MONETARY POLICY AND INFLATIONARY DYNAMICS: THEORY AND EVIDENCE

Thesis submitted in partial fulfilment of the requirements for the award of the Degree of Doctorate of Philosophy in Arts at Jadavpur University, Kolkata

By

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And that neither this thesis nor any part of it has been submitted before for any degree or diploma anywhere/elsewhere.

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KRISHNENDU MAJI

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List of Abbreviations

Abbreviation	Complete Definition
ADF	Augmented Dickey Fuller
AIC	Akaike information criterion
ANN	Artificial Neural Network
AR	Autoregressive
CRR	Cash Reserve Ratio
CRR	Cash Reserve Ratio
DDPG	Deep Deterministic Policy Gradient
DF	Dickey Fuller
DPM	Dynamic Panel Model
DQN	Deep Q Network
DSGE	Dynamic Stochastic General Equilibrium
DW	Durbin-Watson
ERS	Elliott Rothenberg Stock
FEVD	Forecast Error Variance Decomposition
GDP	Gross Domestic Product
GIRF	Generalized IRF
GLS	Generalized Least Square
GMM	Generalized Methods of Moments
HP	Hodrick-Prescott
IRF	Impulse Response Function
KPSS	Kwiatkowski Phillips Schmidt Shin
LAF	Liquidity Adjustment Facility
LOOCV	Leave-One-Out Cross-Validation
MAPE	Mean Absolute Percentage Error
PCA	Principal Component Analysis
PP	Phillips and Perron
PVAR	Panel Vector Autoregression
RBA	Reserve Bank of Australia
RBI	Reserve Bank of India
RL	Reinforcement Learning
SLR	Liquidity Ratio
TAR	Threshold Autoregressive
VAR	Vector Autoregressive
ZLB	Zero Lower Bound

Chapter 1

Introduction and Review of Literature

1.1 Introduction

Monetary policy refers to the central bank's policy for macroeconomic management by influencing and/or targeting money supply, or to be specific credit supply, through the adjustment of policy rate in response to observable variations in inflation and output. Monetary policy has traditionally been seen as the most important tool for ensuring price stability. In this context, it should be mentioned that, central bank utilises a list of quantitative as well as qualitative tools or instruments for monetary management or credit control. The quantitative tools include open market operation, reserve requirement and policy rate. The qualitative tools include credit rationing, changing margin requirements, regulating consumer credit, moral suasion, etc. This thesis is primarily focused on and evolved around policy rate as the key monetary policy instrument. In addition to that, central banks utilize a number of unconventional monetary policy tools to regulate the macroeconomic environment, such as: asset purchase programs or quantitative easing, negative interest rates, targeted long-term refinancing operations, credit easing, etc. However, discussion of all these unconventional monetary policy tools is beyond the scope of this thesis.

In the context of India, the quantitative monetary tools include open market operation, bank rate, reserve requirements (i.e., Cash Reserve Ratio and Statutory Liquidity Ratio), Liquidity Adjustment Facility, which includes key policy rates, i.e., repo rate and reverse repo rate. In addition to that, the RBI utilises a list of qualitative tools for macroeconomic management, such as Margin Requirements, Consumer Credit Regulation, Moral Suasion, Rationing of Credit, Priority Sector Lending, etc.

A well-regulated monetary policy rule is one of the key ingredients of desired macroeconomic stability for any modern economy. The macroeconomic circumstances are the primary determinant of the direction and magnitude of policy intervention. Therefore, the evolving economic environment is supposed to cause certain alterations in the monetary policy impulse. However, the magnitude of the impact of monetary policy impulses on a desired set of variables varies across countries over time. Therefore, both identifying a proper monetary policy response as well as understanding its potential impact on the desired set of variables is necessary. This thesis broadly incorporates both of these aspects of the monetary policy, i.e., impact of monetary policy on key macroeconomic variables as well as the monetary policy response function.

As far as the monetary policy response function is concerned, identifying monetary authorities' reactions to changes in fundamental macroeconomic variables has long been a focus of the academicians as well as policymakers. The latter includes central banks, governments, international agencies such as International Monetary Fund, World Bank etc. Much of the existing literature on this area is based on Taylor's (1993) monetary policy rule. Taylor presents a basic monetary policy rule in which the monetary authority changes the policy rate in response to observable variations in inflation and unemployment rate or equivalently deviation of aggregate output from its potential, i.e., output gap, in the economy. Taylor proposes that variation in inflation and the output gap induce the monetary authority to change its policy rate. Taylor, however, made it clear that the rule he proposed, was not meant to be a precise formula. The proposition was subsequently formalized in studies by Taylor (1996) and Svensson (1997, 2003). Taylor (1996) points out a number of reasons behind using a well-defined monetary policy rule to recommend policy response. These reasons are discussed in the later part of the thesis. The study also recognises the requirement of discretionary actions by central banks under specific circumstances. However, as the study suggests, well-defined rule should be emphasised more than the discretionary actions by central banks. Svensson (1997) illustrates the derivation of reaction function of the central bank given its objective (i.e., minimizing social loss) and knowledge about the structure of the macroeconomic environment or state variables (i.e., structural form of output gap and inflation). Svensson (2003) suggests a number of key points to achieve a good monetary policy rule. These are also discussed in the later part of the thesis.

The monetary policy rule, as specified by Taylor, is extensively used in the relevant literature to demonstrate the policy rule in any macroeconomic model. Alternatively, central banks may prefer to define explicit objectives or goals and follow some decision-making process that involves a robust technique and analysis of available relevant historical data to achieve those objectives. The evaluation of the optimality and robustness of such rule-based policy response could become a horizon to the concerned literature. What should be the appropriate objective for a central bank to strive for when acting in society's best interest? Given economic frictions, the welfare of representative agents is supposed to be optimized by an optimal monetary policy rule.

The impact of monetary policy on key macroeconomic variables remains a major area of research in the field of macroeconomics and the central banking system. Research is being conducted both theoretically and empirically to examine the channels and strength of the monetary policy transmission mechanism. Accurate assessment of the potential impact of such a policy is a key ingredient of successful policy implementation. Any central bank has two possible choices or goals as the policy objective: control of inflation and a lower level of unemployment. During recessionary periods, in order to address sudden increase in unemployment, monetary policy instruments are being used to accelerate economic activity in the economy.

However, pursuing all the goals mentioned above simultaneously is an impossible task for any macroeconomic policy instrument, specifically in the short run using monetary policy. In this context, the success of any policy is largely defined by its goals. Having a definite goal can help the policy maker to assess the effectiveness of its policy as well. After setting up the goal, the next step should be to identify the appropriate policy instrument, its desired magnitude and the direction of its impulse. In order to perform that, policymakers should have an accurate prior understanding of potential impact of policy impulse on a set of variables that are part of the objective function of the policymaker.

To understand the potential impact of monetary policy, the quantity theory of money plays a significant role. The quantity theory of money explains how general price level responds to changes in money supply or monetary policy interventions. One of the major manifestations of quantity theory of money is the concept of neutrality of money. The neutrality of money suggests that changes in the quantity of money supply can affect only the nominal variables (such as price level, rate of interest, exchange rate, etc.) but real variables in the macroeconomic system (such as real output, unemployment, etc.) remain unaffected by such changes. In other words, monetary policy shocks have no effect on real macroeconomic variables. However, the validity of the neutrality of money hypothesis is dependent heavily on validity of a number of restrictive assumptions. The list of assumptions is motioned and described as follows:

1. *Flexibility of price*: In the long run general price level adjusts in response to market circumstances. Such responsiveness of price level ensures the attainment of the full-employment level of production. In particular, changes in the price level are encountered by equal changes in resource prices, especially wages.
2. *Unitary elasticity of expectation*: Consumer price expectation plays a key role in determining the aggregate demand for goods and services in any economy. The elasticity of price expectation is defined as the percentage change in expected change in future price in response to one percentage change in the current price level. Therefore, unitary elasticity of expectation represents a scenario in which the future percentage change in expected price level is equal to the percentage change in present observed price level.
3. *Neutral redistribution effects*: It indicates that, in an economy which operates without friction, in the equilibrium, would give to every agent of production the amount of wealth which that agent creates, i.e., according to its marginal productivity.

All the three assumptions mentioned above fall short of macroeconomic reality, at least in the short-run. Violating any of the assumptions mentioned above (e.g., existence of price rigidities or imperfect expectations) in the short-run enables monetary policy to affect real macroeconomic activity. Therefore, in order to regulate macroeconomic environment policy makers can use monetary policy as one of the instruments. However, the extent of impact of monetary policy and channels through which the monetary policy can affect key macroeconomic variables depends on macroeconomic circumstances. In this context, credit channels play a significant role. The credit rationing models suggests, monetary policy is relatively more effective in regulating real economic activity during periods when credit is scarce than in a scenario when credit is abundant. In other words, the relationship between monetary circumstances and output may have threshold effects or nonlinearities.

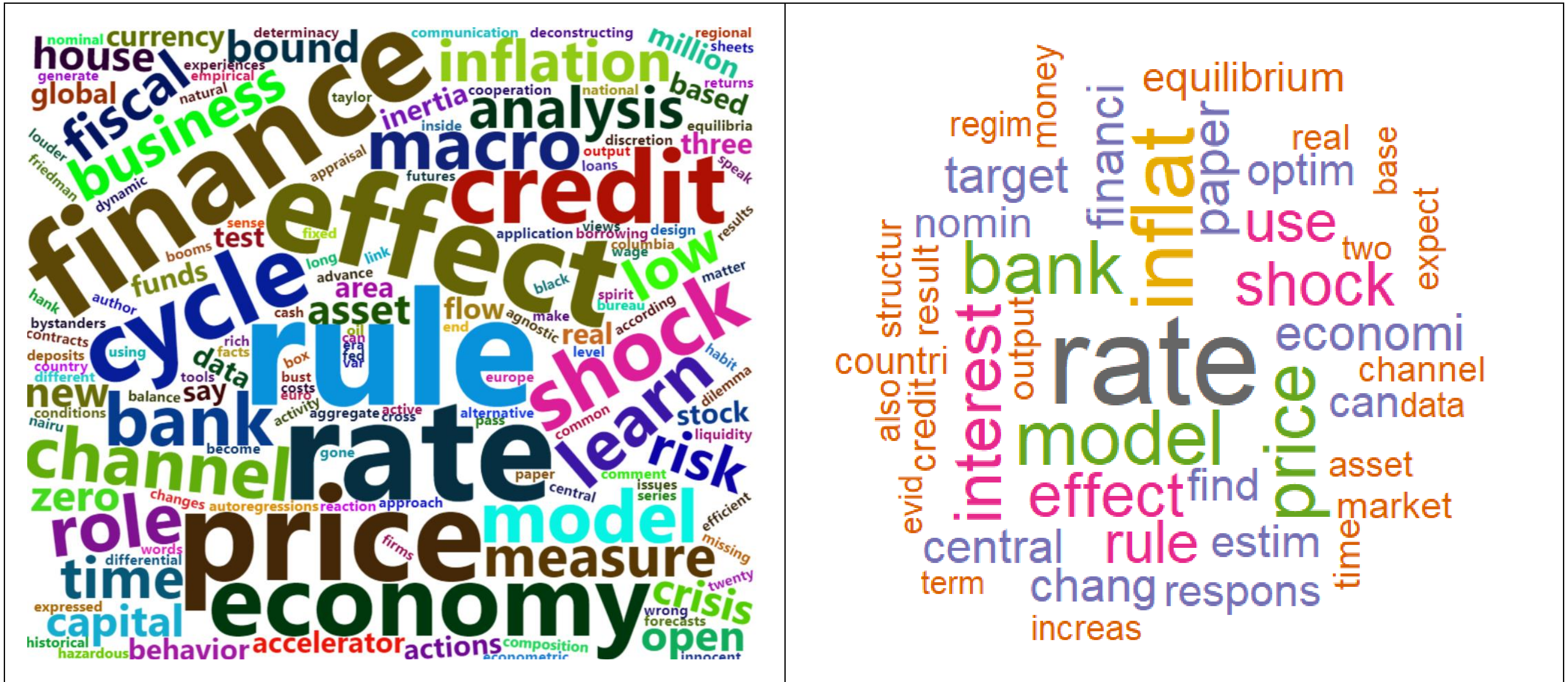
One of the major problems associated with summarising literature on a topic like monetary policy in order to identify the possible areas of research is its vastness. In this context, it is necessary as well as desirable to use the available technology to summarise the exponentially growing literature on monetary policy in a systematic way. Such technology can be based on text mining. A corpus consists of the title and abstract of 100 most cited academic resources (having at least 700 citations) in the field of monetary policy are being explored and analysed to understand the overall area of research for the concerned literature.

The word cloud is one of the most popular ways to visualize the most frequently used terms or words in a corpus of documents. In this study, firstly, the word cloud is used to demonstrate the frequently used words in the title and abstract of a selected set of literature, shown in Panel (A) and (B) of Figure 1.1 respectively. This figure clearly depicts the broad area of research in the field of monetary policy.

Finally, in order to classify the set of documents, the k-means clustering technique is applied to the document-term matrix generated out of the corpus of abstracts. A second set of word cloud is being generated out of the corpus of titles of resources for each cluster. After a number of explorations, three distinct clusters are being identified with a reasonable number of cluster members. The resulting word clouds corresponding to clusters 1, 2 and 3 are being demonstrated in Panels (A), (B) and (C) in Figure 1.2 respectively. The figures demonstrate the three broad categories of research in the field of monetary policy, i.e., (i) money market or financial markets and monetary policy (demonstrated in Panel A), (ii) impact or effectiveness of monetary policy (demonstrated in Panel B) and (iii) monetary policy rule and its optimality (demonstrated in Panel C).

As demonstrated above, a text mining technique can be used to efficiently explore the vast amount of literature in any area of research. In the digital age, when number of electronically available research articles is rising exponentially, this is the only way to perform preliminary exploratory analysis and identify patterns in available literature. This method is helpful in identifying the research gap and finding research questions as well.

Figure 1.1: Word Cloud on Title and Abstract of Literature



(A) Title	(B) Abstract

Figure 1.2: Word Cloud on Title of literature for each cluster members

(A) Cluster 1

(B) Cluster 2

(C) Cluster 3

The dissertation has been divided into the following chapters:

Chapter 1: Introduction and Review of Literature.

Chapter 2: A Comparative Study of the Impact of Monetary Policy on Macroeconomic Variables: A Panel Data Analysis.

Chapter 3: Asymmetry in the Conduct of the Monetary Policy in India.

Chapter 4: Asymmetric Policy Response of RBI using Reinforcement Learning Algorithm.

Chapter 5: Conclusion.

This chapter primarily introduces the dissertation. Section 1.1 elaborates and introduces the idea of monetary policy. Sections 1.2 and 1.3 give a broad summary of some of the relevant literature on monetary policy. Finally, Section 1.4 briefly introduces the subsequent chapters of this dissertation.

1.2 Literature Survey

In one of the earliest pieces of literature on monetary policy Simons (1936) argues in favour of governing the monetary system by definite rule and with minimum of uncertainty for enterprises and investors. As suggested by him, the definite rule is supposed to be simple (at least in principle), and expressive of strong, long-lasting, universal, and reasonable popular sentiments. In addition to that, the rule should prioritise employment and be flexible enough to accommodate changes in technology, minimize inequities as between borrowers and lenders. Simons recommended that, monetary authority with defined policy rule should possess reasonable administrative powers so that it can enforce the monetary rules, and determine the direction of fiscal policy. Finally, it suggested that, the policy rule should stabilize the prices of competitively produced commodities.

As mentioned earlier, most of the current studies on understanding the behaviour of central banks are based on Taylor's (1993) monetary policy rule. The extensive discussions on Taylor's monetary policy rule are given in the subsequent chapters. Taylor (1996) points out six reasons behind using a well-defined monetary policy rule to recommend policy response, namely, (i) time consistency, (ii) forward-looking behaviour in macroeconomic agents, (iii) reducing policy uncertainty, (iv) instruct goal-seeking policymakers to take appropriate action, (v) educate and inform students and general public and (vi) accountability of policymakers. Finally, Taylor discouraged absolute discretionary approach in monetary policymaking.

Favero and Rovelli (1999) propose a methodology to identify the parameters describing the central bank preferences with respect to macroeconomic environment. The empirical method suggests that, a strict inflation targeting regime complemented by real interest rate smoothing delivers an optimal monetary policy rule for the US economy between 1983Q1 to 1998Q3. In addition to that, the study suggests that, the output gap enters into the policy rule of monetary authority only as a leading indicator of future inflation and not play any significant role in constituting the objective function or the loss function of the Fed.

Ball (1999) defines a rule for monetary policy that minimizes a weighted sum of variation in output and inflation. One of the applications of the study is to express the monetary policy rule as a Taylor rule, in which policy rates is sensitive to output and inflation. The empirical result suggests, the coefficients of the optimized policy rule differ from actual policy rule excessed by the US. The study concludes with recognising inflation target as efficient and nominal-income targets as inefficient policy actions. That is, whereas inflation targets reduced output and inflation volatility, nominal-income targets induced just the opposite.

Svensson (2003) is one of the foundational studies that explores the behaviour of central banks using a micro-foundational approach. The study attempts to bridge the gap between representing monetary policy rule by a simple linear equation and the actual policy rule practiced by inflation targeting central banks. The study argues that, it is impossible to represent the monetary rule using a simple linear equation, especially under inflation targeting. The study suggests a number of key points to achieve a good monetary policy rule: (1) target variable(s) (e.g., output gap, inflation) and target level should be well defined along with its weight in the loss function, (2) estimate the sacrifice ratio between or among the potential target variables, (3) identify an operational and simple target rule that approximately optimize the loss function, (4) identify or estimate the marginal impact of policy rate on the target variable(s), (5) set the policy rate according based on understanding of target levels and sensitivity of target variable(s) with respect to policy rate, (6) repeat the process until the desired target(s) is not achieved and finally (7) maintain transparency in the system.

Bernanke and Boivin (2003) explore the possibility of including richer information sets in determining monetary policy rule for the US economy using a factor extraction approach (i.e., dimension reduction). The study confirms that, the use of large datasets can improve forecast accuracy. Finally, the study estimated a monetary policy response function for the US economy under a data-rich environment. The study demonstrates the potential of using a high frequency and high dimensional macroeconomic information in estimating the policy response function.

Boivin and Giannoni (2006) empirically investigate the extent of effectiveness of monetary policy for the U.S. economy over the pre- and post-1980 periods using a vector autoregressive model. The study provides evidence of a reduced impact of policy shocks on concerned variables in the latter period. In addition to that, the study reveals that, responding strongly to inflation expectations improves effectiveness of monetary policy in macroeconomic stabilization in the latter periods.

Blinder et al. (2008) surveyed growing literature to understand the importance of central bank communications for effective monetary policy implementation. The survey clearly gives evidence in favour of importance of central bank communication to influence financial markets, and potentially help to attain its macroeconomic goals. In addition to that, the survey also reveals that, a substantial variation in communication strategies can be found across central banks in reality.

Drechsler, Savov and Schnabl (2017) introduce the deposits channel as a new channel for the transmission of monetary policy. According to the study, the deposits channel can explain the observed strong relationship between the liquidity premium and the policy rate, since deposits are the primary source of liquid assets for households. The estimated results of the study suggest that, the deposits channel can account for the entire transmission of monetary policy through bank balance sheets.

The extensive review of relevant literature for respective chapters are included in the Review of Literature section of each chapter.

1.3 Literature on the Indian Economy

There is an abundance of literature that incorporates studies in the field of monetary policy in the context of the Indian economy. Ray, Joshi and Saggar (1998) explore new features in the policy transmission mechanism in the post-liberalisation periods with increasing integration of financial markets. The study analyses interest rates and exchange rates, two key variables in monetary policy, from 1970-71 to 1996-97. The study reveals that interest rates and exchange rates were endogenously determined in the liberalised regime beginning 1992-93.

Bhattacharyya and Sensarma (2008) examine the efficacy and robustness of alternative monetary policy instruments in transmitting policy signals and its impact on financial market behaviour using a structural vector autoregressive model for the period from 1996M4[1] to 2000M6 (pre-LAF[2] period) and from 2000M7 to 2006M3 (post-LAF period). The estimated results of the study suggest that, the Cash Reserve Ratio (CRR) had a dominant impact on financial markets relative to bank rate, which was identified by the Reserve Bank of India (RBI) as the principal signalling instrument in the pre-LAF period. Whereas, in the post-LAF period reverse repo rate become the most important signalling rate of the RBI. The study also reveals that, the RBI's policy actions had a significant impact on the Indian financial market, but its impact on the stock market remain negligible. In addition to that, the study found evidence of asymmetric impact of the RBI's policy action on financial market.

Hutchison, Sengupta and Singh (2010) examine the structure of the monetary policy rule of RBI, i.e., whether it can be represented by a described by a Taylor-type rule or not. The study investigated an exchange-rate-augmented Taylor rule for India over the period 1980Q1 to 2008Q4. In addition to that, it investigated the potential structural changes in monetary policy rule in the pre- and post-liberalisation periods. The estimated results suggests that, output gap matters more to the RBI than inflation.

[1] In this study the format *YYYY*Q*T* and *YYYY*M*T* are representing *T*th quarter and *T*th month of the year *YYYY* respectively,

[2] LAF stands for liquidity adjustment facility.

Other key findings of the study include, greater sensitivity of monetary policy with respect to CPI inflation and reduction in policy inertia post-1998.

Aleem (2010) empirically examines the transmission mechanism of policy actions of the RBI using vector autoregressive model for the period from 1996Q4 to 2007Q4. The study primarily examines the impact of unanticipated contractionary monetary policy shocks on the real sector. The study recognises the importance of banks in channelizing the monetary policy shock to the real sector of the economy. In addition to that, the study demonstrates that, unanticipated monetary policy shock has only transitory effects on the overnight call money rate, which eventually negatively affect prices and output.

Bhaumik, Dang and Kutan (2011) examine responses of different types of banks to monetary policy interventions of the monetary authority using micro-level data of 58 banks covering the period from 2000 to 2007. The study found evidence of considerable differences in the reactions. e.g., state-owned banks, old private banks and foreign banks reduce credit in response to contractionary monetary policy, among which, reaction of foreign banks is the sharpest. In addition to that, monetary policy transmission mechanism is more effective during tight money periods than easy money periods.

Kapur and Behera (2012) identify the existence of effective interest rate channel of monetary policy and the magnitude of the effect on output and inflation is comparable to that of major advanced and emerging market economies. The results were found to be sensitive to alternative measures of real rate of interest. Despite the RBI's contractionary monetary policy impulses for the years 2010 and 2011, inflation remained irresponsive and high due to the rise in international commodity prices between the period from the second half of 2010 to the first half of 2011.

Khundrakpam and Jain (2012) examine the relative effectiveness of various transmission channels on output growth and inflation using structural VAR (SVAR) models on quarterly data for the period from 1996-97Q1 to 2011-12Q1. The results show that, the external exogenous factors delay the impact of monetary policy. The monetary policy transmission channels that are most effective includes: interest rate channel, credit channel and asset price channel. Exchange rate channel was also found to be weakly transmitting monetary policy impulse. The study concludes that the interest rate channel is the most important channel for monetary policy transmission in India.

Mohanty (2012) finds evidence that contractionary monetary policy of the RBI negatively affects output and inflation with a lag of two quarters and three quarters respectively, which persists for 8-10 quarters using SVAR model for the period 2001Q2 to 2011Q1. This study also identified the importance of interest rate channels in transmitting monetary policy by showing evidence of unidirectional causality from policy rate to output, inflation and various liquidity measures except broad money.

Patra and Kapur (2012) estimate a new Keynesian model for the Indian economy and found that, inflation responds to monetary policy actions with a lag of seven quarters which can be segregated into (a) a lag of three quarters for aggregate demand to respond to changes in rate of interest and (b) a lag of four quarters for inflation to respond to demand conditions. In addition to that, the study finds evidences of an inertial character in inflation data.

Hutchison, Sengupta and Singh (2013) investigate change in policy regime of the RBI using a Markov switching model to estimate a dynamic Taylor rule type policy function using quarterly data from 1987Q1 to 2008Q4. The study finds evidence of presence of two regimes in in this context: (a) 'Hawk' regime, when the RBI puts a greater weight on controlling inflation and (b) "Dove" regime, when it targets output gap and exchange rate to stimulate exports, rather than stabilising inflation. Therefore, the RBI seems not to be following any absolute inflation targeting regime during the analysed time horizon.

Sengupta (2014) analyses the changes in transmission channels of monetary policy in India in the pre-LAF and post-LAF periods using vector auto regression techniques on monthly data from 1993M04 to 2012M03. The empirical results of the study show that, with declining importance, the bank lending channel remains one of the major monetary policy transmission channels in India in the post-LAF period. On the other hand, the set of transmission channels that gain in importance in post-LAF period includes interest rate, asset price and exchange rate channels.

Patra, Khundrakpam and Gangadaran (2017) computes optimal monetary policy rules for India conditional upon a small model of the economy covering the period 2000 to 2014 by minimizing alterative inter-temporal loss functions defined over the variation of inflation, output and policy rate from their respective targets. The study identifies policy rate ranging between 6.25 to 6.70 to be appropriate corresponding to the macroeconomic circumstances prevailing during 2015-16.

Khundrakpam (2017) examines the asymmetric impact of monetary policy in India on different components of aggregate demand and inflation using quarterly data from 1996Q2 to 2013Q4. The estimated results indicate that, unanticipated change in policy rate had a symmetric impact on aggregate demand, but differentially influence the components. The impact of unanticipated change in policy rate on inflation is found to be negative and symmetric. Finally, anticipated change in policy rate have a negative impact on inflation at all levels.

Mohan and Ray (2019) provide a narrative of prevalent monetary policy in India since the mid of 2008 till 2018. The period from 2009 to 2013 was dominated by the cooperation among monetary and fiscal authorities due to economic crisis. After substantial discussion between the Government of India and the RBI during 2013-14, a Monetary Policy Framework Agreement was established on February 20, 2015 that formally adopted flexible inflation targeting.

Balakrishnan and Parameswaran (2022) analyse the low inflation in India since 2016 (i.e., since the adoption of inflation targeting by RBI) to identify the source behind it, i.e., monetary policy or commodity prices. The study identifies that, subdued inflation in India since 2016 is due to the behaviour of commodity prices, and not because of monetary policy response of the RBI. In addition to that, the study recommends the introduction of a different set of policy instruments by RBI to control inflation.

Dasgupta and Chowdhury (2023) investigate the effectiveness of monetary policy under alternative monetary policy rules using a simple 3-equation model. The study estimates the Phillips curve equation and the nature of monetary policy rule in the context of India. The empirical evidences suggest presence of a flat Phillips curve (which makes monetary policy ineffective in controlling inflation), and an operative Taylor-type monetary policy rule. In addition to that, the study found evidence in favour of sensitivity of inflation with respect to cost push factors (e.g., terms of trade, oil prices, etc.). The study concludes that, the presence of a flat Phillips curve along with Taylor-type monetary policy rule, could adversely affect the output gap.

1.4 Structure of the Thesis

The broad arrangement of chapters of this thesis is mentioned in the Section 1.1 of this chapter. Now, the preliminary introduction to the subsequent chapters of this thesis is given in this segment of the thesis. The objective of the Chapter 2 is to empirically investigate the impact of monetary policy on key macroeconomic variables for a list of developed and emerging market economies. The study primarily focused on demonstrating the impact of monetary policy impulse on output growth and inflation control in a panel data analysis. One of the key advantages of panel data analysis over time series or cross section studies is that, it provides more comprehensive understanding about the dynamic relationship among the variables after controlling for the individual heterogeneity. In addition to that, it combines advantages of both, cross section as well as time series analysis. There is a need to study the impact of monetary policy on emerging market economies because of ambiguity in the findings of different empirical studies regarding effectiveness in stabilizing inflation and accelerating output. In addition to that, it is important to compare the impact of monetary policy on key macroeconomic variables for emerging and advanced economies. One of the earliest attempts to study the impact of monetary policy for a set of emerging market economies using a panel vector autoregression (PVAR) technique came from Jawadi et al. (2016). The study shows that monetary policy shocks induced expected macroeconomic consequences for BRICS nations during the period from 1990 to 2013. In addition to that, the study attempts to analyse the spillover effects between monetary and fiscal policy shocks. The study finds the existence of an "accommodative stance" between the two types of policy shocks.

The Chapter 2 explores an unbalanced panel of ten emerging market economies and eleven advanced economies to analyse the impact of monetary policy. The study evaluates the macroeconomic effects of monetary policy using a PVAR model. Impulse-response functions are used to show the response of one variable of interest (e.g., inflation) due to a shock in another variable of interest (e.g., Policy Rate), while holding other shocks constant. In addition to that, the variance decomposition technique is used to better understand the persistence of the effect. Panel data econometrics is a continuously evolving field of study. The exponential growth in availability of data observed on cross-sections of units and over time induced emergence of a number of advanced empirical methodologies exploiting this double dimensionality to manage some of the typical challenges associated with macroeconomic data, e.g., with respect to unobserved heterogeneity. Panel data techniques have a number of statistical superiorities or advantages over time series techniques; e.g., (i) they usually contain more degrees of freedom and more sample variability than cross-sectional data and thus improve the efficiency of econometric estimates; (ii) panel models provide greater capacity for capturing the complexity of individual behaviour than a single cross-section or time series data, (iii) panel models often simplify the computation and statistical inference. It is noteworthy that, most of the empirical studies which were attempted to assess the macroeconomic impact of monetary policy are country-specific studies or time series analysis. Whereas, very few panel data studies are available in the literature in this context, specifically for emerging market economies. This chapter is intended to bridge that gap in the literature.

The Chapter 3 is primarily dedicated to exploring the policy responses of the Reserve Bank of India. Identifying central bank's reactions to changes in fundamental macroeconomic variables has long been a focus of monetary economists. Much of the current material in this area is based on Taylor's (1993) monetary policy rule. Taylor presents a basic monetary policy rule in which the monetary authority changes the policy rate in response to observable variations in inflation rate and unemployment rate or equivalently output gap in the economy. Taylor proposed that variation in inflation and the output gap induce the monetary authority to change the policy rate. The Section 3.1 of Chapter 3 extensively covers the idea of monetary policy rule and Taylor's rule.

The debate over asymmetric monetary policy frameworks was introduced, and approximated Taylor rules have gained popularity as a way to describe the behaviour of the monetary authority. The concerned literature can be summarised by two questions. Firstly, has the central banks' actions been symmetric during high inflation and/or low-income vis-a-vis low inflation and/or high-income regimes? Secondly, Should the central bank react asymmetrically?

Given the policy response function, as depicted by Taylor, the central banks are expected to behave symmetrically in response to changes in major macroeconomic indicators. That is, the strength of the monetary policy response is independent of whether important macroeconomic indicators deviate from some threshold level in a positive or negative direction. However, under some specific circumstances, the rationale for asymmetric monetary policy might be considered as valid and desirable. For example, following the implementation of the inflation targeting regime, central banks may legitimately fear difficulties in securing inflation expectations (risk of credibility loss), which may lead them to employ asymmetric handling of inflation targets. Such asymmetry would imply that, central banks would react more sensitively when inflation forecasts were above the target than in a scenario where inflation forecasts were below the target level. Bunzel and Enders (2010) investigate the possibility of threshold nature of the monetary policy rule; i.e., the central bank acts sensitively in some circumstances than in others (e.g., high inflation scenario or positive output gap) using Threshold Autoregressive Model for the US economy for the period 1965Q3 to 2007Q3. The empirical results support the view that the Taylor rule is a threshold process that is consistent with the hypothesis of opportunistic monetary policy.

The subsequent chapter, i.e., the Chapter 4 is dedicated to exploring the desirability aspects for the asymmetric monetary policy response function in Indian context. The primary objective of the Chapter 4 is to identify or estimate the optimal monetary policy response function of the RBI given its knowledge about the economy and its own preference over the structure of the policy response function. This chapter incorporates two distinct policy response functions, i.e., symmetric and asymmetric policy response functions. In addition to the objective mentioned above, this study also going to compare the relative performance of symmetric and asymmetric policy response of monetary authority. Therefore, the goal of this chapter is to introduce a mechanism to identify and evaluate the optimal monetary policy response of the RBI. In this context, this chapter utilizes a Reinforcement Learning (RL) algorithm to identify the exact form of a well-defined deterministic policy response function.

The subject matter of the RL can be summarized as a problem of optimizing the discounted present value of future flow of reward of an individual (i.e., agent) or a group of individuals within a modelling environment. Therefore, the idea behind RL is to learn behavioural rules or policies based on state observations, that induce expected reward optimizing agent's action. The algorithm is model-free, i.e., complete knowledge of the model equations is not required for implementing such algorithms. The choices under RL are induced by past experiences, thus reduces model uncertainty. Finally, the algorithm does not suffer from the curse of dimensionality, i.e., it is possible to include as many states or control variables in the analysis as necessary without any restrictions. Although, incorporating an additional variable in the problem can increase the computational complexity of the problem by many folds. In a similar study, Hinterlang and Tänzer (2021) implement the Deep Deterministic Policy Gradient (DDPG) algorithm, as suggested by Lillicrap et al. (2015), to identify the optimal monetary policy reaction function for the US. The study incorporates 1987Q3 to 2007Q2 in order to estimate the transition equations. The result suggests that, the Reinforcement Learning based monetary policy rule outperforms other common rules as well as the actual federal funds rate. This study is one of the key starting points for this chapter. In this chapter we are going to use the same algorithm to estimate the optimal values of the parameters of the deterministic policy functions of the RBI.

Chapter 2

A Comparative Study of the Impact of Monetary Policy on Macroeconomic Variables: A Panel Data Analysis

2.1 Introduction

The impact of monetary policy on key macroeconomic variables remains a major area of research in the field of macroeconomics and the central banking system. Research is being conducted both theoretically and empirically to examine the channels and strength of the monetary policy transmission mechanism. Accurate assessment of the potential impact of such a policy is a key ingredient of successful policy implementation. Any central bank has two possible choices as the policy objective: stabilization of inflation and reduction of unemployment.

In the post second world war period, confidence in monetary policy as a policy instrument was reduced substantially. During that time, a significant fraction of economists in practice outlined that a mild variation in interest rate is not going to stabilize the economy or accelerate economic activity, assuming a very low level of interest rate elasticity of money demand. Any drastic measure to stabilize economic activity using monetary policy could potentially adversely affect the debt management exercise during those times, especially during inflationary periods. Although, monetarists consider monetary policy impulse to be the most important policy instrument for regulating key macroeconomic variables, e.g., as popularized by Milton Friedman, the money supply is the principal factor that determines inflation or deflation in an economy. Friedman (1995) elaborated on what monetary policy can and cannot do. Monetary policy has a very limited period effect on interest rates and rates of unemployment, as specified by Friedman. Although, Friedman accepts the importance of monetary policy in effecting real magnitudes with efficiency and its power to stabilize the macroeconomic environment. Finally, he asserts that the use of monetary policy can help to stabilize significant external shocks to the economy.

The standard Keynesian model shows that the effectiveness of monetary policy depends on the sensitivity of real money balance money with respect to interest rate. The greater the interest rate sensitivity of money demand (tending toward the state of a liquidity trap) smaller will be the impact of monetary policy. But at the same time, in a situation where investment is non-responsive to the rate of interest, monetary policy becomes totally ineffective. A few economists suggest selective use of monetary policy, e.g., the Radcliffe Committee Report. Gurley (1960)'s interpretation of the report suggests: "… it is not a good thing to have highly fluctuating interest rates, and since the lending of financial institutions in ordinary times should not be directly controlled, more emphasis should be placed on fiscal policy as a short-run stabilizer, leaving monetary policy to set the tone of longer-run developments". Whereas, "… during emergency situations [e.g., Inflationary Periods], … monetary policy should be used vigorously".

The stability of the macroeconomic environment (i.e., lesser uncertainty for macroeconomic agents) is one of the key determinants for the effectiveness of any policy instrument on desired variables. There is a long list of factors that can potentially influence the impact of the monetary policy and most of these operate through the expectation channel. Most importantly, based on the rational expectation school of thought, as in Lucas (1972), only the monetary expansion that outperforms the expectation of individual agents can affect real economic activity, that is to say only unanticipated monetary policy can only have real effect. In addition to that, researches in the area identifies that there are some structural factors that can influence the potential impact of monetary policy on key macroeconomic variables. A number of such factors include transparency of the central bank, financial development, demography of the country, debt and exchange rate regimes, etc.

Examining the extent of impact of monetary policy on inflation and output for a group of developed and developing market economies is the primary goal of this study. It is possible to demonstrate the effectiveness of monetary policy by showing the impact of monetary policy impulse on output growth and inflation control. Monetary policy can affect general price level either proportionately (i.e., Classical Case: monetary policy has no impact on real variables) or less than proportionately (i.e., rigidities in key macroeconomic prices causing real variables to change). There is a need to study the impact of monetary policy on emerging market economies because of ambiguity in the findings of different empirical studies regarding effectiveness in stabilizing inflation and accelerating output. In addition to that, it is important to compare the impact of monetary policy on key macroeconomic variables for emerging and advanced economies.

This study explores an unbalanced panel of ten emerging market economies and eleven advanced economies to understand the impact of monetary policy on inflation and output. The set of countries includes emerging market economies: Brazil, Chile, Colombia, Hungary, India, Indonesia, Mexico, Russia, South Africa, Czech Rep. (Constitute almost 12% of global GDP) and Advanced Economies: Australia, Canada, Denmark, Iceland, Japan, New Zealand, Norway, South Korea, Switzerland, United Kingdom, and the United States (Constitute almost 41% of global GDP).

The current chapter evaluates the macroeconomic effects of monetary policy using a panel vector autoregression (PVAR) model. In order to understand the impact of the shock to a particular policy variable, typically policy rate, on the other macroeconomic variables of interest Impulse Response Functions (IRFs) are computed and plotted. It also shows the persistence of the impact of the shock, whether temporary or permanent, on the endogenous variables. The Forecast Error Variance Decomposition shows the relative importance of own shoch vis-a-vis other shock in the variability of the impact on the endogenous variables. In this context, it should be mentioned that, PVAR methodology used in this study is a reduced form PVAR technique. Similar to traditional time series technique it also can treat all the variables in the system as endogenous with advantage of having in control of unobserved individual heterogeneity. The panel framework increases efficiency by avoiding possible bias generated out of relatively low degree of freedom under country-level VARs. Panel data econometrics is a continuously evolving field of study. The exponential growth in availability of data observed on cross-sections of units and over time induced emergence of a number of advanced empirical methodologies exploiting this double dimensionality to manage some of the typical challenges associated with macroeconomic data, e.g., with respect to unobserved heterogeneity. Panel data techniques have a number of statistical superiorities or advantages over time series techniques; e.g., (i) they usually contain more degrees of freedom and more sample variability than cross-sectional data and thus improve the efficiency of econometric estimates; (ii) panel models provide greater capacity for capturing the complexity of individual behaviour than a single cross-section or time series data, (iii) panel models often simplify the computation and statistical inference. It is noteworthy that, most of the empirical studies which were attempted to assess the macroeconomic impact of monetary policy are country-specific studies or time series analysis. Whereas, very few panel data studies are available in the literature in this context, specifically for emerging market economies. This chapter is intended to bridge that gap in the literature.

In order to evaluate the macroeconomic impact of monetary policy accurately, this study incorporates two more macroeconomic variables in the empirical model, i.e., oil price and fiscal policy impulse. The oil price is incorporated in this study to introduce a proxy for exogenous supply-side variability in the macroeconomic environment assuming the fact that, monetary authorities cannot entirely isolate their economies from the impact of oil-price shocks and choose appropriate actions to determine the consequence of such a shock to the economy. On the other hand, the presence of fiscal policy impulse in the model helps us to compare the macroeconomic impact of fiscal policy and monetary policy shocks side-by-side. In addition to that, it helps us to evaluate the possible spillover between monetary and fiscal policy shocks.

The rest of the chapter is organized as follows: Section 2.2 of this chapter explores the literature with respect to the objective of the study. Section 2.3 illustrate the theoretical basis behind the structure of empirical model used in this study. Section 2.4 identifies the data used in the analysis and explores those data. Section 2.5 identifies an econometric model that allows us to empirically evaluates the impact of monetary policy on key macroeconomic variables. Section 2.6 conducts empirical analysis and discusses the estimation results. Finally, Section 2.7 concludes and discusses some possible extensions.

2.2 Review of Literature

One of the main contributions that triggered the research to study the impact of monetary and fiscal policy to influence key macroeconomic variables was by Friedman and Meiselman (1963). The study predicts that, the "stock of money" (i.e., monetary policy) is more critical and statistically significant than "autonomous expenditure" (i.e., fiscal policy) in explaining movements in real output.

One of the earliest empirical attempts to study the macroeconomic impact of monetary policy came from Barro (1976). The study examines the hypothesis that only unanticipated movements in money (i.e., unanticipated monetary policy shock) would affect economic activity for the US economy for the period from 1941 to 1973. The empirical study validates the validity of the underlying hypothesis. Although, the study was not directed toward analysing the impact of the anticipated and unanticipated movement in money on inflation. In a subsequent study, Barro (1978) attempts to address that issue by analysing the impact of the unanticipated monetary shock on both output and inflation. One of the major findings of the study was a one-to-one contemporaneous link between anticipated monetary movement and the price level.

Much of the current studies on understanding the behaviour of monetary authority based on Taylor's (1993) monetary policy rule (to be discussed in chapter 3 and 4 in greater details). Taylor presents a basic monetary policy rule in which the monetary authority changes the policy rate (such as bank rate in UK, FED rate in USA and repo rate in India) in response to observable variations in inflation and output in the economy. Taylor proposes that when inflation exceeds its target (or some threshold) level and the output gap deviates from the full employment, the monetary authority tend to respond by increasing the policy rate. Taylor, however, made it clear that his rule was not meant to be a precise formula. The proposition was subsequently formalized in studies by Taylor (1996) and Svensson (1997, 2003).

Favero and Rovelli (1999) propose a methodology to identify the parameters describing the central bank preferences with respect to macroeconomic environment.

The empirical method suggests that, a strict inflation targeting regime complemented by real interest rate smoothing delivers an optimal monetary policy rule for the US economy between 1983Q1 to 1998Q3. In addition to that, the study suggests that, the output gap enters into the policy rule of monetary authority only as a leading indicator of future inflation and not play any significant role in constituting the objective function or the loss function of the Fed.

In a significant contribution to the debate on the macroeconomic impact of monetary policy, Uhlig (2005) proposes a new agnostic method to estimate the effects of monetary policy on the US economy from 1965 to 1996. As far as output is concerned, the study finds that contractionary monetary policy shocks have an ambiguous impact on real GDP, which is not inconsistent with the hypothesis of the Neutrality of Money. Two different indicators of inflation are used in the study, i.e., GDP deflator and CPI Inflation. The results reveal that, responsiveness of CPI Inflation to monetary policy shock is relatively sharper than that of the GDP deflator.

De Luigi (2018) develops a medium-scale non-linear model of the US economy for the period 1967 to 2012 to study the relationship between debt regimes and the effectiveness of monetary policy using a threshold vector autoregression with stochastic volatility. The results of the study suggest that the impact of monetary policy shock is weaker if the debt-to-GDP ratio increases, i.e., the impact of monetary policy is less noticeable in ‘high’ debt regimes.

It is noteworthy that, most of the empirical studies which attempted to assess the macroeconomic impact of monetary policy are country-specific studies or time series analysis. Whereas, very few panel data studies are available in the literature in this context. One of the earliest attempts to address this issue came from Karras (1999).

Using annual data from 1953 to 1990 for a panel of 38 countries and applying a dynamic panel regression model on the dataset, the study suggests that, the impact of monetary policy on key macroeconomic variables is linked with the openness of an economy. i.e., the greater the openness of an economy, the lesser (greater) the output (inflationary) effects of a given monetary shock.

Carranza et al. (2010) in a cross-country study, using 66 countries, attempt to find out the relationship between financial development and the macroeconomic impact of monetary policy. The study suggests that monetary policy has a larger aggregate impact when the financial system is less developed. In addition to that, this impact takes a longer time to appear than in the case of more developed financial systems. i.e., monetary policy effectiveness is inversely proportional to financial development. Although this was a cross-country study, i.e., no panel data modelling techniques was applied to the study.

One of the earliest attempts to study the macroeconomic impact of monetary policy for a set of emerging market economies using a PVAR technique came from Jawadi et al. (2016). The study shows that monetary policy shocks induced expected macroeconomic consequences for BRICS nations during the period from 1990 to 2013. In addition to that, the study attempts to analyse the spillover effects between monetary and fiscal policy shocks. The study finds the existence of an "accommodative stance" between the two types of policy shocks.

Georgiadis and Mehl (2016) attempt to study the effect of financial globalization on macroeconomic impact of monetary policy. The study suggests, there are two opposing channel of forces that determine the net impact of financial globalization on monetary policy effectiveness. In one hand, financial globalization reduces the output effect of a targeted monetary policy, whereas, on the other hand, economies have become increasingly net long[3] in foreign currency due to financial globalization which amplifies the impact of monetary policy. The results of the study show that, for a set of advanced and emerging market economies since the 1990s, the second channel has become the dominating force. As a result, financial globalization has amplified the impact monetary policy on key macroeconomic variables. The study uses a mixed cross-section global VAR model with sign restrictions that enable the model to evaluate possible global monetary policy spillover.

Ma and Lin (2016) investigate the relationship between financial development and the impact of the monetary policy on panel data from 41 economies for the period 2000Q1-2011Q4 applying a dynamic panel regression technique. The study shows that as the financial system gets more developed, the impact of monetary policy on key macroeconomic variables decreases, similar to the result of Carranza et al. (2010). Although, in a study on 39 African countries with annual data from 1990 to 2015 Effiong et al. (2020) find a weak relationship between financial development and strength of monetary policy in affecting key macroeconomic variables.

As the survey of literature on the concerned area of study suggests, empirical studies to examine the impact of monetary policy on key macroeconomic variables for developing economies are scarce and with ambiguous results. In addition to that, none of the studies compares the impact of monetary policy between advanced and emerging market economies. The current study is intended to address this gap in the literature using available academically recognised advanced panel econometric technique. The study reveals number of key observations on extent and persistence of impact of

[3] Net long refers to a condition in which investors have more long positions than short positions.

monetary policy on major macroeconomic variables for emerging and advanced economies. For example, initial impact of monetary policy on key macroeconomic variables is greater in emerging economies relative to advanced economies. However, the impact persists under emerging market economies. The detail discussion on the study and its results are given in subsequent sections of this chapter.

2.3 Theoretical Motivation

The structural form of the reduced form system of equations used in this empirical study can be understood using Svensson (1997). It illustrated the derivation of reaction function of the central bank given its objective (i.e., minimizing social loss) and knowledge about the structure of the macroeconomic environment or state variables (i.e., structural form of output gap and inflation). As suggested in Svensson (1997), the goal of the central bank can be represented as follows:

$$E_t \sum_{\tau=0}^{\infty} \delta^{\tau} L(\pi_{t+\tau}, y_{t+\tau}) \tag{2.1}$$

where, E_t representing the conditional expectation of the central bank given the information available at the period t, δ denoting the discounting factor (i.e., $\delta \in [0,1]$), π_t denoting the rate of inflation and $L(\pi_\tau)$ representing the loss function, which can be represented as follows:

$$L(\pi_\tau) = \frac{1}{2}[(\pi_\tau - \pi^*)^2 + \lambda(y_t - \bar{y})^2] \tag{2.2}$$

where, π^* representing the targeted level of inflation and y_t and $\bar{y}$ are representing the actual and potential output (assumed to be constant in the short run) respectively. λ is the relative weight given to the output stabilization ($\lambda > 0$).

Svensson (1997) represented the structural form of the state variables as follows:

$$\pi_{t+1} = \pi_t + \alpha_1(y_t - \bar{y}) + \alpha_2 x_t + \varepsilon_{t+1} \quad (2.3)$$

$$y_{t+1} = \bar{y} + \beta_1(y_t - \bar{y}) - \beta_2(i_t - \pi_t) + \beta_3 x_t + \eta_{t+1} \quad (2.4)$$

$$x_{t+1} = \gamma x_t + \theta_{t+1} \quad (2.5)$$

where, i_t representing the policy rate and x_t is the external shock variables. As mentioned in the introductory section (i.e., Section 2.1), the current study incorporates two distinct external shock variables, i.e., fiscal policy shock (as an endogenous external shock) and oil price shock (proxy for exogenous supply-side shocks). ε_t, η_t and θ_t are the independent and identically distributed random shocks. α_1, α_2, β_1, β_2, β_3 and γ are the coefficients corresponding to the dynamic structure of the state variables.

Optimizing the above-mentioned objective function (i.e., Equation 2.1) given the structural equations representing the state variables (i.e., Equations 2.3, 2.4 and 2.5) Svensson (1997) derived the optimal structural form of the policy response function, illustrated as follows:

$$i_t = \pi_t + b_1(\pi_t - \pi^*) + b_2(y_t - \bar{y}) + b_3 x_t \quad (2.6)$$

where, i_t is monetary policy rate. b_1, b_2 and b_3 are the coefficients of the policy function. The primary difference between the reaction function represented in Equation 2.6 and Taylor (1993) is the presence of external shocks in the reaction function of the central bank.

In this chapter, we are going to estimate the reduced form system of equations corresponding to the structural form equations illustrated above to understand the dynamic association among the variables. The empirical model used in this study and the corresponding estimation technique is explained extensively in the Empirical Methodology section of this chapter (i.e., Section 2.5).

2.4 Data and Descriptive Statistics

The study uses an unbalanced panel data of ten emerging market economies and eleven advanced or developed economies. The data are available at quarterly frequency over the period from 2001Q1 to 2022Q4. The list of variables included in the present study are as follows:

1. Seasonally adjusted real GDP growth rate ($GDP_{i,t}^{g}$), which represents growth of economic activity.
2. Rate of Inflation ($\pi_{i,t}$), which is based on the CPI.
3. Government Spending growth rate ($GOVEXP_{i,t}^{g}$), calculated using the General Government Final Consumption Expenditure (seasonally adjusted). It is used in the study to represent the fiscal policy shocks (Agnello et al., 2013)
4. Policy Rate ($IR_{i,t}$), which represents the monetary policy instrument shocks.
5. Growth rate of Crude oil price ($OIL_{i,t}^{g}$), which captures exogenous supply side shock. This is the only exogeneous variable in this study, i.e., fluctuations in it primarily driven by events like geopolitical disruptions, natural disasters, or OPEC production decisions, etc. and therefore not directly influenced by other individual country specific variables specified in the model.

Except policy rate, all the other variables included in this empirical study are growth figures, i.e., in percentage change form. Such transformations were carried out to make those concerned variables stationary, which is a necessary condition to estimate a VAR model.

Table 2.1 shows availability of data for each country in the study.

Table 2.1: Country specific size of observations

Country	ISO2 Code	Country Type	Start	End	Obs.
Australia	AU	Advanced	1991Q1	2022Q2	126
Canada	CA	Advanced	1993Q1	2022Q2	118
Denmark	DK	Advanced	1991Q1	2012Q2	86
Iceland	IS	Advanced	2002Q1	2022Q2	82
Japan	JP	Advanced	1991Q1	2017Q1	105
New Zealand	NZ	Advanced	1999Q2	2022Q2	93
Norway	NO	Advanced	1991Q1	2020Q1	117
South Korea	KR	Advanced	1991Q1	2022Q3	127
Switzerland	CH	Advanced	2000Q1	2022Q3	91
United Kingdom	UK	Advanced	1991Q1	2016Q3	103
United States	US	Advanced	1991Q1	2022Q2	126
Brazil	BR	Emerging	1996Q4	2022Q3	104
Chile	CL	Emerging	1996Q2	2022Q2	105
Colombia	CO	Emerging	2005Q2	2022Q2	69
Czech Rep.	CZ	Emerging	1996Q1	2022Q2	106
Hungary	HU	Emerging	1995Q2	2022Q2	109
India	IN	Emerging	1996Q3	2022Q2	104
Indonesia	ID	Emerging	2005Q3	2022Q3	69
Mexico	MX	Emerging	2002Q1	2022Q2	82
Russia	RU	Emerging	2003Q2	2021Q3	74
South Africa	ZA	Emerging	1998Q2	2022Q2	97

Data are sourced from International Financial Statistics (IFS), OECD National Accounts (OECD.Stat) and Federal Reserve Economic Data (FRED).

Table 2.2 & Table 2.3 represents the descriptive statistics and correlation coefficients respectively.

Table 2.2: Summary Statistics

Variables	Mean	Std. Dev.	Min	Max
$GDP^{g}_{i,t}$	0.71	1.86	-23.06	21.40
$\pi_{i,t}$	0.87	1.01	-4.00	9.84
$GOVEXP^{g}_{i,t}$	0.64	4.23	-44.72	48.30
$IR_{i,t}$	5.24	5.19	-0.75	46.00
$OIL^{g}_{i,t}$	1.50	14.96	-68.46	33.74

Note: The terms Mean, Std. Dev., Min and Max are representing arithmetic mean, standard deviation, minimum and maximum respectively.

Table 2.3: Unconditional Correlation Matrix

	$GDP^{g}_{i,t}$	$\pi_{i,t}$	$GOVEXP^{g}_{i,t}$	$IR_{i,t}$
$\pi_{i,t}$	0.09**			
$GOVEXP^{g}_{i,t}$	-0.01	-0.02		
$IR_{i,t}$	0.01	0.44**	0	
$OIL^{g}_{i,t}$	0.35**	0.16**	-0.01	-0.02

Note: * and ** denote statistical significance at the 5% and 1% levels respectively

Finally, in Table 2.4 the presence of unit roots in the data is tested by applying the panel unit root tests. Both first generation unit root tests which includes Maddala-Wu Unit-Root Test[4], Im-Pesaran-Shin Unit-Root Test[5], Choi's[6] modified P, Inverse Normal and Logit Unit-Root Test; as well as second generation unit root tests, i.e., Pesaran's CIPS test for unit roots[7] are being applied to the data.

[4] Maddala, G. S., & Wu, S. (1999)
[5] Im, K. S., Pesaran, M. H., & Shin, Y. (2003)
[6] Choi, I. (2001)
[7] Pesaran, M. H. (2007).

All the test results show that all the panel variables used in this study are stationary, i.e., integrated of order zero, $I(0)$. In order to identify the order of integration for $OIL^{g}_{i,t}$ we applied Augmented-Dickey-Fuller (ADF) test[8], Phillips and Perron (PP) test[9]. The result suggests existence of stationarity in the variable at 1% level of significance (Calculated Test Statistic: -6.78 & -7.79 respectively).

Table 2.4: Panel Unit Root Tests

Test	$GDP^{g}_{i,t}$	$\pi_{i,t}$	$GOVEXP^{g}_{i,t}$	$IR_{i,t}$
Maddala-Wu	503.20**	183.56**	531.17**	132.86**
Im-Pesaran-Shin	-25.32**	-16.85**	-24.75**	-5.52**
Choi's modified P	50.32**	15.45**	53.37**	9.91**
Choi's Inverse Normal	-19.56**	-8.77**	-18.39**	-6.87**
Choi's Logit	-30.55**	-10.87**	-32.24**	-7.66**
Pesaran's CIPS	-4.79**	-4.70**	-5.49**	-2.40**

Note: * and ** denote statistical significance at the 5% and 1% levels respectively

2.5 Estimation Methodology

Since the seminal contribution of Sims (1980) on vector autoregressive models (VAR) to study the dynamic relationships among key macroeconomic variables, VAR models are considered as a starting point to study dynamic relationships among variables that include more than one endogenous variable. These models are extensively studied in the field of econometrics. One of the primary problems for empirical studies to estimate VAR with time series data is that, data of sufficient length for reliable inferences are very limited in availability. Over the past decades, a long list of empirical studies which are intended to understand underlying dynamic behaviour among macroeconomic variables applied panel data modes with fixed effects. A PVAR

[8] Dickey, D. A., & Fuller, W. A. (1979) and Dickey, D. A., & Fuller, W. A. (1981)
[9] Phillips, P. C., & Perron, P. (1988)

model is a combination of a single equation dynamic panel model (DPM) and a VAR Model. Any dynamic panel data can be characterized by two important features: (1) individual panel member-specific heterogeneity and (2) element of the cross-sectional dependence. Therefore, individual panel members not only respond to their own member-specific idiosyncratic shocks, but they also respond to common shocks. The empirical methodology used in this study primarily focused on estimating idiosyncratic shocks.

This study is based on a reduced-form Panel Vector Auto-Regression (PVAR) approach, which can be used to analyse the transmission of idiosyncratic shocks across countries over time. The first PVAR model was introduced by Holtz-Eakin et al. (1988) which was an equation-by-equation estimation technique. Binder, Hsiao and Pesaran (2005) extended the method with a restriction of the possibility of a single lag for endogenous variables. One of the major criticisms of these methods is that latent heterogeneity in lagged dependent variables leads to inconsistent estimation. PVAR technique is still an evolving field in the econometrics literature with vast popularity among empirical researchers. Sigmund and Ferstl (2021) modified and extended the model with several lags for endogenous variables and included exogenous variables in the existing literature to implement the PVAR technique using Generalized Methods of Moments (GMM). The GMM estimation technique is being used to estimate the parameters of the Stationary PVAR model with fixed effects. Empirical applications mostly use a fixed-effects specification. The method allows classical structural analysis for PVAR models such as impulse response functions (orthogonal as well as generalized), bootstrapped confidence intervals for impulse response analysis, and forecast error variance decompositions.

The PVAR model can be represented as follows:

$$Y_{i,t} = \mu_i + \sum_{l=1}^{P} \boldsymbol{A}_l Y_{i,t-l} + \boldsymbol{B} X_{i,t} + \varepsilon_{i,t} \tag{2.7}$$

$Y_{i,t}$ represents the vector of endogenous variables, i.e., $Y_{i,t} = [GDP^g_{i,t}, \pi_{i,t}, GOVEXP^g_{i,t}, IR_{i,t}]$. $X_{i,t}$ represent the vector of exogenous variable, i.e., $OIL^g_{i,t}$. The method allows existence of a set of predetermined variables in the model that are potentially correlated with past errors. However, $OIL^g_{i,t}$ is included in the estimation of panel VAR as a strictly exogeneous variable, i.e., the current study assumed that, the variable is not correlated with current or past errors. The assumption is reasonable enough as fluctuations in it primarily driven by events like geopolitical disruptions, natural disasters, or OPEC production decisions, etc. and therefore not directly influenced by other individual country specific variables specified in the model. The Equation 2.7 is the reduced form version of the structural form system of equations illustrated in the Section 2.3.

It is assumed that, all the unit roots of the matrix $\boldsymbol{A}$ fall inside unit circle, which represents co-variance stationarity for endogenous variables. Since we are dealing with quarterly data, we assumed $P = 4$ (The order of autoregression), which was further verified using Andrews Lu MMSC Criteria[10]. A two-step procedure was adopted to estimate the PVAR model as suggested by Sigmund and Ferstl (2021).

In a PVAR model, in order to remove the fixed effects, two types of transformations can be performed: first-difference transformation and forward orthogonal transformation. In the case of a PVAR estimation with balanced panel data, both transformations lead to similar results. But, in the case of unbalanced panel data,

[10] Andrews, D. W., & Lu, B. (2001)

forward orthogonal transformation is considered to be the preferred transformation technique. In this study, forward orthogonal transformation is used in the estimation process.

The PVAR can potentially increase the efficiency of the result, as it avoids the bias that might be generated by the low degrees of freedom of country-level VAR models. In addition to that, an estimated PVAR model can be further utilized to generate impulse response functions and to understand variance decomposition as in the case of a time series VAR model. The impulse response function (IRF) is a tool used extensively in time series econometrics to study the effects of a shock or impulse. IRFs track the effects of a shock to one of the endogenous variables on all other endogenous variables in the system. It is a very common tool to explore the dynamic relationship among variables under vector autoregressive model. In this study, we are using the concept of generalized impulse response function (GIRF) as suggested by Pesaran and Shin (1998). On the other hand, forecast error variance decomposition (FEVD) is used to identify the proportion of variation in each of the endogenous variables that can be explained by exogeneous shock to other endogenous variables in the system. FEVD is a standard tool to understand the variability in the macroeconomic variables.

Finally, to evaluate the performance and generalizability of the model, cross-validation technique is used. Produce a more accurate estimate of a model's performance is the main objective of cross-validation. In this study we are using the Leave-One-Out Cross-Validation (LOOCV) technique. This approach is computationally expensive but can provide a more accurate estimate. For a dataset with N data points, LOOCV technique involves re-estimating the model N-times by leaving out a single data point each time and using the remaining $(N-1)$ data points. One of the advantages of LOOCV technique is that, it provides an unbiased estimate of the model's performance. We implemented the technique in this study in a different way. Number of countries in this study is considered as the number of data points (N). We re-estimated the PVAR model N-times for developed and emerging economies separately to check the variability in the shape of the IRFs. This study can provide some impression about the sensitivity of the results with respect to changes in the sample.

2.6 Empirical Findings

The estimated PVAR equations are reported in the Table 2.5. The estimated equations reveal a number of noteworthy observations. Firstly, advanced economies are following some form of interest rate smoothing monetary policy rule. However, no such pattern can be identified for EMEs. Secondly, exogeneous oil price movement significantly influence monetary policy rule for both emerging as well as advanced economies. However, the direction and magnitude of impact differs. Thirdly, fiscal policy found to have significant impact on real output growth rate of EMEs. No such impact can be identified for advanced economies. Fourthly, movement in the output growth rate is significantly associated with oil price movement for both types of economies. Fifthly, monetary policy found to have desired directional impact on inflation for both advanced and emerging market economies. Similarly, for both types of economies, oil price movement found to have expected directional impact on inflation. However, strength or magnitude of impact is more in case of EMEs for both monetary policy and oil price shocks. Finally, for advanced economies fiscal policy found to remain unaffected by movement in any of the variables in the system. However, monetary policy does have significant impact on fiscal policy in case of emerging market economies.

Table 2.5: Estimated Dynamic Panel VAR Equations

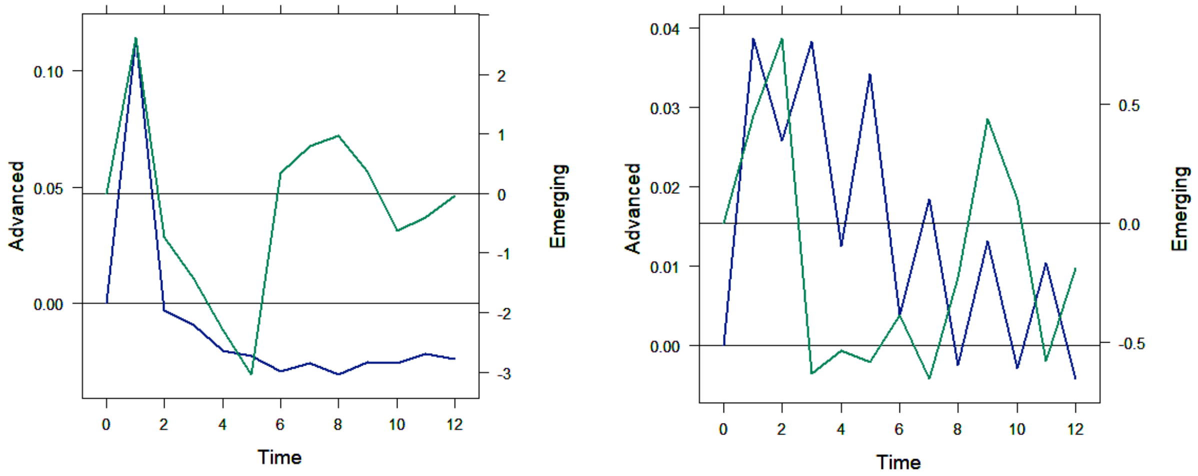
Coefficients		Dynamic Panel VAR Estimated Equations							
		$IR_{i,t}$		$GDP^g_{i,t}$		$\pi_{i,t}$		$GOVEXP^g_{i,t}$	
Variables	Lag	Advanced	Emerging	Advanced	Emerging	Advanced	Emerging	Advanced	Emerging
Constant		0.0058	-0.0033	0.0433	-0.0032	0.0113	-0.0021	0.0261	0.0012
$IR_{i,t}$	1	0.2198**	-0.081	0.0252	0.0457	-0.0171	-0.0557*	-0.0085	0.032
	2	0.2195**	-0.1534	0.0093	-0.0251	-0.0208	-0.1402*	0.0011	0.0714*
	3	0.2194**	-0.2112	0.0059	-0.0686	-0.0227*	-0.2044*	0.0013	0.0939
	4	0.2199**	-0.2549	-0.0091	-0.0847	-0.0199	-0.2464*	-0.0092	0.1241
$GDP^g_{i,t}$	1	0.0526	0.0191	-0.1092	0.0445	-0.0552	0.0609	-0.078	0.0336
	2	0.0327	0.0234	0.278	-0.006	0.0885	0.0367	0.0504	0.1126
	3	0.0477*	0.0464	-0.1162	0.018	-0.0306	0.0537	0.0343	-0.2074
	4	0.0322	0.0235	0.2866	0.1703*	0.0409	0.0054	0.0021	0.0241
$\pi_{i,t}$	1	0.0468	0.044	0.0645	0.0908	0.0952	0.0793	-0.1494	-0.0575
	2	0.0298	0.0339	0.1119	0.0415	0.0635	0.0524	-0.0984	-0.0737
	3	0.0324	0.0307	0.0299	0.0351	0.0577	0.0507	-0.0947	0.003
	4	0.0235	0.0167	0.0968	0.0328	0.0381	0.0375	-0.0866	0.0298
$GOVEXP^g_{i,t}$	1	0.0326	0.0806	0.0286	0.0747	0.0312	0.1583	-0.0518	-0.0183
	2	-0.0051	-0.0862	0.0908	0.2507	0.0438	-0.1622	-0.0242	-0.5341
	3	0.0345	-0.0086	0.0346	-0.2557	0.0462	-0.0238*	-0.049	-0.1066
	4	0.0252	0.0205	0.1115	-0.2179	0.0661	0.0222	-0.0271	0.464
$OIL^g_{i,t}$		0.0089**	-0.3209**	0.0317**	0.1265**	0.0158**	0.4022**	-0.0011	-0.0278

Note: * and ** denote statistical significance at the 5% and 1% levels respectively

The effects of a monetary policy shock, i.e., a positive shock to the nominal central bank rate (a one-standard-deviation positive interest rate shock, i.e., a monetary contraction) on key macroeconomic variables is given in Figure 2.1 using the concept of IRF. For the convenience of representation, dual-axis time plot has been used in this study.

Figure 2.1: Impulse-response functions to the Monetary Policy Shock

(A) Inflation	(B) Real GDP growth rate

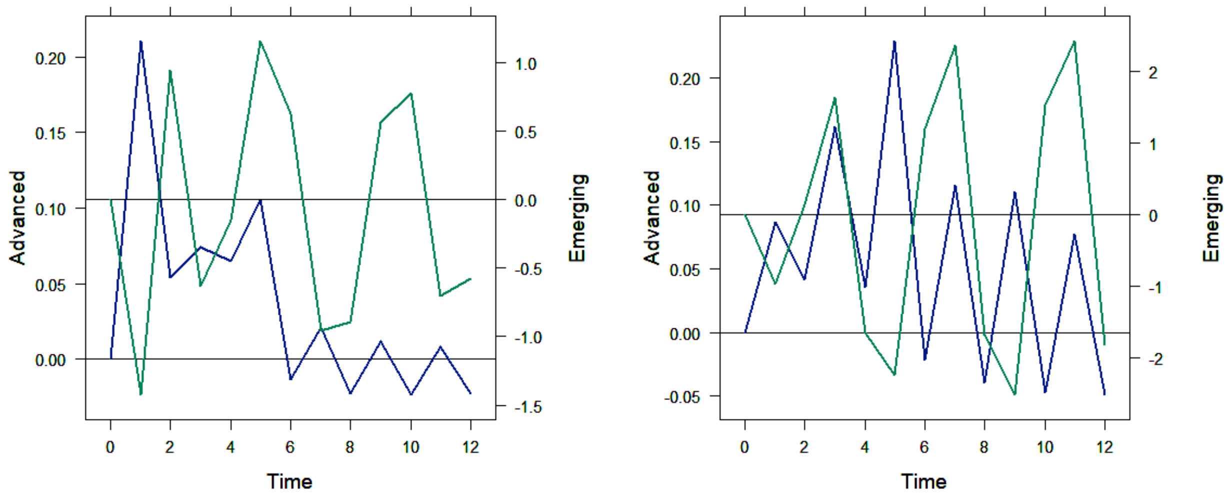


Note: Both the figures give the impulse responses (over 12 quarters) to a one-standard-deviation positive interest rate shock (i.e., a monetary contraction). The blue and green line corresponds to the response of concerned variables for Advanced and Emerging economies respectively.

As the Figure 2.1 shows the impact of monetary policy shocks on Inflation (Panel A) and Real GDP growth rate (Panel B) for EMEs differs substantially from that of Advanced Economies. The magnitude of impact is always greater in emerging economies relative to that of advanced ones. As far as inflation is concerned, monetary policy shocks clearly stabilize it and the impact persists for advanced economies. On the other hand, contractionary monetary policy doesn't have a persistent impact on inflation dynamics for emerging market economies. As the diagram (Panel A) shows, the IRF corresponding to EMEs shows an oscillatory behaviour with no sign of persistence. The impact of monetary policy on the Real GDP growth rate for EMEs shows sign of persistence with oscillatory tendency. However, the diagram shows sign of a short-term contraction in the Real GDP growth rate for the EMEs. On the other hand, contractionary monetary policy remains ineffective in stabilizing real GDP growth rate for advanced economies. Relatively higher magnitude of impact of monetary policy on inflation and output gap can be explained by degree of development in the financial system. Studies such as Ma and Lin (2016) identified that, effectiveness of monetary policy declines as the financial system becomes more developed. However, for persistence of impact of monetary policy credibility of central bank play a key role. The credibility of central bank can be considered as a key determinant of difference in persistence of impact of monetary policy between the two types of economies.

Figure 2.2: Impulse-response functions to the fiscal policy Shock

(A) Inflation	(B) Real GDP growth rate

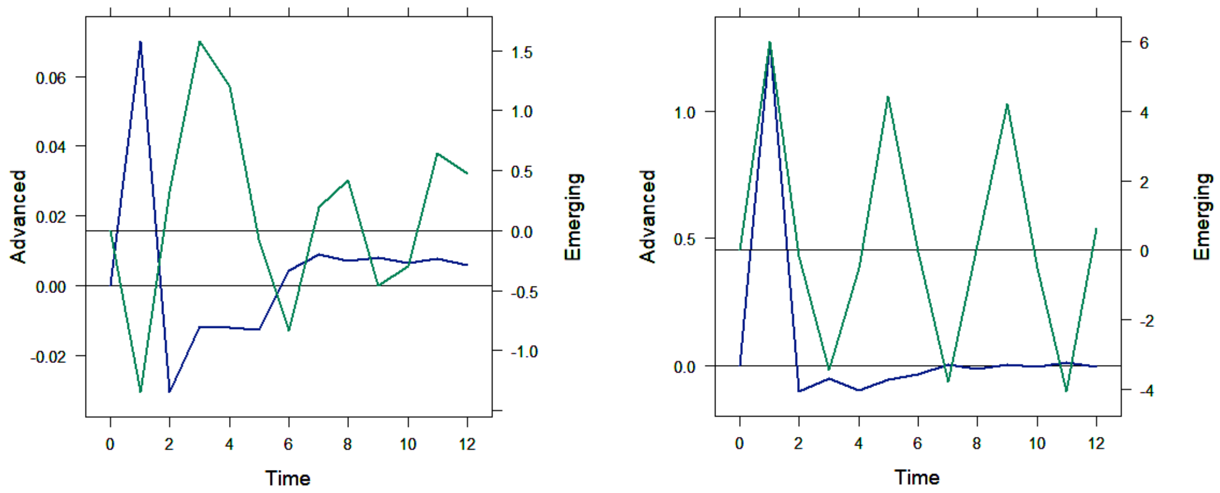


Note: Both the figures give the impulse responses (over 12 quarters) to a one-standard-deviation positive government spending shock (i.e., an expansionary fiscal policy shock). The blue and green line corresponds to the response of the concerned variables for Advanced and Emerging economies respectively.

Figure 2.2 depicts the impact of fiscal policy impulse on Inflation (Panel A) and real GDP growth rate (Panel B). Similar to monetary policy impulse, effect of expansionary fiscal policy impulse in advanced economies differs substantially from that of emerging market economies. As expected, the magnitude of impact is greater in the EMEs relative to advanced economies. The IRFs corresponding to fiscal policy impulse on both inflation and real GDP growth rate show an oscillating behaviour with no sign of decay. On the other hand, impact of fiscal policy impulse on Inflation for advanced economies shows expected shape of IRF; i.e., initially expansionary fiscal policy causes inflation to rise for approximately 5 quarters and eventually the impact gradually disappears. Therefore, for advanced economies impact of fiscal policy impulse on inflation doesn't persist. Similarly, impact of fiscal policy impulse on real GDP growth rate for advanced economies shows no sign of persistence with initial acceleration in economic activity.

Figure 2.3: Impulse-response functions showing policy interactions

(A) Monetary Policy Shock to Fiscal Policy	(B) Fiscal Policy Shock to Monetary Policy



Note: Both the figures give the impulse responses (over 12 quarters) to a one-standard-deviation positive Monetary Policy shock on government spending (Panel A) and to a one-standard-deviation positive fiscal policy shock on Monetary Policy linked rate of interest (Panel B) respectively. The blue and green line corresponds to the response of the concerned variables for Advanced and Emerging economies respectively.

Finally, Figure 2.3 shows interaction between fiscal and monetary policy shocks. Similar to all the other estimated IRFs, it also shows magnitude of impact is greater in the EMEs relative to advanced economies. In addition to that, the diagram shows, IRFs corresponding to the EMEs oscillate. As result it is difficult to unambiguously state the direction of policy interactions for emerging market economies. The IRFs corresponding to advanced economies show no sign of persistence. Although, contractionary monetary policy shock has its desired negative impact on government spending.

As mentioned earlier, the FEVD is used to investigate the fraction of the fluctuations in the endogenous variables that is due to fiscal and monetary policy. The FEVD results corresponding to monetary and fiscal policy are summarised in Table 2.6 and 2.7 respectively. Table 2.6 shows that, unexplained variation in the policy rate explained a sizable amount of variation in the output growth rate (8.7%) and inflation (2.3%) in advanced economies. Similar cannot be said in case of emerging market economies. However, as far as fiscal policy is concerned, as shown in Table 2.7, it is responsible for relatively greater proportion of variation in output growth in case of emerging economies (7.8%) than advanced ones (2.7%). The opposite is true for inflation (9.7% and 1.1% for advanced and emerging economies respectively).

Table 2.6: Forecast-error variance decomposition due to the interest rate shock

	Advanced				Emerging			
Quarter	$IR_{i,t}$	$GDP^{g}_{i,t}$	$\pi_{i,t}$	$GOVEXP^{g}_{i,t}$	$IR_{i,t}$	$GDP^{g}_{i,t}$	$\pi_{i,t}$	$GOVEXP^{g}_{i,t}$
1	1.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
2	0.985	0.009	0.003	0.002	0.998	0.000	0.001	0.001
3	0.982	0.012	0.004	0.002	0.996	0.001	0.001	0.002
4	0.956	0.030	0.008	0.006	0.995	0.001	0.001	0.003
5	0.945	0.034	0.012	0.009	0.995	0.001	0.001	0.003
6	0.928	0.046	0.014	0.012	0.994	0.001	0.001	0.004
7	0.919	0.051	0.016	0.013	0.993	0.001	0.001	0.005
8	0.902	0.063	0.019	0.016	0.992	0.001	0.001	0.006
9	0.894	0.068	0.020	0.018	0.991	0.001	0.001	0.006
10	0.883	0.077	0.021	0.019	0.990	0.001	0.001	0.007
11	0.876	0.080	0.022	0.021	0.989	0.001	0.001	0.008
12	0.867	0.087	0.023	0.022	0.989	0.002	0.001	0.008

Note: Percentage of the variation in the column variable that is explained by the policy rate.

Table 2.7: Forecast-error variance decomposition due to a fiscal policy shock

	Advanced				Emerging			
Quarter	$IR_{i,t}$	$GDP^{g}_{i,t}$	$\pi_{i,t}$	$GOVEXP^{g}_{i,t}$	$IR_{i,t}$	$GDP^{g}_{i,t}$	$\pi_{i,t}$	$GOVEXP^{g}_{i,t}$
1	0.003	0.003	0.075	0.919	0.050	0.050	0.001	0.899
2	0.004	0.012	0.084	0.901	0.053	0.049	0.006	0.892
3	0.004	0.018	0.088	0.890	0.089	0.055	0.008	0.848
4	0.004	0.018	0.093	0.885	0.113	0.061	0.010	0.815
5	0.004	0.020	0.096	0.881	0.081	0.059	0.009	0.852
6	0.004	0.022	0.096	0.878	0.089	0.061	0.010	0.840
7	0.004	0.023	0.096	0.877	0.074	0.066	0.009	0.851
8	0.004	0.024	0.096	0.876	0.076	0.071	0.010	0.842
9	0.004	0.025	0.096	0.876	0.065	0.070	0.010	0.856
10	0.004	0.025	0.096	0.875	0.065	0.074	0.011	0.851
11	0.004	0.026	0.096	0.874	0.059	0.073	0.010	0.857
12	0.004	0.027	0.096	0.874	0.061	0.078	0.011	0.850

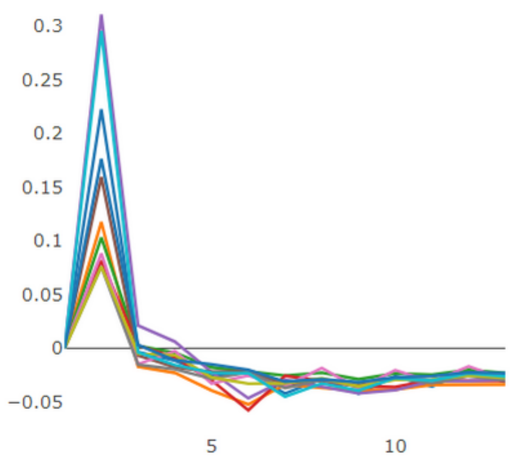
Note: Percentage of the variation in the row variable that is explained by the fiscal policy shock.

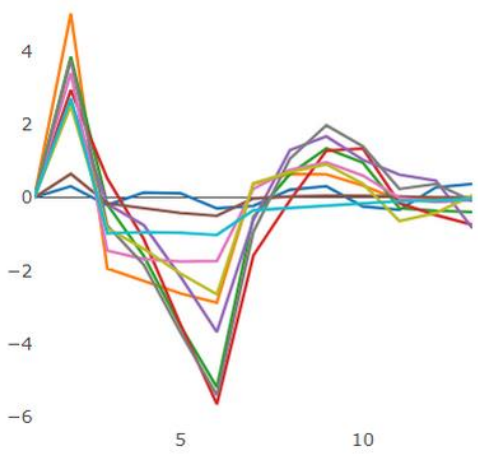
As the Figure 2.5 suggests, the average behaviour of IRFs under LOOCV technique shows the similar pattern as the model with complete datasets. e.g., IRFs corresponding to emerging market economies show oscillatory behaviour. Similarly, impact of monetary policy impulse on inflation for advanced economies persists.

Figure 2.5: LOOCV IRFs

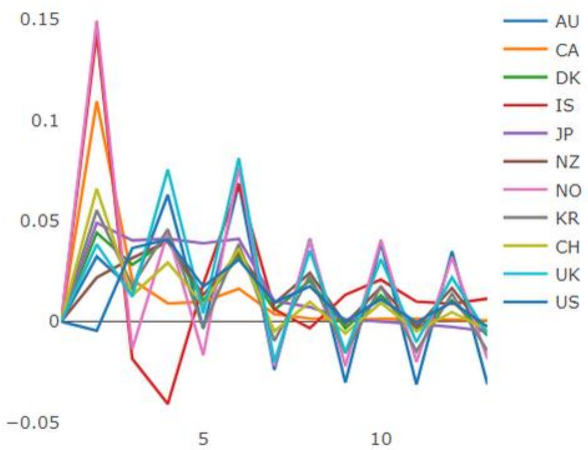
Advanced Economies	Emerging Economies

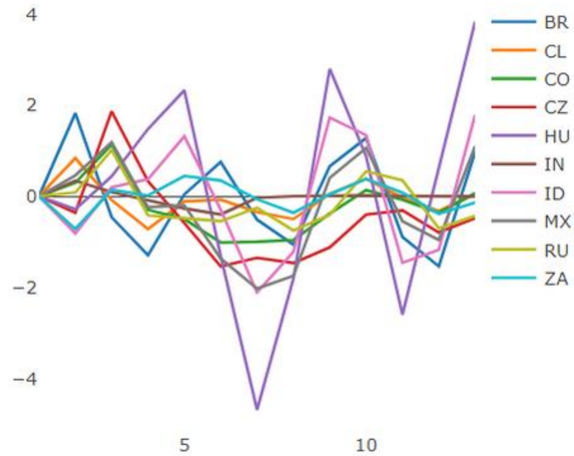
Monetary Policy Shock to Inflation



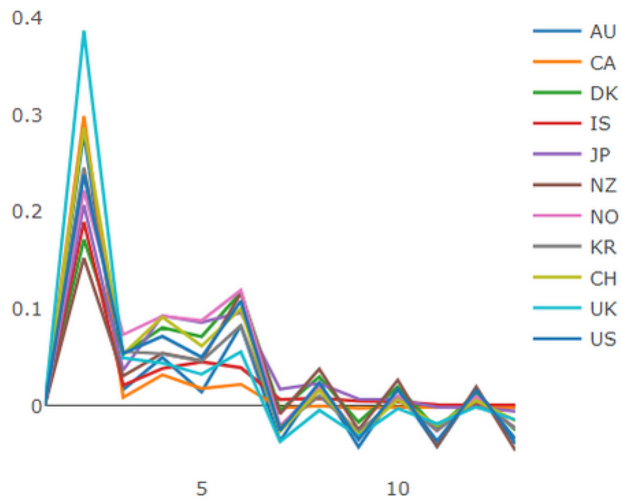


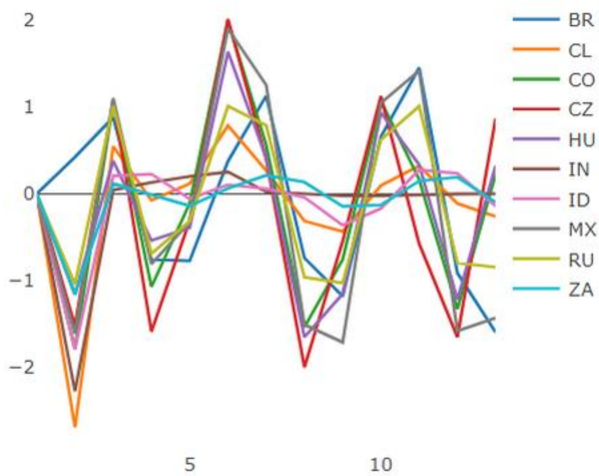
Monetary Policy Shock to Output





Fiscal Policy Shock to Inflation

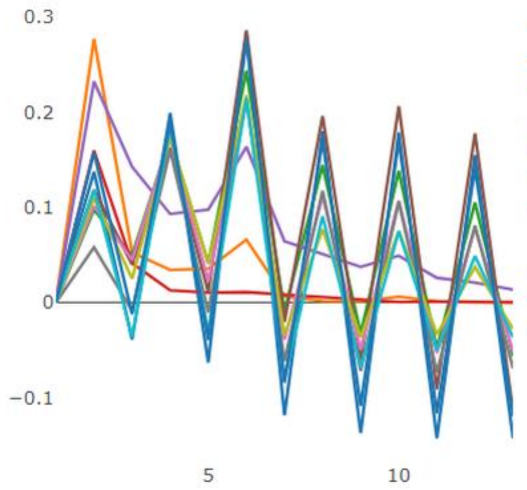


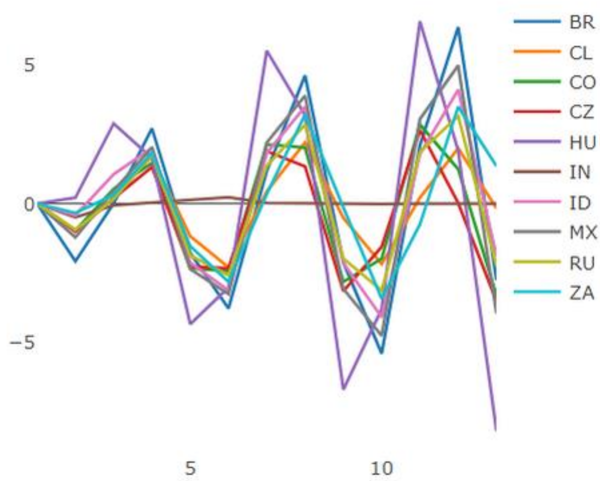


Note: IRF corresponding to a country represent IRF corresponding to a PVAR model that exclude that particular country (LOOCV technique).

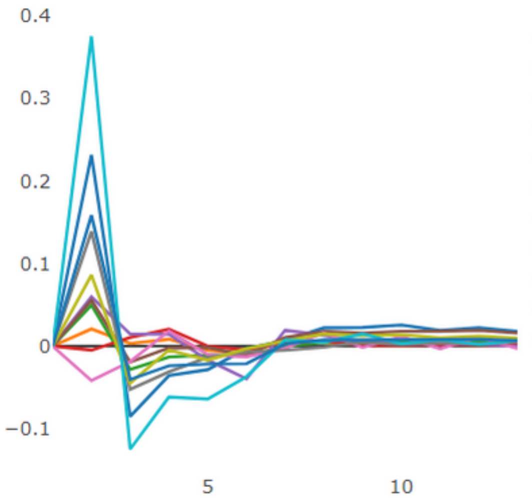
Advanced Economies	Emerging Economies

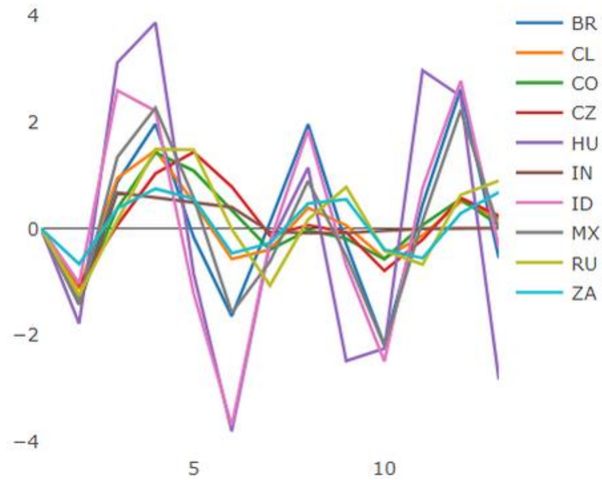
Fiscal Policy Shock to Output



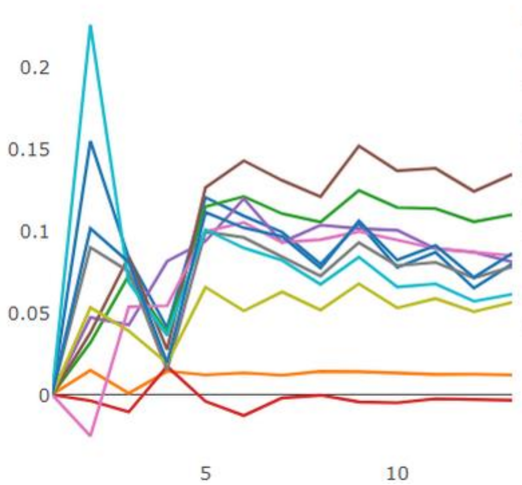


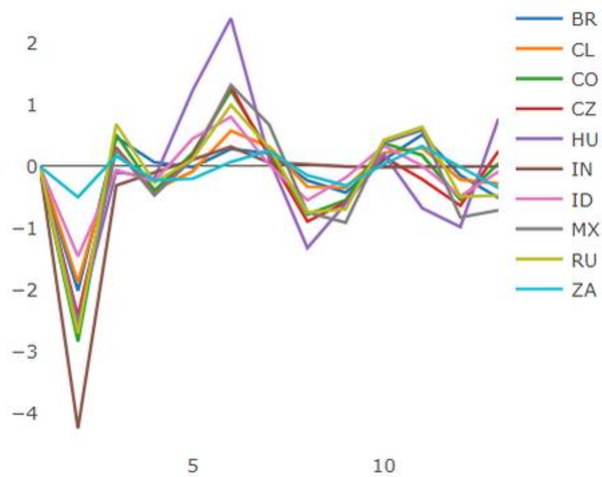
Monetary Policy Shock to Fiscal Policy





Fiscal Policy Shock to Monetary Policy





Note: IRF corresponding to a country represent IRF corresponding to a PVAR model that exclude that particular country (LOOCV technique).

2.7 Conclusion

The primary objective of this study is to investigate the macroeconomic impact of monetary policy for a set of advanced economies and EMEs. This study explores an unbalanced panel of ten EMEs and eleven advanced economies using a PVAR model. The impulse-response functions and the variance decomposition technique are being used to address the areas of investigation of the study. In order to evaluate the impact of monetary policy accurately, this study incorporates two more macroeconomic variables in the empirical model, i.e., oil price and fiscal policy shocks. The oil price is part of this analysis to introduce a proxy for exogenous supply-side shocks and the presence of fiscal policy shock in the model helps us to compare the impact of fiscal policy and monetary policy shocks side-by-side. In addition to that, it helped us to evaluate the possible policy interactions.

The estimated PVAR model includes seasonally adjusted real GDP growth rate, rate of inflation, government spending growth rate, monetary policy related interest rate as endogenous variables and growth rate of crude oil price as an exogenous variable. Panel unit root tests are being applied to the concerned panel variables to identify their order of integration. All the test results reveal that all the panel variables are stationary, i.e., integrated of order zero, *I(0)*. In addition to that, the only time series variable in the model, i.e., growth rate of crude oil price, also found to be stationary, i.e., integrated of order zero.

The estimated PVAR equations reveal a number of noteworthy observations. Firstly, advanced economies are following some form of interest rate smoothing monetary policy rule. However, no such pattern can be identified for EMEs. Secondly, exogeneous oil price movement significantly influence monetary policy rule for both emerging as well as advanced economies. However, the direction and magnitude of impact differs. Thirdly, fiscal policy found to have significant impact on real output growth rate of EMEs. No such impact can be identified for advanced economies. Fourthly, movement in the output growth rate is significantly associated with oil price movement for both types of economies. Fifthly, monetary policy found to have desired directional impact on inflation for both advanced and emerging market economies. Similarly, for both types of economies, oil price movement found to have expected directional impact on inflation. However, strength or magnitude of impact is more in case of EMEs for both monetary policy and oil price shocks. Finally, for advanced economies fiscal policy found to remain unaffected by movement in any of the variables in the system. However, monetary policy does have significant impact on fiscal policy in case of emerging market economies.

The analysis of all the IRFs in this study suggest that, the magnitude of impact of both monetary and fiscal policy on all the concerned variables are always greater in emerging economies relative to that of advanced ones. In addition to that, IRFs of the EMEs show oscillatory behaviour. Finally, except impact of monetary policy impulse on inflation for advanced economies, none of the policy impulse on any other variable for any categories of country set (i.e., advanced and the EMEs) shows signs of persistence. All the results on IRF analysis are cross validated by the LOOCV technique. The LOOCV technique suggests a similar pattern in the IRFs, i.e., supports the results generated from estimated models on complete datasets.

Finally, the FEVD is used to investigate the fraction of the fluctuations in the endogenous variables that is due to fiscal and monetary policy. The result suggests, unexplained variation in the policy rate explained a sizable amount of variation in the output growth rate and inflation in advanced economies. Similar cannot be said in case of emerging market economies. However, as far as fiscal policy is concerned, it is responsible for relatively greater proportion of variation in output growth in case of emerging economies than advanced ones. The opposite is true for inflation.

Chapter 3

Asymmetry in the Conduct of the Monetary Policy in India

3.1 Introduction

Identifying monetary authorities' reactions to changes in fundamental macroeconomic variables has long been a focus of monetary economists. Most of the current material in this area is based on Taylor's (1993) monetary policy rule. Taylor presented a basic monetary policy rule in which the monetary authority changes the policy rate (e.g., repo rate in India) in response to observable variations in inflation rate and unemployment rate or equivalently output gap in the economy. Taylor proposed that variation in inflation and the output gap induce the monetary authority to change the policy rate. Taylor, however, made it clear that, the rule he proposed, was not meant to be a precise formula.

The debate over asymmetric monetary policy framework was introduced, and approximated Taylor rules have gained popularity as a way to describe the behaviour of the monetary authority. The concerned literature can be summarised by two questions. Firstly, have the central bank's actions been symmetric during high inflation and/or low-income vis-a-vis low inflation and/or high-income regimes? Secondly, should the central bank react asymmetrically? This chapter is primarily dedicated to exploring the policy response of the central bank of India, i.e., RBI. The next chapter, i.e., Chapter 4 is dedicated to analysing the desirability aspects for the asymmetric monetary policy response function in Indian context.

Given the policy response function, as depicted by Taylor, the central banks are expected to behave symmetrically in response to changes in major macroeconomic indicators. That is, the strength of the monetary policy response is independent of whether important macroeconomic indicators deviate from some threshold level in a positive or negative direction. However, under some specific circumstances, the rationale for asymmetric monetary policy might be considered as valid and desirable. For example, following the implementation of the inflation targeting regime, central banks may legitimately fear difficulties in securing inflation expectations (i.e., risk of credibility loss), which may lead them to employ asymmetric handling of inflation targets. Such asymmetry would imply that, central banks would react more sensitively when inflation forecasts were above the target level than in a scenario where inflation forecasts were below the target level. Another possible explanation could be, central banks may have greater aversion toward recessions than to expansions. This asymmetric behaviour of the central banks is termed as ‘opportunistic’ behaviour in the literature. Opportunism essentially suggests that the Taylor rule should be nonlinear, with harsh anti-inflationary measures only being implemented when inflation is high compared to a certain threshold level. Such an asymmetric tendency in the behaviour of central banks leads to nonlinear pattern in the Taylor rule equation. Nonlinearity in the Taylor rule in practice segregates monetary policy into high-response and low-response regimes.

The presence of asymmetry in the response function is not only specific to monetary policy response of the central banks. Academic studies revealed existence of asymmetry in the response functions in other areas. For example, Soroka (2006) found strong evidence of asymmetric responses of public to information in mass media. i.e., individuals’ responses to positive and negative information are asymmetric. More specifically, negative information has a greater impact on individuals' attitudes than positive information.

This chapter is focused on detecting the existence of asymmetric behaviour over the choice of policy rate of the RBI. Over the past two decades, there have been major changes in the objective, methodology, and instruments of RBI's monetary policy. In this context, the RBI is currently following a flexible inflation targeting regime by maintaining a headline CPI inflation target of 4% with an upper and lower tolerance bound of 6% and 2% respectively[11].

Unprecedented capital inflows created new problems for monetary management, which led to a modification in how monetary policy was conducted. In this context, the development of a full-fledged Liquidity Adjustment Facility (LAF) from June 2000 facilitated the modulation of liquidity conditions on a daily basis. In this mechanism, while liquidity was absorbed at the reverse repo rate (floor), liquidity injection was done at the repo rate (ceiling) by the RBI. There are other policy rates and ratios of which repo rate has become the most important since 2001. The earlier monetary policy rate was bank rate, which still exists. Nowadays, the repo and reverse repo rates are the key policy rates of RBI, which are closely interconnected to each other. In order to affect the general monetary and credit conditions in the economy, the RBI modifies policy rate. As a result, RBI significantly rationalized its refinancing facilities and decreased its reliance on Cash Reserve Ratio (CRR) for operations involving liquidity management. However, the Bank Rate is still used to indicate the direction of policy over the medium term.

The primary focus of this chapter is to empirically explore the policy response function of the RBI with respect to macroeconomic fluctuations. In this process, this study puts light on the existence and possible nonlinearity in the RBI’s Taylor rule

[11] Art of Monetary Policy Making: The Indian Context - Shaktikanta Das (RBI Bulletin September 2023)

equation. The availability of empirical literature on opportunistic or asymmetric monetary policy in the context of Indian economy is noticeably scarce. This study is intended to address this particular gap in the literature. The results of this study can give us some idea about the responsiveness of RBI's monetary policy rules toward changes in the macroeconomic environment of the economy. In addition to that, the study is intended to explore the existence of consistency or stability in the RBI's monetary policy rule.

The rest of the chapter is organized as follows: Section 3.2 explores the literature with respect to the objective of this study from the relevant sources. The Section 3.3 specified the empirical methodology used in this study. Section 3.4 specifies the set of variables that are used in the study, elaborates the sources of data and performs a number of preliminary exploratory data analysis. The Section 3.5 shows and summarizes the list of results found in this study. Finally, Section 3.6 concludes this chapter.

3.2 Review of Literature

Till date only a handful of empirical investigations have attempted to estimate asymmetric reaction functions of central banks, specifically for emerging market economies like India. As specified in Section 3.1, the monetary policy rule, as specified by Taylor, was not intended to be an exact linear function. It has been suggested in a number of academic works that a nonlinear rule (either in inflation or the output gap) may be able to describe the reaction function of central banks better than the linear specification. For example, Dolado, Maria-Dolores and Naveira (2005) search for asymmetries in the policy responses of central banks of five advanced economies (i.e., Germany, France, Spain, US and Euro area), for the period 1980 to 2001, with respect to inflation and output gaps by estimating Euler equation which allows for the interaction between expected inflation and the output gap. In addition to that, the study applies an ordered probit model in order to detect the discrete nature in the variability of the policy rate. The study finds contrasting results. i.e., while European central banks after the 1980s found to have nonlinearity in the policy rules; however, in case of the Fed a linear preference cannot be rejected. The study points out at labour market rigidities to explain such variation in the result.

Lo and Piger's (2005) identify the existence of variation in the responsiveness of monetary policy regimes correspond to whether or not the economy is in a recessionary period using Markov Regime Switching Model. The study covers the US economy for the period from 1960Q3 to 2002Q4. The Monetary impulses are found to be much more responsive during recessionary periods than otherwise.

Leu and Sheen (2006) find evidence for asymmetric behaviour (to inflation and the output gap in downturns and upturns) in Australian monetary policy during the period from 1984 to 1990. While, during 1991 to 2002, actions of Australian monetary authority become much more predictable, asymmetric only with respect to output and act more intensely in downturns.

Empirical study conducted by Surico (2007) analyses the U.S. quarterly data spanning the period 1960Q1 to 2003Q2. The estimated results show that, U.S. monetary policy can be effectively characterized by a nonlinear policy rule during the pre-Volcker[12] (before 1970s) regime only, where the source of nonlinearity generated from output gap. In particular, the Fed attaches a greater weight to contractions of output than to expansions of output.

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[12] Paul Adolph Volcker Jr. was the 12th chairman of the Federal Reserve from 1979 to 1987. Volcker was widely credited for removing the high levels of inflation seen in the United States throughout the 1970s and early 1980s, with measures known as the Volcker shock.

Cukierman and Muscatelli (2008) theoretically and empirically explore preferences of monetary authorities using a standard New-Keynesian framework for the UK and the US over various sub-periods by means of hyperbolic tangent smooth transition regressions. The study finds evidences of non-linear rules. The shape of the preference of central bank found to be related to whether inflation targeting policy is in place or not. In addition to that, political events also found to have profound impact on the preference of central banks. This study clearly segmented the preference of central banks between recession avoidance preferences and inflation avoidance preferences.

Bunzel and Enders (2010) investigate the possibility of threshold nature of the monetary policy rule; i.e., the central bank acts sensitively in some circumstances than in others (e.g., high inflation scenario or positive output gap) using Threshold Autoregressive Model for the US economy for the period 1965Q3 to 2007Q3. The empirical result supports the view that the Taylor rule is a threshold process that is consistent with the hypothesis of opportunistic monetary policy.

Srinivasan, Ramachandran and Kumar (2010) empirically evaluate this hypothesis of asymmetric monetary policy rule using U.S. data for the period 1987Q3 to 2005Q3. The study supported the presence of asymmetry in monetary policy rule by empirically showing that, the Fed gives greater importance to inflation stabilization during periods of high inflation, but prioritise output stabilization during periods with lower inflation via favourable supply shocks.

Vašíček (2012) examines the degree of symmetry in monetary policy rule in three European Union members (i.e., the Czech Republic, Hungary, and Poland) with inflation targeting regime for the period ranging between January 1998 to March 2010. The study uses Generalized Method of Moments estimation to identify potential sources of asymmetry. The study finds marginal evidence in favour of asymmetric monetary policy rule.

Tawadros (2016) examines the hypothesis that the Reserve Bank of Australia (RBA) follows an asymmetric monetary policy rule for different sub-periods ranging between 1984Q1 to 2014Q2. The empirical result shows, while the RBA follows a symmetric monetary policy rule for the periods without inflation targeting, it adapts to asymmetric monetary policy rule for the periods with inflation targeting. In addition to that, the study suggests that, this asymmetric reaction was generated from asymmetric preferences of monetary authority.

The survey of literature clearly depicts the fact that, there is a scarce of studies on the concerned area of research on developing or emerging market economies like India. The present study attempts to bridge that gap. The study primarily explores the policy responses of the RBI with respect to changing macroeconomic environment. In addition to that, it should be mentioned that, most of the studies mentioned above reveals evidences in favour of asymmetric response of central banks in advanced economies. It would be interesting to explore how central bank from an emerging market respond with respect to macroeconomic circumstances.

3.3 Methodology

The Taylor Rule as described in Section 3.1, represents the relationship between policy response of central bank and available information about key macroeconomic variables, that can be summarised mathematically using the following linear stochastic equation:

$$i_t = \gamma_0 + \pi_t + \alpha_1(\pi_t - \pi^*) + \beta y_t + \gamma_1 i_{t-1} + \gamma_2 i_{t-2} + \varepsilon_t \qquad (3.1)$$

Where, i_t is monetary policy linked nominal rate of interest (i.e., policy rate), π_t is rate of inflation, π^* is the targeted rate of inflation, y_t is the output gap measured as percentage deviation of real GDP from its trend values, and $\gamma_0, \gamma_1, \gamma_2, \beta, \alpha_1$ are parameters of the model. The lagged values of the interest rate in the Taylor rule equation show the central bank's intention to smooth out fluctuations in interest rates over time and give the system some inertia. In addition to that, in econometric methodology, lag values of the dependent variables are incorporated in the regression model to eliminate the presence of any serial correlation.

For the purpose of estimation, the Taylor rule equation can be further reduced to the following equation:

$$i_t = \alpha_0 + \alpha\pi_t + \beta y_t + \gamma_1 i_{t-1} + \gamma_2 i_{t-2} + \varepsilon_t \qquad (3.2)$$

Where, $\alpha_0 = (\gamma_0 - \alpha_1\pi^*)$ and $\alpha = (1 + \alpha_1)$. As specified earlier, $(\gamma_1 + \gamma_2)$ represents the degree of interest rate smoothing.

Svensson (2003) argues that, it is impossible to represent the monetary rule using a simple linear equation as represented by equation (3.1), especially under inflation targeting. This study is intended to bridge the gap between representing monetary policy rule by a simple equation such as equation (3.1) and the actual policy rule practiced by inflation targeting central banks. Presence of nonlinearities in the preference of monetary authority implies that, some form of threshold model is reasonable. Therefore, it seems reasonable to consider the possibility of a threshold model to represent the sensitivity of responsiveness of the RBI with respect to changes in macroeconomic environment. The most obvious choice for the threshold variable is the inflation rate, since it is believed that the monetary authority will behave aggressively when inflation is high. We also looked at the notion that, the output gap is the threshold variable, since it is equally feasible that the RBI responds aggressively to a negative output gap. A standard threshold autoregressive (TAR) model with respect to current problem can be represented as follows:

$$i_t = (1 - I_t)(\beta_0 + \beta_1\pi_t + \beta_2 y_t + \beta_3 i_{t-1} + \beta_4 i_{t-2}) + I_t\left(\alpha_0 + \alpha_1\pi_t + \alpha_2 y_t + \alpha_3 i_{t,1} + \alpha_4 i_{t-2}\right) + \varepsilon_t \quad (3.3)$$

Where, $I_t = 1$ if $x_{t-d} > \tau$ and 0 otherwise, and x_{t-d} is the magnitude of the threshold variable with delay of periods d. In this study, we assume $d = 1$. The essential feature of the equation is that, there are two linear segments for the Taylor rule. If $\beta_i = \alpha_i$ for all i, the model is linear. That hypothesis can be tested by using standard F-test. Therefore, as specified in equation (3.3), a nonlinear monetary policy rule allows central banks to have asymmetric preference over the choice of interest rate smoothing parameters. That is, during favourable scenarios the smoothing parameters are taking reasonably higher values than during difficult macroeconomic scenarios. However, for the purpose of convenience of estimation, we are using the following representation of the equation (3.3):

$$i_t = (\beta_0 + \beta_1\pi_t + \beta_2 y_t + \beta_3 i_{t-1} + \beta_4 i_{t-2}) + I_t\left(\alpha_0 + \alpha_1\pi_t + \alpha_2 y_t + \alpha_3 i_{t,1} + \alpha_4 i_{t-2}\right) + \varepsilon_t \quad (3.4)$$

In equation (3.4), statistical significance of the parameter α can establish the presence of asymmetric pattern in the behaviour of the RBI with respect to macroeconomic environment.

The value of the threshold parameter (τ) is unknown and must be estimated along with the other parameters of the model. The estimated value of τ can be obtained using a grid search over all potential values of the threshold variable. In order to ensure the existence of adequate number of observations on each side of the threshold, it is necessary to eliminate certain fraction of observations (i.e., 15%) from both side of the ordered values of the threshold variable. The literature on TAR model suggested that, the value of τ that corresponds to the smallest residual sum of square corresponding to the estimated model can be considered to be the estimate of the threshold level. Following this logic, some form of information criterion can be used to identify the value of τ. In this study we choose τ such that the Akaike Information Criterion[13] (AIC) corresponding to the estimated model is minimum.

3.4 Data and Exploratory Analysis

Data are sourced from OECD National Accounts (OECD.Stat) and Database on Indian Economy, RBI's Data Warehouse. Our data set consists of quarterly values of seasonally adjusted GDP Deflator (P_t), seasonally adjusted real GDP and repo rate over the period from 2001Q2 to 2023Q1. The four-quarter inflation rate (π_t) is constructed using the following equation:

$$\pi_t = 100 \times ln\left(\frac{P_t}{P_{t-4}}\right) \tag{3.6}$$

The choice of GDP deflator to calculate the rate of inflation is primarily driven by the fact that, Bunzel and Enders (2010) in a similar study to identify the structure of policy response of the Federal Reserve used the same path. In addition to that, in the context of India, the alternative to GDP deflator, i.e., Consumer Price Index (CPI), is highly correlated with it. Above all, the estimated results show, estimated Taylor rule equation

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[13] Generic function calculating AIC for one or several fitted models can be estimated using the following formula:

$$AIC = -2ln(L) + \theta k \tag{3.5}$$

where, L is log-likelihood estimate of the model, k represents the number of parameters that are estimated (including the error variance); and $\theta = 2$ for usual AIC and $\theta = ln(n)$ for Schwarz's Bayesian criterion (i.e., BIC or SBC). In this study, we are using usual definition of AIC, i.e., $\theta = 2$. Given the formula, lower value of AIC representing a relatively superior fit for the dependent variable, however, it's not a fit measure as such.

fits better with GDP deflator than with CPI inflation[14]. i.e., regression equation with GDP deflator inflation as explanatory variable better explains the variation in the policy rate than CPI inflation.

Repo rate (i_t) is used in this study to represent the policy rate of the RBI. Other such rates, such as, reverse repo rate, bank rate etc., are linked with repo rate. As a result, it is reasonable to use repo rate as a representative indicator of monetary policy impulse of the RBI. In an exploratory study on different policy instruments of the RBI, i.e., policy rates, which includes repo rate, reverse repo rate and bank rate; and policy ratios, which includes Cash Reserve Ratio (CRR) and Statutory Liquidity Ratio (SLR), for the period 2001Q2 to 2020Q1, found evidences of co-movement of all the policy rates. The exploratory study using the Principal Component Analysis (PCA) with VARIMAX rotation identified a single component to explain a sizable amount of variation in all the policy rates taken together. The result corresponding to this exploratory analysis is reported in Figure A3.1 and Table A3.2 of Appendix for this chapter. This finding clearly supports in favour of co-movement of policy rates.

Finally, the Hodrick-Prescott (HP) filter [15] is used to transform the real GDP and eventually to estimate the output gap.[16] However there are number of limitations of the HP filter, such as, (a) it introduces spurious dynamic relations that have no basis in the underlying data-generating process, (b) filtered values at the end of the sample are very different from those in the middle, and are also characterized by spurious dynamics and (c) a statistical formalization of the problem typically produces values for the smoothing parameter vastly at odds with common practice, as demonstrated by

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[14] Based on AIC.

[15] Hodrick, R. J., & Prescott, E. C. (1997). Postwar US business cycles: an empirical investigation. Journal of Money, credit, and Banking, 1-16.

[16] Bunzel and Enders (2010) also used the HP filter to estimate the output gap.

Hamilton (2018). However, it is one of the most widely used tools to remove short-term and cyclical fluctuations associated with the business cycles in macroeconomic data. In addition to that, Dritsaki and Dritsaki (2022) demonstrate the superiority of the HP filter over one of the alternatives, i.e., the Hamilton's Regression, in terms of the ability to perform the dynamic forecasting of macroeconomic variables.

As mentioned above, the HP filter disintegrates short-term and cyclical movements in the data from the long-term trend. This technique provides us with the trend values of real GDP. Therefore, the output gap can be estimated by subtracting filtered series from the actual values of the real GDP. The HP filter chooses the trend value such that it minimizes:

$$\sum_{t=1}^{T}(y_t - T_t)^2 - \lambda\sum_{t=2}^{T-1}\{(T_{t+1} - T_t) - (T_t - T_{t-1})\}^2 \tag{3.7}$$

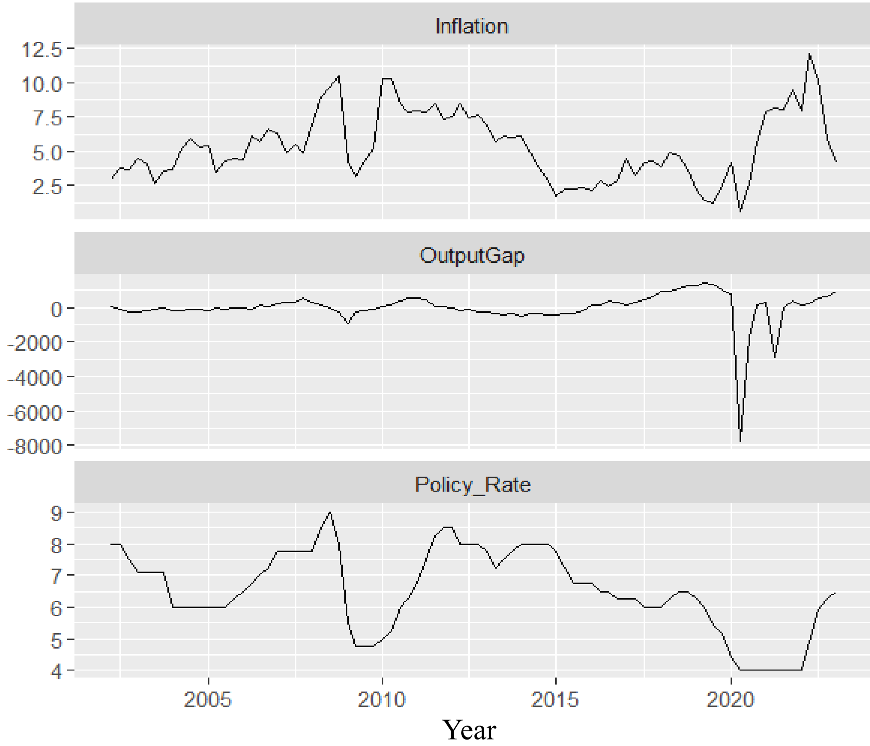
Where, y_t and T_{t+1} representing the original series and its trend values respectively. λ is the smoothing parameter supposed to take values following the equation $(1600 \times p_q^4)$, where, p_q indicates number of periods per quarter. Since we are using quarterly data for this study, $\lambda = 1600$. The estimated HP filter can be represented by the following equation:

$$HP = [\lambda L^2 - 4\lambda L + (1 + 6\lambda) - 4\lambda L^{-1} + \lambda L^{-2}]^{-1} \tag{3.8}$$

Where, L stands for lag operator.

The time paths of π_t, y_t and i_t for the 2001Q2 to 2023Q1 period are shown in Figure 3.1. In the figure, inflation and policy rate are represented in percentage term and output gap is represented in Rs. 10^9 (i.e., one billion Indian Rupee). Such a standardization for the variable output gap was done for the ease of understanding the output gap numbers.

Figure 3.1: The Taylor Rule Variables



Source: OECD National Accounts (OECD.Stat) and Database on Indian Economy, RBI's Data Warehouse

In order to account for the possibility of structural change, we use the data to estimate Taylor rules for the entire sample period as well as for a number of sub-samples. These sub-samples are identified through a process of identifying structural changes in the data using a widely used statistical technique. Bai (1994) laid the foundation for estimating structural breaks in time series regression models, while Bai (1997ab) and Bai & Perron (1998) extended this work to include multiple breaks. In this study, break-points are identified using the algorithms suggested in Bai & Perron (2003). The algorithm is efficient enough to identify historical break points. The technique applies a dynamic programming approach, i.e., the Bellman principle, in order to identify the breakpoints given the number of breaks. The main computational effort is to estimate a triangular matrix, which gives the residual sum of squares (RSS) for a segment starting at observation t and ending at t', such that, $t < t'$. Using this algorithm, we found out three break points in the given data: 2020Q1 (based on output gap), 2014Q1 (Based on inflation) and 2019Q2 (Based on policy rate). Based on this result, we choose four subsamples for further analysis to understand parameter stability, i.e., 2002Q2 to 2014Q1, 2002Q2 to 2019Q2, 2002Q2 to 2020Q1 and 2014Q1 to 2023Q1.

Before proceeding further, it should be mentioned that, all the variables are tested for stationarity using a number of standard statistical tests for all the relevant sub-samples as mentioned above. All the unit root tests are performed only with drift or intercept component, without incorporating deterministic time trend, since there is no reason to assume that any of these variables are trend stationary. The primary reason behind such a presumption is that, the list of variables used in this study generally don't possess any definite trend over a long time horizon, instead these variables oscillate around its long run average. Figure 3.1 clearly graphically reflect that fact. The list of tests deployed in this study includes: Augmented-Dickey-Fuller (ADF) test[17], Phillips and Perron (PP) test[18], Kwiatkowski Phillips Schmidt Shin (KPSS) test[19], Elliott Rothenberg Stock (ERS) test[20] and Schmidt and Phillips (SP) test[21]. In case of ADF, PP, ERS and SP tests the null hypothesis of unit root is tested against the alternative of stationarity and all these tests are left tailed test. In contrast to that, in case of KPSS test, the null hypothesis of stationary is tested against the alternative of unit root process.

For the last few decades, a great deal of empirical studies analysed the dynamic properties of economic and financial time series. If a variable is characterized by a unit

[17] Dickey, D. A., & Fuller, W. A. (1979) and Dickey, D. A., & Fuller, W. A. (1981)
[18] Phillips, P. C., & Perron, P. (1988)
[19] Kwiatkowski, D., Phillips, P. C., Schmidt, P., & Shin, Y. (1992)
[20] Elliott, G., Rothenberg, T.J. and Stock, J.H. (1996)
[21] Schmidt, P., & Phillips, P. C. (1992)

root process, then the shocks to that variable will have a prolonged or permanent impact on that variable. However, impact of shocks to a stationary time series is transitory in nature. The inflation rate is one of the most rigorously analysed macroeconomic variables. Impact of macroeconomic shocks (such as, monetary and fiscal policy shocks, oil price shock etc.) on inflationary dynamics (whether permanent or transitory) is one of the key areas of study in the field of macroeconomics, i.e., the study on the persistence of the inflation series. Dynamic behaviour of inflation has a far-reaching implication on macroeconomic theories. For example, sticky-price hypothesis implies price level to be integrated of order zero, i.e., *I(0)*; whereas, Phillips curve hypothesis suggests presence of unit root in prices. In addition to that, the presence of unit root in inflation has important consequences in macroeconomic theories such as, Fisher hypothesis, the consumption-based capital asset pricing model, the stabilization policy, the mechanics of international convergence etc. As far as empirical studies are concerned, a large body of studies have applied cointegration methodology that relies on the assumption that, inflation is a *I(1)* process. Whether inflation series is best described as a stationary or a unit root process has not yet been conclusively resolved. Empirical results vary from country to country. But, conclusion of all those studies largely depends on the chosen empirical methodology. Numerous tests for unit root are proposed over the years by several econometricians. Reliability of such tests are challenged due to number of reasons, such as, severe size distortions, low power in those tests etc.

Since 1970s and early 1980s, most of the industrialized as well as developing countries experienced rapid growth in general price level. One of the most important achievements of macroeconomic policy in recent times has been the reduction of inflation rates primarily in industrialized countries mainly due to inflation targeting measures. Several economists suggested, adaption of inflation targeting measures can potentially lower and stabilize the inflation rate by improving the credibility and accountability of central bank of the respective country.

All the results corresponding to unit root test are reported in the Table A3.1 of the Appendix of this chapter. Among all these tests, perhaps, the ADF is the most widely used unit root test. The results of the ADF test found no evidence of unit root in output gap and policy rate. On the other hand, one of the most popular non-parametric unit root tests, i.e., the PP test, which allows for weak dependence and heterogeneity of the error process, found stationarity in inflation series in most of the sub-samples. One of the most common limitations of the ADF and the PP test is that, both the tests possess low power if the true data-generating process is an autoregressive process of order 1, i.e., AR(1), with a coefficient close to one. This problem is addressed in the ERS test. In this study we have estimated the DF-GLS version of the ERS test, which is a modified ADF-type test. The estimated results suggest, both output gap and policy rate are stationary process. The test also found stationarity in inflation series for one of the sub-samples (i.e., 2014Q1 to 2023Q1). The SP test is another alternative to DF-type unit root tests, which deals with the problem associated with nuisance parameters (i.e., the coefficients of the deterministic regressors). The result of the test suggest stationarity in the inflation series for the entire range. The result of this test also found no evidence of unit root in other two variables in most sub-samples. Among all the tests mentioned above, the KPSS test is the only test where a null hypothesis of stationarity is tested against the alternative of non-stationarity in the series. The KPSS test is a conservative test and the results of the test should be taken carefully. In this study, the results of the KPSS test indicates stationarity in all the sub-samples for each of the variables. Based on the results of the unit root tests (discussed above), this study proceeds further with the assumption that all the three variables included in the study are best categorized as a stationary process or integrated of order zero, i.e., *I(0)*.

Table 3.1 reports estimated Taylor rules for each of these sub-samples without assuming asymmetric behaviour. $\sum \gamma_i = 0$ is tested in the column corresponding to $\sum \gamma_i$ of the table to test the presence of policy persistence. The table reports the sum of estimated coefficient along with its statistical significance and the value of the AIC corresponding to each estimated equation. The AIC values are key indicator to compare different model specifications. Therefore, in later part of this chapter these values are going to be compared with its counterpart values from asymmetric or threshold model specifications.

Table 3.1: Estimated Taylor rule over time (i.e., Equation 3.2)

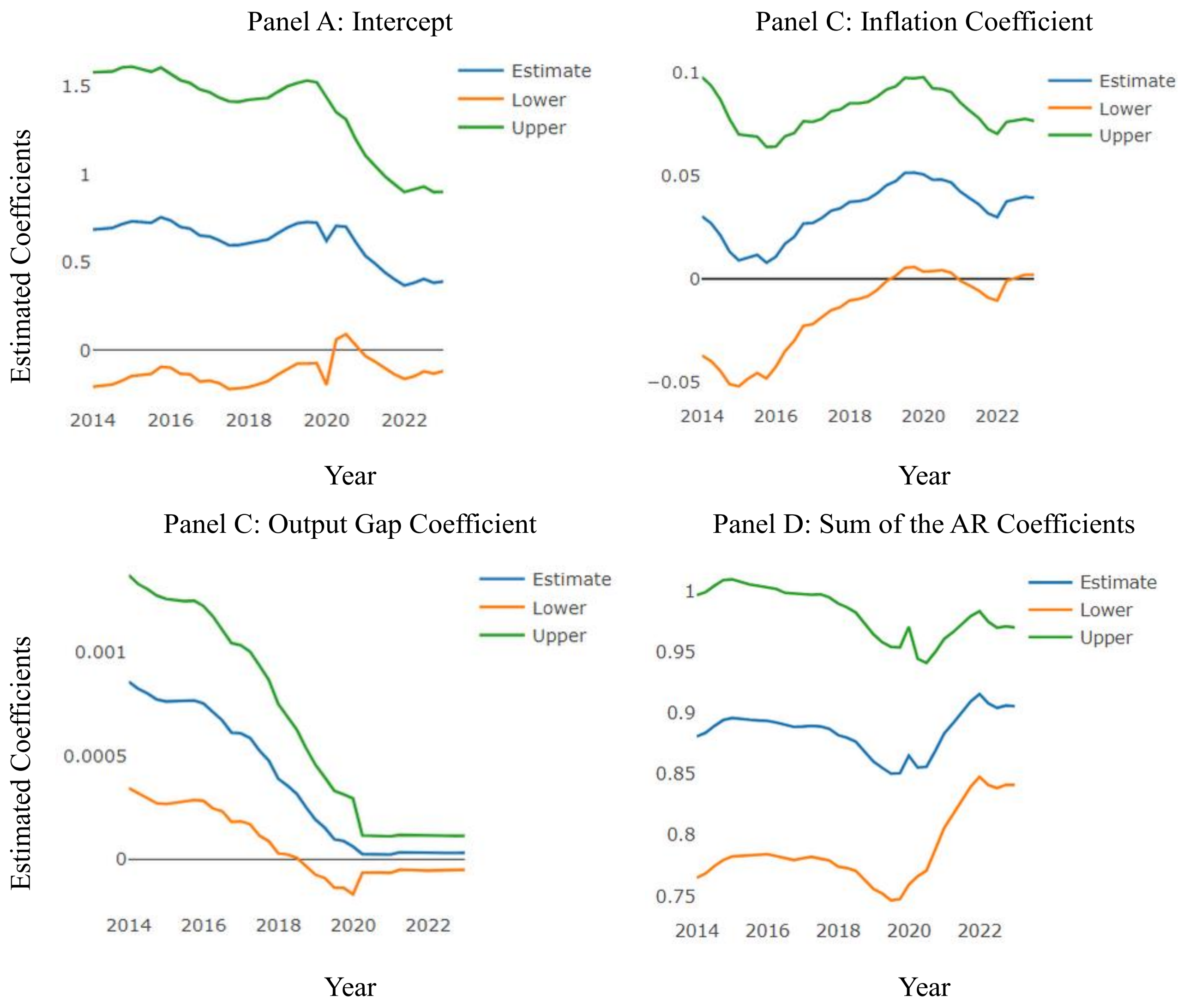
Start	End	α_0	α	β	$\sum \gamma_i$	AIC
2002Q2	2014Q1	0.686	0.030	0.001***	0.881***	-80.140
	2019Q2	0.721*	0.047**	0.000	0.855***	-126.797
	2020Q1	0.622	0.051**	0.000	0.865***	-127.913
	2023Q1	0.391	0.039**	0.000	0.906***	-155.640
2014Q1	2023Q1	-0.497	0.072***	0.000	1.026***	-104.902

Note: *, **, and *** denote statistical significance at the 10%, 5% and 1% levels respectively.

The estimated Taylor rules found to be reasonable enough with variation in estimated coefficients among the sub-samples. The estimated coefficient corresponding to output gap (i.e., β in the Equation 3.2) is mostly insignificant across the sub-samples and very marginally around the value zero (except period between 2002Q2 and 2014Q1), which indicates the fact that, the RBI puts very little importance on output gap while deciding policy rate. On the other hand, the estimated coefficient corresponding to inflation (i.e., α in the Equation 3.2) is mostly significant across the sub-samples (except period between 2002Q2 and 2014Q1) at 5% level of significance, indicating the fact that, the RBI puts significant weightage on inflation while setting-up policy rate; and the coefficient varies across the sub-samples. The sum of the coefficients of the lagged interest rates (i.e., $\sum \gamma_i$ in the Equation 3.2) statistically significant and its estimated value is reasonably close to unity, suggesting a substantial amount of interest rate smoothing by the monetary authority. A marginal variation in the degree of interest rate smoothing can be seen from the estimated results. Nevertheless, the predicted parameters ought to remain constant over time if a linear symmetric Taylor rule adequately captures the actions of the RBI. This result provide little evidence in favour of policy symmetry of the RBI as the estimated values of the parameters varies across the sub-samples.

We utilized conventional recursive estimation technique to check the variability of the parameters in the estimated Taylor rules over a reasonable span of time. i.e., for each time period *T* in the interval 2014Q1 to 2023Q1, we estimated the Taylor Rule equation using observations 2002Q2 through *T*. As a result, we obtained 37 regression equations each containing an estimate of concerned parameters. The time paths of the estimated coefficients are displayed in Panels A through D of Figure 3.2. If the parameters are constant over time, the time path supposed to show no specific graphical pattern. As the diagram shows, all the coefficients show substantial degree of variability over the time horizon. The Panel D of Figure 3.2 shows, the parameter representing the degree of interest rate smoothing behaviour of the RBI remain very close to unity over the time horizon. The coefficient corresponding to output gap, as shown in Panel C of Figure 3.2, seems to decline steadily, and eventually stabilise at a level which is very close to zero. Therefore, Figure 3.2 clearly shows the presence of parameter instability in the data generating process. The estimated values of the parameter corresponding to inflation also depict the similar perception about parameter variability. Remaining part of this chapter primarily focused on understanding the choice of RBI with respect to policy rate using threshold estimation techniques.

Figure 3.2: Recursive Estimation of the Taylor Rule Parameters



Note: Respective estimated parameter values are plotted (measured along the vertical axis) over the given time horizon (measured along the horizontal axis) from 2001Q2 to 2023Q1

The blue, green and orange lines are representing the estimated coefficients and its upper and lower 95% confidence interval.

Finally, to identify the presence of asymmetry in the policy response of the RBI, we perform a simple descriptive statistics analysis. The exploration reveals that, the ratio of standard deviation of policy rate where inflation is greater than 4% in the preceding period relative to otherwise is greater than unity. It indicates that, the central bank reacts sharply to inflation when it is greater than the target level. In addition to that, the same exploration reveals that, average level of the policy rate is greater during high inflation periods than otherwise.

3.5 Empirical Findings

The F-test to identify the presence of nonlinearity in the data in given in Table 3.2. The null hypothesis of the test suggests presence of no threshold behaviour. The table summarises the threshold level and corresponding F-statistics for each sub-sample assuming lag of inflation and output gap as threshold variables separately. Notice that there is strong evidence of threshold behaviour in all the sample periods. If we consider the magnitude of the estimated F-statistic to be an indicator of the strength of evidence for asymmetry, lag of inflation rate should be chosen as the threshold variable. However, by the same logic lag of output gap should be considered as the threshold variable for the sub-sample containing observations between 2014Q1 to 2023Q1. Although, for the rest of this chapter, we choose the lag of inflation to be the threshold variable. The results in the Section 3.4 also support that choice.

Table 3.2: Test for Threshold Process

Start	End	Inflation as threshold		Output gap as threshold	
		τ	F-stat	τ	F-stat
2002Q2	2014Q1	6.503	8.199***	115.569	5.876***
	2019Q2	6.347	28.324***	134.895	10.824***
	2020Q1	6.539	32.309***	74.875	11.711***
	2023Q1	7.168	35.795***	84.964	20.430***
2014Q1	2023Q1	6.587	3.989**	141.205	16.156***

Note: *, **, and *** denote statistical significance at the 10%, 5% and 1% levels respectively.

We separately estimated the threshold Taylor rule equation for each subsample assuming lag of inflation as the threshold variable. The estimated result is reported in Table 3.3. The estimated range of lag of inflation as the threshold values varies between 6.347 to 7.168, which is quite reasonable as the threshold value for the inflation rate, since, upper tolerance limit of the RBI with respect to inflation is fixed at 6%. It shows, the RBI reacts to changes in inflation only when it exceeds the upper tolerance limit. This result clearly shows the presence of asymmetry in the reaction of the RBI with respect to changes in level of inflation. When inflation crosses the upper tolerance limit, there is a switch in the behaviour of the RBI with respect to the choice of policy rate.

As indicated by the AIC values, the fits of the threshold models are superior to those of the counterpart linear model (i.e., by comparing AIC values of Table 3.1 and Table 3.3). The result shows that, in most of the sub-samples (except 2014Q1 to 2023Q1), when lag of inflation is above threshold level, the estimated coefficient corresponding to output gap is substantially greater than that of a scenario when inflation is below threshold level. That is, the RBI is far more responsive to contemporaneous movements in output gap whenever inflation exceeds the threshold inflation level. Although, no such evidence can be found from estimated equation of full sample. Moreover, the sum of the interest rate smoothing coefficients is found to be unaffected by change in lag of inflation beyond the threshold level, which suggests, the RBI is persistently following an interest rate smoothing policy. The study found no clear signal about responsiveness of policy rate with respect to change in inflation. For example, sub-samples corresponding to time horizon 2002Q2 to 2014Q1 both the parameters corresponding to rate of inflation found to be insignificant. On the other hand, estimated model corresponding to the sub-sample indicating the time horizon from 2002Q2 to 2019Q2, 2020Q1 and 2023Q1 shows that, variation in inflation rate significantly affect the policy rate, but exceeding lag of inflation rate beyond the threshold level has no significant impact on that responsiveness. Exactly opposite result can be found for the sub-sample corresponding to time horizon 2014Q1 to 2023Q1. i.e., the RBI respond to rate of inflation only if it exceeds the threshold level.

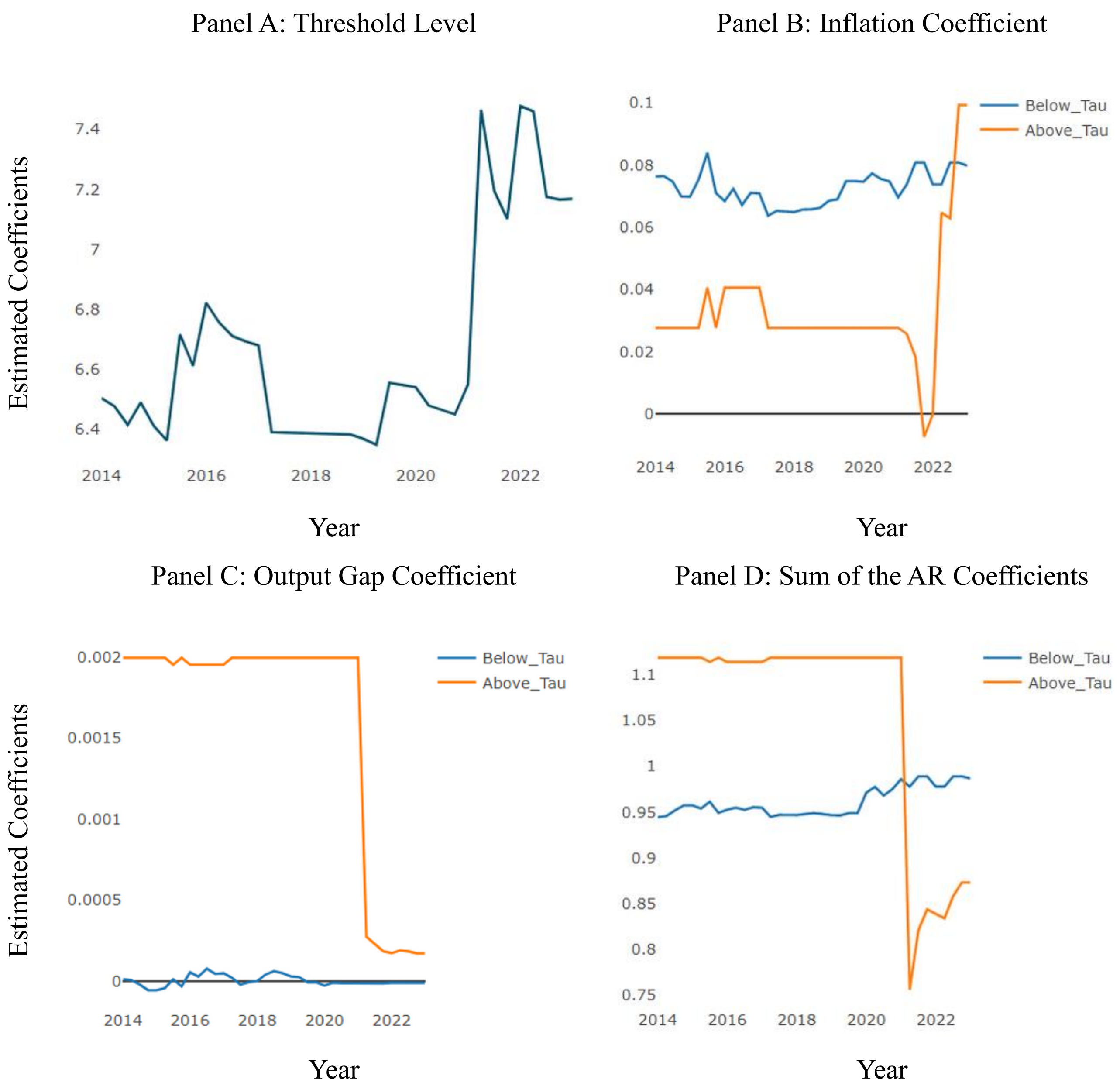
Finally, we utilized conventional recursive estimation technique, as specified earlier, to check the variability of the parameters of the estimated threshold Taylor rules parameters over time. Figure 3.3 shows the degree of parameter instability in the data generating process. Panel A of Figure 3.3 shows the variability of the threshold level (i.e., the tolerance level of RBI with respect to rate of inflation) over time. It shows a substantial upward shift in the inflation tolerance level of the RBI from 2021Q2. i.e., structural change in reaction of the RBI with respect to the threshold variable (i.e., lag of inflation) occurs at a higher level beyond 2021Q2 relative to preceding periods. This shift in the estimated parameters corresponding to the slope dummies is clearly visible from Panel B, C and D of Figure 3.3. The Panel B of Figure 3.3 clearly shows that, responsiveness of the RBI to change in inflation beyond the threshold level of inflation (which also experience an upward shift) shifted upward beyond 2021Q2, whereas that of output gap shifted downward. As far as the interest rate smoothing parameter is concerned, it also experienced a sharp downward shift post 2021Q2. Therefore, we may conclude that, post 2021Q2, the RBI becomes much more tolerant with respect to inflation, whereas, it responded sharply whenever inflation level crosses that increased tolerance or threshold level. Post 2021Q2, to control inflation beyond the estimated threshold level, the RBI compromised with interest rate smoothing behaviour as well.

Table 3.3: The Estimated Threshold Models (i.e., Equation 3.4)

The Threshold Variable: π_{t-1}									
Start	End	τ	β_1	α_1	β_2	α_2	$\beta_3 + \beta_4$	$\alpha_3 + \alpha_4$	AIC
2002Q2	2014Q1	6.503	0.076	-0.049	0.000	0.002***	0.944***	0.175	-90.112
	2019Q2	6.347	0.069**	-0.041	0.000	0.002***	0.946***	0.173	-158.549
	2020Q1	6.539	0.075**	-0.047	0.000	0.002***	0.971***	0.148	-161.083
	2023Q1	7.168	0.080***	0.020	0.000	0.000	0.986***	-0.114*	-173.579
2014Q1	2023Q1	6.587	0.055	0.162**	0.000	0.000	1.002***	0.222	-106.645

Note: *, **, and *** denote statistical significance at the 10%, 5% and 1% levels respectively.

Figure 3.3: Recursive Estimation of the Taylor Rule Parameters of the Threshold Model



Note: Respective estimated parameter values are plotted (measured along the vertical axis) over the given time horizon (measured along the horizontal axis) from 2001Q2 to 2023Q1

The blue and orange lines are representing the estimated coefficients where the inflation is below and above the threshold level respectively.

3.6 Conclusion

The primary goal of this study the presence of asymmetry in the behaviour of the RBI regarding the choice of policy rate. Over the last few decades, there have been major changes to the objectives, methodology, and instruments of the RBI's monetary policy. For example, the RBI is currently following a soft inflation targeting strategy with a CPI inflation target of 4% with an upper and lower tolerance limit of $\pm 2\%$. Along with the introduction of Liquidity Adjustment Facility (LAF) from June 2000, the RBI is following some form of Taylor rule by adjusting policy rate (e.g., repo rate) to regulate short run macroeconomic fluctuations. Taylor rule is a basic monetary policy rule in which the monetary authority changes the short-term interest rate in response to observable variations in inflation and output gap in the economy. The primary focus of this study is to check the existence of nonlinearity in RBI's Taylor rule equation, i.e., existence of asymmetry in the behaviour of the RBI.

Our data set consists of quarterly values of seasonally adjusted GDP Deflator, seasonally adjusted real GDP and repo rate over the period from 2001Q2 to 2023Q1. The Hodrick-Prescott (HP) filter is used to transform the Real GDP and eventually to estimate the output gap. Preliminary exploratory study supports the presence of nonlinearities in the preference of the RBI and thus support use of the TAR model to explore the preference pattern empirically with one period lag of inflation as the threshold variable. Estimated TAR models corresponding to a number of sub-samples suggests that, the estimated threshold level of lag of inflation always lies above the upper tolerance level of the inflation target, i.e., 6%.

In addition to finding the evidence supporting the presence of asymmetry in the response of the RBI, this study finds out a number of interesting results:

1. The RBI is more responsive to contemporaneous movements in output gap whenever inflation exceeds the threshold inflation level than otherwise.
2. The RBI is persistently following an interest rate smoothing policy.

3. The study found no clear signal regarding responsiveness of policy rate with respect to change in inflation, i.e., sign, magnitude and statistical significance of concerned parameters varies across sub-samples.

Applying conventional recursive estimation technique, we found that, post 2021Q2, the RBI becomes much more tolerant with respect to inflation, whereas, it responded sharply whenever inflation level crosses that increased tolerance or threshold level. Post 2021Q2, to control inflation beyond the estimated threshold level, the RBI compromised with interest rate smoothing behaviour.

Appendix

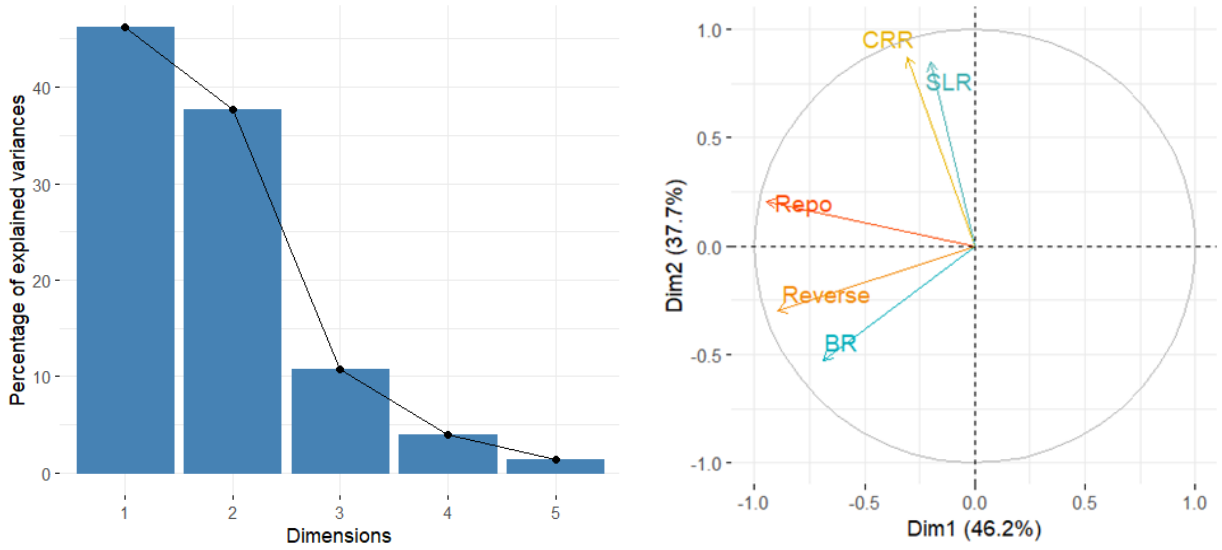
Table A3.1: Unit Root Tests

Variables	Sub-periods Start	Sub-periods End	ADF	PP	ERS	SP	KPSS
Inflation	2002Q2	2014Q1	-1.682	-2.7301*	-0.6253	-0.8071	0.1386
		2019Q2	-0.9567	-2.4104	-0.8338	-1.6762	0.1643
		2020Q1	-0.9974	-2.6761*	-0.8844	-1.6768	0.1586
		2023Q1	-1.8485	-3.0252**	-1.2978	-2.9086*	0.102
	2014Q1	2023Q1	-1.9477	-2.063	-1.8224*	-1.8092	0.1249
Output Gap	2002Q2	2014Q1	-3.0114***	-2.113	-2.9075***	-2.7528	0.1132
		2019Q2	-0.2227	-0.3734	-0.9849	-2.1774	0.1174
		2020Q1	-2.2798**	-1.4743	-1.9331*	-2.7353	0.1233
		2023Q1	-3.7326***	-6.6536***	-3.6849***	-6.1199***	0.05
	2014Q1	2023Q1	-3.5835***	-4.4723***	-2.2421**	-4.0935***	0.0962
Policy Rate	2002Q2	2014Q1	-2.8884*	-2.0543	-2.5561**	-3.207**	0.0774
		2019Q2	-3.426**	-2.3156	-2.6581***	-3.3398**	0.0764
		2020Q1	-2.8128*	-1.7271	-2.0761**	-2.8393*	0.0995
		2023Q1	-3.0233**	-2.1828	-2.3187**	-3.8604***	0.1289
	2014Q1	2023Q1	-2.0798	-1.7169	-1.3532	-2.308	0.1152

Note: *, **, and *** denote statistical significance at the 10%, 5% and 1% levels respectively.

Figure A3.1: Visualization of Principal Components Analysis

Scree Plot	Biplot



Note: ‘Repo’, “Reverse’ and ‘BR’ representing the repo rate, reverse repo rate and bank rate respectively

Table A3.2: Results of Principal Component Analysis

Importance of Components					
	Components or Dimensions				
	1st	2nd	3rd	4th	5th
Standard deviation	1.519	1.373	0.733	0.446	0.266
Proportion of Variance	0.462	0.377	0.108	0.040	0.014
Cumulative Proportion	0.462	0.839	0.946	0.986	1.000
Loadings (Pre-Rotation)					
BR	0.454	0.383	0.594	0.543	
Repo	0.624	-0.150	-0.122	-0.296	0.697
Reverse	0.589	0.219	-0.352	-0.249	-0.647
CRR	0.201	-0.634	-0.342	0.657	
SLR	0.133	-0.617	0.625	-0.354	-0.292
Loadings (Post-Rotation)					
BR	0.816	-0.292			
Repo	0.840	0.484			
Reverse	0.944				
CRR		0.922			
SLR		0.869			

Chapter 4

Asymmetric Policy Response of RBI Using Reinforcement Learning Algorithm

4.1 Introduction

A well-regulated monetary policy rule is one of the key ingredients of achieving desired macroeconomic stability for any modern economy. Taylor (1993) proposed and demonstrates that actual monetary policy decisions can be described by a simple linear rule. The proposition was subsequently formalized in studies by Taylor (1996) and Svensson (1997, 2003). This rule, as demonstrated in the previous chapter, is extensively used in the relevant literature to demonstrate the monetary policy rule in macroeconomic models. In this context, central banks may prefer to define explicit set of objectives and follow some decision-making process that involve analysing available relevant historical data in order to achieve those objectives. The evaluation of optimality and robustness of such rule-based policy response could become a research goal to the concerned literature. What is the appropriate objective for a central bank to strive for when acting in society's best interest? Given economic frictions, the welfare of representative agents is supposed to be optimized by the optimal monetary policy.

The primary objective of this chapter is to identify or estimate the optimal monetary policy response function of the RBI given its knowledge about the macroeconomic transition equations[22], preference over the structure of the policy response function and restrictions to policy response. This study incorporates two

[22] Transition Equation represent a system of equations to demonstrate the interrelationships between the state and control variables.

distinct policy response functions, i.e., symmetric and asymmetric policy response functions, as demonstrated in the previous chapter. In addition to the objective mentioned above, this study also intended to compare the relative performance of symmetric and asymmetric policy response of monetary authority. Therefore, the present chapter is intended to introduce a mechanism to estimate the optimal monetary policy response of the RBI. The philosophy that encourages to perform such a study is the assumption that, a learning algorithm that learns from past observations can out-perform ad-hoc human choices. In this context, this study utilizes a Reinforcement Learning (RL) algorithm to identify the exact form of a well-defined deterministic policy response function.

The subject matter of the RL can be summarized as a problem of optimizing the discounted present value of future flow of rewards (or penalties) of an individual (i.e., agent) or a group of individuals within a modelling environment. Therefore, the idea behind RL is to learn behavioural rules or policies based on state observations, that induce expected reward optimizing agent's action. The algorithm is model-free, i.e., complete knowledge of the model equations is not required for implementing this algorithm. The individual choices under RL are induced by past experiences, thus reduces model uncertainty. Finally, the algorithm does not suffer from the curse of dimensionality, i.e., it is possible to include as many states or control variables in the analysis as necessary without any restrictions. Although, incorporating an additional variable in the problem can increase the computational complexity of the estimation process by many folds.

The Deep Q Network (DQN) algorithm is among the most popularly used deep RL algorithms that can solve problems with high-dimensional observation spaces. But, unfortunately the DQN algorithm is only applicable to discrete and low-dimensional action spaces and that makes it inappropriate for using in this study, since action space for a monetary authority (i.e., policy rate of interest) is a continuous variable. Policy gradient algorithms are most appropriate RL algorithm to address a problem with continuous action spaces. Policy gradient algorithms typically processed by sampling the stochastic policy and adjusting the policy parameters in the direction of greater cumulative reward. Replacing stochastic policy by some deterministic policy introduces a new RL algorithm (Silver et al., 2014) called Deterministic Policy Gradient Algorithms. An updated version of that algorithm is as demonstrated by Lillicrap et al. (2015), called the Deep Deterministic Policy Gradient (DDPG) Algorithm. The technique's simplicity, as shown in the study, is its main characteristic and strength. i.e., it requires only a simple actor-critic architecture and learning algorithm with very few "moving parts". Such a straightforwardness in the methodology facilitates its implementation and scalability to larger networks and more complicated issues. This study utilizes the essence of the DDPG algorithm to identify the parameters of both symmetric as well as asymmetric monetary policy response function that optimizes the goals of the monetary policy authority. The study is focused primarily on Indian economy and conduct of the RBI, but the methodology can be replicated for any economy. An explicitly defined quadratic loss function is used in this study to specify the goal of the monetary authority. Although, functional form, variables and the parameters of the objective function can be modified or changed to understand the variation in the optimal monetary policy response in future studies.

This study can be best described as a sequence of two distinct steps for each type of policy response functions: (a) estimating macroeconomic transition equations using appropriate empirical model and (b) estimating the parameters of the policy response function given its structure and understanding about the external environment.

While defining the shape of policy function of the RBI, stabilization rules, as described in the Taylor rule, play the key role. In addition to that, central banks generally follow a short-term interest rate smoothing behaviour, that causes policy rate to move at a relatively sluggish pace. Evidence of such preference of the RBI is demonstrated in the previous chapter (i.e., Chapter 3). In addition to the objectives of stabilizing output and inflation, this pattern in the behaviour of the monetary authority can be understood as including the goal of limiting interest rate volatility within its objective function. Finally, due to computational reasons the assumption of Zero Lower Bound (ZLB) of policy rate is introduced in this study. According to Keynesian frictions, optimal nominal interest rate is bound to be positive, i.e., to have a ZLB. In practice, a number of advanced economies experienced a phenomenon of positive but almost zero monetary policy linked rate of interest for a brief period of time.

The exploration for an optimal monetary policy function is intended to find a policy rate which is sufficiently low to maintain a deflationary pressure in the economy along with satisfying the binding ZLB and goal of macroeconomic stabilization and inflation rate target. Under such a circumstance finding an optimal monetary policy response path becomes a vital area of research in the field of macroeconomics.

The remainder of the chapter is organized as follows. Section 4.2 mentioned the relevant literature corresponding to the underlying area of study. Section 4.3 illustrated the methodology used in this study. Section 4.4 specified the set of data used for this study. Section 4.5 demonstrated the results of the study. Finally, section 4.6 concludes the study.

4.2 Review of Literature

This study is intended to supplement the literature on optimal policy response functions for monetary authority, specifically the RBI. Although, the volume of research in the said area is extremely vast, the fundamental commonality in the literature is that, underlying methods are grounded in optimal control theory. The primary basis of any of such studies cannot be formulated without some of the key concepts, such as, Dynamic Programming and the Bellman equation, Bellman (1957a, b); value function and policy function iteration, Howard (1960), etc. In the subsequent segment of this section, we are going to discuss some of the studies within the literature of optimal monetary policy reaction functions which are related to this study.

Taylor (1993) discourages discretionary approach while defining monetary policy rule and mechanically follow any particular algebraic formula to be the policy response function of monetary authority. Instead encourages data driven decision making using updated econometric techniques in a policymaking environment. The study defines an ideal policy rule as a function that could suggest changes in policy rate in response to changing macroeconomic environment. In this chapter, we are trying to push this definition bit further by introducing some degree of dynamism in the parameters of a well-defined deterministic policy response function.

Taylor (1996) points out six reasons behind using a well-defined policy rule to recommend policy response by changing policy instrument(s), namely, (i) time consistency, (ii) forward looking behaviour in macroeconomic agents, (iii) reduce policy uncertainty, (iv) instruct goal-seeking policymakers to take appropriate action, (v) educate and inform students and general public and (vi) accountability of policymakers. Finally, Taylor discourages absolute discretionary approach in monetary policy making. Except the fourth reason, all other reasons behind using a well-defined monetary policy rule are satisfied while using a Taylor rule policy response function. This current chapter is intended to address this fourth reason in the context of the RBI using a RL algorithm.

Rotemberg and Woodford (1997) evaluate alternative monetary policy rules of United States using a quantitative forecasting model of output, interest rate and inflation. The study found that, policy rule that minimized the volatility of inflation rate requires high degree of variability in policy rate. Finally, the study illustrated a constrained policy rule, restricted by the variability of interest rates, can substantially reduce the average inflation level.

Fuhrer (1997) defines optimal monetary policy as the estimated trade-off between inflation/output-gap variance faced by monetary policy makers when policy makers are concerned about the deviations of inflation around target and output around potential. He estimates the variance trade-off in this context for the United States. The study concludes that, approximately balanced responses to policy goals are consistent with reasonable preferences over inflation and output variability.

Favero and Rovelli (1999) illustrate a method to identify the preferences of central bank by estimating the Euler equations using GMM for the solution of the intertemporal optimization problem relevant to the central banker in the context of United States. The key findings of the study include: (a) the structure of the economy determines the persistence of rate of interest, (b) although ‘strict’ inflation targeting dominates ‘flexible’ inflation targeting, the actual behaviour of the policy rates cannot be described by the pure "strict" inflation targeting approach.

Sack and Wieland (2000) analyses the Interest-Rate Smoothing behaviour of monetary authority and argues in favour of it. According to the study, it is optimal to have some degree of inertia in the monetary policy rate specifically due to three reasons: (a) forward-looking behaviour of market participants, (b) measurement error associated with key macroeconomic variables and (c) uncertainty regarding relevant structural parameters.

Amato and Laubach (2004) in their study defines the objective of monetary policy such that it remains consistent with welfare maximization, which includes output acceleration, as well as inflation and output gap stabilization. Even with higher implicit weight of the variance of output in the welfare function, the study finds evidence of increase in that under optimal policy. The results of the study also suggest that, a simple interest rate rule can achieve the optimal welfare allocation, irrespective of the degree of habit formation. Finally, it reports that, the optimal responses to both inflation and the lagged interest rate are declining along with the size of the habit.

Hinterlang and Tänzer (2021) implement the Deep Deterministic Policy Gradient (DDPG) algorithm, as suggested by Lillicrap et al. (2015), to identify the optimal monetary policy reaction function for the US. The study incorporates 1987Q3 to 2007Q2 in order to estimate the transition equations. The result suggests that, the Reinforcement Learning based monetary policy rule outperformed other common rules as well as the actual federal funds rate. This study is one of the key starting points for this current chapter. In this chapter we are going to use the same algorithm to estimate the optimal values of the parameters of the deterministic policy functions of the RBI. To the best of our knowledge, this is the first paper applying (deep) RL in order to identify optimal monetary policy in the context of Indian economy.

4.3 Methodology

This section elaborates the description of the methodology used in this study. The methodology can be referred as an interactive exploration of the monetary policy authority with external macroeconomic environment. Such an interaction of monetary authority can depict its choices given the macroeconomic environment and chosen policy function, which further can be evaluated against social welfare or reward.

Structure: The general structure of the macroeconomic environment consists of a single agent, i.e., Central Bank, which interacts with an unknown environment E, receiving a vector of observations or signal x_t (which includes contemporaneous as well as lagged observations on inflation, i.e., π_t and output gap, i.e., y_t), takes a policy action i_t (i.e., the policy rate) and receives a reward, which can be considered as a social welfare received given the macroeconomic signal received in that period. The agent or monetary authority assumed to follow a policy function which is structurally non-adaptive. i.e., its functional form remains unaltered with respect to its observation on macroeconomic environment. Although, the values of the parameters of the policy function can be changed and chosen appropriately such that the goal of the monetary authority is optimised. Such a nature of the policy function is useful to compare multiple optimised structurally differentiated policy response functions. All elements of the system are described in below:

The Environment: The environment E is one of the key elements of this study, that determines the next period macroeconomic signal, i.e., x_t in response to the agent's current and past actions. As specified earlier, in this study the environment is external to the agent or monetary authority. This part of the system is approximated by a two-equation system including π_t and y_t respectively. The primary goal of this environment is to project the state of next period given current state of the economy and choice of policy by central bank, i.e., policy rate. Therefore, it can be viewed as a forecasting structure. The general structure of the system of transition equations can be represented as follows:

$$y_t = \hat{f}^y(y_{t-1}, y_{t-2}, \pi_{t-1}, \pi_{t-2}, i_{t-1}, i_{t-2}) + e_t^y \tag{4.1}$$

$$\pi_t = \hat{f}^\pi(y_{t-1}, y_{t-2}, \pi_{t-1}, \pi_{t-2}, i_{t-1}, i_{t-2}) + e_t^\pi \tag{4.2}$$

where inflation and output gap depend on lagged and contemporaneous values of themselves as well as contemporaneous and lagged values of the policy rate. e_t^y and e_t^π are the random error components corresponding to output gap and inflation equations respectively. $\hat{f}^y$ and $\hat{f}^\pi$ representing the functional form of the transition equations for output gap and inflation respectively.

It should be noted that, the transition equations incorporate maximum of two period lags for each variable. By restricting the system of transition equations in that way, we aim for a parsimonious model structure. Hinterlang and Tänzer (2021) also used similar structural form for these equations. Finally, two algorithms are being utilized separately to estimate the transition equation system. The respective forecasting techniques are being elaborated as follows:

(a) Dynamic Linear Regression Model: The forecasting model used in this scenario can be represented by a standard linear regression model with s_t^m, $m \in \{y, \pi\}$, representing the input vectors as follows:

$$\hat{f}^m = c^m + \alpha^{m'} s_t^m \tag{4.3}$$

Where, c^m and α^m representing the bias and the slope coefficient respectively.

(b) The Artificial Neural Network (ANN): In addition to a more traditional linear time series forecasting technique to estimate the transition equation, a popular

supervised machine learning algorithm, i.e., the ANN, is used in this study to perform the same task. In this context equations corresponding to inflation and output gap are being estimated separately using ANN. The ANN representation of the transition equation is given as follows:

$$\hat{f}^m = b_0^m + \sum_{j=1}^{h} v_j^m G\left(w_j^{m'} s_t^m + b_j^m\right) \qquad (4.4)$$

Where, w_j, v_j , $j = 1, 2, \ldots., h$, and b_i, $i = 0, 1, \ldots., h$ are weights and biases to be estimated. The hyperbolic tangent sigmoid function, i.e., $\tanh(x) = \frac{e^x - e^{-x}}{e^x + e^{-x}}$, is used as the activation function (G) in this study, which map on the interval $[-1,1]$. The number of hidden units h represents a hyperparameter that we determine by considering the prediction power (i.e., Mean Absolute Percentage Error or MAPE) of the estimated model.

One of the key drawbacks of ANNs is that estimated parameters of the model are difficult to interpret using economic logic. On the other hand, the dynamic linear regression model, however, is restricted by its predetermined linear form and might consequently miss certain dynamics of the actual time series data.

The Agent: As mentioned earlier, the monetary authority or the central bank of the economy is the only agent in this study. The agent chooses its action on the basis of observed economic states. In this context, the structure of the central bank policy function needs additional discussion. The policy function of the central bank represents its nominal interest rate setting behaviour in response to observations from the environment. This study assumes that, the policy function and its parameters remain fixed. This approach helps to compare different policy regimes.

The Policy Function: The policy function represents the choice of action for the agent given the observations on the state variables. Therefore, the monetary authority observes certain state variables, that serve as inputs to the policy function. In this context, two separate deterministic functions are being used as the policy function of the representative monetary authority.

Firstly, a reduced form of standard symmetric Taylor rule, as described below, is considered as the reaction function of the monetary authority to variation in the macroeconomic scenario:

$$i_t = \max(v_t, 0) \tag{4.5}$$

where,

$$v_t = \gamma_0 + \alpha\pi_t + \beta y_t + \gamma_1 i_{t-1} + \gamma_2 i_{t-2} + \eta_t \tag{4.6}$$

and, η_t = policy exploration noise, is assumed to follows a standard normal distribution with mean zero and variance unity.

γ_0, γ_1, γ_2, β, α_1 are parameters of the model. The lagged values of the interest rate in the Taylor rule equation show the central bank's intention to smooth out fluctuations in interest rates over time and give the system some inertia (as described in Chapter 3). Therefore, $(\gamma_1 + \gamma_2)$ represents the degree of interest rate smoothing. The representation of the policy function satisfies the ZLB criterion. The ZLB condition is incorporated in this policy function in order to avoid unnecessary computation and thus improving the speed of computation, and restricting policy rate to only economically viable numbers, specifically for Indian economy. As specified in the last chapter, the RBI is currently following an inflation targeting strategy with an inflation target of 4% with an upper and lower tolerance limit of ±2%.

Secondly, an asymmetric monetary policy rule can be represented by Equation 4.5 with v_t illustrated as follows:

$$\begin{aligned} v_t = I_t\{\gamma_{10} + \alpha_1\pi_t + \beta_1 y_t + \gamma_{11} i_{t-1} + \gamma_{12} i_{t-2}\} + \\ (1 - I_t)\{\gamma_{20} + \alpha_2\pi_t + \beta_2 y_t + \gamma_{21} i_{t-1} + \gamma_{22} i_{t-2}\} + \eta_t \end{aligned} \tag{4.7}$$

and, $I_t = 1$ if $x_{t-d} > \tau$ and 0 otherwise, and x_{t-d} is the magnitude of the threshold variable with delay of periods d. In this study, we assume $d = 1$. The essential feature of the equation is that, there are two linear segments for the Taylor rule. If $\gamma_{10} = \gamma_{20}$, $\alpha_1 = \alpha_2$, $\beta_1 = \beta_2$, $\gamma_{11} = \gamma_{21}$ and $\gamma_{12} = \gamma_{22}$ the policy function becomes the standard Taylor rule policy function without asymmetric behaviour.

The Loss Function: The standard quadratic loss function (or negative of reward function) for a monetary authority is used in this study to represent the loss function of the monetary authority. The mathematical structure of the loss function is represented as bellow:

$$\ell_t = \left[\omega_\pi(\pi_{t+1} - \pi^*)^2 + \omega_y y_{t+1}^2\right] \tag{4.8}$$

Where, π^* is the targeted rate of inflation. As demonstrated by Debortoli et al. (2019), we choose equal weights for inflation deviation from its target level and output gap in this study, i.e., $\omega_\pi = \omega_y = 0.5$. Future research could consider alternative structure of the loss functions. There is a separate literature on designing loss function for central banks. The methodology illustrated in this study can be implemented with different structure of the loss function with varying magnitude of weights for output gap and inflation. In this context, it should be mentioned that, in order to check the robustness of the results of this study, we re-estimated the policy function with alternative magnitude of weights indicating two different scenarios, i.e., (a) Scenario I: $\omega_\pi = 0.75$ and $\omega_y = 0.25$, (b) Scenario II: $\omega_\pi = 0.25$ and $\omega_y = 0.75$.

The objective function of the central bank is considered as the present discounted value of future flow of loss ($\mathcal{L}_t$) which can be represented by following equation:

$$\mathcal{L}_t = \sum_{i=1}^{T} \delta^i \ell_i \tag{4.9}$$

where, δ representing the discounting factor. The monetary authority tends to adjust the policy coefficients in an optimal way in order to minimize $\mathcal{L}_t$. For any value of the discounting factor (less than unity), distanced losses contribute marginally toward $\mathcal{L}_t$. Therefore, estimate of $\mathcal{L}_t$ for any *T*, representing the time horizon, which is reasonably large, should be considered as a good approximator of the infinite horizon reward function. This study using $\delta = 0.997$ and $T = 1000$.

The estimated value of the parameters of the policy function using the above-mentioned methodology considered as the optimal policy parameters in this study. The study allows both symmetric as well as asymmetric policy regimes. In this study, the magnitudes of the threshold variable (τ) is considered to be equal to the inflation target level (i.e., 4%).

The methodology explained above implemented for 1000 iterations for both symmetric as well as asymmetric policy regime to explore the variation in the estimated parameters in different iterations. The estimated results are summarized in the result section (i.e., Section 4.5).

The optimization technique used in this study driven by an algorithm suggested in Nelder and Mead (1965). Although the algorithm is relatively slow, but its robust and commonly used in a number of most popular scientific programming languages. Finally, like any other optimization algorithm, it also requires initial values for the parameters to be optimized over, i.e., a specific parameter values to start with. The coefficient from estimated Taylor rules of previous chapter (i.e., Chapter 3) is being used in this study as the starting points, both for symmetric as well as asymmetric policy functions.

4.4 Data

This chapter utilizes the same set of variables, i.e., inflation, output gap and policy rate; and the methodology to compute those variables as of last chapter (i.e., Chapter 3). Although, this chapter uses a marginally different time horizon. To be specific, in this chapter we are using same time horizon as that of Chapter 3 excluding the COVID period, i.e., from 2001Q2 to 2019Q4. Such exclusion was necessary to remove outliers from the dataset.

4.5 Result

This section initiates with presenting the fit of the estimated results of the representative economy, i.e., dynamic linear regression and ANN respectively. The relative effectiveness of different policy regimes is going to be discussed in the later part of this section. Table 4.1 summarizes the estimated results for the dynamic linear regressions.

The Durbin-Watson test statistic corresponding to both the models for both the variables indicates that, error terms are serially uncorrelated. The result also indicates that, for both the variables, the model with single lag order of the explanatory variables is the most parsimonious one. This particular finding is in line with the results of Hinterlang and Tänzer (2021). For inflation as the explanatory variable, model with single lag order outperforms the other model in terms of the MAPE as well. For output gap as the explanatory variable, model with single lag order outperformed by the model with two lag orders in terms of the MAPE by a small margin. Finally, all the dynamic linear regression models yield a good fit with the given dataset, indicated by the value of Adjusted R^2, which is approximately equal to 70% and 62% for inflation and output gap respectively.

Table 4.1: Estimated results of the dynamic linear regressions

Independent Variables		Dependent Variable			
		Inflation		Output Gap	
		Model 1	Model 2	Model 1	Model 2
Intercept		2.068**	2.175*	407.764***	444.207***
Inflation	Lag 1	0.825***	0.890***	3.756	-22.319
	Lag 2		-0.077		28.724*
Output Gap	Lag 1	0.001**	0.001	0.786***	0.780***
	Lag 2		-0.001		-0.046
Policy Rate	Lag 1	-0.169	0.138	-63.805***	-3.716
	Lag 2		-0.314		-67.091
Adjusted R^2		0.695	0.691	0.625	0.627
MAPE (%)		21.0	21.1	119.6	97.7
F-statistic		53.60***	26.32***	39.35***	20.09***
DW-statistic		1.78	1.99	1.72	1.80

Note: *, **, and *** denote statistical significance at the 10%, 5% and 1% levels, Model 1 and 2 indicating estimated transition equation with single lag and two lag respectively.

Table 4.2 summarises the MAPE of ANN models corresponding to inflation and output gap. It shows that, the best ANN model fit for inflation and output gap as the dependent variable are Model 2 and Model 1 respectively. But at the same time for output gap, dynamic linear model out-perform the ANN model based on MAPE criterion. On the other hand, in case of inflation, the ANN result out-perform the result from dynamic linear regression by a very small margin. Unfortunately, all the estimated models to forecast output gap perform poorly with respect to its prediction power, as demonstrated by MAPE (Table 4.1 and 4.2).

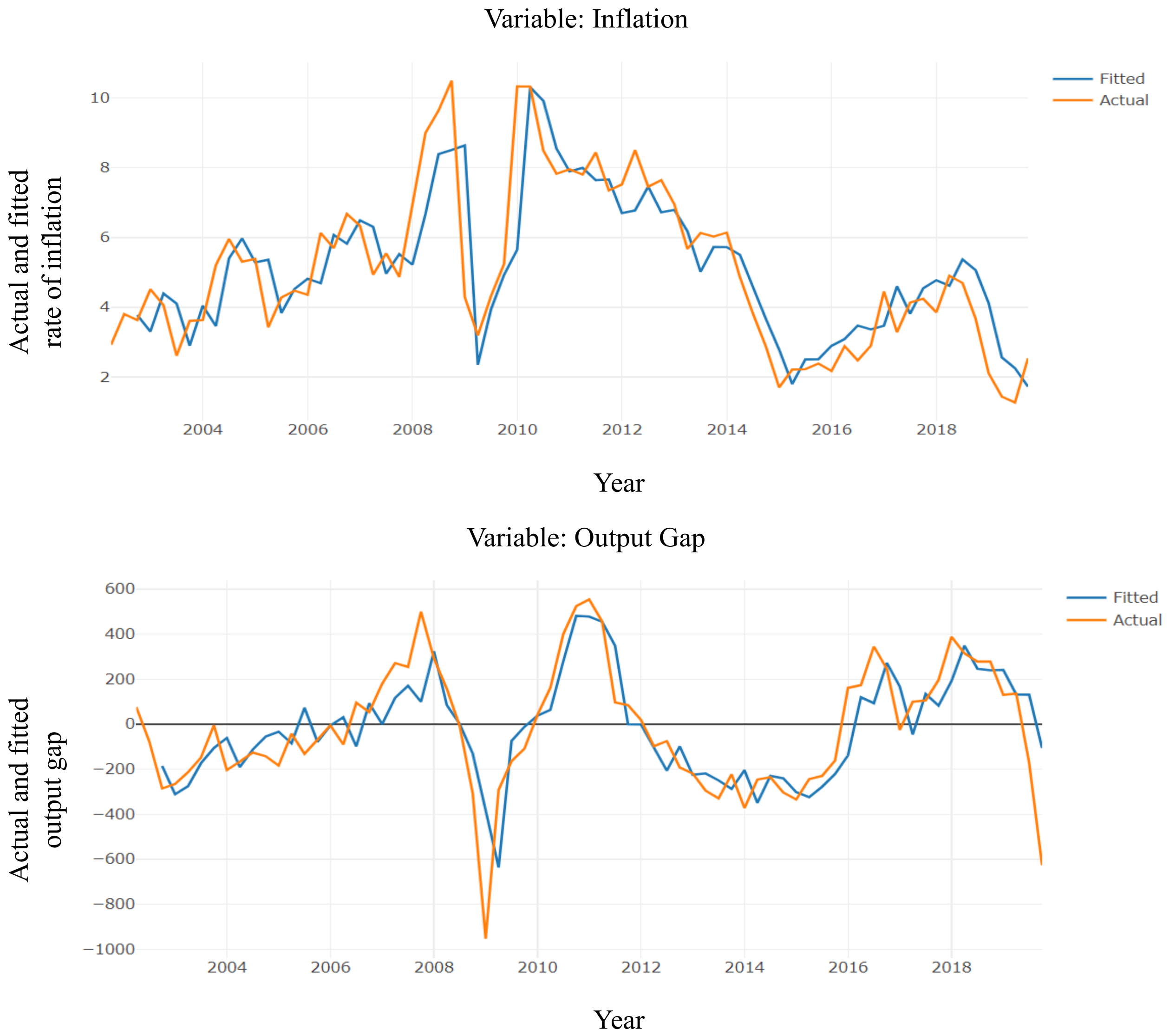
Table 4.2: The ANN Model Fit (MAPE in Percentage)

Dependent Variable	Models	
	Model 1	Model 2
Inflation	19.7	18.7
Output Gap	175.8	247.5

Note: Model 1 and 2 indicating estimated transition equation with single lag and two lag respectively.

Estimated results reflected in Table 4.1 and 4.2 can be used to argue that, the dynamic linear regression models are clearly a better choice for considering as the forecasting structure for output gap. On the other hand, the above-mentioned tables also suggest, with a very marginal sacrifice with respect to power of prediction, the dynamic linear regression model can be used as the forecasting structure for inflation, which is easily understandable relative to the ANN model. The Table 4.1 also suggests that, the models with a single lag of the variables as the explanatory variable is the relatively parsimonious model, since sacrifice of goodness of fit is not substantial enough with respect to the other model which includes greater number of explanatory variables. Therefore, finally, to create the external environment to the RBI, we use the estimated dynamic linear regression models (i.e., Model 1 in Table 4.1) for both inflation and output gap. The fitted results are given in the Figure 4.1.

Figure 4.1: Fitted Model



Note: This figure shows the fitted and actual values of inflation ad output gap (measured along the vertical axis) over the chosen time horizon (along the horizontal axis), i.e., from 2001Q2 to 2019Q4.

Table 4.3 and Figure 4.2 demonstrated the expected log of reward, i.e., $log(R_t)$, under symmetric and asymmetric monetary policy reaction functions respectively. The estimated result clearly demonstrated that, optimized reaction function under asymmetric policy rule outperforms optimized standard symmetric policy rule with respect to inflation and output gap. In addition to that, the result also shows, log value of expected social loss under symmetric and asymmetric policy rule are marginally deviates from each other with a significant overlapping region. Therefore, if optimized, the RBI can achieve similar level of social loss using either of the reaction function. In this context, choice of structure of the reaction function largely depends on central banks' preference over policy consistency and encouraging economic activity. It can be explained using the results demonstrated in Table 4.4 and Figure 4.3.

Table 4.3: Expected Loss

	Symmetric Policy Regime			Asymmetric Policy Regime		
	Median	Percentiles 5%	Percentiles 95%	Median	Percentiles 5%	Percentiles 95%
$log(\mathcal{L}_t)$	14.403	13.728	14.559	13.854	13.695	14.190

Figure 4.2: Distribution of expected loss under different policy regime

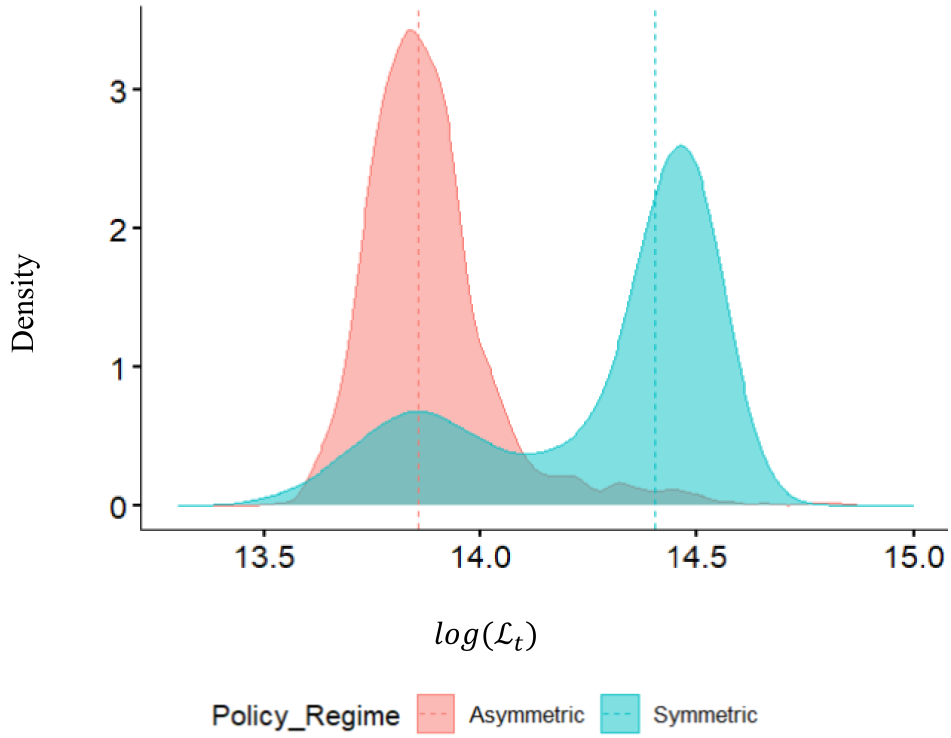


Table 4.4 shows the exact specification of the optimal monetary policy function for the RBI under symmetric as well as asymmetric policy regime. The estimated result suggests a number of key observations. These findings are illustrated as follows:

1. The bias term of the policy function (γ_0) under asymmetric policy response should be close to zero when realized inflation exceed its threshold level (i.e.,

$\pi_{t-1} > \tau$). The bias should be positive for both symmetric policy response and asymmetric policy response during periods when inflation does not exceed the threshold level (i.e., $\pi_{t-1} \leq \tau$)

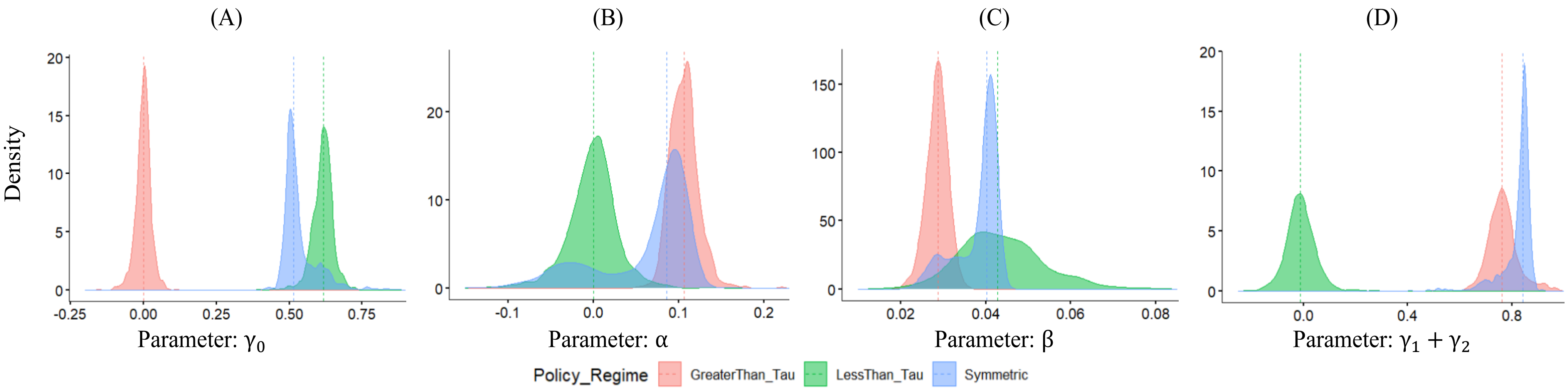
2. A greater emphasis on interest rate smoothing (indicated by $\gamma_1 + \gamma_2$, the degree of interest rate smoothing) should be given under symmetric monetary policy regime. As far as asymmetric reaction function is concerned, interest rate smoothing should not be considered by the policy makers while setting policy rate when inflation rate is less than the target level of 4%. On the other hand, it should be emphasised when realized inflation is more than the target level.
3. As expected, for usual symmetric policy function, rising price level should be followed by contractionary monetary policy. For asymmetric policy regime, monetary policy response should remain neutral or irresponsive to change in inflation rate if it is less than the target level. But if $\pi_{t-1} > \tau$, the contractionary policy response of the RBI should be sharper than in case of symmetric policy.
4. Finally, the monetary authority should always consider stabilization of output gap, irrespective of policy regime. However, the emphasis on output gap stabilization should be reduced if $\pi_{t-1} > \tau$ under asymmetric monetary policy regime.

Finally, the robustness checks mentioned in the methodology section yield similar findings (Table A4.1 and A4.2 in the Appendix of this chapter). In addition, the estimated policy functions corresponding to two possible scenarios (Scenario I and Scenario II) suggest almost similar parameter values, which are very close to the loss function with equal weights. The additive nature of the policy function possibly is the prime reason behind such results. Future research on this issue can consider loss functions with non-additive structures to test the robustness of the results of this study.

Table 4.4: Estimated Coefficients of Optimal Monetary Policy Rule

Coefficients	Symmetric Policy Regime			Asymmetric Policy Regime					
				$\pi_{t-1} > \tau$			$\pi_{t-1} \leq \tau$		
	Median	Percentiles		Median	Percentiles		Median	Percentiles	
		5 Percentile	95 Percentile		5 Percentile	95 Percentile		5 Percentile	95 Percentile
γ_0	0.515	0.479	0.648	0.001	-0.044	0.039	0.617	0.558	0.667
α	0.086	-0.051	0.110	0.106	0.083	0.134	0.000	-0.052	0.043
β	0.040	0.027	0.043	0.029	0.024	0.033	0.043	0.029	0.062
γ_1	1.047	0.809	1.088	0.847	0.820	0.869	0.458	0.382	0.575
γ_2	-0.205	-0.233	-0.072	-0.087	-0.151	0.022	-0.476	-0.529	-0.427

Figure 4.3: Distribution of the Estimated Coefficients of Optimal Monetary Policy Rule



4.6 Conclusion

This study is intended to introduce a machine learning based mechanism to identify optimal monetary policy response of central bank in the context of Indian economy. The study is focused primarily on Indian economy and conduct of the Reserve Bank of India over the period from 2001Q2 to 2019Q4. This study incorporates two distinct policy response functions, i.e., symmetric and asymmetric policy response functions. The study intended to compare the relative performance of symmetric and asymmetric policy response of the RBI. Our data set consists of quarterly values of seasonally adjusted implicit GDP Deflator, seasonally adjusted real GDP and repo rate. Repo rate is used in this study to represent the policy rate of the RBI. The Hodrick-Prescott (HP) filter is used to remove the trend and cyclical fluctuations from the real GDP and eventually the filtered series is subtracted from the original series to get the estimates of output gap.

This study utilizes the concept of a reinforcement learning (RL) based algorithm, i.e., Deep Deterministic Policy Gradient (DDPG) Algorithm, as suggested by Lillicrap et al. (2015), to identify the optimal parameter values of the policy response functions. An explicitly defined quadratic loss function is used in this study to specify the goal of the monetary authority. The methodology implemented for 1000 times for both symmetric as well as asymmetric policy regime to explore the variation in the estimated results in different iterations.

The methodology used in this study can be referred as an interactive exploration of the monetary policy authority with external macroeconomic environment. The general structure of the macroeconomic environment consists of a single agent, i.e., Central Bank, which interacts with an unknown environment E, receiving a vector of observations or signal x_t (which includes contemporaneous as well as lagged observations on inflation π_t and output gap y_t), takes an action i_t (i.e., the policy rate) and receives a reward $\mathcal{L}_t$. The environment can be viewed as a forecasting structure represented by a set of transition equations. Two algorithms are being utilized separately to estimate the transition equation system, i.e., dynamic linear regression model and the artificial neural network (ANN). However, after a few explorations we choose the estimated dynamic linear regression models to create the external environment to the monetary authority. The subsequent explorations in this study estimates the parameters of optimal monetary policy rule for both usual symmetric monetary policy regime and asymmetric policy response along with revealing a few interesting observations.

Firstly, the optimized reaction function under asymmetric policy rule marginally out-performs optimized standard symmetric policy rule in terms of social loss with significant overlapping region. Which indicates, monetary authority can achieve similar level of welfare using either of the reaction function. Secondly, a greater emphasis on interest rate smoothing should be given under symmetric monetary policy regime. As far as asymmetric reaction function is concerned, interest rate smoothing should not be considered by the RBI while setting policy rate when inflation rate is less than the target level of 4%. On the other hand, it should be emphasised when realized inflation is more than the target level. Thirdly, as expected, for usual symmetric policy function, rising price level should be followed by contractionary monetary policy. For asymmetric policy regime, monetary policy response should remain irresponsive to change in inflation rate if it is less than the target level. But if it exceeds the threshold, the contractionary policy response of the RBI should be sharper than in case of symmetric policy. Finally, the monetary authority should always consider stabilization of output gap, irrespective of policy regime. Although, the emphasis on output gap stabilization should be reduced if inflation exceeds its target level under asymmetric monetary policy regime.

There are numerous numbers of factors to consider when updating a central bank's monetary policy approach than are considered in this paper. Future research could therefore consider loss functions that incorporate several other relevant variables. While this chapter focuses on a reaction function for the repo, one might also consider reaction functions with respect to other monetary policy instruments. Adding more variables to expand the representation of the macroeconomic environment and the central bank's regulated variables should be the next step for further research, as dimensionality is not a cause of concern in case of the DDPG algorithm. Application of this algorithm in this context in practice requires updating all the elements of the algorithm (i.e., data, best fitted model to represent the environment and the structure of the policy function) on a regular basis. In order to check the robustness of the results of this study, we re-estimated the policy function with alternative magnitude of weights indicating two different scenarios in order to understand the robustness of the current results, which yield similar findings. In addition to that, the estimated policy functions corresponding to two possible scenarios (Scenario I and Scenario II) suggest almost similar parameter values, which are very close to the loss function with equal weights. The additive nature of the policy function possibly is the prime reason behind such a result.

Appendix

Table A4.1: Expected loss with varying weightages in the loss function

		Symmetric Policy Regime			Asymmetric Policy Regime		
			Percentiles			Percentiles	
		Median	5%	95%	Median	5%	95%
$log(\mathcal{L}_t)$	Scenario I	13.700	13.036	13.866	13.159	13.008	13.486
	Scenario II	14.808	14.101	14.964	14.265	14.085	14.603

Table A4.2: Estimated coefficients of optimal policy rule with varying weightages in the loss function

Coefficients	Symmetric Policy Regime		Asymmetric Policy Regime			
			$\pi_{t-1} > \tau$		$\pi_{t-1} \leq \tau$	
	Scenario I	Scenario II	Scenario I	Scenario II	Scenario I	Scenario II
γ_0	0.518	0.517	0.000	0.002	0.616	0.619
α	0.084	0.084	0.105	0.105	0.001	0.105
β	0.040	0.040	0.029	0.029	0.044	0.043
γ_1	1.045	1.046	0.846	0.847	0.456	0.455
γ_2	-0.204	-0.206	-0.093	-0.092	-0.477	-0.475

Chapter 5

Conclusion

This thesis intended to study three broad area of research in the field of macroeconomics: macroeconomic impact of monetary policy (i.e., Chapter 2), monetary policy response function (i.e., Chapter 3) and desirability or optimality of monetary policy response function (i.e., Chapter 4).

Chapter 2, investigates the impact of monetary policy on key macroeconomic variables for a set of advanced and EMEs. This study explores an unbalanced panel of ten EMEs and eleven advanced economies to understand the macroeconomic impact of monetary policy using a Panel VAR model. The impulse-response functions and the variance decomposition technique are used to address the areas of investigation of the study. In order to estimate the macroeconomic impact of monetary policy accurately, this study incorporates two more macroeconomic variables in the empirical model, i.e., oil price and fiscal policy shock. The oil price is part of this study to introduce a proxy for exogenous supply-side shocks and the presence of fiscal policy shock in the model helps us to compare the macroeconomic impact of fiscal policy and monetary policy shocks side-by-side. In addition to that, it helped us to evaluate the possible policy interactions.

The estimated PVAR equations reveal a number of noteworthy observations. Firstly, advanced economies are following some form of interest rate smoothing monetary policy rule. However, no such pattern can be identified for EMEs. Secondly, exogeneous oil price movement significantly influence monetary policy rule for both emerging as well as advanced economies. However, the direction and magnitude of impact differs. Thirdly, fiscal policy found to have significant impact on real output growth rate of EMEs. No such impact can be identified for advanced economies. Fourthly, movement in the output growth rate is significantly associated with oil price movement for both types of economies. Fifthly, monetary policy found to have desired directional impact on inflation for both advanced and emerging market economies. Similarly, for both types of economies, oil price movement found to have expected directional impact on inflation. However, strength or magnitude of impact is more in case of EMEs for both monetary policy and oil price shocks. Finally, for advanced economies fiscal policy found to remain unaffected by movement in any of the variables in the system. However, monetary policy does have significant impact on fiscal policy in case of emerging market economies.

The analysis of all the IRFs in this study suggests, the magnitude of impact of both monetary and fiscal policy on all the concerned variables are always greater in emerging economies relative to that of advanced ones. However, IRFs of the EMEs shows oscillatory behaviour. Finally, except impact of monetary policy impulse on inflation for advanced economies, none of the policy impulse on any other variable for no categories of country set (i.e., advanced and the EMEs) shows sign of persistence. All the results on IRF analysis are cross validated using the LOOCV technique. The LOOCV technique suggests the similar pattern in the IRFs, i.e., supports the results generated from estimated models on complete datasets. Finally, the FEVD is used to investigate the fraction of the fluctuations in the endogenous variables that is due to fiscal and monetary policy. The result suggests, unexplained variation in the policy rate explained a sizable amount of variation in the output growth rate and inflation in advanced economies. Similar cannot be said in case of emerging market economies. However, as far as fiscal policy is concerned, it is responsible for relatively greater proportion of variation in output growth in case of emerging economies than advanced ones. The opposite is true for inflation.

As far as monetary policy response function is concerned, Chapter 3 is dedicated to understand the structural form of the policy response function of the RBI. To be specific, it is a study to identify the presence of asymmetric behaviour of the RBI regarding the choice of policy rate. Over the last two decades, there have been major changes to the objectives, methodology, and instruments of the RBI's monetary policy. For example, the RBI is currently following a soft inflation targeting strategy with a CPI inflation target of 4% with an upper and lower tolerance limit of $\pm 2\%$. Along with the introduction of LAF from June 2000, the RBI is following some form of Taylor rule by adjusting policy rate to regulate short run macroeconomic fluctuations. Taylor rule is a representation of monetary policy rule in which the monetary authority changes the short-term interest rate in response to observable variations in inflation and output gap in the economy. The primary focus of this study is to check the existence of nonlinearity in RBI's Taylor rule equation, i.e., existence of asymmetry in the behaviour of the RBI using the TAR model.

Preliminary exploratory study of Chapter 3 supports the presence of nonlinearities in the preference of the RBI and thus support use of the TAR model to explore the preference pattern empirically with one period lag of inflation as the threshold variable. Estimated TAR models corresponding to a number of sub-samples suggests that, the estimated threshold level of lag of inflation always lies above the upper tolerance level of the inflation target, i.e., 6%.

In addition to finding the evidence supporting the presence of asymmetry in the response of the RBI, this study finds out a number of interesting results. Firstly, the RBI is more responsive to contemporaneous movements in output gap whenever inflation exceeds the threshold inflation level than otherwise. Secondly, The RBI is persistently following an interest rate smoothing policy. Thirdly, the study found no clear signal regarding responsiveness of policy rate with respect to change in inflation, i.e., sign, magnitude and statistical significance of concerned parameters varies across sub-samples. Finally, the study concludes by applying conventional recursive estimation technique. Post 2021Q2, the RBI becomes much more tolerant with respect to inflation, whereas, it responded sharply whenever inflation level crosses that increased tolerance or threshold level. Post 2021Q2, to control inflation beyond the estimated threshold level, the RBI compromised with interest rate smoothing behaviour.

The policy response function described in Chapter 3 can be re-estimated using other policy variables of the RBI, such as, reverse repo rate, bank rate, CRR, SLR, etc. In addition to that, different methodologies can be used to estimate the output gap, which further can be used to re-estimate the policy response function. Such studies can confirm the robustness of the current study.

The next chapter, i.e., Chapter 4, is dedicated to introduce a machine learning based mechanism to identify optimal monetary policy response of the RBI, and to understand the desirability of its asymmetric response to macroeconomic environment. This study compares the relative performance of two distinct policy response functions, i.e., symmetric and asymmetric policy response functions for the RBI using a RL algorithm, i.e., DDPG Algorithm, as suggested by Lillicrap et al. (2015), to identify the optimal parameter values of the policy response functions. An explicitly defined quadratic loss function is used in this study to specify the goal of the monetary authority. The methodology used in this chapter can be referred as an interactive exploration of the monetary policy authority with external macroeconomic environment. The general structure of the macroeconomic environment consists of a single agent, i.e., Central Bank, which interacts with an unknown environment, receiving a vector of observations or signal (which includes contemporaneous as well as lagged observations on inflation and output gap), takes a policy action and receives some reward. The environment can be viewed as a forecasting structure represented by a set of transition equations. The subsequent explorations in this study estimates the parameters of optimal monetary policy rule for both usual symmetric monetary policy regime and asymmetric policy response along with revealing a few interesting observations.

The exploratory study of Chapter 4 identifies a number of interesting results. Firstly, the optimized reaction function under asymmetric policy rule marginally out-performs optimized standard symmetric policy rule in terms of social loss with significant overlapping region. Which indicates, monetary authority can achieve similar level of welfare using either of the reaction function. Secondly, a greater emphasis on interest rate smoothing should be given under symmetric monetary policy regime. As far as asymmetric reaction function is concerned, interest rate smoothing should not be considered by the RBI while setting policy rate when inflation rate is less than the target level of 4%. On the other hand, it should be emphasised when realized inflation is more than the target level. Thirdly, as expected, for usual symmetric policy function, rising price level should be followed by contractionary monetary policy. For asymmetric policy regime, monetary policy response should remain irresponsive to change in inflation rate if it is less than the target level. But if it exceeds the threshold, the contractionary policy response of the RBI should be sharper than in case of symmetric policy. Finally, the monetary authority should always consider stabilization of output gap, irrespective of policy regime. Although, the emphasis on output gap stabilization should be reduced if inflation exceeds its target level under asymmetric monetary policy rule.

As far as Chapter 4 is concerned, there are numerous numbers of factors which can be incorporated in the model for updating the policy response function. Future research could therefore consider loss functions that incorporate several other relevant variables. While this chapter focus on a reaction function for the repo, one might also consider reaction functions with respect to other monetary policy instruments. Adding more variables to expand the representation of the macroeconomic environment and the central bank's regulated variables should be the next step for further research, as dimensionality is not a cause of concern in case of the DDPG algorithm. Application of this algorithm in this context in practice requires updating all the elements of the algorithm (i.e., data, best fitted model to represent the environment and the structure of the policy function) on a regular basis.

Results of Chapter 3 demonstrated the presence of asymmetry in the behaviour of the RBI. On the other hand, Chapter 4 shows that, the optimized reaction function under asymmetric policy rule marginally out-performs optimized standard symmetric policy rule in terms of social loss. Taking both the results together, we may conclude that, asymmetric policy response of the RBI for the given time horizon may not considered as opportunistic behaviour. On the contrary, such a behaviour can be considered as socially desirable. Such a finding clearly suggests and recommend extensive use of advanced computational techniques to identify the optimal policy response for the policy making bodies given the policy goals.

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