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Nonlinear Reaction functions: Evidence from India

Abstract: This paper uses time-series data from India and tests for asymmetries in policy preferences of the Reserve Bank of India (the Central Bank of India, hereafter RBI). The results show evidence in favour of preference asymmetries in monetary policy reaction function in India and hence nonlinearities in the Taylor-rule. Evidence of both recession avoidance preference (RAP) as well as inflation avoidance preference (IAP) is established. And it is found that RAP is dominant over IAP, thus confirming nonlinearities in reaction function which in the present case turns out to be concave in inflation and output gap. Further, the results indicate preference asymmetries in both the objectives. The coefficient weights to positive and negative inflation and output gap differ over long time horizons thus confirming asymmetric policy preferences. Specifically the RBI seems to be more averse to a negative output gap (contraction) as compared to an equal positive gap. In addition, the RBI appears to be more averse to a positive inflation gap as compared to an equal negative gap.

Keywords: Reaction function, Taylor-rule, Preference asymmetry, Output gap, Inflation gap

JEL Classification: E52, E58.

1. Introduction

The reaction function of a central bank is a quadratic loss function expressed in twin objectives - price stability and economic activity. The objective of policy-makers is to minimize this loss function and the main tool to achieve this goal is short-term interest rates. There is abundance of literature on reaction functions which depict short-term interest rates as linear function of inflation and output gap. One such reaction function is the Taylor rule (1993) according to which short-term policy rates set by a central bank should be a linear function of inflation and output deviations from their desired or potential levels. The premise of this linear framework is based on the presumption that quadratic loss function is to be minimized by policymakers subject to the condition that economic structure is linear. However, growing literature has been recently pointing towards non-quadratic nature of the loss function. In principle, the quadratic specification of loss function necessitates that policy makers give equal importance to both positive and negative gaps of output and inflation from their targets. However, in practice it is rare to see such modelling. The reason for such a mismatch in theory and practice given by several policy practitioners is that this kind of modelling has limited justification other than that of methodical malleability. This non-quadratic nature may be because of asymmetric policy preferences which may result in non-linear reaction functions. The reasons for these asymmetric policy preferences can come from complex economic structures. One such complexity is the fact that slowing down an overheated economy is easy than stimulating a slow economy or, in other words, closing a positive output gap may be easier than closing a negative gap, the others being like overreaction to policy signals (Naini and Naderian, 2016), inflation combativeness etc. Besides, there are other reasons for the reaction function to be nonlinear as Blinder (1998) claims "In most situations the central bank will take far more political heat when it tightens pre-emptively to avoid higher inflation than when it eases pre-emptively to avoid higher unemployment." Hence, it can be deduced from this argument that institutional framework like central bank independence, political influence etc. have substantial impact on decision making of central banks, which in turn may result in asymmetric policy preferences and, hence, nonlinear reaction functions.

From the literature we identified two types of asymmetric policy preferences, namely inflation avoidance and recession avoidance. Inflationary avoidance preference is defined as a situation wherein policymakers tend to be more cautious about positive inflation gap as compared to negative inflation gap, whereas recession avoidance preference is defined as a situation when policy makers tend to be more averse about negative output gap than to positive output gap. In this paper we will empirically test for these asymmetries in the Indian context.

2. The Taylor-Rule

A rule for monetary policy is a set of guidelines for monetary authorities to calibrate monetary instruments to reach final objectives such as a predetermined inflation rate. Policy rules prevent authorities from impromptu decision-making, which results in what is being called discretionary monetary policy. Discretionary policy affects the decision making by economic agents, thereby resulting in sub-optimal economic growth. While rule guided monetary policy is contemplated to be better than discretionary policy, but the conditions and assumptions under which this statement holds true are debatable (Woodford, 2003).

This leads us to an important issue of the design of these rules for better monetary policy. By better monetary policy we mean the policy that stabilizes price level or inflation around a desired or predetermined average level, and at the same time stabilizes output around its potential level. Thus a policy rule acts as a guide for how to use the policy tools (or instruments) to achieve its objectives based on the overall information about the economy. A policy rule outlines the behaviour of the policy authorities. Thus authorities are presumed to peruse the rule and to modify it accordingly as new information about economy keeps on arriving. The inclinations of unexpected policy moves should be steered clear of. There is abundance of literature that points towards the credibility of central bank, as is clear from the literature that central bank should commit to rules in order to get efficiency of its policy (Kydland and Prescott, 1977).

A number of central banks around the world practice rule guided monetary policy, hence one or other form of the monetary policy rule is used. Predominantly, the most popular is inflation targeting. In an inflation targeting regime, a central bank employs its monetary policy instruments to anchor inflation to a predetermined target level of inflation. For example, the Bank of England targets a symmetrical inflation rate of 2% with $\pm$ 1% deviation on either side. Unlike instrument rules where policy rates are directly linked to the objectives like minimizing output and inflation gaps, inflation targeting is more adjustable. However, policy rules provide additional degrees of freedom which are extremely valuable for policy makers. Whatever the underlying rule, the most important conditions for effective implantation of a rule guided monetary policy is transparency and accountability of the central bank. These features of transparency and accountability increase the credibility of the central bank which in turn results in the effective implementation of the policy actions. Policy credibility is seen as one of the reasons for popularity of rule guided monetary policy literature.

There are certain criteria which are believed should be satisfied by policy rules in general. These criteria as outlined by Lewis and Mizen, 2000 are:

1. A rule should be simple and clear. The simplicity and lucidity allows understanding the working mechanism of the rule.

2. The variables on which the rule depends should be easily and accurately measurable.
3. Econometric models should readily estimate the rule.
4. The rule should have the ability to accurately describe the history of the policy instruments.

But looking at the literature it becomes clear that not all the criteria stated above are met by all the monetary policy rules. For example, if an optimal rule is built on a comprehensive macro-econometric model taking the holistic view of the economy, it will not possibly be simple. The complexity of the model makes it difficult to understand the proper working of the rule and its interactions with the model variables. But that should not be discouraging. Economists have been able to design simple rules which approach optimality under certain assumptions. The other issue is that of measurement. Some variables are easily measurable like output or inflation while others are not like this frequently used variable - the output gap. The other issue is that of estimation of the policy rules, some rules are estimated easily by econometric models in a timely fashion while others are simple hypothesized in general terms. Finally, there is the issue of explaining the past. It is possible that a rule is simple, clear, and easily estimable and performs well but cannot explain the recent past. Thus taking the overall picture, designing an ideal or optimal has many trade-offs and policy makers and academicians are striving to get the best of both worlds.

A number of central banks in developed economies as well as in emerging economies accentuate the importance of short-term interest rate as main or key monetary policy instrument. Short-term interest rate has become an operating target of monetary policy around the world (Friedman, 2000). Where central banks have adopted short-term interest rates as operating targets or key instruments of their monetary policy, their reaction function can be mapped by some version of the Taylor Rule. The Taylor-Rule simply says that short-term or policy interest-rates should be related to deviations of output from its potential level and deviation of inflation from its pre-set target level. The following is the basic specification of a simple Taylor-rule:

$$r = r^{*} + \psi_{\pi}(\pi_t - \pi^{*}) + \psi_{y}(y_t - y_L)$$

Where *r* is the short-term policy rate decided and by the central bank; *r** is long-run equilibrium rate;[1] ψ_{π} and ψ_{y} are the "policy reaction coefficients"; $(\pi_t - \pi^{*})$

[1] The equilibrium rate is assumed to be approaching long-term steady-state growth rate of the economy.

is the "inflation gap", defined as deviation of actual inflation π_t from target inflation π^* and $y_t - y_L$ is the "output gap", defined as deviation of "actual output" from the potential output level.

The short-term policy rate as suggested by the Taylor-rule is set according to two components. The first is inflation target. The government or the central bank sets a long-term inflation target around which the central bank will anchor the actual inflation rate. This target level of inflation varies from economy to economy e.g. the Bank of England targets 2% $\pm$ 1% inflation while the RBI has an inflation target of 4% $\pm$ 2%. It should be noted that the inflation target is being revised from time to time. The second component is policy response to the changing macroeconomic environment, which in the Taylor-rule is captured by the fluctuations in output and inflation.

The Taylor-rule suggests that when setting policy rates monetary authorities should "lean against the wind" or, to put it simply, the rule suggests that when output is higher than its potential level, the central bank should raise the interest rate. The rule suggests the same response to increasing inflation i.e. central bank should increase the policy rates in response to increase in actual inflation rate than its target level. However, in case of inflation being higher than target level, simple leaning against the wind does not give the desired results. This is because of Fisher effect[2]. Thus, taking into account this problem Taylor suggested that policy rates should be increased more than increase in inflation. Given the Fisher effect, a one-to-one response from policy rates to inflation gap is as useless as treading water. Therefore, the Taylor-rule suggests that monetary authorities must raise the real short-term interest rate (policy rate) to reduce inflation. In other words, this means more than proportional increase in nominal policy rate. This policy of increasing nominal policy interest rate more than proportionally in response to an increase in inflation is known as the "Taylor principle".

Although it has been widely acknowledged that a rule based monetary policy results in output stabilization and price stability, however there is no agreement about the weights of the stabilization coefficients. In other words there is no unanimity about the weights to output and inflation gaps. The weights depend upon the preferences of the central banks which depend on a host of factors. The theoretical underpinning of a preference function is conceptualized in the form a loss function. The loss function is the preference function which is to be minimized by the central bank. The following represents a basic loss function:

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2 The Fisher effect or Fisher hypothesis is defined as "one-to-one relation between nominal interest rate and expected inflation".

$$L_t = \lambda_\pi(\pi_t - \pi^*)^2 + \lambda_y(y_t - y_L)^2$$

Thus, the values of λ varies from one central bank to another. The difference between the values of λ_π and λ_y shows the preference of the central bank. A central bank which is more concerned about price stability will try to keep high value of λ_π as compared to λ_y and vice-versa. Thus, preference function which stems from the quadratic loss-function makes it clear why parameter values differ in the loss-function. The Taylor principle suggests $\lambda_\pi > 1$, which implies as inflation increases in the economy, bringing it down requires an increase in real interest rate.

3. Asymmetries and Non-linearities in the reaction function:

The theory of optimal monetary policy in both developed as well as in developing economies has reached to a wider agreement on main policy framework in recent years. Monetary policy is objectified as monetary authorities aiming to minimize a quadratic loss function expressed in terms of deviation of output and inflation from their potential and pre-set target levels, respectively. Most of the recent literature on monetary policy has used this framework to analyse monetary policy by estimating various forms of reaction function, particularly the Taylor-rule, according to which short-term or policy interest-rates should be related to deviations of output from its potential level and deviation of inflation from its pre-set target level.[3] From the theoretical perspective, this type of linear reaction function is conceivable by minimizing the quadratic loss function expressed in terms of output and inflation gaps.

However, a good amount of recent literature has cast doubt about the quadratic nature of loss-function. These studies point towards the fact that asymmetric policy objectives lead to non-quadratic loss-functions. Hence the reaction functions derived from such non-quadratic loss functions may not be linear, thus casting a doubt over the linearity of the reaction functions. In order to understand the meaning and nature of nonlinearities in a loss function, we take a look on policy preferences and see how asymmetric policy preferences expressed as differential policy response to output and inflation gaps leads to these nonlinearities in the reaction function. We adopt the specifications of Clarida et al. (1999), and the subsequent formalization process by Cukierman and Muscatelli (2008) in which

[3] In addition, some other augmented forms of reaction function are also used, for details see Krušković, (2017).

the economic structure is assumed to be New Keynesian. Cukierman and Muscatelli (2008) derived the interest-rate reaction function of a central bank with two policy preferences. First is inflationary avoidance preference (IAP) - defined as a situation wherein policymakers tend to be more cautious about positive inflation gap as compared to negative inflation gap. The second policy preference is recession avoidance preference (RAP) - defined as a situation when policy makers tend to be more averse about negative output gap than to positive output gap. The main theoretical results from this specifications (Cukierman and Muscatelli, 2008) is that we are able to determine the nature of nonlinearity in the reaction function expressed in both inflation and output gaps. The model implies that the reaction function is concave in both the gaps if RAP dominates and it is convex in both the gaps if IAP dominates.

To understand these model implications let us start with a loss function of the Central bank where recession avoidance preference dominates, which means the central bank will be more averse to negative output gap as compared to an equal size positive output gap. This means the central bank will lean heavily against the negative output gap. Thus, if output is lower than the potential level, the central bank will respond by cutting the rates more heavily in order to stimulate the economy. Whereas when output exceeds the potential, the response from the central bank in terms of a rate hike will not be of the same nature as in the case of negative gap. Thus making on this presumption that central bank's policy response to a positive output gap is weaker as compared to a negative gap, as the size of gap increases on either side the aversion to the gap decreases gradually, thus implying that the reaction function is concave.

Now consider a loss function with dominant inflationary avoidance preference. This means the central bank will be more averse to positive inflation gap as compared to an equal size negative inflation gap. This means the central bank will lean heavily against the positive inflation gap. So, if inflation is higher than the pre-set target the central bank will respond by raising the rates more heavily in order to stabilize the price level, whereas when inflation dips below the target, response from the central bank in terms of a rate cut will not be of the same nature as in case of positive gap. Again, making on this presumption that central bank's policy response to a positive inflation gap is stronger as compared to a negative gap, implies that the reaction function is convex in terms of inflation gap.

The loss function of the central bank which it aims to minimize is expressed as:

$$\phi = E_0 \sum_{t=0}^{\infty} \theta^t L_t \qquad (1)$$

Where θ is the discount factor and L_t is expressed in terms of the output and inflation gaps as follows:

$$L_t = \beta f(y_t - y^*) + g(\pi_t - \pi^*) \tag{2}$$

The eq. 2 implies that losses are minimal when the gaps are minimal and larger otherwise. Eq. 2 can be written as:

$$L_t = \beta f(z_t) + g(\iota_t) \tag{3}$$

Where y_t is actual output, y^* is potential output, π_t is realized or actual inflation, π^* is inflation target, β is positive coefficient, $y_t - y^*$(z_t in eq. 3) is output gap, and $\pi_t - \pi^*$(ι_t in eq. 3) is inflation gap.

The functions *f* and *g* have the following properties:

$$f'(z_t) < 0 \quad \text{for } z_t < 0, \; f'(z_t) \geq 0 \quad \text{for } z_t \geq 0,$$

$$f''(z_t) > 0, \; f'''(z_t) \leq 0, \; \text{ and } \; f(0) = f'(0) = 0$$

$$g'(\iota_t) > 0 \; \text{ for } \iota_t > 0, \; g'(\iota_t) \leq 0 \; \text{ for } \iota_t \leq 0,$$

$$g''(\iota_t) > 0, \; g'''(\iota_t) \geq 0 \; \text{ and } \; g(0) = g'(0) = 0$$

where the tags represent the order of partial derivatives of the functions. As we know second-order partial derivative of quadratic equations are positive the same is assumed here but unlike general quadratic specifications of symmetry around zero, $f(z_t)$ and $g(\iota_t)$ are not. The third partial derivative of the functions gives the idea of asymmetric policy response or, in other words, differential treatment to positive and negative output and inflation gaps.

Consider the RAP, when policy makers tend to be more averse about negative output gap than to positive output gap. It is characterized by third derivative of $f(z_t)$ being negative. The negative value of third derivative means that the marginal loss decreases as the gap goes up or in other words the marginal loss is lower at a positive output gap (actual output being greater than potential) than marginal loss at an equal negative output gap (actual output being less than potential). When the third derivative is zero i.e. $f'''(z_t) = 0$ this is the case of symmetric losses and we say there is no RAP which means the second order derivative is constant i.e. loss-function is quadratic.

Now coming to IAP when policy makers tend to be more averse about negative output gap than to positive output gap. It is characterized by the third derivative of $g(\iota_t)$ being positive. The positive value of third derivative means that the marginal loss increases as the gap goes up or, in other words, the marginal loss is larger at a positive inflation gap (actual inflation exceeds target level) than marginal loss at an equal negative inflation gap (actual inflation is less than target level). When the third derivative is zero i.e. $g'''(\iota_t) = 0$ this is case of symmetric losses and we say there is no IAP which means the second order derivative is constant i.e. loss function is quadratic.

Now building upon the assumptions of New Keynesian framework as described in Clarida et al. (1999), the inflation and output gap is expressed as:

$$\pi_t = \lambda z_t + cE_t\pi_{t+1} + \varepsilon_t \tag{4}$$

$$z_t = -\omega(r_t - E_t\pi_{t+1}) + E_t z_{t+1} + \rho_t \tag{5}$$

Eq. 4 implies that inflation in current period π_t depends on current output gap and current expectations of future inflation $E_t\pi_{t+1}$. Eq. 5 implies that output gap z_t depends on its future expected values $E_t z_{t+1}$ and on real rate of interest. The demand shock is represented by ρ_t and cost shock by ε_t, λ, c and ω are positive parameters. The shocks ε_t and ρ_t are i.i.d. processes which cannot be forecast by the central bank based on the currently available information. The central bank aims to minimize eq. 1 subject to the constraint given by eq. 4 and eq. 5. Substituting eq.4 and eq. 5 in eq. 1 we get

$$\phi = E_0 \sum_{t=0}^{\infty} \theta^t \begin{pmatrix} \beta f[-\omega(r_t - E_t\pi_{t+1}) + E_t z_{t+1} + \rho_t] + \\ g[\lambda(-\omega(r_t - E_t\pi_{t+1}) + E_t z_{t+1} + \rho_t + cE_t\pi_{t+1} + \varepsilon_t - \pi^*) \end{pmatrix} \tag{6}$$

The first-order optimization condition which gives the optimal rate of interest which minimizes the losses expressed in terms of output gap and inflation gap can be written as:

$$\beta E_t f'[.] + \lambda E_t g'[.] = 0, \quad t = 0,1,2,3 \tag{7}$$

Eq. 7 shows that optimal choice of interest rate by the central bank is a function of expected inflation and output gap. The asymmetric policy preferences can be derived from comparative statics of eq. 7.

Now taking total derivative of eq. 7 with respect to $E_0\pi_1$ and $E_0 z_1$ we get

$$\frac{dr_0}{dE_0\pi_1} = \frac{\omega\beta E_0 f_0''[.] + \lambda(\omega\lambda + c)E_0 g_0''[.]}{\omega\beta E_0 f_0''[.] + \lambda^2 E_0 g_0''[.]} \tag{8}$$

$$\frac{dr_0}{dE_0 z_1} = \frac{\beta(1+\lambda\omega)E_0 f_0''[.] + \lambda^2(1+\omega\lambda + c)E_0 g_0''[.]}{\omega\beta E_0 f_0''[.] + \lambda^2 E_0 g_0''[.]} \tag{9}$$

Where

$$f_0'' = f''[-\omega(r_0 - E_0\pi_1) + E_0 z_1 + \rho_0] \tag{10}$$

$$g_0'' = g''[\lambda\{-\omega(r_0 - E_0\pi_1) + E_0 z_1 + \rho_0\} + cE_0\pi_1 + \varepsilon_0 - \pi^*] \tag{11}$$

Since eq. 7 gives the optimal rate of interest rate (policy rate) to be set by the central bank for minimizing the loss-function expressed in the output and inflation gap, the curvature of the central bank's reaction function can be found from eq. 7. The curvature of the central bank's reaction function can be found by calculating second derivative of eq. 7 with respect to inflation gap and output gap. These derivatives will show the relationship between policy preferences (RAP and IAP) and the shape (curvature) of the reaction function. Thus taking derivative of eq. 7 with respect to $E_0\pi_1$ and $E_0 z_1$ we get:

$$\frac{d^2 r_0}{d(E_0\pi_1)^2} = \frac{\beta\lambda c^2}{\omega T^3}\left(\beta(E_0 f''[.]_0)^2 E_0 g_0'''[.] + \lambda(E_0 g_0''[.])^2 E_0 f_0'''[.]\right) \tag{12}$$

$$\frac{d^2 r_0}{d(E_0 z_1)^2} = \lambda^2 \frac{\beta\lambda c^2}{\omega T^3}\left(\beta(E_0 f''[.]_0)^2 E_0 g_0'''[.] + \lambda(E_0 g_0''[.])^2 E_0 f_0'''[.]\right) \tag{13}$$

Where;

$$T = \beta E_0 f_0''[.] + \lambda^2 E_0 g_0''[.] \tag{14}$$

From the properties of functions *f* and *g* described above and eq. 4 and eq. 5 we know all terms in equations 12 and 13 are positive except for $E_0 f_0'''$. From these equations (12 and 13) we have different specifications of reaction function in presence RAP and IAP. The presence and absence of RAP and IAP is determined by the sign and absolute measured value of $E_0 f_0'''$ and $E_0 g_0'''$. In presence of RAP $E_0 f_0'''$<0 and in presence of IAP $E_0 g_0'''$>0. Now let us turn towards the curvature of the reaction function of the central bank for different policy preferences.

I. The central bank has RAP and no IAP.

In such a situation we have $E_0 f_0'''<0$ and $E_0 g_0'''=0$, and thus equations 12 and 13 reduce to

$$\frac{d^2 r_0}{d(E_0\pi_1)^2} = \frac{\beta\lambda c^2}{\omega T^3}\left(\lambda(E_0 g_0''[.])^2 E_0 f_0'''[.]\right)$$

$$\Rightarrow \frac{d^2 r_0}{d(E_0\pi_1)^2} = \frac{\beta\lambda^2 c^2}{\omega T^3}\left((E_0 g_0''[.])^2 E_0 f_0'''[.]\right) \qquad (15)$$

And

$$\frac{d^2 r_0}{d(E_0 z_1)^2} = \lambda^2 \frac{\beta\lambda c^2}{\omega T^3}\left(\lambda(E_0 g_0''[.])^2 E_0 f_0'''[.]\right)$$

$$\Rightarrow \frac{d^2 r_0}{d(E_0 z_1)^2} = \lambda^3 \frac{\beta\lambda c^2}{\omega T^3}\left((E_0 g_0''[.])^2 E_0 f_0'''[.]\right) \qquad (16)$$

Since $E_0 f_0'''<0$ in presence of RAP. Both the second derivatives of reaction function turn out to be negative, therefore, from basic calculus we conclude that the reaction function is concave in terms of both inflation gap as well as in output gap.

II. The central bank has IAP and no RAP.

In such a situation we have $E_0 f_0'''=0$ and $E_0 g_0'''>0$, and thus equations 12 and 13 reduce to

$$\frac{d^2 r_0}{d(E_0\pi_1)^2} = \frac{\beta^2\lambda c^2}{\omega T^3}\left((E_0 f_0''[.])^2 E_0 g_0'''[.]\right) \qquad (17)$$

And

$$\frac{d^2 r_0}{d(E_0 z_1)^2} = \lambda^2 \frac{\beta^2\lambda c^2}{\omega T^3}\left((E_0 f_0''[.])^2 E_0 g_0'''[.]\right) \qquad (18)$$

since $E_0 g_0'''>0$ in presence of IAP. Both the second derivatives of reaction function turn out to be positive, therefore, from basic calculus we conclude that the reaction function is convex in terms of both inflation gap as well as in output gap.

III. The central bank has both RAP as well as IAP.

In such a situation, the curvature of the reaction function depends on which preference (RAP or IAP) dominates. If the absolute value of $E_0 f_0'''$ and of $E_0 g_0'''$ are such that

$$\beta(E_0 f''[.]_0)^2 E_0 g_0'''[.] \text{ offsets } \lambda(E_0 g_0''[.])^2 E_0 f_0'''[.] \quad \text{And}$$

$$\beta(E_0 f''[.]_0)^2 E_0 g_0'''[.] \text{ offsets } \lambda(E_0 g_0''[.])^2 E_0 f_0'''[.]$$

Then the reaction function is approximately linear.

And if the absolute value of $E_0 f_0''' > E_0 g_0'''$ which means RAP dominates IAP

$$\beta(E_0 f''[.]_0)^2 E_0 g_0'''[.] < \lambda(E_0 g_0''[.])^2 E_0 f_0'''[.] \quad \text{And}$$

$$\beta(E_0 f''[.]_0)^2 E_0 g_0'''[.] < \lambda(E_0 g_0''[.])^2 E_0 f_0'''[.]$$

$$\Rightarrow \frac{d^2 r_0}{d(E_0 \pi_1)^2} < 0 \text{ and } \Rightarrow \frac{d^2 r_0}{d(E_0 z_1)^2} < 0$$

or, in other words, when RAP dominates IAP, i.e. $E_0 f_0''' > E_0 g_0'''$, the reaction function is concave in both gaps.

And if the absolute value of $E_0 f_0''' < E_0 g_0'''$ which means IAP dominates RAP

$$\beta(E_0 f''[.]_0)^2 E_0 g_0'''[.] > \lambda(E_0 g_0''[.])^2 E_0 f_0'''[.] \quad \text{And}$$

$$\beta(E_0 f''[.]_0)^2 E_0 g_0'''[.] > \lambda(E_0 g_0''[.])^2 E_0 f_0'''[.]$$

$$\Rightarrow \frac{d^2 r_0}{d(E_0 \pi_1)^2} > 0 \text{ and } \Rightarrow \frac{d^2 r_0}{d(E_0 z_1)^2} > 0$$

or, in other words, when IAP dominates RAP, i.e. $E_0 f_0''' < E_0 g_0'''$, the reaction function is convex in both gaps.

IV. The central bank is inflation targeter.

In such a situation β=0 in the loss-function (eq.2). And when β=0 eq. 12 and eq. 13 become equal to zero. And from basic calculus we know that the function whose second derivative is zero, the function is linear. Hence for an inflation targeter central bank, the reaction function is linear.

4. Literature Review

The literature on theoretical and empirical studies of asymmetry and nonlinearity of monetary policy offers some neoteric methods to delve into the subject. Persson and Tabellini (1999) with the help of imperfect information and backward-looking voting system, claimed that politicians who seek reappointment equip central banks to withstand the populist narrative like responding aggressively to stimulate the economy or stabilizing the prices in an ongoing upward inflationary spiral. These preference asymmetries result in substantial nonlinearities. Cukierman and Muscatelli (2003) and Martin and Milas (2004) found evidence of nonlinear reaction functions for a group of varied economies. Ruge-Murcia (2003) used game-theoretic framework where policymakers weighed negative and positive inflationary gaps differently. The study found statistically significant asymmetric reaction functions for UK, Sweden and Canada, and these results were significantly different from symmetric specification of models estimated for these countries. Cukierman and Gerlach (2003) found asymmetric preferences based nonlinear reaction function for some OECD economies. They estimated a nonlinear interest rate reaction function expressed in terms of output and inflation gap. Nobay and Peel (2003) in their study applied asymmetric modelling of policy preferences and concluded that analysing policy preferences using asymmetric modelling is more realistic than symmetric modelling as used by majority of studies. They showed how results differ significantly in asymmetric modelling of reaction function as compared to standard linear reaction functions based on quadratic loss-function. For the U.S. economy, Dolado et al. (2004) estimated the interest rate reaction function and found it to be asymmetric only in inflation particularly after 1983. Siklos and Wohar (2005) showed how careful analysis based on asymmetric error-correction frameworks can most likely overcome the problems like structural breaks in the underlying data structure.

Dolado et al. (2005) used a different approach by specifying nonlinearities in Phillips curve and keeping the central bank's loss-function quadratic. The study used Euler equation approach in line with Clarida et al. (1998) and found significant evidence for nonlinearities in the reaction function under this framework for France, Spain and Germany but they found no such evidence for USA. The study found that central banks in Europe are more averse to positive inflation and output gaps as compared to equal negative gaps. The study ascribed these findings to the presence of labour market rigidities in these European economies.

Now coming to the Indian context there is a good number of studies which studied reaction function in this context. An early contribution by Virmani (2004) estimated the policy reaction function of the RBI with two alternative operating targets - monetary base and interest rate. Thus estimating two different monetary policy rules, McCallum rule based on monetary base and the Taylor-rule based on interest rate. The study found that a backward-looking McCallum rule performs well in terms of explaining the monetary base over the sample period study. The study concludes that output stabilization or nominal income targeting seems to be main concern of RBI. Mohanty and Klau (2004) in their panel study of 13 emerging market economies including India used real effective exchange rate augmented Taylor-rule. The study used quarterly data from 1995 to 2002. The study found that output gap and exchange rate changes in the Indian context significantly determine short-term interest rate whereas they found very low coefficient of inflation.

Ranjan et al. (2007) in their study from 1951-2005 concluded that monetary policy index significantly responds to inflation and output gaps during the study period. The results were robust for different output gap measure. Hutchison et al. (March 2010) estimated an augmented reaction function for India, allowing for regime switching between the pre- and post-liberalization using Markov-chains. The study found RBI seems to be more averse towards output gap than towards inflation. The study found that policy operations of RBI seem to have undergone a change post-1998. In the first phase i.e. prior to 1998 inflation seems to be more concern of RBI while as in latter period exchange rate and output gap seems to be target. These findings were further confirmed by Bhupal Singh (2010). The study confirmed that monetary policy has undergone a change in pre- and liberalization period. The study found that in pre-liberalization monetary policy responded actively to output gaps while as in post-liberalization the focus is more on inflation. In a recent study by Lokendra and Bhanumurthy (2016), the authors find significant response of monetary policy towards output gaps, exchange rate changes and inflation. The authors documented that reaction function showed significant time-varying behaviour.

All the studies reviewed in Indian context have assumed symmetric policy response or a linear central bank reaction function. However, as literature shows, it may be a misspecification of the reaction function. Therefore, it is important to investigate the reaction function in an asymmetric framework. This paper tries to examine the issue of asymmetric reaction function in the Indian context at empirical level.

5. Data description and empirical method

This paper uses time-series data from India and tests for asymmetries in policy preferences of the RBI. Monthly data from June 2000 to December 2014 is used. The sample period is from starting date of LAF[4] and ends with beginning of new inflation target regime. The variables used in this study are the weighted average of call money rates (CMR) as short-term policy rate, output and inflation gap. For output, Index of industrial production (IIP) is taken and the output gap is measured by the HP filter. Wholesale price index (WPI) is taken for Inflation. Since there was no official inflation target in India during the period of this study, we took the previous three-month average as expected or desired inflation target. All the data is obtained from the Database of Indian Economy, RBI. The descriptive statistics of variables used are reported in table 1.

Table 1: Descriptive Statistics

Variables/Statistics	CMR	IG	OG
Mean	6.580	-0.093	4.845
Std. Dev.	2.015	1.167	0.275
Skewness	0.250	0.179	-0.290
Kurtosis	3.725	4.274	1.521
Jarque-Bera	5.647	12.763	18.418
Probability	0.059	0.002	0.000

The empirical estimation is carried by using NARDL (Shin et al., 2014). The following nonlinear error correction model is used for estimation:

$$\Delta r_t = \rho + \alpha r_{t-1} + \theta_1^+ OG_{t-1}^+ + \theta_1^- OG_{t-1}^- + \theta_2^+ IG_{t-1}^+ + \theta_2^- IG_{t-1}^- + \sum_{i=1}^{p-1} \eta_j \Delta r_{t-i}$$

$$+\sum_{i=0}^{q-1} \pi_{1,i}^+ \Delta OG_{t-i}^+ + \sum_{i=0}^{q-1} \pi_{1,i}^- \Delta OG_{t-i}^- + \sum_{i=0}^{q-1} \pi_{2,i}^+ \Delta IG_{t-1}^+ + \sum_{i=0}^{q-1} \pi_{2,i}^- \Delta IG_{t-1}^- + e_t \qquad (19)$$

where r_t is CMR, *OG* is output gap and *IG* is inflation gap. The cointegration test applied on the above model (eq. 19), is an *F*-test on the joint hypothesis that the coefficients of the lagged level variables are jointly equal to zero. The general-to-specific approach is followed for the final NARDL specification. The preferred specification is chosen by starting with max p = max q = 12, and dropping all

[4] Interim LAF was introduced in April 1999.

insignificant lags. The inclusion of insignificant lags may lead to imprecision in the estimation, which may introduce noise into the dynamic multipliers.

6. Empirical Results

Although NARDL can be used irrespective of the order of integration. However, to ensure that none of the variables used is *I(2)* as NARDL is not applicable in such a case, we have used Ng and Perron (2001) unit root test, which is considered more robust compared to other unit root tests. The results reveal none of the variables is *I(2)* and are reported in Table 2. We also used ADF and DF-GLS unit root tests. The results of these tests also corroborate the results of Ng and Perron (2001).Therefore, we may conclude that none of the variables used in the study is *I(2)*.

Table 2: Unit root tests

Variables/ Statistics	C				C+T			
	MZa	MZt	MSB	MPT	MZa	MZt	MSB	MPT
CMR	-7.369	-1.905	0.259	3.379	-14.413	-2.652	0.184	6.516
IG	-44.179	-4.673	0.106	0.627	-47.588	-4.842	0.102	2.096
OG	1.174	2.728	2.325	360.020	-2.894	-1.040	0.359	27.181
1% level	-13.800	-2.580	0.174	1.780	-23.800	-3.420	0.143	4.030
5% level	-8.100	-1.980	0.233	3.170	-17.300	-2.910	0.168	5.480
10% level	-5.7	-1.62	0.275	4.45	-14.2	-2.62	0.185	6.67
First Difference								
CMR	0.166	0.200	1.205	81.433	-4.304	-1.447	0.336	20.985
IG	-0.852	-0.648	0.761	28.443	-4.808	-1.418	0.295	18.210
OG	-27.455	-3.704	0.135	0.897	-75.054	-6.126	0.082	1.215
1% level	-13.800	-2.580	0.174	1.780	-23.800	-3.420	0.143	4.030
5% level	-8.100	-1.980	0.233	3.170	-17.300	-2.910	0.168	5.480
10% level	-5.7	-1.62	0.275	4.45	-14.2	-2.62	0.185	6.67

We start the analysis with the results of cointegration and asymmetry/symmetry test. The results are reported in Table 3. The FPSS test confirms the existence cointegration. The FPSS value exceeds the upper critical value of 6.26 for $k=2$. Where k is number of independent or explanatory variables and does not take into account the decomposition of variables as positive and negative partial sums as required in NARDL. The Wald-test suggests rejection of long-run symmetry, hence providing significant evidence for long-run asymmetry. The Wald-test statistics does not allow us to reject the null of short-run symmetry for output gap, however for inflation gap there is evidence of short-run asymmetry as well. The overall evidence therefore is absence of short-run asymmetry from monetary policy to output gap and presence of short-run asymmetry from monetary policy to inflation gap. And there is statistically significant evidence for presence of long-run asymmetry for both output and inflation gap.

Table 3: Short and long run symmetry tests

Exog. var.	Long-run effect [+]		Long-run effect [-]	
	coef.	P>F	coef.	P>F
OG	0.747	0.08	3.490	0.00
IG	0.072	0.00	0.035	0.10
	Long-Run Wald-Statistics WLR		Short-Run Wald-Statistics WSR	
	F-stat	P>F	F-stat	P>F
OG	49.84	0.00	0.361	0.54
IG	67.88	0.00	4.807	0.03
Bound cointegration test			F statistic 14.74	
χ^2_{SC} 2.340 (0.392)			χ^2_{HET} 3.110 (0.192)	

Notes: The upper panel of the table shows the long-run asymmetric effect on the dependent variable. In the lower panel, W_{LR} denotes the Wald test for long-run symmetry testing and W_{SR} denotes the Wald test for short-run symmetry testing. χ^2_{SC} and χ^2_{HET} denote LM test for serial correlation and heteroskedasticity respectively.

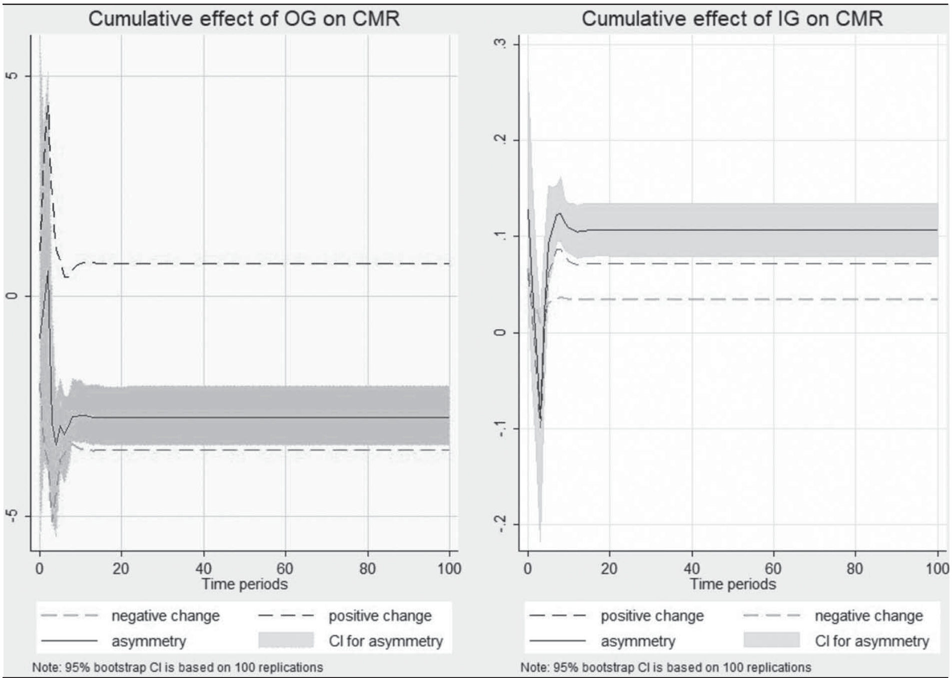
Figure 1 shows the dynamic effects of a unit negative/positive changes in output and inflation gap on CMR. The blue line is the line of asymmetry. The value of this line at any given point indicates asymmetry at that point. Figure 1 indicates that there is long-run negative asymmetry in case of output gap as the blue line shows that the response is asymmetric towards negative changes as compared to equal positive changes. However, in case of inflation, there is weak long-run positive asymmetry as the blue line shows that the response is asymmetric towards positive changes as compared to equal negative changes. Over the long horizon the response is asymmetric in both cases; however, the nature of asymmetry differs.

Table 3 points that coefficient weights to positive and negative inflation and output gap differed over long time horizons thus confirming asymmetric policy preferences. Specifically the absolute value of coefficient for negative output gap is greater than absolute value of the coefficient for positive gap. It can be seen that policy response to negative output gap is stronger than positive output gaps during the study period, corroborating the fact that slowing down an overheated economy is easy than stimulating a slow economy or, in other words, closing a positive output gap may be easy than closing a negative gap. Thus negative long-run asymmetry in case of output gap may be due to weak pass-through from policy rates to long-term market interest rates. Thus the RBI seems to be aware of complexities in pass-through process and hence its policy response to a negative output gap is proportionally stronger than for a positive output gap.

As far as inflation gap is concerned the coefficients are significant but are very small. The coefficient for positive inflation gap is greater in absolute terms as compared to negative inflation gap. The RBI does not seem to uphold the Taylor principle, as response to inflationary gaps is very weak during the study period. The positive long-run asymmetry in case of inflation gap reflects the RBI's aversion towards accelerating inflation. Since inflation in Indian context is not solely a monetary phenomenon this reflects the fact that there are other factors to which RBI may be looking to bring down the inflationary expectations like- food prices, fuel prices, globalization etc. which are not under the direct influence of the RBI. This may be the reason why long-run policy response to inflationary gaps seems to be muted. However, as documented by Petersen (2007), when the reaction function is nonlinear the effectiveness of monetary policy does not require upholding the Taylor principle. Howsoever, the RBI seems to be averse to a positive inflation gap as compared to an equal negative gap. This is the case of IAP presence.

Therefore, the results have produced evidence in favour of preference asymmetries in monetary policy reaction function in India and hence nonlinearities in Taylor-rule. Based on the simulations we found evidence of both recession avoidance preference as well as inflation avoidance preference. However, the former is dominant over the latter, thus confirming nonlinearities in reaction function which in the present case turns out to be concave in inflation and output gap, as output stability is preferred over inflation stability or we can say RAP dominates IAP. Thus the reaction function is concave in both the gaps. The results are in line with other studies which found dominance of RAP prior to introduction of inflation targeting and thereafter IAP dominates the reaction function of a central bank (De Bondt 2005). Besides asymmetric objectives, reaction function in principle can be nonlinear because of other factors like nonlinear aggregate supply curve, political influence (Persson and Tabellini 1999) etc. which we have not dealt with in this study.

Figure 1: Plot of dynamic multipliers



7. Conclusion

This paper empirically investigates asymmetries in reaction function of the RBI using time-series data from June 2000 to December 2014. The sample period is from the starting date of LAF and ends with the beginning of new inflation target regime. The variables used in study are weighted average of call money rates as short-term policy rate, output and inflation gap. The Index of Industrial Production (IIP) is taken for output and the output gap is measured by the HP filter. The wholesale price index (WPI) is taken for Inflation. Since there was no official inflation target in India during the period of this study, we took the previous three-month average as expected or desired inflation target.

The results produced evidence in favour of preference asymmetries in monetary policy reaction function in India and hence nonlinearities in the Taylor-rule. Based on the simulations, we found evidence of both recession avoidance preference as well as inflation avoidance preference. However, the former is dominant over the latter, thus confirming nonlinearities in reaction function which in the present case turns out to be concave in inflation and output gap, as output stability is preferred over inflation stability. The results indicate asymmetries in both objectives. The coefficient weights to positive and negative inflation and output gap differed over long time horizons, thus confirming asymmetric policy preferences.

Specifically, the RBI seems to be more averse to a negative output gap (contraction) as compared to an equal positive gap. In addition, the RBI appears to be more averse to a positive inflation gap as compared to an equal negative gap. However, the response to output gaps is proportionally stronger than response to inflation gaps.

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