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Bhavesh Salunkhe
Anuradha Patnaik

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THE IMPACT OF MONETARY POLICY ON OUTPUT AND INFLATION IN INDIA: A FREQUENCY DOMAIN ANALYSIS

Bhavesh Salunkhe[1]
Anuradha Patnaik[2]

Abstract

In the recent past, several attempts by RBI in the form of tight money policy to control inflation have ended up slowing the growth process, provoking a prolonged discussion among the academicians and policy makers in India. There has been a wide consensus among economic thinkers that monetary policy should have a single objective of a low and stable inflation which can create a conducive environment for growth. In this backdrop, the present study uses the frequency domain causality approach developed by Lemmens *et al.*, (2008) to test the causal relationship between a narrative monetary policy index (MPI) and inflation; and MPI and output in India for the sample period January 2008 to June 2015. Since the output gap is one of the determinants of future inflation, an attempt has been made to analyse the relationship between output gap and inflation in India in the frequency domain. The study found the bi-directional causality between MPI and inflation; and the unidirectional causality between MPI and output. While the casualty from MPI to inflation was significant only in the short to medium run, the causality from MPI to output was found to be significant across all time horizons. It was also found that the output was more sensitive to monetary policy shocks than inflation. Furthermore, the bidirectional causality between MPI and Inflation denotes that the monetary policy was responding more to inflation than the output. The output gap and inflation relationship was found to be positive as reported in earlier studies. Furthermore, the output gap causes inflation only in the short to medium run.

***Key Words*: Granger Causality, Frequency Domain, Monetary Policy, Output gap.**

***JEL Codes*: C32, E52, E58**

[1] Junior Research Fellow, Department of Economics (Autonomous), University of Mumbai, Mumbai.
Email: bhaveshsalunkhe@gmail.com (corresponding author)

[2] Assistant Professor, Department of Economics, University of Mumbai, Mumbai.
Email : Dr.A.Patnaik75@gmail.com

1. INTRODUCTION:

The growth-inflation trade-off and the role of monetary policy has provoked a prolonged debate among policy makers and academicians in India (Mohanty, 2013). This is because low growth and high inflation have been seen to be coexisting for a considerable period of time. The conventional economic theory suggests that a low inflation would help accelerate the real growth of the economy by stimulating overall consumption and investment. As a result, there has been a wide consensus among economic thinkers that the monetary policy should have a single objective of a low and stable inflation so that by anchoring the inflation expectations in a desired way, the monetary policy can create a conducive environment for growth (Rajan and Prasad 2008).

However, in the recent past it has been observed that the several attempts by the RBI in the form of tight money policy, though, failed to contain inflation, eventually ended up slowing the growth process. Thus, the persistently high inflation along with a low growth has become a puzzle for monetary authorities in India (Mohanty, 2013). At this point, it is important to note that inflation inflicts a real cost on the economy, as its major burden is borne by the poor which eventually leads to distributional inequalities (Mohanty, 2013, 2014).

The famous Phillips curve (Phillips,1956) depicted the short term direct relationship between inflation and growth *i.e.*, high growth is accompanied by high inflation. However, persistently high inflation beyond a particular threshold level could pose serious challenges to growth in the long run (Mohaddes & Raissi, 2014). The Phillips curve also implies a positive link between the output gap and inflation. It is important to note that along with the level of output gap, a change in the output gap also affects the inflation.

Monetary policy decisions are based on different indicators that provide vital information on the prospects of future inflation and output growth. The output gap can be used as one of the indicators of inflation for monetary policy. The important task for policy makers, therefore, is to study the link between the output gap and inflation and thereby ensure the required changes in policy rates. Against this backdrop, the present study uses the frequency domain Granger Causality approach developed by Lemmens *et al.*, (2008) to primarily test the impact of monetary policy on output and inflation, and then analyse the relationship between the output gap and inflation in India, which will provide essential information regarding the prevailing output gap and inflation dynamics in India.

The present study differs from earlier studies on the following counts:1) Lemmens *et al.*, (2008) frequency domain Granger Causality method is being used for the first time to test the effectiveness of monetary policy in India.2) The narrative monetary policy index has been constructed by the authors which is different from the earlier studies (Romer & Romer (1989), Brunner & Meltzer (1989), Bhattacharya & Ray (2007), and Patnaik (2010)) with respect to the changed operating procedure of monetary policy during the sample period under consideration. The rest of the paper is organised as follows: Section 2 reviews the literature, section 3 analyses the trend in variables under the study, the data sources & the scheme of empirical estimation is given in section 4, whereas section 5 comprises the methodological aspects, section 6 briefs about the results of empirical estimation and their analysis, and finally, section 7 concludes.

2. THE REVIEW OF LITERATURE:

The review of literature in this paper has been divided into two sub sections. The first section comprises of the existing theoretical literature on the output gap and inflation *i.e*., the Phillips curve relationship in India and the impact of monetary policy on inflation and output in India, whereas the second section reviews the existing literature on the Granger causality in frequency domain.

2.1.1 Output gap and inflation: A literature review

The conventional economic theory suggests a positive relationship between the output gap and inflation as summarized in the Phillips curve (Phillips,1956). The output gap is defined as deviation of the actual output from its potential level, where potential output is the level of output at which the rate of inflation is stable given the productive stock of the capital. The potential output demonstrates the supply side of the economy in the form of the level of production at normal utilization of factors of production given the current state of technology. The potential output is thus determined by the availability of factors of production and technological progress. Since the prices are sticky in the short run, the demands shocks provoke the supply reaction causing the actual output to differ from its potential level. A persistent positive output gap (real output above potential level) indicates a mounting inflationary pressures due to excess demand in the economy, which in turn necessitates a tight monetary policy to smoothen the aggregate demand pressures. Conversely, a negative output gap (real output below potential level) denotes deflationary pressures in the economy, as aggregate supply exceeds demand, that necessitates an easy monetary policy to fuel the aggregate demand. Therefore, the output gap provides an essential signal to monetary policy. Like the ups and downs in the GDP growth, the output gap also can move either in positive or negative direction which is undesirable. The output gap suggests that the economy is working in an inefficient mode either overusing or underusing its resources. Since the output gap is one of the significant determinants of inflation, it has immediate implications to monetary policy. During the different phases of business-cycles, the output gap would be different, provoking a prompt response from monetary authorities. In an inflation targeting framework, a negative output gap indicating a fall in the actual output below its potential (full capacity) level, would result into a deflationary pressure on prices. The Central Bank, under given circumstances, will have to stop inflation from falling below the target level by lowering interest rates to push the aggregate demand up, which would eventually lead to a higher growth in the output. Similarly, the opposite case would happen when the output gap is positive, which builds upward pressure on prices. Hence, the central bank will have to change the stance of monetary policy eyeing the deviations of the actual output from the potential output. Since potential output and the output gap are unobservable directly, they are estimated from the given data.

It is important to note that researches in Indian context find asymmetric relation between the output gap and inflation. The existing literature suggests two contradictory views regarding the existence of Phillips curve or a positive relationship between the output gap and inflation. The one group of studies shows that the positive relationship between the output gap and inflation as depicted in the Phillips curve does exist in India (Paul (2009), Singh, Kanakaraj, & Trivedi (2011), Mazumder (2011), Seth & Kumar (2012)).

In the other group of studies, Bhalla (1981**)**, found no relationship between the output gap and inflation, whereas some other studies depict the evidence of a negative relationship between the output gap and inflation which is in contrast to the conventional economic theory Phillips curve (Rangarajan 1983), Bhattacharya and Lodh (1990), Callen and Change (1999). Furthermore, Brahmananda and Nagaraju (2002) found a negative correlation coefficient for inflation and output growth. Virmani (2004) analysing the different methods of calculating the output gap for India found a negative relationship between the output gap and inflation in one of the outcomes. The above mentioned literature provides mixed views regarding the output gap and inflation relationship in India.

2.1.2 Monetary policy, output and inflation: A literature review

The effectiveness of monetary policy is tested through its ability to achieve the final objectives of growth and price stability. There exists an extensive literature in India examining the impact of monetary policy on growth and inflation. An attempt has been made to test, empirically, the strength as well as effectiveness of each of the channels of monetary policy transmission, separately through different econometric techniques. However, the results are mixed.

Most of the studies analysing the impact of monetary policy either on aggregate demand or inflation and output demonstrate the evidence of a significant impact of monetary policy on output and inflation (Al-Mashat 2003, Aleem 2010, Mohanty (2012), Khundrakpam (2012, 2013). The tight monetary policy has a negative impact on growth and inflation, whereas the easy monetary policy has a positive impact. However, the transmission of monetary policy to the final objectives occurs with a lag. Khundrakpam & Jain (2012) estimates the impact of monetary policy on inflation and GDP growth by using SVAR model for the period 1996-97:Q1 to 2011:Q1. The study illustrates that the positive shock to the policy rate leads to slowdown in credit growth with a lag of two quarters, which eventually has a negative impact on GDP growth and Inflation. Kapur and Behera (2012) analyses the impact of monetary policy on the output and inflation during the period 1996:Q1 to 2011:Q4. They found the significant impact of monetary policy on output and inflation, but the impact on inflation was modest.

Nachane, Ray & Ghosh (2002) explores whether monetary policy has a similar impact across the states in India. They found that the core states *i.e*., the states with more concentration of manufacturing units and relatively well developed banking infrastructure tend to be more sensitive to monetary policy shocks than the others. Ghosh (2009), examining the response of India’s industrial output to monetary policy shocks, found that the impact of monetary policy shocks on industrial output differs across industries. In the same line, Singh and Rao (2014) examine the impact of monetary policy shocks on the output at aggregate level as well as sector-wise output level for the period 1996:Q1 to 2013:Q4. They found that the impact of monetary policy on the output differs across the sectors in the economy. Furthermore, the relevance of each channel of monetary transmission varies across the sectors. Thus, the study signifies the need for sector specific monetary policy in India.

In contrast to the studies mentioned above, Bhattacharya, Patnaik & Shah (2011) found a weak monetary policy transmission in India, in line with the other low income economies which have a weak and small financial sector. Their evidence show that interest rates do not affect aggregate demand. However, the study suggests that interest rates can impact inflation, in the presence of strong exchange rate pass-through.

From the existing literature one thing that strongly felt is that the monetary policy does have an impact on the output and inflation but with a lag. Furthermore, the impact of monetary policy is short lived, and it differs across the sectors of the economy.

2.2 Granger causality in frequency domain: A literature review

Peirce (1979) and Geweke (1982) proposed two alternative approaches for decomposing Granger Causality between twotime series over the spectrum. While Peirce (1979) decomposed an R- squared measure for time series at each frequency over the spectrum, Geweke (1982) suggested the spectral representation of a bi-variate Vector Autoregressive (VAR) model of time series. Later, Hosoya (1991) and Yao & Hosoya (2000) proposed various testing procedures for Geweke's spectral Granger Causality approach. Furthermore, Breintung and Candelon (2006) developed a simple testing procedure for causality across frequencies by imposing linear restrictions on the autoregressive parameters in a bivariate VAR framework. Recently, Lemmens *et al.* (2008) reconsidered the Peirce (1979) approach and developed a new non-parametric testing procedure for the same and compared the size and power properties of their test with that of Breintung and Candelon.

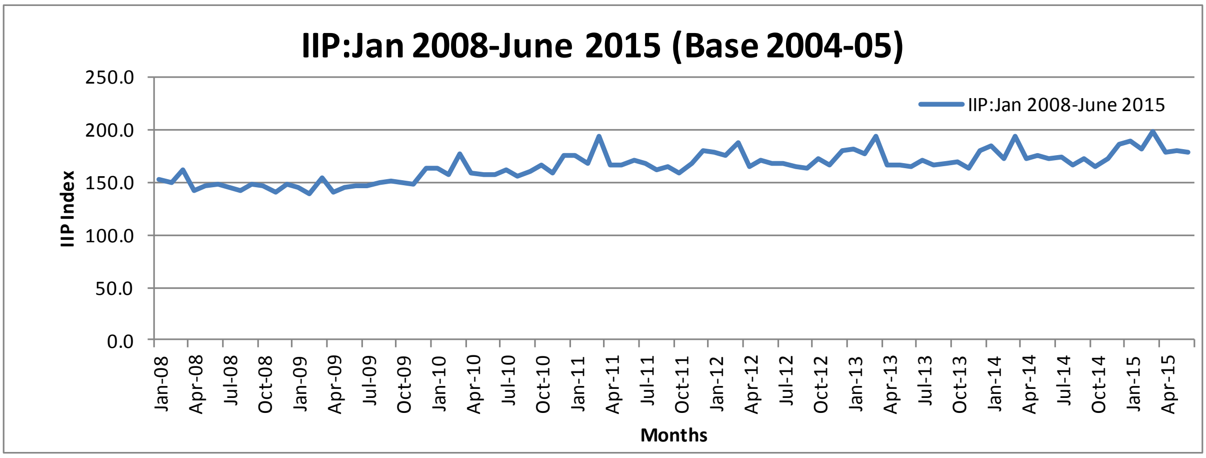
There are few studies in the Indian context which are based on the frequency domain analysis. Some of these are Nachane & Lakshmi (2001), Sharma, Kumar, & Hatekar (2010)), Tiwari (2012). Tiwari (2012), using the Lemmens *et al.*, (2008) approach, analyses the Granger causality in the frequency domain between producers' prices measured by WPI and consumer' prices measured by CPI during the period Jan 1957 to Feb 2009. The study provides the evidence of an unidirectional causality going from CPI to WPI for business cycles of 12 months and beyond and business cycles of two and less months. Also, the evidence of bidirectional causality between WPI and CPI was found for the business cycles of five and four months. Sharma, Kumar, Hatekar (2010) explore the causality relationship between money, output and prices for the period 1997 to 2009. Analysing the Granger causality in the Lemmens *et al.*, (2008) frequency domain setup, they found the unidirectional causality running from money supply (M3) to output (IIP) and Money supply (M3) to Prices (WPI). However, the money supply Granger causes the output only in short run, whereas the causality running from money supply to prices exists only at the business cycle frequencies. Nachane & Lakshmi (2001) applies evolutionary spectrum technique to study the time varying lag length and lag coefficients of monetary policy.

The present study attempt to test whether the different economic variable such as the output gap, monetary policy shocks, inflation, and economic activity (IIP) demonstrate causal relationships and if it is so, see whether the relationships exist only at low frequency (long term) cycles or at high frequency (short term) cycles.

3. TRENDS OF THE VARIABLES UNDER THE STUDY:

At this point, it is important to analyse the time series plot of the variables under investigation. Figure 1 shows the movements in the IIP series over a sample period.

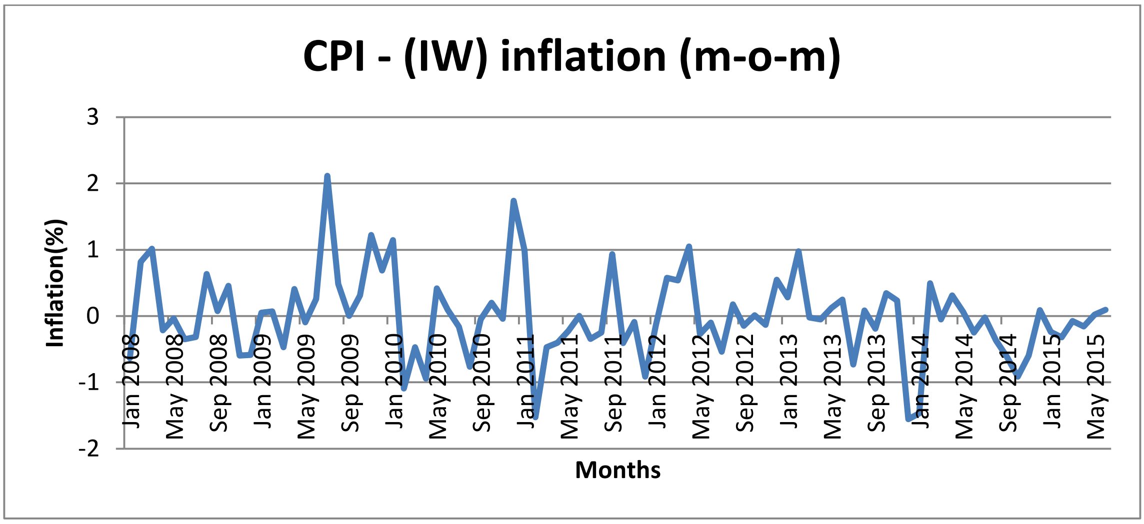
Figure 1: Index of Industrial Production (IIP) (2008-2015)



As it can be seen from the plot, the IIP index was almost stable for the first two years (2008 to 2009). In the post 2009 period, the IIP shows the upward trend. However, the growth seen in the IIP post 2009 is negligible, which confirms the subdued performance of the economy in that period.

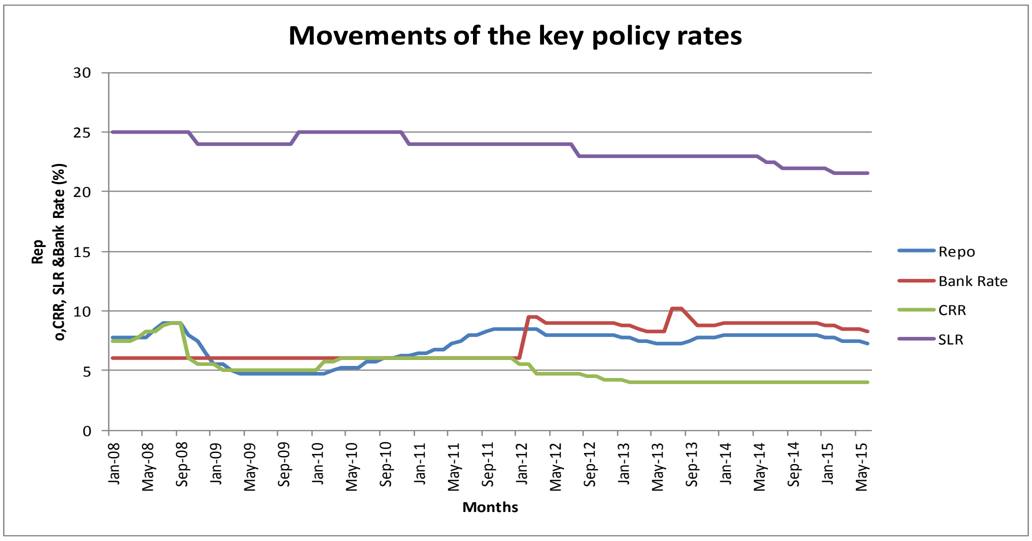
Similarly, figure 2 depicts the path of CPI (IW) inflation (m-o-m) for the period under study. As it can be seen in figure 2, the month-on-month CPI-IW inflation was the highest in mid 2009 period. On few occasions, the prices have actually fallen as shown by the negative inflation. However, for most of the months, the inflation is in positive zone.

Figure 2: CPI-(IW) inflation (Jan 2008-June 2015)



To analyse the monetary policy stance over the period under study, it is essential to see the plot of the key monetary policy variables over a period of time. Figure 3 provides an overview of the movements of the repo rate, Bank rate, CRR and SLR for Jan 2008 to June 2015.

Figure 3: Movements of the policy variables (Jan 2008-June 2015)



The CRR and SLR have been reduced over a period of time indicating an accommodative stance of monetary policy. However, the bank rate was constant for the first few years, but shows a sharp rise in Jan 2012 and remains almost stable thereafter except the rise again during May 2013 to October 2013 period, which was a period of high volatility in the financial markets in India. Finally, the repo rate, the key monetary policy rate signalling policy stance today, signifies the expansionary monetary policy in the post 2008 financial crisis, but demonstrates a gradual tightening of monetary policy in the subsequent years as upward spiral in inflation posed a biggest risk to the consumers and investors.

Table 1. Changes in Repo, Bank rate, CRR, and SLR (Jan 2008-June 2015)

Effective date	Repo Rate	Bank Rate	CRR	SLR
26-04-2008	7.75	6	7.75 (+ 0.25)	25
10-05-2008	7.75	6	8 (+0.25)	25
24-05-2008	7.75	6	8.25 (+0.25)	25
11-06-2008	8 (+0.25)	6	8.25	25
25-06-2008	8.5 (+0.5)	6	8.25	25
05-07-2008	8.5	6	8.5 (+0.25)	25
19-07-2008	8.5	6	8.75(+0.25)	25
30-07-2008	9 (+0.5)	6	8.75	25
30-08-2008	9	6	9 (+0.25)	25
11-10-2008	9	6	6.5 (-2.5)	25
20-10-2008	8 (-1.0)	6	6.5	25
25-10-2008	8	6	6 (-0.5)	25
03-11-2008	7.5 (-0.5)	6	6	25
08-11-2008	7.5	6	5.5 (-0.5)	24 (-1)
08-12-2008	6.5 (-1)	6	5.5	24
05-01-2009	5.5 (-1.0)	6	5.5	24
17-01-2009	5.5	6	5 (-0.50)	24
05-03-2009	5 (-0.50)	6	5	24
21-04-2009	4.75 (-0.25)	6	5	24
07-11-2009	4.75	6	5	25 (+1)
13-02-2010	4.75	6	5.5 (+0.50)	25
27-02-2010	4.75	6	5.75 (+0.25)	25
19-03-2010	5 (+0.25)	6	5.75	25
20-04-2010	5.25 (+0.25)	6	5.75	25
24-04-2010	5.25	6	6 (+0.25)	25
02-07-2010	5.5 (+0.25)	6	6	25
27-07-2010	5.75 (+0.25)	6	6	25
16-09-2010	6 (+0.25)	6	6	25
02-11-2010	6.25 (+0.25)	6	6	25
18-12-2010	6.25	6	6	24 (-1)
25-01-2011	6.5 (+0.25)	6	6	24
Effective date	Repo Rate	Bank Rate	CRR	SLR
17-03-2011	6.75 (+0.25)	6	6	24

03-05-2011	7.25 (+0.50)	6	6	24
16-06-2011	7.5 (+0.25)	6	6	24
26-07-2011	8 (+0.50)	6	6	24
16-09-2011	8.25 (+0.25)	6	6	24
25-10-2011	8.5 (+0.25)	6	6	24
28-01-2012	8.5	6	5.5 (-0.50)	24
13-02-2012	8.5	9.5 (+3.5)	5.5	24
10-03-2012	8.5	9.5	4.75 (-0.75)	24
17-04-2012	8 (-0.50)	9 (-0.5)	4.75	24
11-08-2012	8	9	4.75	23 (-1)
22-09-2012	8	9	4.5 (-0.25)	23
03-11-2012	8	9	4.25 (-0.25)	23
29-01-2013	7.75 (-0.25)	8.75 (-0.25)	4.25	23
09-02-2013	7.75	8.75	4 (-0.25)	23
19-03-2013	7.5 (-0.25)	8.5 (-0.25)	4	23
03-05-2013	7.25 (-0.25)	8.25 (-0.25)	4	23
15-07-2013	7.25	10.25 (+2.25)	4	23
20-09-2013	7.5 (+0.25)	9.5 (-0.75)	4	23
07-10-2013	7.5	9 (-0.50)	4	23
29-10-2013	7.75 (+0.25)	8.75 (-0.25)	4	23
28-01-2014	8 (+0.25)	9 (+0.25)	4	23
14-06-2014	8	9	4	22.5 (-0.50)
09-08-2014	8	9	4	22 (-0.50)
15-01-2015	7.75(-0.25)	8.75 (-0.25)	4	22
2-0202015	7.75	8.75	4	21.5 (-0.50)
04-03-2015	7.50 (-0.25)	8.5 (-0.25)	4	21.5
02-06-2015	7.25 (-0.25)	8.25 (-0.25)	4	21.5

Source: RBI's database on Indian economy

The table 1. summarizes the changes in monetary policy variables along with their dates of announcement. It is clear from the table that the repo rate was changed 32 times, bank rate and CRR were changed 14 times and 18 times, respectively, whereas the SLR was changed only four times. Hence, the repo rate is the most actively used monetary policy instrument in India, followed by CRR.

4. DATA SOURCES AND SCHEME OF EMPIRICAL ESTIMATION:

The present study primarily analyses the causality between Monetary Policy Index (MPI) & inflation; and MPI & output, and then the causality between the output gap & inflation by using the frequency domain causality approach developed by Lemmens *et al.*, (2008). The month-on-month CPI (IW) inflation is taken as a proxy for overall inflation, whereas the log transformed Index of Industrial Production (IIP) denotes the output. The study uses a monthly frequency data for the period January 2008 to June 2015. The data for IIP has been sourced from the Central Statistics Office (CSO), whereas on the various monetary policy instruments (Repo, Bank rate, CRR, SLR) and CPI-IW have been obtained from the RBI's Database on Indian Economy.

The empirical estimation under the study involves the following steps:

I. Testing the data for stationarity.
II. Constructing the narrative monetary policy index.
III. Calculating the output gap.
IV. Granger Causality test- Frequency domain analysis.

5. METHODOLOGY:

5.1 Construction of a narrative monetary policy index:

To examine the impact of monetary policy on output and inflation, the study uses a narrative monetary policy approach. Romer & Romer (1989) propounded "a narrative approach" to measure shifts in the stance of monetary policy in the U.S. The same idea was later extended by Brunner & Meltzer (1989) by constructing a monetary policy index. In the Indian context, Bhattachrya & Ray (2007) and Patnaik (2010) constructed the same monetary policy index in their respective analysis. A monetary policy index depicts a numerical scale which capture the stance of monetary policy as deduced from policy documents. It includes the mapping of policy related announcements to on a quantitative scale by assigning a number indicating a magnitude of easing or tightening of monetary policy stance. Tracking monetary policy in this way over a period of time would give us a time series values describing different phases of expansionary, contractionary, and a neutral monetary policy. In the present study, the index was formed using the four monetary policy tools namely, the repo rate, the bank rate, a Cash Reserve Ratio (CRR), and the Statutory Liquidity Ratio (SLR). If all four were reduced (easy monetary policy), then the index takes the value 4, if any three were reduced it takes the value 3, if any two were reduced it takes the value two, and if only one were reduced it takes the value 1. Similarly, if all four were hiked, the index takes the value (-4), if any three were hiked the index takes the value (-3), if any two were increased the index takes the value two, if any one was increased the index takes the value (-1). Hence, the index eventually ranges between -4 and 4. Table 1, summarizes the key monetary policy announcements regarding the Repo rate, Bank rate, CRR & SLR. On the basis of those announcements, the narrative monetary policy index has been constructed for Jan 2008 to June 2015 (see the table 4). The operating procedure of monetary policy in India has evolved over a period of time. On May 2011, the RBI put in place a new operating procedure of monetary policy, wherein the weighted average overnight call money rate was accepted as the operating target of monetary policy. The new operating procedure announced the repo rate as a single independently varying policy rate which would signal the policy stance. It also introduced a marginal standing facility (MSF) for scheduled commercial banks. Since the MSF was introduced only from 2011, and our sample period starts from 2008, the narrative monetary policy index constructed here doesn't include the MSF. It includes only those instruments which are common to both pre and post period of the change in operating procedure of monetary policy in India. This helps us to hedge against the possible threat of structural break in the data.

5.2 Hodrick-Prescott Filter to derive the output gap:

Since potential output and the output gap are unobservable directly, they are estimated from the given data. There are number of methods applied to estimate the potential output and the output gap. Measures of the output gap are derived from different statistical and the structural techniques such as Hodrick-Prescott Filter (1997), Kalman Filter, Production function approach etc. The statistical methods use the "statistical" criteria to decompose the output data into cyclical and trend components, where the output gap is measured as the difference between the actual output and the underlying trend. The HP filter is one of the popular statistical techniques which are used to measure the output gap. It decomposes the output in a long run trend and cyclical components. The trend is interpreted as a measure of the potential output, whereas the cyclical components measure the output gap. This statistical method does not use any inputs regarding the determinants of each of the components. The present study uses the Hodrick-Prescott (H-P) filter to calculate the output gap. The HP filter is a pure statistical technique and suffers from major limitations. One of the major limitations of this filter is an arbitrary choice of λ, a smoothing parameter which determines the variance of the trend output estimate. Since the data used in the present is of monthly frequency, the λ has been set to be equal to 129,600.

5.3 Granger causality in frequency domain:

Granger (1969) developed a time series data based approach to test the causal relationship between variables in econometric models. According to the approach a variable X Granger causes variable Y if variable Y can be better predicted using the past values of both X and Y than it can be predicted using the past values of Y alone. To understand the link between economic variables, studying the pattern of causality in different time horizon becomes important. Since a stationary series is the sum of uncorrelated components, each component can be represented by a single frequency ordinate. Hence, it is possible to decompose the full causal relationship by frequency.

In the frequency domain, a stationary process can be expressed as a weighted sum of sinusoidal components with a certain frequency. These frequency components can be analysed separately as quickly moving components representing short term movements and slowly moving components denoting long term movements (Lemmens, Croux, & Dekimpe ,2008). Furthermore, the analysis of a time series in the frequency domain *i.e.*, a spectral analysis could provide information supplementary to the one obtained through the time domain analysis (Granger, 1969; Priestley, 1981). The extent and direction of causality can differ between the frequency bands (Granger & Lin, 1995). The conventional time domain causality approach fails to account for the possibility of changing extent and direction of causality between frequencies (Lemmens *et.al.,* 2008). Also, decomposing Granger Causality (GC) over the spectrum helps to understand possible different Granger Causality relationships across different frequencies. Granger (1969) also suggested that a spectral density approach would provide a better-off and a more complete picture than a one shot GC measure which is applied across all periodicities (*e.g.,* in the short run, over the business cycle frequencies, and in the long run). Hence, instead of computing a single one shot Granger causality (GC) measure for the full causal relationship, the GC is calculated for each individual frequency separately, thus, helping us to decompose the GC in the frequency domain.

On the backdrop of this, the present study uses the Lemmens *et al*., (2008) Granger Causality (GC) approach to analyse the causality between the narrative Monetary Policy Index (MPI) & inflation; and MPI & output and the causality between the output gap and inflation in the frequency domain. To proceed with the Lemmens *et al*., (2008) approach to calculate Granger

Causality (GC) measure, the autoregressive moving average (ARMA) filtered innovation series has been used for all the variables. The lag length incorporated into the analysis has been selected as M=$\sqrt{T}$ (Diebold, 2001). The study follows Shrama, Kumar & Hatekar (2010), Tiwari (2012) and Hatekar & Patnaik (forthcoming), for the details regarding the Lemmens *et al*., (2008) approach. The methodology concerning the frequency domain analysis (Lemmens *et al*., 2008) has been directly taken from the above mentioned studies.

The Lemmens *et al*., (2008) reconsidered the Peirce (1979) Granger causality approach and proposed a new non parametric testing procedure for the same. Let X_t and Y_t be two stationary time series of length T. The goal is to test whether X_t Granger causes Y_t at a given frequency λ. The frequency domain analysis is performed on the univariate innovations series, u_t and v_t, derived from filtering the X_t and Y_t as univariate ARMA processes. The derived innovation series u_t and v_t, which are white-noise processes with zero mean, possibly correlated with each other at different leads and lags.

Let $S_u(\lambda)$ and $S_v(\lambda)$ be the spectral density functions, or spectra, of u_t and v_t at frequency $\lambda \in]0,\pi[$, defined by

$$S_u(\lambda) = \frac{1}{2\pi}\sum_{k=-\infty}^{\infty}\gamma_u(k)e^{-i\lambda k} \qquad \text{------------------------} \quad (1)$$

$$S_v(\lambda) = \frac{1}{2\pi}\sum_{k=-\infty}^{\infty}\gamma_v(k)e^{-i\lambda k} \qquad \text{------------------------} \quad (2)$$

where $\gamma_u(k) = \mathrm{Cov}(u_t, u_{t-k})$ and $\gamma_v(k) = \mathrm{Cov}(v_t, v_{t-k})$ represent the autocovariances of u_t and v_t at lag k. The idea of the spectral representation is that each time series may be decomposed into a sum of uncorrelated components, each related to a particular frequency λ [3]. The spectrum can be interpreted as a decomposition of the series variance by frequency. The

[3] The frequencies λ_1, λ_2, ….., λ_N are specified as follows:

$$\lambda_1 = 2\pi / T$$
$$\lambda_2 = 4\pi / T$$
$$\vdots$$

The highest frequency considered is $\lambda_N = 2N\pi / T$

where $N \equiv T/2$, if T is an even number and $N \equiv (T-1)/2$, if T is an odd number (see Hamilton, p.159, 1994).

portion of variance of the series occurring between any two frequencies is given by area under the spectrum between those two frequencies. In other words, the area under $S_u(\lambda)$ and $S_v(\lambda)$, between any two frequencies λ and $\lambda + d\lambda$, gives the portion of variance of u_t and v_t respectively, due to cyclical components in the frequency band (λ , $\lambda + d\lambda$).

The cross spectrum represents the cross covariogram of two series in frequency domain. It allows determining the relationship between two time series as a function of frequency. Let $S_{uv}(\lambda)$ be the cross spectrum between u_t and v_t series. The cross spectrum is a complex number, defined as,

$$S_{uv}(\lambda) = C_{uv}(\lambda) + iQ_{uv}(\lambda)$$

$$= \frac{1}{2\pi} \sum_{k=-\infty}^{\infty} \gamma_{uv}(k) e^{-i\lambda k} \qquad \text{----------------------------------} \quad (3)$$

where $C_{uv}(\lambda)$ is called cospectrum and $Q_{uv}(\lambda)$ is called quadrature spectrum. These are, the real and imaginary parts of the cross-spectrum, respectively and $i = \sqrt{-1}$. Here $\gamma_{uv}(k)$ = Cov (u_t, v_{t-k}) represents the cross-covariance of u_t and v_t at lag k . The cospectrum $Q_{uv}(\lambda)$ between two series u_t and v_t at frequency λ can be interpreted as the covariance between two series u_t and v_t that is attributable to cycles with frequency λ. The quadrature spectrum looks for evidence of out-of-phase cycles (see Hamilton, p.274, 1994). The cross-spectrum can be estimated non-parametrically by,

$$\hat{S}_{uv}(\lambda) = \frac{1}{2\pi} \left\{ \sum_{k=-M}^{M} w_k \hat{\gamma}_{uv}(k) e^{-i\lambda k} \right\} \qquad \text{------------------------} \quad (4)$$

with $\hat{\gamma}_{uv}(k) = \hat{COV}(u_t, v_{t-k})$ the empirical cross-covariances, and with window weights w_k, for $k = -M,..,M$. The equation (4) is called the *weighted covariance estimator*, and when the weights (w_k) are selected as $1 - |k|/M$, the Bartlett weighting scheme is obtained. The constant M denotes the maximum lag order considered. The spectra of Equation (1) and (2) are estimated in a similar way. This cross-spectrum allows us to compute the coefficient of coherence $h_{uv}(\lambda)$ defined as,

$$h_{uv}(\lambda) = \frac{|S_{uv}(\lambda)|}{\sqrt{S_u(\lambda)S_v(\lambda)}} \quad \text{------------------------} \quad (5)$$

The coefficient of Coherence can be interpreted as the absolute value of a frequency specific correlation coefficient, measuring the strength of linear association between two time series. It takes the values between zero and one. The squared coefficient of coherence has an interpretation similar to the R-squared in a regression context. Lemmens *et al*. (2008) have shown that, under the null hypothesis that $h_{uv}(\lambda) = 0$, the estimated squared coefficient of coherence at frequency λ, with $0 < \lambda < \pi$ when appropriately rescaled, converges to a chi-squared distribution with 2 degrees of freedom[4], denoted by χ^2_2.

$$2(n-1)\hat{h}^2_{uv}(\lambda) \xrightarrow{d} \chi^2_2 \quad \text{------------------------------} \quad (6)$$

where $\rightarrow^d$ stands for convergence in distribution, with $n = T / \left(\sum_{k=-M}^{M} w_k^2\right)$. The null hypothesis $h_{uv}(\lambda) = 0$ versus $h_{uv}(\lambda) > 0$ is then rejected if

$$\hat{h}_{uv}(\lambda) > \sqrt{\frac{\chi^2_{2,1-\alpha}}{2(n-1)}} \quad \text{------------------------------------} \quad (7)$$

with $\chi^2_{2,1-\alpha}$ being the $1-\alpha$ quantile of the chi-squared distribution with 2 degrees of freedom.

The coefficient of coherence in Equation (5) gives a measure of the strength of the linear association between two time series, frequency by frequency, but does not provide any information on the direction of the relationship between two time series. Lemmens *et al* (2008) have decomposed the cross-spectrum (Equation 3) into three parts: (i) $S_{u\Leftrightarrow v}$, the instantaneous relationship between u_t and v_t; (ii) $S_{u\Rightarrow v}$, the directional relationship between v_t and lagged values of u_t; and (iii) $S_{v\Rightarrow u}$, the directional relationship between u_t and lagged values of v_t, *i.e.*,

$$S_{uv}(\lambda) = [S_{u\Leftrightarrow v} + S_{u\Rightarrow v} + S_{v\Rightarrow u}]$$

[4] For the endpoints $\lambda = 0$ and $\lambda = \pi$, one only has one degree of freedom since the imaginary part of the spectral density estimates cancels out.

$$= \frac{1}{2\pi}\left[\gamma_{uv}(0) + \sum_{k=-\infty}^{-1}\gamma_{uv}(k)e^{-i\lambda k} + \sum_{k=1}^{\infty}\gamma_{uv}(k)e^{-i\lambda k} \right] \quad \text{---------------} \quad (8)$$

The proposed spectral measure of GC is based on the key property that u_t does not Granger cause v_t if and only if $\gamma_{uv}(k) = 0$ for all $k < 0$. The goal is to test the predictive content of u_t relative v_t to which is given by the second part of Equation. (8), *i.e*.

$$S_{u\Rightarrow v}(\lambda) = \frac{1}{2\pi}\left[\sum_{k=-\infty}^{-1}\gamma_{uv}(k)e^{-i\lambda k} \right] \quad \text{-----------------------------------} \quad (9)$$

The Granger coefficient of coherence is then given by,

$$h_{u\Rightarrow v}(\lambda) = \frac{\left|S_{u\Rightarrow v}(\lambda)\right|}{\sqrt{S_u(\lambda)S_v(\lambda)}} \quad \text{-----------------------------------} \quad (10)$$

Therefore, in the absence of GC, $h_{u\Rightarrow v}(\lambda) = 0$ for every λ in [0,Π] interval. The Granger coefficient of coherence takes values between zero and one (Pierce, 1979). Granger coefficient of coherence at frequency λ is estimated by

$$\hat{h}_{u\Rightarrow v}(\lambda) = \frac{\left|\hat{S}_{u\Rightarrow v}(\lambda)\right|}{\sqrt{\hat{S}_u(\lambda)\hat{S}_v(\lambda)}}, \quad \text{---------------------------------} \quad (11)$$

with $\hat{S}_{u\Rightarrow v}(\lambda)$ as in Equation (4), but with all weights w_k =0 for $k \geq 0$. The distribution of the estimator of the Granger coefficient of coherence is derived from the distribution of the coefficient of coherence Equation (6). Under the null hypothesis $\hat{h}_{u\Rightarrow v}(\lambda) = 0$, the distribution of the squared estimated Granger coefficient of coherence at frequency λ, with $0 < \lambda < \pi$ is given by,

$$2(n'-1)\hat{h}^2_{uv}(\lambda) \xrightarrow{d} \chi^2_2 \quad \text{-------------------------------} \quad (12)$$

where n is now replaced by $n' = T / \left(\sum_{k=-M}^{-1} w_k^2\right)$. Since the w_k s', with a positive index k, are set equal to zero when computing $\hat{S}_{u\Rightarrow v}(\lambda)$, in effect only the w_k with negative indices are taken into account. The null hypothesis $\hat{h}_{u\Rightarrow v}(\lambda) = 0$ versus $\hat{h}_{u\Rightarrow v}(\lambda) > 0$ is then rejected if

$$\hat{h}_{u\Rightarrow v}(\lambda) > \sqrt{\frac{\chi^2_{2,1-\alpha}}{2(n'-1)}} \quad \text{----------------------------} \quad (13)$$

Afterward, the Granger coefficient of coherence given by Equation (11) is calculated and tested for the significance of causality by making use of Equation (13).

Applying the above mentioned methodology, first, the causality between monetary policy index (MPI) & inflation; and MPI and output has been tested, and then the causal relationship between the output gap and inflation has been explored to suggest measures to achieve a striking balance between the growth and inflation in India.

6. Results of empirical estimation and their analysis:

6.1 Unit root tests:

Since stationarity of a series is a prerequisite for Granger causality analysis in the time as well as frequency domain, all the variables under study are tested for stationarity using the ADF test, PP test and the Zivot-Andrews test. While the ADF and PP tests check for the level stationarity of a series, the Zivot-Andrews test checks for the unit root in the presence of a structural break in the series. The results of all these tests are discussed in the table 2 below.

Table 2: Unit root tests

Variable	Test statistic		
	ADF test	PP test	Zivot-Andrews test
CPI (IW) inflation	-5.6632*** (0.01)	-72.79*** (0.01)	-8.0351*** (0.01)
Log (IIP)	-4.1334*** (0.01)	-65.498*** (0.01)	-8.0865*** (0.01)
MPI	-3.2332* (0.08)	-60.184*** (0.01)	-7.1755*** (0.01)
Output gap	-6.6608*** (0.01)	-114.68*** (0.01)	-13.0774*** (0.01)

(Figures in parentheses indicate probability value.)

Note: ‘***’, ‘**’, & ‘*’ denotes statistical significance at 1%, 5%, and 10%, respectively.

As shown in the table, all the variables are stationary in the level form. Both the ADF test, as well as the PP test reject the null hypothesis of a unit root in the series, at 1% level of significance. The IIP is shown to be trend stationary. Similarly, the Zivot-Andrews test also rejects the null of a unit root for all the variables.

Along with the above mentioned unit root tests, it is important to test the data for the presence of seasonal unit roots. This is because, if the seasonal unit roots are present in the data, it would be necessary to do seasonal differencing to attain stationarity. The present study applies the Beaulieu & Miron (1993) methodology to test for the seasonal unit roots in the log transformed IIP and CPI inflation series. Beaulieu & Miron (1993) extended the methodology developed by Hylleberg *et al*. (1990), to test for the seasonal integration in monthly frequency data. The results of seasonal unit root test illustrate the absence of unit roots at seasonal as well as non seasonal frequencies. The results are not reported here. However, one cannot deny the possibility of deterministic and stationary stochastic seasonality in the series. Hence to account for the same, the IIP and inflation series are filtered using seasonal dummies.

6.2 Constructing the narrative monetary policy index:

The narrative monetary policy index in the Table 3 has been constructed with the help of Table 1 which incorporates the announcements regarding changes in the monetary policy variables. The narrative monetary policy index suggests that a neutral monetary policy was pursued 44 times, the expansionary monetary policy was conducted on 24 occasions, whereas the contractionary monetary policy was implemented 22 times. Hence, for most of the times

Table 3: A Narrative Monetary Policy Index (January 2008-June 2015)

Year	Months											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2008	0	0	0	-1	-2	-2	-3	-1	0	3	3	1
2009	2	0	1	1	0	0	0	0	0	0	-1	0
2010	0	-2	-1	-2	0	0	-2	0	-1	0	-1	1
2011	-1	0	-1	0	-1	-1	-1	0	-1	-1	0	0
2012	1	-1	1	2	0	0	0	1	1	0	1	0
2013	2	1	2	0	2	0	-1	0	0	1	0	0
2014	-2	0	0	0	0	1	0	1	0	0	0	0
2015	2	1	2	0	0	2	-	-	-	-	-	-

(*Source*: Author's Calculations)

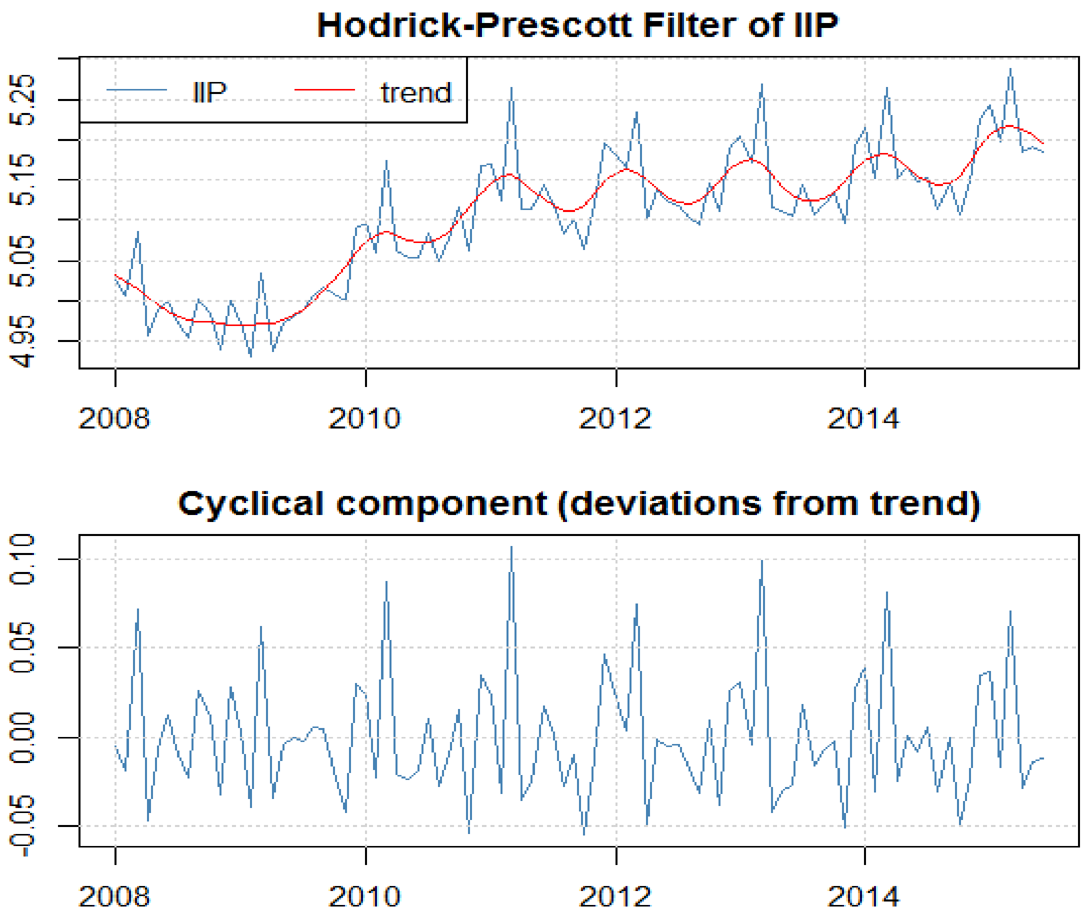
the monetary policy was neutral *i.e.*; policy rates were kept unchanged (status quo stance). During 2010 to 2011 period, monetary policy was highly contractionary. However, in post 2014, except Jan 2014, stance of monetary policy is either neutral or expansionary.

6.3 Estimation of the output gap and Inflation relationship:

The output gap and inflation relationship provides necessary inputs in the monetary policy decisions. The present study uses the HP Filter to estimate the output gap. The HP filter decomposes the actual output into trend and cyclical components. Since the original IIP series was trend stationary in the level form, the de-trended log IIP series has been used to estimate the output gap.

The plot of the actual output along with the potential output (trend) and the output gap (cycles) as given by the HP filter is depicted in figure 4.

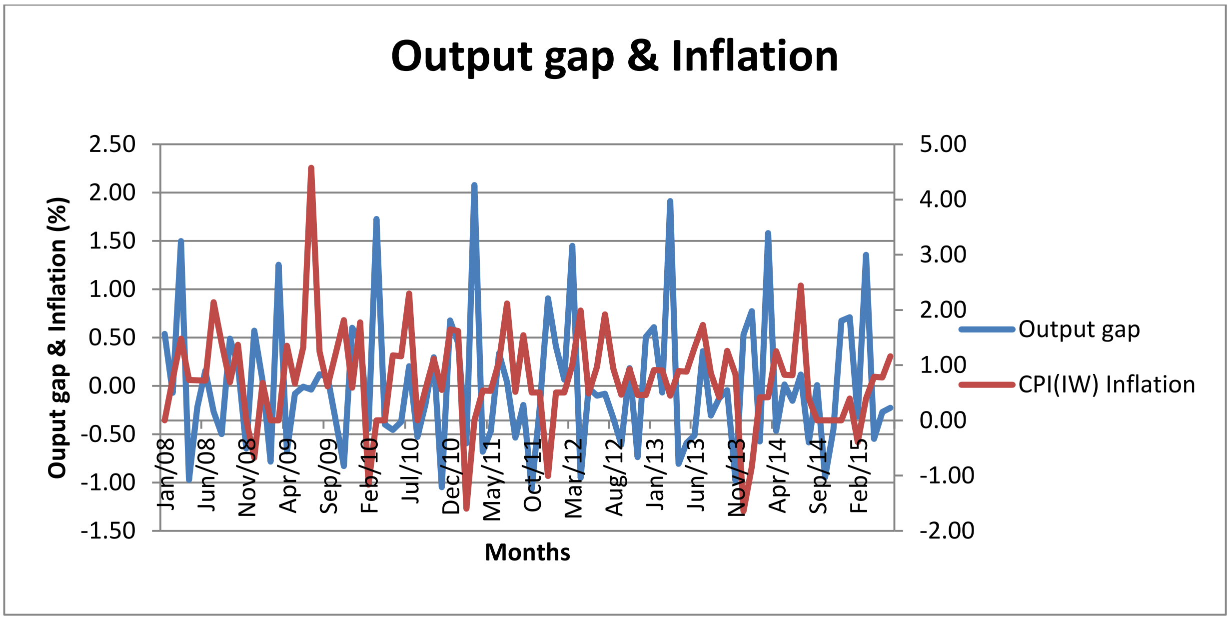
Figure 4: Actual output, output gap and potential output



Since the output gap is considered to be one of the determinants of future inflation, the movements of the output gap, therefore, have an implication for monetary policy formulation. The figure 5 demonstrates the output gap and inflation co-movements in India during the period of January 2008-June 2015.

As can be seen from the graph, the output gap and inflation move in tandem with a positive and lagged relationship between the two. The positive output gap which indicates the aggregate demand pressures in the economy, leads to an increase in inflation with a lag of around two to four months. Similarly, the negative output gap leads to a fall in inflation in the subsequent period with a lag.

Figure 5: Output gap and Inflation (January 2008-June 2015)

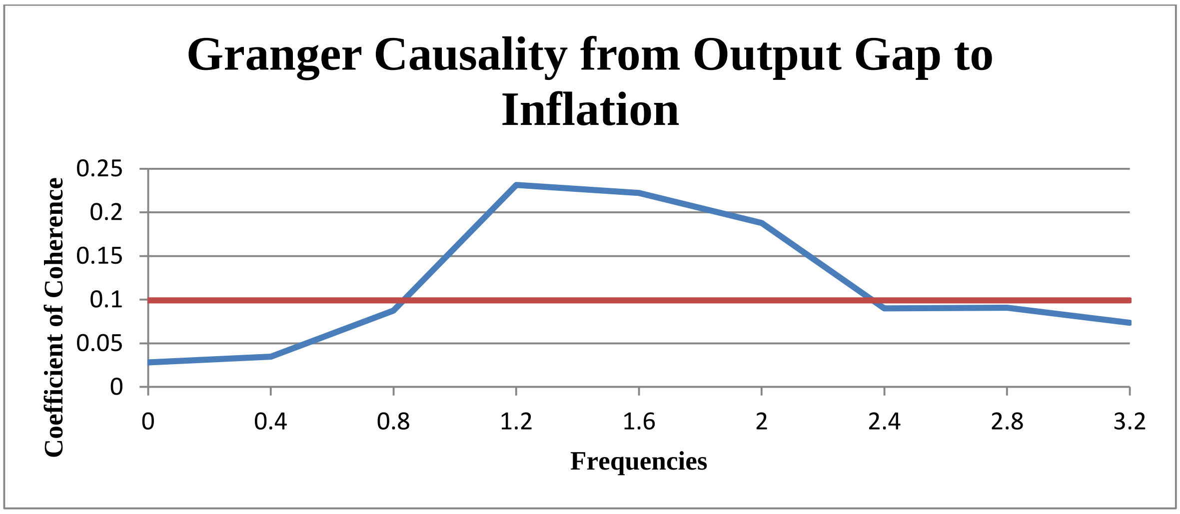


6.4 Granger Causality in frequency domain:

The results of the GC test in the frequency domain are discussed below with help of the figures showing the coefficient of coherence between two series for all the frequencies. All the figures depict the test statistics along with their critical values at 5% significance level (a line horizontal to the x-axis) for all frequencies in the interval (0, Π). The horizontal axis represents the frequency (ω) in the fractions of Π. The frequency (ω) can be converted into time period (T) by applying the formula: T=2Π/ ω, where 'T' is the total time period (months in this study) and 'ω' is an angular frequency denoting a cycles per month, because the data are of monthly frequency. To interpret the results over the spectrum, all the frequencies are grouped into three frequency bands *i.e.*, short run (range ω ∈ [1.5-3.2]), medium run (range ω ∈ [0.5-1.5]), and long run (range ω ∈ [0.0-0.5]). These three frequency bands correspond to the cycles of a duration two months to four months, four months to 12 months, and 12 months and beyond, respectively. These cycles with different time horizons replicate a true data generating process for each series under study. The GC measures are shown in the figure 5 to 10. All the figures report the Granger coefficient of Coherence along with critical values at 5% significance level.

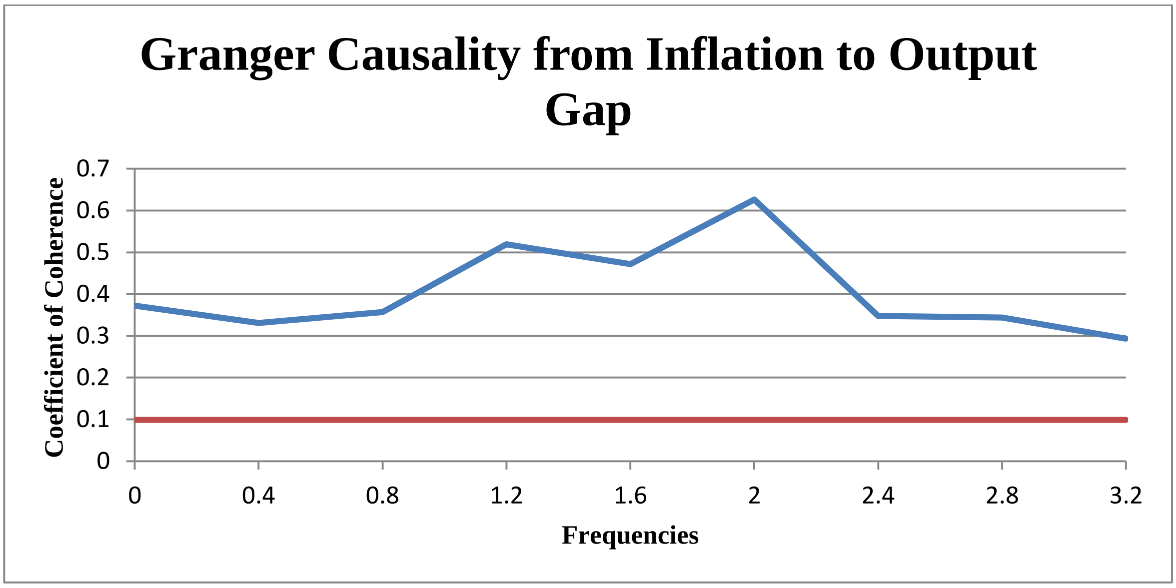
The results of the causality test in the frequency domain suggest a bi-directional causality between the output gap and inflation. However, the causal relationship differs across frequencies.

Figure 6: Causality from Output gap to Inflation



The figure 6 shows the Granger coefficient of coherence for the causality running from the output gap to inflation. It can be seen that the output gap Granger causes inflation in the frequency band of ω ∈ [0.8-2.4], reflecting a low to medium frequency cycles of two months to seven months. Also, the magnitude of Granger coefficient of coherence varies over the given frequency range with the highest magnitude of 0.23 occurring at frequency 1.2, which corresponding to the cycles of 5 months. For all other frequencies, the causal relationship seems to be insignificant. It can be concluded that the output gap is a leading indicator of future inflation in India only in the short to medium run. The evidence suggests the absence of link between the output gap and inflation in the long run which is in line with the Phillips curve analysis. Since, the output gap is seen as one of the determinants of future inflation, monetary policy aiming to target inflation has a major intake from these results. At least in the short to medium run, monetary policy can take a hint from the output gap movements to decide the policy stance.

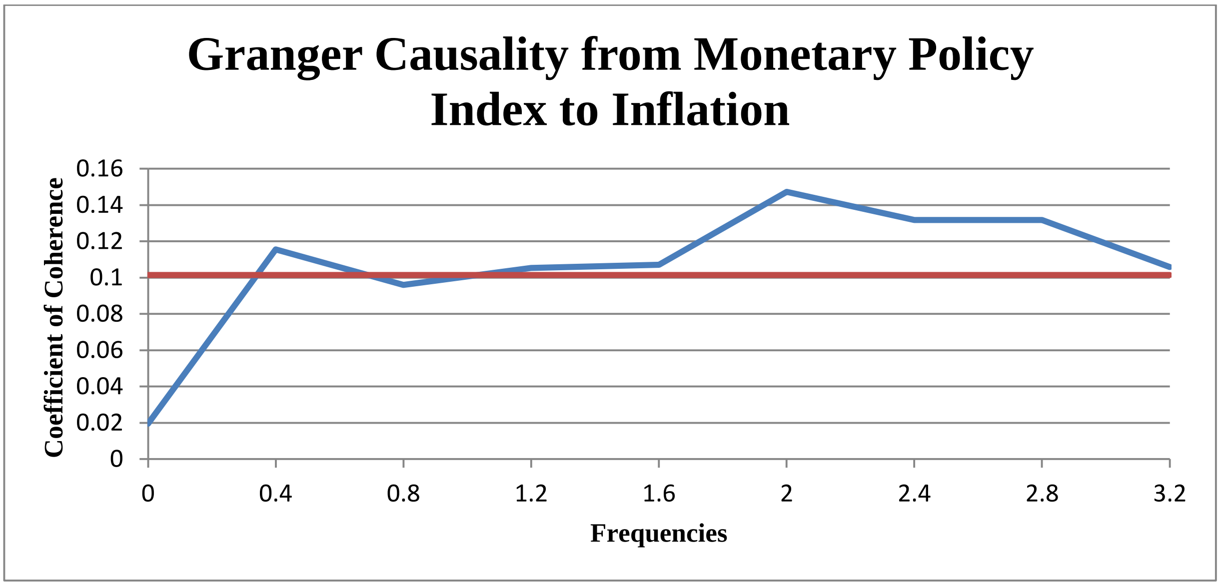
Figure 7: Causality from inflation to the output gap



The figure 7 illustrates the significant reverse causal relationship running from inflation to the output gap across all frequencies, which denotes that the inflation Granger causes the output gap in the short, medium as well as long runs. Here also, the magnitude of the coefficient of coherence varies across frequencies It reaches the highest value of 0.62 at frequency 2, corresponding to the cycle of 3 months. To sum up the analysis, the present study found the evidence of a bi-directional frequency domain causality between the output gap and inflation in India. However, the causality differs across the frequencies. While the causality running from the output gap to inflation found to be significant in the short to medium run only, the reverse causality running from inflation to output found to be significant across all frequencies.

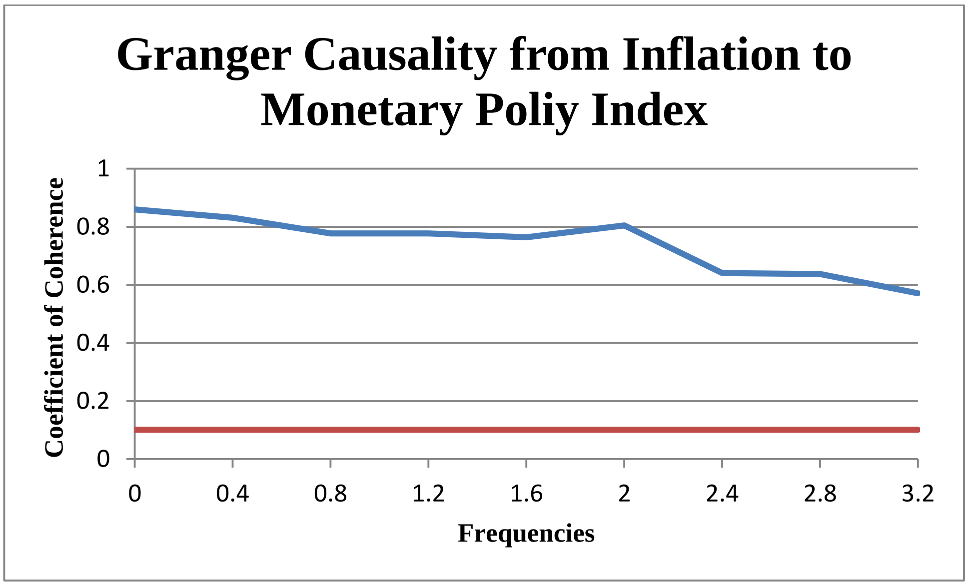
In the next step the impact of monetary policy on the output and inflation has been analysed by applying the Granger causality technique in frequency domain. First, an attempt has been made to assess the causal relationship between the narrative monetary policy index (MPI) (which captures a stance of monetary policy) and Inflation and then, a causal relationship between the MPI and the output has been examined.

Figure 8: Causality from Monetary Policy Index to Inflation



As illustrated in the figure 8, the Granger coefficient of coherence indicating the causality running from monetary policy to inflation, is significant in the frequency range of $\omega \in [0.3,0.7]$ and $\omega \in [1.2\ ,3.14]$, corresponding to the cycles of 8 to 17 months and 2 to 5 months, respectively. The coefficient of coherence takes the maximum value of 0.15 at frequency 2, which corresponds to the cycles of 3 months. From the given frequency range, it is very much clear that the monetary policy has a predictive power regarding inflation only in the short to medium time horizon. Especially, at all lower frequencies (below 0.3) the causality is insignificant, which brings out the important evidence suggesting that the link between monetary policy and inflation does not exist in the long run. The magnitude of the causality also varies over the frequencies. The magnitude is high in the range of high frequencies (short time horizon), which postulate that the monetary policy is more effective in impacting inflation in the short run. However, such impact does not exist in the long run.

Figure 9: Reverse causality from inflation to monetary policy index



The reverse causality running from inflation to monetary policy is significant across all frequencies, since the price stability is a prime objective of monetary policy in India that necessitates an immediate response from monetary policy if prices start rising. The magnitude of causality varies over the short, medium, and the long run.

To sum up the analysis of Granger causality between MPI and inflation, the study found the evidence of a bi-directional causality between the MPI and inflation. While, the causality running from monetary policy impulses to inflation appears to be significant only in the short to medium run, the reverse causality going form inflation to monetary policy impulses is significant over all time horizons. The significant reverse causality across all frequencies clearly highlights the fact that monetary policy in India is very sensitive to price fluctuations. The significant casual relationship between the monetary policy impulses and inflation only over the short to medium run signifies the inability of monetary policy in controlling inflation in the long run in India.

After investigating the impact of monetary policy on inflation, the next step in the analysis is to examine the impact of monetary policy on the output as measured by the Index of Industrial Production (IIP), using the Granger causality technique in the frequency domain.

Figure 10: Causality from Monetary Policy Index to Output.

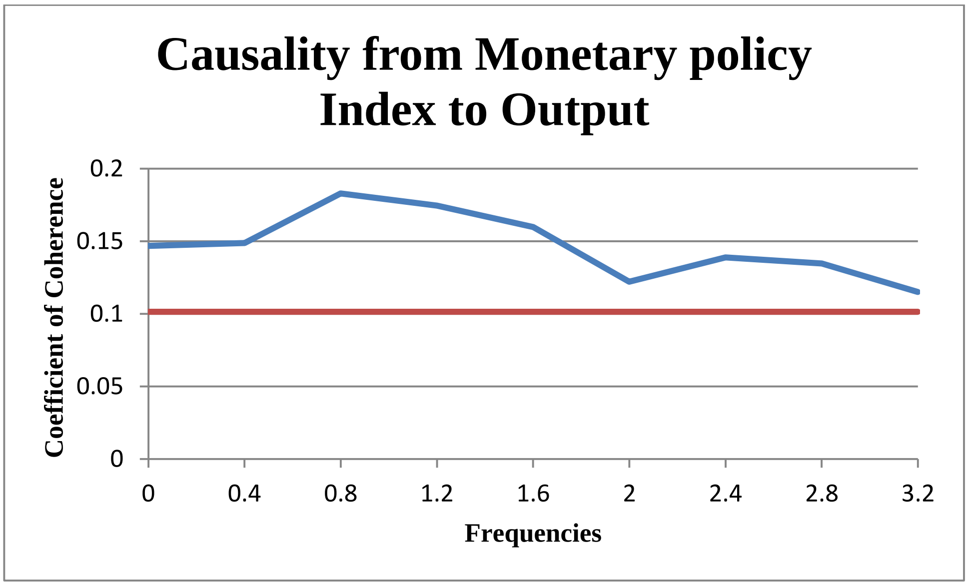
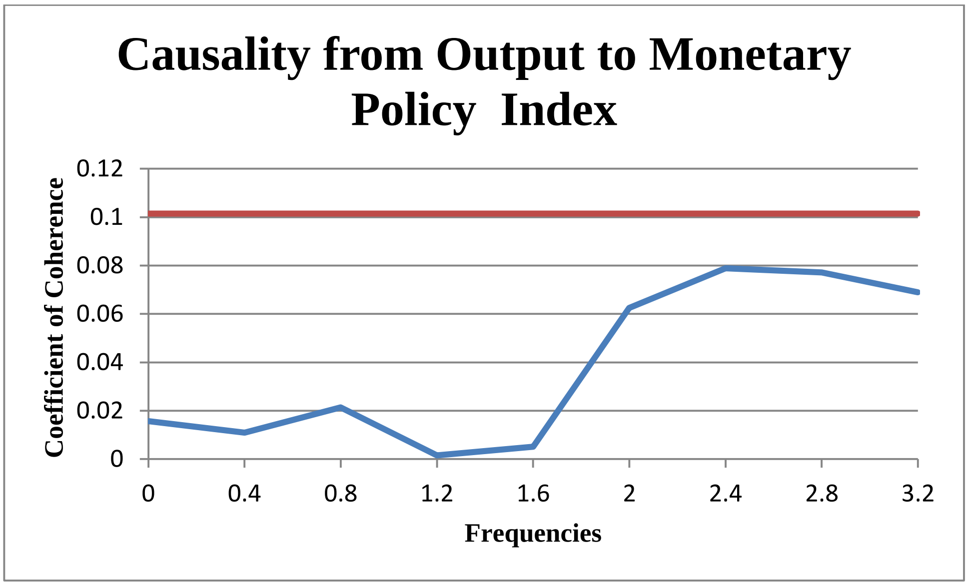


Figure 10, shows a Granger coefficient of Coherence for monetary policy and output over a different frequency bands. Surprisingly, the causality between monetary policy and Output is significant across all frequencies, which confirms that a significant link between monetary policy and output prevails in India over the short, medium and long terms. However, the magnitude of causality differs over the different time horizons. The causality is weak in the high frequency range ω ∈ (2, 3.14), then it becomes stronger in the medium frequency range ω ∈ (2, 0.5), but again at lower frequencies ω ∈ (0.0, 0.5) it becomes less intense as compared to the medium frequencies, but more stronger than the high frequencies. This has important interpretations. Since the causal link is strongest over a medium run frequencies corresponding to the cycles of 4 to 12 months, the impact of monetary policy is felt maximum in the medium run *i.e.*, the span of 4 to 12 months. The coefficient of coherence takes the maximum value of 0.18 at frequency 0.8, corresponding to the cycles of 7 months. Similarly, relatively less stronger impact occurs over long run frequencies corresponding to the cycles of more than 12 months period. It means in the long run the intensity of the impact of monetary policy becomes less. However, in comparison to the medium and long run, the impact of monetary policy seems to be weak over the short term frequencies corresponding to the cycles of less than four months. The coefficient of coherence takes the minimum value of 0.12 in the high frequency range.

Figure 11: Causality from output to monetary policy index



The reverse causality going from output to MPI, is insignificant over all the frequencies indicating the feedback from the output to MPI is not robust.

To sum up the analysis, the study finds the evidence of a unidirectional causality running from monetary policy to output in India. Though, the causality is significant across all the frequencies, the magnitude of it varies over the short, medium and long runs. The impact of monetary policy on output seems to be weak in the short run, but the maximum impact occurs over a medium to long run. However, the reverse Granger causality is found to be insignificant across all frequencies.

The results of monetary policy impact on output and inflation provide some interesting insights. The causality between the MPI and inflation is found to be bidirectional, whereas that between the MPI and output is unidirectional. It brings out one important finding that in recent past the monetary policy decisions are being made on the basis of inflation outcomes rather the output as there is a significant reverse causality from inflation to the MPI but not from output to MPI. Thus, the monetary policy is focusing only on inflation control. However, the results depict that the output is more sensitive to monetary policy impulses than inflation because the magnitude of causality is seen to be higher in case of the former. Furthermore, the causality between the monetary policy impulses and output is found to be significant across all frequencies, which is not true for inflation. This is because the inflation in India in the recent past, is majorly determined by the supply side factors, therefore the monetary policy is not able to tame it. However, the attempts of tight monetary policy to compress inflation, ended up impacting the output more than the inflation.

Since the impact of monetary policy on inflation persists only in the short to medium run, the monetary authorities could take some clues from the output gap and inflation relationship while setting policy rates. This is because the output gap is one of the determinants of future inflation and could prove necessary inputs in the policy formulation. The results discussed above have shown a positive and lagged relationship between the output gap and inflation in India. Also, the causality results indicate that the output gap Granger causes inflation only in the short to medium run, corresponding to the cycles of two to seven months. Hence, to control inflation in the short to medium time horizon the output could be one of the indicators of future inflation.

7. POLICY IMPLICATIONS AND CONCLUSION:

The present study uses the frequency domain causality approach developed by Lemmens *et al*., (2008) to analyse the causal relationship between the narrative monetary policy index (MPI) & inflation; and MPI & output. The study found the bidirectional causality between MPI and inflation and the unidirectional causality between MPI and output. The bidirectional causality between MPI and inflation denotes that the monetary policy was responding more to inflation than the output. While the casualty from MPI to inflation was significant only in the short to medium run, the causality between MPI and output was found to be significant across all the time horizons. Also, it was found that the output is more sensitive to monetary policy shocks than inflation. This has an important policy implication. The tight monetary policy pursued in the recent past to control inflation, in fact, impacted the output more than the inflation. There is a need to strike a fine balance between these two. The output growth should not suffer due to the attempts of controlling inflation. Furthermore, the output gap and inflation relationship could provide essential inputs to control inflation. The present study, therefore, analyses the output gap and inflation causality in India. The output gap and inflation relationship was found to be positive as reported in earlier studies. It was found that the output gap Granger causes inflation only in the short to medium run. The monetary authorities striving to control inflation in the short to medium run can see the output gap as one of the determinants of short to medium run inflation in future and shape the policy accordingly.

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