Asymmetries in the Monetary Policy Reaction Function: Evidence from India

Irfan Ahmad Shah

Centre for Development Studies

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Abstract

This paper analyzes the reaction function of monetary authority in India from $1996Q_1$ to $2018Q_4$ using nonlinear Taylor rule. It has been found that monetary policy reaction function (MPRF) in India is asymmetric and is influenced by the state of the economy, determined by the lagged interest rate. To capture such asymmetry, we have used a set of nonlinear models including smooth transition regression (STR) model, threshold regression (TR) model and Markov-Switching regression (MSR) model. The analysis discloses that Reserve Bank of India (RBI) aggressively reacts towards output gap during recessionary periods compared to non-recessionary periods. This exhibits that preference of monetary authority in India may better be characterized as recession avoidance preference compared to inflation avoidance preference. Further, we have found a high degree of inertia in the policy rates of the RBI.

Keywords: Monetary Policy Taylor rule Regime-Switching Asymmetric preferences.
JEL: E52 E58 E42

1 Introduction

Taylor (1993) rule, that describes the reaction of monetary authority toward inflation and output gap has dominated much of the monetary policy literature since the early

1990s (i.e. Jung (2017) and Asso, Kahn, and Leeson (2010)). One of the reason is that Taylor rule is simplistic in nature and clearer in describing the behaviour of monetary authority. As a result, it has widely been used as a policy tool to guide, design and evaluate the behaviour of monetary authority. However, a basic flaw with this rule is its underlying assumption of linearity which considers equal reaction of monetary authority towards inflation or output gap above and below it's target. Further, this assumption of linearity considers policy decisions independent of the state of economy. This implies that monetary authority while formulating their policy decisions neither consider the level of inflation/output gap nor does they consider the state of the economy. This assumption has widely been criticized in the literature. A number of studies including Ma, Olson, and Wohar (2018), Nobay and Peel (2003), Cukierman and Gerlach (2003), Gerlach (2003), Ruge-Murcia et al. (2001), Ruge-Murcia (2004), Bec, Salem, and Collard (2002), Dolado, Marıa-Dolores, and Naveira (2005) and Surico (2007) argue that the response of monetary authority towards a particular shock is not necessarily a function of that shock per se rather it is influenced by many other factors. These factors include a) preferences of policymakers b) uncertainty in the economy c) political pressure on policymakers and d) structure of the economy. Depending upon the nature of these factors, the response of monetary authority towards inflation/output gap may also vary. A brief illustration of how these factors may induces asymmetry or nonlinearity in the response of monetary authority is given below:

Considering the preferences of policymakers, Cukierman and Muscatelli (2008) argue that such preferences may be categorised under two broad headings: recession avoidance preference (RAP) and inflation avoidance preference (IAP). In RAP, monetary authority is more concerned to negative output gap compared to positive output gap. In IAP, the focus however, is more on positive inflation gap compared to negative inflation gap. Policymakers with RAP will put more weight on output gap during recessionary period than non-recessionary period while policymakers with IAP are more aggressive towards inflation above the target than below it. This asymmetry in the preference of policymakers may induce asymmetry in the reaction function of monetary authority. Further, asymmetry in the reaction function may also be induced due to uncertainty regarding the future state of the economy. Cukierman and Gerlach (2003) have argued that uncertain economic conditions makes policymakers more sensitive towards employment/output. This results in aggressive response to employment/output when it is below the target than when it is above the target. Orphanides and Wilcox (2002) have explained such asymmetry through the approach popularly known as "Opportunity Cost of Disinflation". According to this approach, to dampen inflationary pressure in the economy, monetary authority does not increase policy interest rate proportionately. They rather wait for external positive shocks to mitigate the effects of high inflation because proportionate rise in policy rate may negatively affect the output growth. As a result, there is a policy bias inducing asymmetry in the reaction function[1]. Other possible sources of asymmetry as argued by Judd and Rudebusch (1998) are the chairmanship of central banks, the external pressure by political parties and the structure of the economy.

A plethora of studies analysing such asymmetries have been conducted across different countries. Some of them include Dolado, Marıa-Dolores, and Naveira (2005), Surico (2007), Bunzel and Enders (2010), Martin and Milas (2004), Aksoy, Orphanides, Small, Wieland, and Wilcox (2006), Castroa (2008) and Bec, Salem, and Collard (2002). It is observed that monetary authority across countries show significant asymmetry in their response towards inflation and output gap in different regimes/situations. These regimes are classified as low/high inflation or output growth regimes, recessionary and non recessionary (or boom) period *etc*. Considering the case of India, most of the studies including Virmani (2004); Patra and Kapur (2012); Mohanty and Klau (2005); Inoue (2010); Singh (2010); Hutchison, Sengupta, and Singh (2010) used linear framework to analyse MPRF. The focus of these studies is to understand whether monetary authority reacts more to inflation, output gap or exchange rate. They however ignored to analyse whether such response is symmetric or not. The question that remains pertinent is whether RBI considers economic conditions while formulating its policy decisions or is its policy decisions independent of the state of economy. A few studies including Hutchison, Sengupta, and Singh (2013), Kumawat and Bhanumurthy (2016) and Ajaz (2019) have incorporated such asymmetries while analysing MPRF. Hutchison, Sengupta, and Singh (2013) using a Markov-Switching model categorised the behaviour of RBI into "Dovish" and "Hawkish"regime. In the former regime RBI reacts more to output however the focus shifts to inflation in the latter regime. This study however is limited to pre-Global financial crisis (GFC) and uses IIP data as a proxy for GDP data. In another study, Kumawat and Bhanumurthy (2016) found time varying response of monetary authority towards lagged

[1] Bénassy (2007) also agree with the view that optimal response of monetary authority is nonlinear. Using general equilibrium model with non-Recardian equivalence approach Bénassy (2007) showed that policymakers respond actively to inflation only when it is above the target.

values of output gap, inflation and the exchange rate. Ajaz (2019) using nonlinear ARDL model showed RBI having both RAP and IAP. We differ from these existing studies in the following way:

Unlike other studies we analyse MPRF consider both the possibilities of regime switches both to be observed as well as unobserved/probabilistic in nature. For observed regime switches TR and for unobserved regime switches MSR is used. Further, to consider the possible problem of endogeniety in the contemporaneous Taylor rule, TR with instrumental variable estimation using GMMs is used. Our study not only covers pre and post-GFC period but also includes the period under the recent inflation targeting regime. Moreover, to analyse MPRF, our threshold model uses lagged interest rate as a switching variable to divide the sample into high interest rate (recessionary) and low interest rate (non-recessionary) periods. We found clear evidence of asymmetric response in the reaction function. The reaction being more to output gap compared to inflation and the exchange rate. The response towards output gap further increases as the economy plunges into recession. in other words we found RBI more bent towards RAP than IAP. A high degree of of inertia in policy interest rates is also found especially during non-recessionary periods.

The essence of this study is that it not only highlights the asymmetric behaviour of the RBI but also provides robust estimates based on threshold and MSR models. Further, we argue that using linear Taylor rule not only ignores asymmetric preferences but also provides inaccurate and misleading results. The rest of the paper is organized as follows. In section 2 we review selected literature followed by the methodology and data description in section 3. Section 4 discusses the results while conclusion is given in section 5.

2 Literature review

While analysing asymmetries in the MPRF Martin and Milas (2004) observed that before adopting inflation targeting approach in 1992, Bank of England (BoE) was more focussed on stabilizing output than inflation. However, post-1992, BoE's response was more to inflation when inflation was above the target than when it was below the target. Such asymmetries were observed across other countries as well. Dolado, Marıa-Dolores, and Naveira (2005) from their study observed that Fed as well as the ECB react aggressively when inflation or the output gap is above the target than when it is below the target.

In the case of China Klingelhöfer and Sun (2018) found People's Bank of China (PBC) reacting more to negative output gap and positive inflation gap. The bank however, seems to be tolerant with high economic growth and low inflation. Bunzel and Enders (2010); Surico (2007); Aksoy, Orphanides, Small, Wieland, and Wilcox (2006) have arrived to a similar conclusion with Fed showing both RAP and IAP. They argue that Fed responds aggressively to inflation when it crosses the target. The response to output gap is aggressive only when output is below the target. Similar findings were observed by Castroa (2008) for the BoE and the ECB.

However, to consider the state of economy such a recession or boom, as a source of asymmetry a number of studies such as Bec, Salem, and Collard (2002); Brüggemann and Riedel (2011); Altavilla and Landolfo (2005); Zhu and Chen (2017); Assenmacher-Wesche (2006); Owyang and Ramey (2004); Zheng, Xia, and Huiming (2012) have been carried out. Though different in their results, these studies unanimously argue that response of monetary authority is influenced by the state of the economy. A study by Bec, Salem, and Collard (2002) found that Fed reacts aggressively to inflation during expansion compared to recession however, Bundesbank puts more weight on both inflation and the output gap during expansion compared to recession. Contrary to this Brüggemann and Riedel (2011); Altavilla and Landolfo (2005); Zhu and Chen (2017) found that BoE and the ECB put more on output gap during recession and inflation becomes a concern only during non-recessionary periods. Even there has been evidences of monetary authorities shifting their preferences from output stabilization to price stabilization (Assenmacher-Wesche, 2006; Owyang and Ramey, 2004; Zheng, Xia, and Huiming, 2012; Owyang and Ramey, 2004). Such studies in Indian context are limited.

A number of studies such as Virmani (2004); Patra and Kapur (2012); Mohanty and Klau (2005); Inoue (2010); Singh (2010); Hutchison, Sengupta, and Singh (2010) analysed MPRF in India. These studies linearly examined whether monetary authority in India reacts more to inflation, output gap or the exchange rate. While Mohanty and Klau (2005); Inoue (2010) found output gap and exchange rate significantly affecting reaction of monetary authority, such was not the case for inflation. Hutchison, Sengupta, and Singh (2010) using structural-break analysis reached to similar conclusion. Singh (2010) analysing annual data from 1950-51 to 2008-09 found monetary authority reacting more actively to output gap till 1987-88, the focus thereafter shifted to inflation. Patra and

Kapur (2012) using forward-looking approach found RBI more focussed to Inflation compared to output gap. Studies such as Hutchison, Sengupta, and Singh (2013); Kumawat and Bhanumurthy (2016); Ajaz (2019) using nonlinear framework found that the preferences of the RBI are asymmetric. To analyse such asymmetric preferences we use a set of nonlinear models including STR model, TR model and the MSR model. The essence of incorporating all these models is: a) to find robust estimates from comparative analysis b) to have regimes both being endogenous as well as exogenously determined. We also use TR model with instrumental variable using GMMs to consider the problem of endogeneity. This model has not yet been used in Indian context to analyse the behaviour of monetary authority.

3 Methodology and Data

To analyse the asymmetric behaviour of monetary authority in India, we have considered nonlinear time series models such STR model, TR model and MSR model. Both STR and TR model consider that the regimes are exogenously determined and are observed in nature. In MSR model, threshold variable is endogenously being determined with in the model and is probabilistic in nature. We begin with STR model as:

3.1 Smooth-transition regression model

The general form of smooth transition (STR) model as given by Teräsvirta et al. (1996); Teräsvirta (2004):

$$i_t = \phi^{'} z_t + \theta^{'} z_t G(\gamma, c, s_t) + u_t,\, u_t \sim iid(0, \sigma^2) \tag{1}$$

with ϕ and θ representing parameter vectors of linear and nonlinear parts respectively. z_t represents the vector of explanatory and the lagged dependent variables. s_t represents transition variable and the transition value also known as location parameter is given by c. When s_t is less than c, we get linear parameters and once s_t crosses over the value of c we get nonlinear parameters. The speed of the transition is obtained by the slope parameter γ and the transition function which is assumed to be logistic (LSTR) is given below as:

$$G(\gamma, c, s_t) = \Big(1 + exp\Big[- \gamma\, (\Pi_{k=1}^{K}(s_t - c_k)\Big]\Big)^{-1}$$

The value of $\gamma > 0$ is the identification criteria with K defining the number of transition points. For K=1, we have LSTR1 with $\phi + \theta G(\gamma, c, s_t)$ changing monotonically as a function of s_t from ϕ to $\phi + \theta$. For K=2, we have LSTR2 and the parameters change symmetrically around $(c_1 + c_2)/2$ where this logistic function attains its minimum value. The value of γ determines whether there is a smooth transition or an abrupt shift between regimes. If the value of γ is low, we have a smooth transition however, if the value is large, the regime shifting is abrupt and is represented by a threshold regression model as given below:

3.2 Threshold models

The baseline threshold model for our Taylor rule equation is given as:

$$
\begin{aligned}
i_t = &\Big(\alpha_0^L + \alpha_1^L \, \hat{y}_t + \alpha_2^L \, \pi_t + \alpha_3^L \, e_t + \rho_1 \, i_{t-1}\Big) 1(q_{t-1} \leq \gamma) \\
&+ \Big(\alpha_0^H + \alpha_1^H \, \hat{y}_t + \alpha_2^H \, \pi_t + \alpha_3^H \, e_t + \rho_2 \, i_{t-1}\Big) 1(q_{t-1} > \gamma) + \varepsilon_t \quad (2)
\end{aligned}
$$

where i_t, $\hat{y}_t$, π_t and e_t represents policy interest rate, output gap, inflation rate and the percentage change in exchange rate respectively. The superscripts (L) and (H) represents whether the parameters belong to low or high regime, determined by the indicator function $1(\cdot)$.

For STR or TR model where regimes are observed and being exogenously determined, a few things are quite important while selecting the threshold variable: a) threshold variable(s) should be decided intuitively so that they divide the sample into identifiable regimes for a comparative analysis b) among the set of all possible threshold variables, only those variables that have strongest power of rejecting linearity should be considered. For our analysis in particular lag interest rate satisfy all the criteria. It strongly rejects the assumption of linearity compared to inflation and output gap. This variable as used by Brüggemann and Riedel (2011) distinguishes the economy into recessionary (when interest rates are high) and non-recessionary (when the interest rates are low).

3.3 Markov-Switching Regression models

MSR models, although used long back by Lindgren (1978) and Baum, Petrie, Soules, and Weiss (1970), were first introduced by Neftici (1982) and Sclove (1983) to analyse business cycles. None of them however described the method for calculating the likelihood function of these models. Hamilton (1989) motivated by Goldfeld and Quandt (1973) popularized such models by using iterative algorithm analogous to Kalman filter for estimating MSR models. These models attracted overwhelming attention because they provide a convenient framework for analysing nonlinear models- nonlinearity arising due to switching behaviour in the economy. The benefit of using such model as argued by Assenmacher-Wesche (2006) is that no a-priori assumption is to be made on the cause of the regime shifts. It is as *letting the data to speak* and then interpret the results.

Following Woodford (2001), we have specified a two regime MSR model for the Taylor's rule as:

$$i_t = c_{0st} + \alpha_{st}\hat{y}_t + \beta_{st}\pi_t + \gamma_{st}e_t + \eta_{st}i_{t-1} + \varepsilon_{st} \tag{3}$$

$$\varepsilon_{st} \sim N\ (0, \sigma_{st}^2) \tag{4}$$

where c_{0st} is the intercept term and i_t being the nominal interest rate is a function of output gap $\hat{y}_t$, inflation rate π_t, percentage change in exchange rate e_t and the lagged interest rate, i_{t-1}. The parameters of this equation such as $\alpha, \beta, \gamma, \eta$ and σ are state dependent based on the state variable s_t that represents the probability of being in a different state of world. s_t being probabilistic in nature, is governed by discrete state of Markov-stochastic process which is defined by the transition probabilities. The transition probabilities are represented as:

$$p_{ij} = Pr(s_t = i|s_{t-1} = j)\ \hat{P} = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1m} \\ p_{21} & p_{22} & \cdots & p_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ p_{m1} & p_{m2} & \cdots & p_{mm} \end{bmatrix}$$

Where p_{ij} is the probability that state i is followed by state j and $\hat{P}$ is the correspondent transition matrix such that $p_{11} + p_{21} + ... + p_{m1} = 1$. For two states, the transition probabilities are given as:

$$\hat{P} = \begin{bmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{bmatrix}, \text{ where } p_{11} + p_{21} = 1 \text{ and } p_{12} + p_{22} = 1.$$

In order to estimate MSR model, we use probability density function of interest rate as $f(i_t|\psi_{t-1}; \theta)$ where ψ_{t-1} represents the past information and θ contains all the parameters. The density function can also be written as a joint density of i_t and s_t as: $f(i_t|\psi_{t-1};\theta) = f(i_t, s_t = k|\psi_{t-1};\theta)$.

Since joint density function can be written as a product of conditional and marginal density, we have $f(i_t, s_t = k|\psi_{t-1};\theta) = f(i_t|s_t = k, \psi_{t-1};\theta).f(s_t = k|\psi_{t-1};\theta)$ which may also be written as $f(i_t, s_t = k|\psi_{t-1};\theta) = f(i_t|s_t = k, \psi_{t-1};\theta).P(s_t = k|\psi_{t-1};\theta)$.

Given the marginal density function, it would be easy to estimate $f(i_t, s_t = k|\psi_{t-1};\theta)$. However, the problem with MSMs is that the regimes are governed by unobserved Markov-stochastic which are probabilistic in nature. So, we use Maximum Likelihood Estimation (MLE) technique that enables us to find the likelihood function, given the sample data. The likelihood function to be estimated is the weighted average of density functions for the given regimes. The weights being the probability of each regime.

For $s_t = k$ where k is the number of regimes, we have

$$ln\ L = \sum_{t=1}^{T} ln \sum_{k=1}^{n} f(i_t|s_t = k, \psi_{t-1};\theta)\ Pr(s_t = k|\psi_{t-1};\theta) \tag{5}$$

where $Pr(s_t = k|\psi_{t-1};\theta)$ represents the probability in each regime (also known as filtered probability). For two regimes (n = 1, 2), the filtered probability is given as:

$$Pr(s_t = k|\psi_{t-1};\theta) = \sum_{z=1}^{2}\ Pr(s_t = k|s_{t-1} = z) Pr(s_{t-1} = z|\psi_{t-1};\theta) \tag{6}$$

Once $Pr(s_t = k|s_{t-1} = z)$, $(k = 1, 2$ and $z = 1, 2)$, are obtained, the transition probabilities can be updated because the value of i_t is observed after t^{th} interaction or at the end of time period t. The updated probability is as follows;

$$Pr(s_t = k|\psi_t;\theta) = Pr(s_t = k|\psi_{t-1}, i_t;\theta) \tag{7}$$

$$Pr(s_t = k|\psi_t;\theta) = \frac{f(s_t = k, i_t|\psi_{t-1};\theta)}{f(i_t|\psi_{t-1};\theta)} \tag{8}$$

The updated probability is calculated as

$$Pr(s_t = k|\psi_t; \theta) = \frac{f(i_t|s_t = k, \psi_{t-1}; \theta)}{\sum_{k=0}^{1} f(i_t|s_t = k, \psi_{t-1})\ Pr(s_t = k|\psi_{t-1})} \tag{9}$$

These equations can be used to obtain $Pr(s_t = k|\psi_{t-1}), \quad t = 1, 2, ..., T$ however to start the process initial condition is required which is given as $Pr(s_0|\psi_0)$. Based on equation (3.8), we estimate the interest rate equation.

3.4 Data

For the conduct of monetary policy in India, we consider the period from $1996Q_1$ to $2018Q_4$. This period includes MIA adopted in 1998 and a few years of ITA adopted recently in 2014-15. The starting date is fixed based on the availability of quarterly GDP data from 1996 onward. Variables such as short term interest rate, output gap, inflation and exchange rate are used. We use call money rate as a proxy for short term interest rate as used by Hutchison, Sengupta, and Singh (2013). For output data, GDP at factor cost at constant prices is used. Due to unavailability of GDP at factor cost from $2014 - 15Q_1$ onward, GVA at basic price is used[2]. Output gap is estimated as percentage difference of actual output and its potential output, estimated through Hodrick-Prescott filter method. For inflation rate, we use wholesale price index (WPI) given the fact that RBI till 2014 was targeting WPI inflation. It was only after the Urjit Patel committee report in 2014 (Patel, Chinoy, Darbha, Ghate, Montiel, Mohanty, and Patra, 2014) that RBI started targeting inflation based on CPI (combined) inflation. For exchange rate, we use Indian rupee against US Dollar. The data is obtained from *Handbook of Statistics,* RBI and the *FRED Database.*

From the data under consideration we observe a significant variation in the variables over the given time frame. The call money rate has varied from a minimum of 3.2 percent to a maximum of 15.71 percent, with an average rate of 6.8 percent. This is quite understandable given the way inflation, output gap as well as exchange rate have behaved over time. The WPI inflation in India varied from 11.05 percent during GFC to -4.5 percent in the recent times. Exchange rate has fluctuated by -12.6 percent to 24.96 percent while output gap varied from -5.5 percent to 3.08 percent. These fluctuations can be seen in the Figure 1 below:

[2] We use seasonally adjusted GDP data series from 1996 to 2018 from FRED

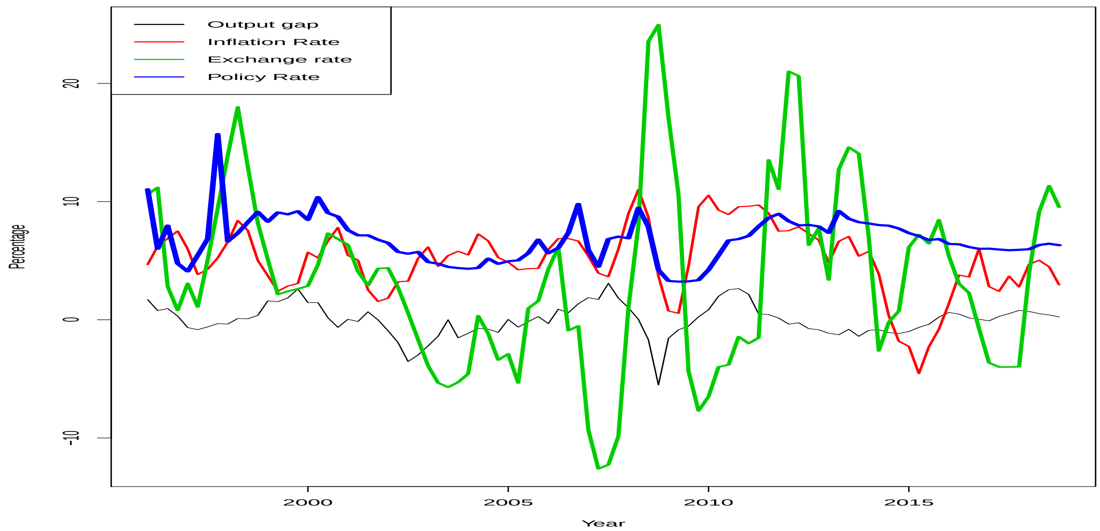


Figure 1: All Variables

4 Empirical analysis

To analyse asymmetry in the MPRF, we begin by testing nonlinearities due to smooth-transition in all the variables along with their lag values and the trend. The results obtained are shown below in Table 1. The null hypothesis of linear model against LSTR1 model is rejected for lag policy rate, exchange rate and the trend[3]. Among all these potential transition variables, lag policy interest rate has the strongest test rejection. So, we consider lag policy rate as our transition variable and use grid search to find out initial values of slope γ and the transition value c[4]. The advantage of using such a grid-search is that it creates log-linear grid in γ and linear grid in c. We found the value of (γ) and c to be 10 and 7.5.

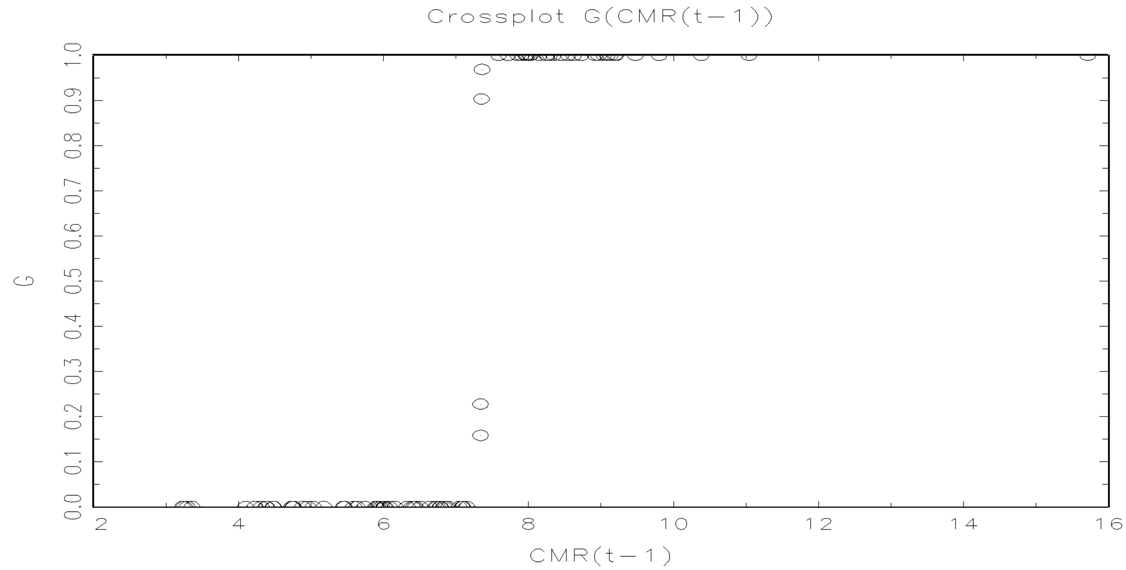
Table 1: Testing Linearity against STR

Transition Variable	F	F4	F3	F2	Suggested model
CMR^*_{t-1}	0.000116	0.016	0.433	0.000104	LSTR1
$USDyoy_t$	0.00147	0.486	0.0292	0.00103	LSTR1
t	0.000443	0.133	0.145	0.000174	LSTR1

[3]For other variables the suggested model is linear and thus not shown in Table 1

[4]A similar study in which lag policy rate has been considered as transition variable is carried out by Brüggemann and Riedel (2011) in the context of UK.

Figure 2: Transition Function



Using these values obtained from the grid-search in the estimation with lagged interest rate as transition variable, we found the actual transition value to be 7.34 percent. Based on this transition value the entire sample is divided into two regimes- recessionary with policy rate above 7.34 percent and non-recessionary regime with policy rate below 7.34 percent. The non-recessionary part is also reflected by the linear part wherein monetary authority responds to inflation as well as exchange rate, the coefficients being 0.12 and .05 respectively and not to the output gap (Table 2). It is only in the nonlinear (recessionary) part when the policy rate is above transition value, monetary authority aggressively responds to output gap with a coefficient of 0.47. During recessionary period neither inflation nor the exchange rate seems to be focus of the RBI. This shows that during non-recessionary period monetary authority in India shows inflation avoidance preference (IAF) while the preferences shifts strongly to recessionary avoidance as the economy plunges into recession.

To test the robustness of the model, we conducted a set of tests. From auto-correlation and nonlinearity tests, we found that no such autocorrelation or the remaining nonlinearity in the model. However, while analysing the slope, we found γ to be 543, which reflects that the regime switching in our model is not smooth rather abrupt. This is depicted in the transition function diagram as shown in Fig 2. To counter this problem we use threshold regression rather than smooth regression model as given below:

Table 2: Taylor rule estimation with STR

	Lag interest rate as threshold variable	
	Linear Part	Nonlinear Part
Constant	-0.131	10.47^{***}
	(1.083)	(1.773)
$\hat{y}_t$	0.162	0.47^{*}
	(0.153)	(0.258)
π_t	0.118^{*}	-0.146
	(0.066)	(0.12)
e_t	0.05^{*}	0.013
	(0.03)	(0.053)
i_{t-1}	0.97^{***}	-1.27^{***}
	(0.17)	(0.23)
Transition value c	7.34	
Gamma γ	542.9	
R^2	59.3	
Note:	*p<0.1; **p<0.05; ***p<0.01	

4.1 Threshold model

Threshold regression (TR) models introduced long back in the early 1980s became quite popular due to their simple specification and easy to estimate and interpret property. A number of studies including Taylor and Davradakis (2006); Bunzel and Enders (2010); Koustas and Lamarche (2012); Zhu and Chen (2017) used TR models to analyse nonlinear behaviour of monetary authority across different countries. We use such a model in Indian context. Following Hansen (1996, 2000) and assuming inflation target to be constant which is subsumed in the constant term, we estimate equation (2) as described above. The coefficients of inflation, output gap and the exchange rate are expected to be positive because an increase in inflation, output gap or a depreciation in exchange rate is countered by an increase in the policy rates. The results obtained however are given below in Table 3:

While column 1 represents coefficients of the entire sample, column 2 and 3 depicts regime wise estimates. Column 2 represents the regression coefficients with threshold value below 6.83 while the regression coefficients above it are shown in column 3. Regression coefficients above 6.83 correspond to recessionary period while that of below 6.83 represent non-recessionary period.

At the outset, it is clear that that the response of monetary authority in India towards output is positive and statistically significant across the regimes. The response however becomes aggressive from 0.246 to 0.59 as the economy enters into a recessionary phase[5]. Also, the RBI becomes vigilant about exchange rate fluctuation during recessionary period compared to non-recessionary period when RBI is more focussed on the past interest rate. Considering the inflation coefficients, it seems that the RBI does not react significantly to inflation. These findings may be affected due to the possible problem of endogeniety in the model. To counter such a problem, we use Instrumental variable estimation (IVE) with threshold regression using generalised method of moments (GMMs) technique. This method has been used by Taylor and Davradakis (2006) for analysing nonlinear behaviour of the Bank of England (BoE). Recently, Koustas and Lamarche (2012) used such an approach with Caner and Hansen (2004) multi-step estimation strategy to take care of possible heterogeneity and serial correlation in the estimation process. We apply such a method in Indian context[6]. The results obtained are shown below in Table 4:

[5]This however is in consonance with the findings from the STR model.

[6]The instruments used for the estimation are first two lagged values of inflation, output gap and the exchange rate.

Table 3: Taylor rule with lagged interest rate as a threshold variable

	Lag interest rate as threshold variable		
	Linear Regression	Regime 1	Regime 2
Constant	3.62^{***}	1.079	10.31^{***}
	(1.126)	(0.709)	(0.1.52)
$\hat{y}_t$	0.41^{***}	0.246^{**}	0.592^{***}
	(0.107)	(0.094)	(0.19)
π_t	0.012	0.045	0.039
	(0.039)	(0.045)	(0.0052)
e_t	0.060^{**}	0.0152	0.071^{*}
	(0.028)	(0.0184)	(0.039)
i_{t-1}	0.422^{**}	0.79^{***}	-0.345^{*}
	(0.165)	(0.098)	(0.178)
Threshold Value		≤ 6.83	> 6.83
Observations	91	49	42
Degree of freedom	86	44	37
Sum of Squared Errors	193.51	19.792	99.757
Residual Variance	2.25	0.449	2.696
R-Squared	0.40	0.699	0.189
Note:	*p<0.1; **p<0.05; ***p<0.01		

It is observed that the RAP of the RBI is evident from IVE as well. The response of the RBI towards output gap increases from 0.25 to 0.302 as the economy enters into recessionary phase. We also observe that the inflation coefficients equal to 0.101 is significant during recessionary regime compared to non-recessionary regime. Further, the degree of inertia of policy rates is found to be high, around 0.84 in non-recessionary period. Considering the long run coefficients, we observe that the Taylor rule condition is satisfied only for the output gap, being greater than 0.5. For inflation rate, the longrun coefficient is found to be much lower than unity.

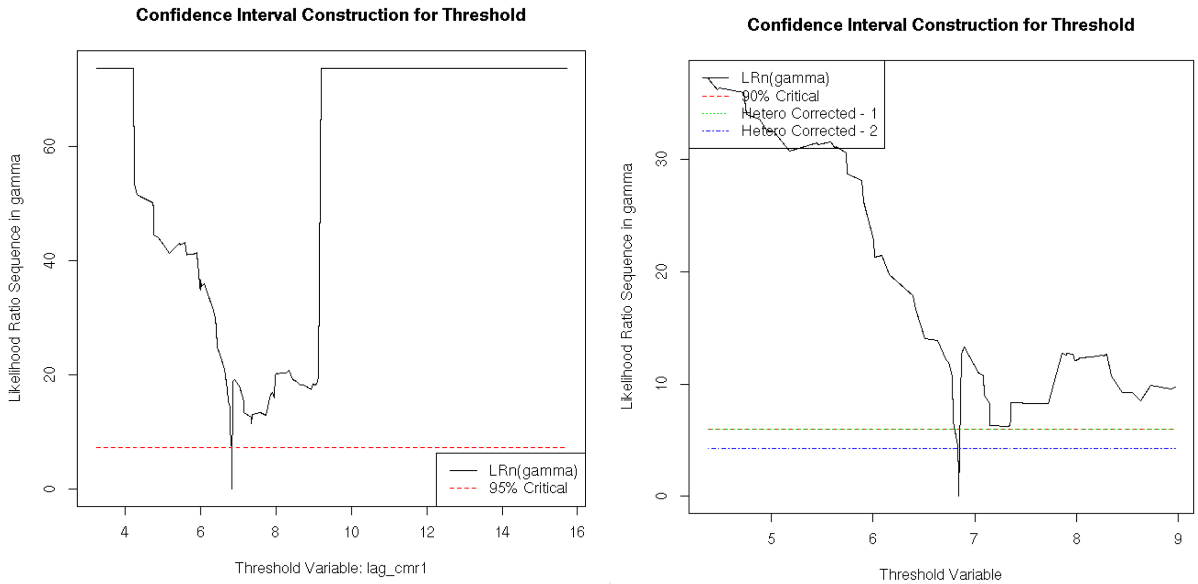
Considering the robustness of the statistics we observe that the threshold value estimated in our model is quite exact lying within the confidence interval. The exactness of

Table 4: Taylor rule with instrumental variable estimation

	Lag interest rate as threshold variable	
	Regime 1	Regime 2
Constant	0.874	8.889***
	(0.595)	0.925)
$\hat{y}_t$	0.257**	0.302*
	(0.102)	(0.167)
π_t	0.033	0.101*
	(0.0432)	(0.054)
e_t	-0.0071	0.0037
	(0.023)	(0.053)
i_{t-1}	0.84***	-0.141
	(0.084)	(0.111)
Threshold	< 6.83	> 6.83
Observations	44	40
Degree of freedom	39	35
Note:	*p<0.1; **p<0.05; ***p<0.01	

threshold value is tested by inverting the likelihood ration (LR) statistic as described in (Franses, Van Dijk, et al., 2000, pp 85). These LR-statistic are shown in Figure 3. The first panel represents the LR-statistic of threshold model without IVE while the second panel depicts LR-statistic of threshold model with IVE. In both these figures, the portion below the 95 percent critical level is small reflecting the exactness of threshold value.

Figure 3: Exactness of Threshold Value



4.2 Markov-Switching results

A common assumption throughout the above analysis is that the threshold variable is observed and determined exogenously. We relax this assumption and consider the regimes to be endogenously determined. To capture such a behaviour, we use MSR models with a baseline equation in which policy rate is a function of inflation, output gap, exchange rate and lag dependent variable. All the variables including the intercept term and the variance of error term are allowed to switch as given below:

$$i_t = c_{0st} + \alpha_{st}\hat{y}_t + \beta_{st}\pi_t + \gamma_{st}e_t + \eta_{st}i_{t-1} + \varepsilon_{s_t} \tag{10}$$

$$\varepsilon_{s_t} \sim N\ (0, \sigma^2_{st}) \tag{11}$$

The results obtained from MSR model are shown below in Table 5. Given the value of the intercept term regime 1 is the high interest rate (recessionary) regime and regime 2 as the low interest rate (non-recessionary) regime. Considering the output gap, the results are very much in line with TR or STR model. The RBI reacts to output gap more aggressively during recessionary phase compared to non-recessionary phase. The coefficient on output gap during recessionary phase is 1.04 compared to 0.16 in non-recessionary phase. The coefficient on exchange rate (0.187) is statistically significant only during recessionary phase. This implies that RBI significantly reacts to exchange fluctuations when the economy is in recessionary phase, the response is insignificant during non-recessionary period. Further, as found earlier as well, the degree of inertia to policy interest rate is quite high (0.94) during non-recessionary period. Although low, we found the coefficient on inflation to be statistically significant. Considering the longrun coefficients, we found the output gap coefficients to be 7.28 during recessionary phase compared to 1.12 during non-recessionary period. This is well within the Taylor rule recommendations, however for the longrun inflation rate coefficient during non-recessionary phase, it is 0.26 much below the recommended value of Taylor rule.

Table 5: Taylor rule with MSM

	All variables switching	
	Regime 1	Regime 2
Constant	7.18^{***}	0.22
	(1.67)	(0.257)
$\hat{y}_t$	1.04^{**}	0.16 ***
	(0.362)	(0.0408)
π_t	-0.0379	0.0371^{*}
	(0.1919)	(0.0147)
e_t	0.187^{**}	-0.0082
	(0.0713	(0.008)
i_{t-1}	-0.086	0.9432^{***}
	(0.1776)	(0.0396)
Note:	*p<0.1; **p<0.05; ***p<0.01	

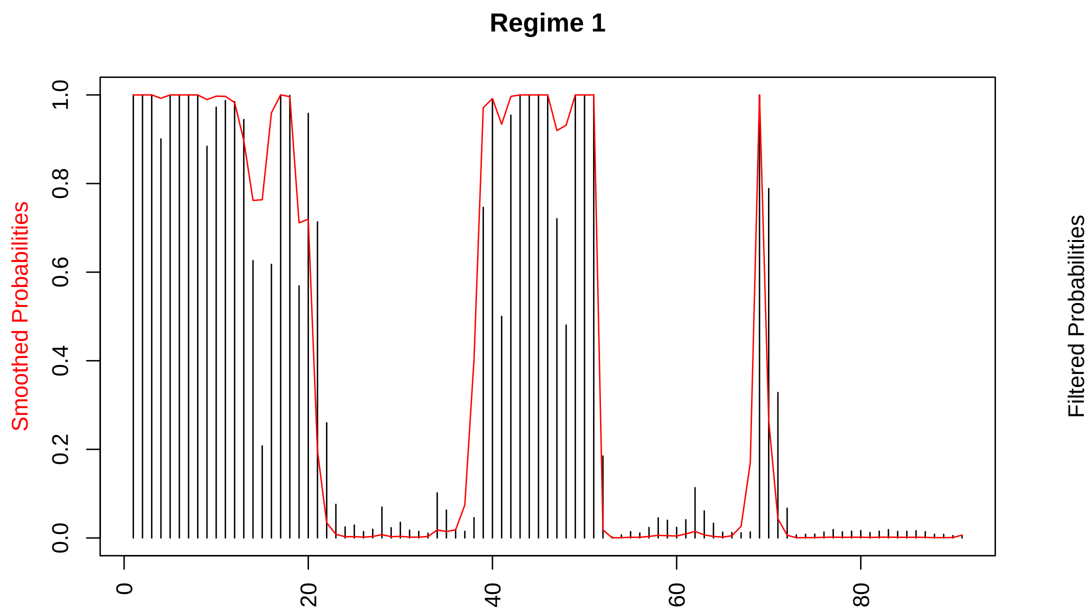
We have plotted smoothed probabilities of the two regimes to understand when the economy is in either of the regimes (Fig 4). At any point in time, if the probability of being in a particular regime (say Regime 1) is above 0.5, we consider the economy is in regime 1 otherwise it is in regime 2. Given the Figure 4, we observe that the probability of the economy to be in regime 1 (recessionary regime) during first 20 quarters is quite high, however for next 20 quarters it is supposed to be in regime 2. The regimes may shift back depending upon the transition probabilities as given in Table 6. The probability of already being in regime 1 and staying in the same regime, given by p_{11} is 0.92 while the probability of shifting to regime 2, $1 - p_{11}$ is 0.076. Similarly the probability of being in regime 2 and staying in the same regime, given by p_{22} is 0.94 and the probability of shifting to regime 1, $1 - p_{22}$ is 0.06. However, to estimate the expected duration of each regime we have: expected duration of regime 1 given by $\left(\dfrac{1}{1 - p_{11}}\right)$ is around 13 quarters while for regime 2 it is $\left(\dfrac{1}{1 - p_{22}}\right)$ around 16 quarters. So, on an average if an economy is in regime 1, the expected duration of staying in that regime is around 13 quarters before shifting to regime 2. However, if the economy shifts to regime 2, it stays there for around 16 quarters before shifting to regime 1.

Table 6: Transition Probabilities

	All variables switching	
	Regime 1	Regime 2
Regime 1	0.923	0.0626
Regime 2	0.0761	0.937

We further plot policy interest rate against smoothed probabilities to analyse the way policy rates have behaved over the regimes (Fig 5). It is observed from Fig. 5 that during recessionary regime as shown in Panel (a), the interest rates are high and volatile compared to non-recessionary period where the RBI has high degree of inertia to policy rates. So, both TR as well as MSR models offer similar explanations regarding the behaviour of monetary authority of India. The RBI seems to be more bent towards RAP with policymakers responding aggressively to output gap during recessionary phase.

Figure 4: Smoothed Probabilities



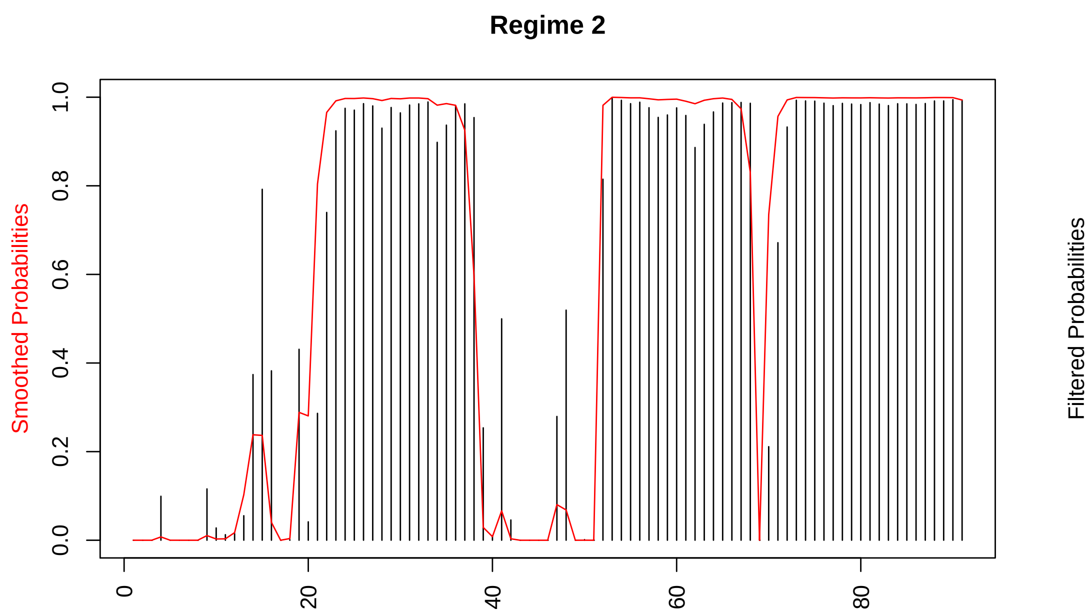
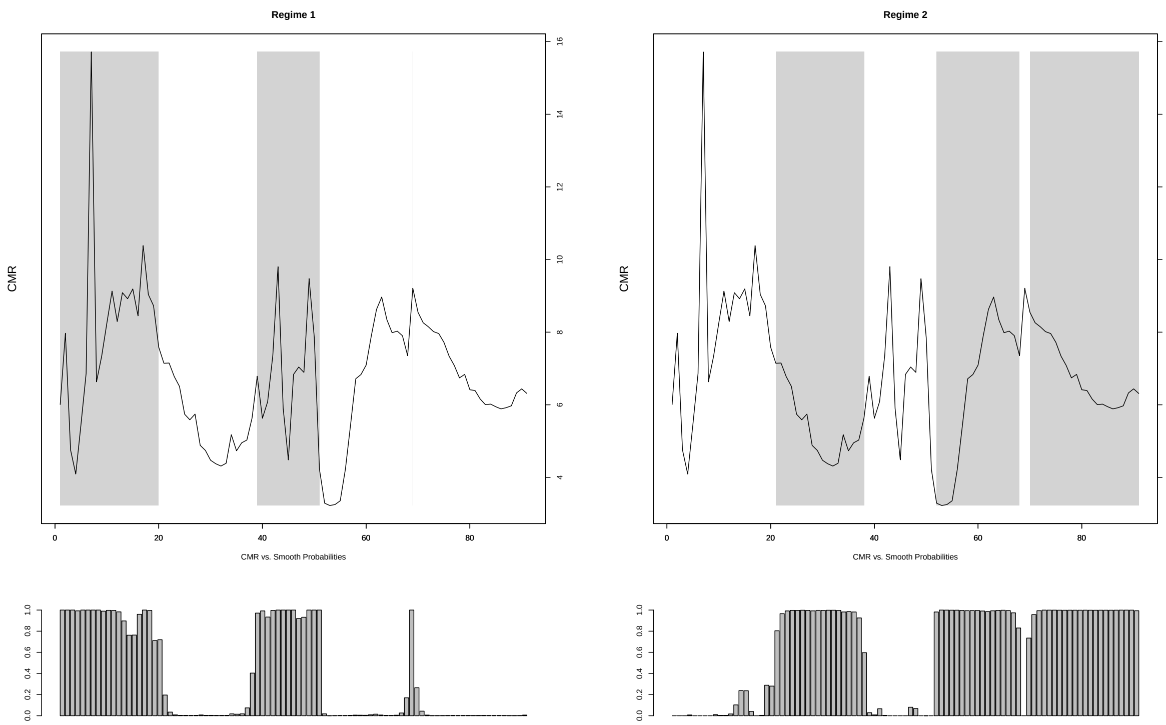


Figure 5: Smoothed Probabilities vs Policy Interest Rate

(a) Regime 1 (b) Regime 1



4.3 Discussion of Results

From all the three models that we estimated in this paper, we found a significant response of monetary authority towards output gap. This response becomes aggressive as the economy drifts towards recession highlighting the RAP of the RBI. A number of other paper including Inoue (2010); Hutchison, Sengupta, and Singh (2010, 2013) and Mohanty and Klau (2005) that analysed MPRF in India using linear or nonlinear framework also found output gap matters more to the RBI compared to inflation. However, in most of the developed countries, monetary authority does react aggresively to output gap during recession but they focus on reducing inflation in non-recessionary conditions (Brüggemann and Riedel, 2011; Zhu and Chen, 2017; Altavilla and Landolfo, 2005; Bec, Salem, and Collard, 2002). This gives a feeling that in most of the developed countries, primary focus of the monetary authority is to stablize prices rather than boosting growth. For a developing country like India, the focus however seems to be more on output growth than on stablizing inflationary pressure. It was only in 2014-15 that India shifted its policy framework from multiple indicator approach towards flexible inflation targeting approach to stabilize prices (Patel, Chinoy, Darbha, Ghate, Montiel, Mohanty, and Patra, 2014). Considering the case of other developing countries Baaziz, Labidi, and Lahiani (2013) argued that monetary authority of South-Africa is more concerned about recession even at the expense of inflationary pressure. Jawadi, Mallick, and Sousa (2014) considering inflation as threshold variable in the case of Brazil and China found that monetary authority in Brazil responds more to output gap and exchange rate in the nonlinear part. For China, the monetary authority responds to inflation but the policy seems to be accommodative. Considering the case of Russia Esanov, Merkl, and de Souza (2005) found that the preference of monetary authority over the time has shifted from targeting inflation to exchange rate stabilization. Moreover, we also found high degree of inertia in the policy rates especially in non-recessionary phases. This interest rate smoothing shows how persistent policymakers are towards adjusting their interest rate given the past rates. Considering longrun coefficients, we found Taylor rule condition are satisfied only by output gap but not the inflation indicating the accomodative behaviour of the RBI. Such behaviour has also been observed by Hutchison, Sengupta, and Singh (2013) , Baaziz, Labidi, and Lahiani (2013) and Jawadi, Mallick, and Sousa (2014) for India, South-Africa, Brazil and China respectively. Another interesting result in Indian context from transition and smoothed probabilities of MSR model is that if the economy is in recession, there is high probability (0.92) that the economy will stay in that regime for about next three years before shifting to non-recessionary phase. Similarly, if the economy is in non-recessionary phase, their is a probability of 0.94 that the economy will be in the same phase for around next four years.

5 Conclusion

We analyse the behaviour of monetary authority in India over time to understand how the state of the economy has played a role in monetary policy decision making. The decisions of monetary authority are captured through policy interest rate and analysed through Taylor's rule. In order to incorporate the state of the economy, we adopted nonlinear framework using (nonlinear) models such as STR, TR and MSR models. The state of economy is distinguished based on the lagged interest rate, with high interest rate corresponding to recessionary phase and low to non-recessionary phase. From our analysis, we found that there is significant asymmetry in the monetary policymaking in

India. Monetary authority reacts more to output gap compared to inflation and exchange rate. The reaction towards output gap however becomes more aggressive during recession compared to non-recessionary periods. The RBI seems to be more bent towards RAP compared to IAP. We also found high degree of policy inertia to interest rates especially during non-recessionary phase.

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