demand by adequate tightening of the monetary policy. The tightening of the monetary policy in the aftermath of GFC from March 2009 to June 2011 was inadequate in terms of the standard Taylor rule and therefore monetary policy could not succeed in controlling prices.

The post-crisis stimulus and late response to inflation in aftermath of the GFC has been a major policy error of the recent time. Former Governor of the RBI in his speech noted the following. “In 2008, a massive infusion of liquidity was seen as the best bet. Indeed, in uncharted waters, erring on the side of caution meant providing the system with more liquidity than considered adequate. This strategy was effective in the short-term, but with hindsight, we know that excess liquidity may have reinforced inflation pressures. With the benefit of hindsight, of course, I must admit in all honesty that the economy would have been better served if our monetary tightening had started sooner and had been faster and stronger” (Subbarao, 2013).

The second episode relates to the period from June 2013 to March 2016, when interest rate remained high despite inflation trending down. There was a regime shift from MIA to FIT and therefore the glide path was strictly followed. Inflation would have otherwise softened due to favorable supply shocks like softening of crude oil prices, a record level of food-grain production, and supply management by the government. Both growth and inflation were systematically overpredicted (Monetary Policy Reports, April 2016, April 2017). As tightening was more than warranted by the Taylor principle, real interest rate went up, which harmed growth since then despite several structural reforms undertaken by the government. According to the optimization made in this study, the rule-based interest rate under FIT during the last quarter of 2018 ranges roughly from 4% to 5% as against 6.5% maintained by RBI in December 2018 policy. The range maybe 4% to 4.75% if we try to achieve a real interest rate of 1.75%. More recently, efforts are being made to normalize monetary policy close to the Taylor rule. In fact, the repo rate has been reduced successively by a cumulative 135 basis points to 5.15% up to October 2019. For 2019-20, the growth prospect has deteriorated further and the inflation outlook remains benign in the medium-term. Therefore, there is space for reducing the repo rate further.

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Appendix I: Definition of Variables

π –Inflation rate based on the year-on-year logarithmic change in the consumer price index

y – Output gap based on the composite index measured by Bhoi *et al*. (2017)

SS – Rainfall deviation from long term average taken as an exogenous supply shock

$\Delta NEER$ – Growth rate in the nominal effective exchange rate (36- commodity trade-weighted) measured using year-on-year logarithmic change

$\Delta REER$ – Growth rate in the real effective exchange rate (36-commodity trade-weighted) measured using year-on-year logarithmic change

r – Nominal rate of interest measured using weighted average call money rate

RR – The real rate of interest measured using the difference of weighted average call money rate and CPI inflation rate

π^{food} – Inflation rate based on the food component of consumer price index measured using year-on-year logarithmic change

$nfcgr$ – Year-on-year logarithmic change in non-food bank credit

$rnfcgr$ – Year-on-year logarithmic change in real non-food bank credit

ffr – Federal Funds Rate

$G7GR$ – The growth rate of G7 countries measured using the year-on-year logarithmic change in G7 GDP

DD – Exogenous demand shock denoted by gross fiscal deficit as a percentage of GDP

π^{gap} – Difference between inflation and inflation target (taken as 4%)

$YIELD_{gap}$ – Difference between India and US 10-year treasury yields

inv_gap – Gap in gross fixed capital formation (GFCF) measured using HP-filter