MONEY AND INFLATION: EVIDENCE FROM P-STAR MODEL

Sunil Paul
Sartaj Rasool Rather
M. Ramachandran

MSE
Mentoring Excellence

MADRAS SCHOOL OF ECONOMICS
Gandhi Mandapam Road
Chennai 600 025
India

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Dr.Sunil Paul

Assistant Professor, Madras School of Economics
sunilpaul@mse.ac.in

Dr. Sartaj Rasool Rather

Assistant Professor, Madras School of Economics
sartajrasool@gmail.com; sartajrasool@mse.ac.in

and

Prof. M. Ramachandran

Professor, Department of Economics,
Pondicherry University, Puducherry-14

Role of Money in Explaining Inflation: Evidence From P-Star Model

Sunil Paul, Sartaj Rasool Rather and M. Ramachandran

Abstract

This study uses P-star model to examine the role of money in explaining inflation in India. In particular, we compare the performance of traditional Phillips curve approach against P-star model in forecasting inflation. Moreover, the study estimates P-star model using the alternative measures of money such as simple sum and Divisia M3, to examine the relevance of aggregation theoretic monetary aggregates in explaining inflation. The empirical results indicate that P-star model with real money gap has an edge over traditional Phillips curve approach in forecasting inflation. More importantly, we found that the P-star model estimated with Divisia real money gap performs better than its simple sum counterpart. These results highlight the role of money in explaining inflation in India.

ACKNOWLEDGEMENT

INTRODUCTION

Understanding the nature and dynamics of inflation has dominated the macroeconomic research both on theoretical and empirical front over the years. It is widely believed that the growth rate of money is a crucial determinant of rate of inflation in the long run. The role of money supply in determining inflation is demonstrated by the traditional quantity theory which proposes a proportional relationship between inflation and the growth rate of money, which is subsequently reinstated by Friedman, (1956). Soon after Friedman's famous dictum that "Inflation is always and everywhere a monetary phenomenon" a large number of theoretical and empirical studies have attempted to investigate the role of money in determining inflation across different countries.

Among various theoretical models, the popular one for studying the inflation dynamics has been the Philips curve relationship which was first documented by Philips (1958). Under this approach, fluctuations in inflation are attributed to resource utilization or slack in an economy. In the late 1960s, Friedman (1968) and Phelps (1967) highlighted the role of inflation expectations in understanding the dynamics of inflation and prompted the researchers to incorporate the inflation expectations in the estimation of Philips' relationship. More recently, the New Keynesian Philips curve derived from the optimizing behaviour of monopolistically competitive firms has significantly enhanced the understanding of short-run inflation dynamics. Under this New Keynesian framework, inflation is perceived to be a function of real marginal cost and expected future inflation. In yet another development, Gali and Gartler (1999) extended this new Keynesian model to allow for a fraction of firms to follow the back ward rule of thumb in setting prices; thereby reemphasizing the need to capture the persistent component of inflation. Subsequently,

more recent empirical literature has modeled inflation as function of real marginal cost, expected inflation and the past inflation as well.

Although theoretically very appealing, the estimation of Philips curve relationship has remained as a challenge for the researchers. In empirical estimation of the Philips relationship, defining and measuring the relevant measure of resource utilization or output gap has been very difficult but crucial for its consistent empirical evaluation. On the one hand, some researchers rely on purely statistical measures, such as deviations of output from its long term trend or from some measure of the frictionless level of economic activity. Also, there are attempts to measure output gap based on economic theory; the most popular among them is the production function approach. Apart from this, Wynne and Solomon (2007) have emphasized number of hurdles which make the construction of conventional measures of output gap very difficult in emerging economies. More importantly, under this approach, no direct role is assigned to growth of money supply in explaining inflation.

There are plenty of theoretical and empirical studies which have examined inflation dynamics using the traditional Philips curve approach for both the developing and the developed countries (see for e.g. Gordon (2011) and Gali *et. al.* (2001)). The empirical evidence from developed countries has by and large been consistent with theoretical predictions and successful in explaining the inflation over time. However, from the perspective of developing countries the empirical literature has not been much successful in explaining the inflation of respective countries.

An alternative to Philips curve analysis is the P-star approach which emphasizes the role of real monetary developments in explaining inflation (Hallman *et. al.* 1991). The foundation of P-star model is built on the famous quantity theory of money. Under this approach, the

aggregate price is assumed to adjust to the deviation of actual price from its long run equilibrium. In essence, the P-star approach links the short run fluctuations in inflation to the determinants of long run equilibrium price (p^*) such as the money supply, potential output and the equilibrium velocity. Under this approach, depending on whether the actual price is below, above or at its equilibrium level, the aggregate price is likely to rise, fall or remain unchanged. Empirically, the model is estimated in its reduced form that relates short-term changes in inflation to price gap defined as deviation of actual price from its equilibrium value.

The P-star approach to inflation dynamics has gained popularity in recent years especially due to its close link with the long tradition of mainstream monetary theory and its firm roots in the quantity theory of money. In the literature, a number of empirical studies have examined the performance of the p-star model in explaining the inflation dynamics for various countries [see, for example Hallman and Anderson 1993, Hallman *et. al.* (1991) and Kool and Tatom (1994)]. In particular, Hoeller and Poret (1991)] estimated P-star model for 20 OECD counters and found that the P-star model performs better than models based on output gap alone. Similarly, several studies pertaining to Euro Area used P- star model and found significant evidence in favor of it (Toèdter and Reimers 1994; Nicoletti-Altimari 2001; Gerlach and Svensson 2003; and Czudaj 2011). It is important to note that these studies emphasized the direct association between money and prices.[1] In empirical literature, however, the use of P-star model has been confined mainly to developed countries and its application to less developed countries appears to be scanty.

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[1] This is consistent with the argument of (Nelson, 2002) that monetary aggregates contain some additional information about inflation through certain important transmission channels

In the Indian context, there are few attempts to investigate the inflation dynamics using different approaches including Philips curve and P-star model. For example, Nachane and Laskshmi (2002 have found some evidence in favour of P-star models augmented with velocity gap. However, they report theoretically implausible coefficient with respect to output gap and poor forecasting performance of output and price gap models. Their findings are in contrast with many other empirical studies which emphasize the role of structural factors in explaining inflation in India (see e.g.,Balakrishnan *et. al.* 1994). On the other hand, many earlier studies such as Rangarajan and Arif (1990) and Virmani (2004) attempted to examine the determents of inflation using Philips curve framework, but empirical results are largely inconsistent with the theoretical prediction. More recently, Paul (2009), Singh *et. al.* (2011) and Mazumder (2011) provided evidence supporting the existence of Philips relationship in India. These studies argued that the use of appropriate measures of inflation and output gap and the accommodation of supply shocks helps in tracing the Phillips curve relationship in India.

In this context, this study uses P-star model to examine the role of money in explaining inflation in India. In particular, we compare forecasting performance of P-star and Philips curve model. Here, unlike earlier literature, the P-star model is estimated using real money gap so as to examine the direct association between inflation and money as emphasized by Gerlach and Sevnsson (2003). Apart from this, the availability of high frequency data on monetary aggregates (but not on output) makes the money gap measure more attractive in the present context. Moreover, the study examines the relevance of various measures of money by estimating the P-star model using simple sum and

theoretically consistent Divisia monetary aggregates.[2] Note that this assumes crucial importance as the errors in the measurement of monetary aggregates may quite often lead to misleading results (Barnett and Chauvet, 2011b).[3]

INFLATION DYNAMICS: THE THEORETICAL PARADIGMS

Although theoretical developments in this respect provide a number of alternative approaches to model inflation, we have focused on two prominent approaches which are popular in policy discourse: Quantity theory based P-star model and the New Keynesian Phillips curve. The new Keynesian version of Philips curve became prominent since 1990s and is considered to be the standard benchmark for modeling inflation. The standard new Keynesian Phillips curve specifies inflation as a function of expected inflation and excess demand or marginal cost measured by output gap, unemployment rate etc. The P-star approach has been derived from Quantity theory of money and it links the short run dynamics of observed inflation to the determinants of long run equilibrium inflation.

New Keynesian Phillips Curve
The new Keynesian Philips curve is a modified version of Phillips curve introduced by Philips (1958). Earlier versions of Phillips curve postulate that there exists a stable tradeoff between (wage or price) inflation and unemployment or output. Policy makers soon began to exploit the Philips relation which gave them a choice of lowering unemployment or increasing output at the cost of higher inflation and vice-versa. However, high rates of unemployment and inflation during 1970s were inconsistent

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[2] See Ramachandran et. al.(2010), and Paul and Ramachandran (2011, 2013) for a detailed discussion on the relevance of the various monetary aggregates in India.

[3] For a detailed review on monetary aggregates see Barnett and Chauvet (2011a).

with the Phillips relation. In this respect Phelps (1967) and Friedman (1968) argued that the tradeoff between inflation and unemployment is not a permanent or long-run phenomenon.

Friedman-Phelps critique put forward two important propositions in modeling inflation: (i) it distinguished the relationship between inflation and output in the short-run and long-run; and (ii) it introduced the role of expectations in price adjustment process. The explicit role of expectations in the inflation dynamics carried the debate further on how the expectations can be formed. Phelps (1967) assumed adaptive expectation hypothesis in modeling expectations. Adaptive expectations assume that expectations are formed based on the past experience alone. Lucas (1972) and Sargent and Wallace (1975), however, argued that economic agents make expectations rationally and are capable of making accurate expectations taking all relevant information into account. Thus, rational expectations hypothesis implied that only unanticipated changes in the price level would affect output in the short run. In essence, the short run tradeoff between output and prices arise due to misperceptions or imperfect information on the part of price setting agents (Lucas 1972).

The Lucas (1972) and Sargent and Wallace (1975) propositions were based on the assumption that prices adjust instantaneously to the departure of prices from its market clearing level. However, the available empirical evidences in favour of sluggish price adjustment as observed by Gordon (1976) undermine their arguments. Indeed, the role of supply shocks gained importance in predicting inflation during the 1970s. Accordingly, Gordon (1977, 1982) extended the expectation augmented Phillips curve by incorporating supply shocks, which is now popularly known as the "triangle" model. As the name suggests, the triangle model characterize the inflationary process on inertia, demand pressure and

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supply shocks. The empirical version of the triangle model of inflation (π_t) is:

$$\pi_t = \alpha \pi_{t-1} + \gamma(u_t - u_t^n) + \delta Z_t, \tag{1}$$

where the lagged inflation (π_{t-1}) captures inertia in inflation, the deviation from unemployment rate (u_t) from its natural rate (u_t^n) measures excess demand and Z_t is a measure of supply shocks.

Triangle model of inflation dominated the literature untill the new Keynesian Phillips curve proposed by Calvo (1983) and Gali and Gertler (1999) became prominent. The new Keynesian Phillips curve may be derived from a price setting behavior of monopolistically competitive firms. Under this framework, the aggregate price level (p_t) at period $'t'$ is expressed as a combination of lagged price level (p_{t-1}) and optimum resent price at current period $(\tilde{p}_t)$ as follows:

$$p_t = \theta p_{t-1} + (1 - \theta)\tilde{p}_t. \tag{2}$$

where $(1-\theta)$ is a random fraction of firms which change their prices. The optimum price $(\tilde{p}_t)$ is determined by profit maximization objective of the firms which are assumed to follow Calvo type pricing. The optimum price $(\tilde{p}_t)$ may be expressed follows:

$$\tilde{p}_t = (1 - \theta\beta) \sum_{k=0}^{\infty} (\theta\beta)^k E_t \widetilde{mc}_{t+k}, \tag{3}$$

where β denotes subjective discount factor and $\widetilde{mc}_t$ is the nominal marginal cost expressed as a deviation from its steady state level. The

new Keynesian Phillips curve is obtained by substituting equation (3) into (2) as follows:

$$\pi_t = \beta E_t \pi_{t+1} + \frac{(1-\theta)(1-\theta\beta)}{\theta}(mc_t), \tag{4}$$

where π_t denotes inflation measured as $(p_t - p_{t-1})$, mc_t is the percentage deviation of firms real marginal cost from its steady state level. Alternatively, empirical studies use output gap as a proxy for real economic activity. Gali and Gertler (1999) observe that a log linear relationship between marginal cost and output gap can be established under certain assumption $i.e. mc = k(y_t - y_t^*)$. Making use of this relation, we can express equation (4) as follows:

$$\pi_t = \beta E_t \pi_{t+1} + \gamma(y_t - y_t^*), \tag{5}$$

where y_t is log of output, y_t^* is log of natural level of output and $\gamma = k[(1-\theta)(1-\theta\beta)/\theta]$.

Thus, the new Keynesian Phillips curve incorporates price rigidities into the model while retaining the assumption of rational expectation, which is forward looking. Consequently, the inflation is assumed to depend on current and future economic conditions alone (Clarida *et. al.*, 1999). However, empirical studies often report that output gap leads inflation which contradicts the theoretical proposition. In this respect, Gali and Getler (1999) proposed a 'hybrid new Keynesian Phillips curve' including a lagged inflation implying θ fraction of firms are backward looking while setting the price. The hybrid version of new Keynesian Philips curve is expressed as:

$$\pi_t = \beta^f E_t \pi_{t+1} + \beta^b \pi_{t+1} + \gamma(y_t - y_t^*), \qquad (6)$$

where β^f and β^b are the coefficients which capture the price adjusting behavior of forward and backward looking firms.

Due to its lucid micro theoretic foundations, large number of empirical studies attempted to establish this relationship using the data from various countries. Although, by and large the empirical studies from the developed countries supported this relationship, the evidence from developed countries seems to be mixed. In the literature, number of empirical studies from developed countries has failed to establish the short run association between output and inflation as predicted by the theory. Similarly, the forward looking term in the hybrid version of new Keynesian models was found to play very limited role in explaining inflation dynamics (Rudd and Whelan, 2005). Nonetheless, the new Keynesian models have contributed significantly in understanding inflation dynamics and are widely used in empirical studies.

P –Star Models

The P-star approach, first proposed by Hallman *et. al.* (1991), is based on the quantity theory of money. Under this approach, the short run fluctuations in inflation are attributed to the determinants of long run equilibrium price. Theoretically, the long run equilibrium price (*p**) is determined by current money supply, potential income and the equilibrium velocity. In this framework, the actual aggregate price is assumed to adjust to its deviation from equilibrium level. In other words, it predicts that the actual price will rise, fall or remain unchanged depending on if the actual price is below, above or equal to its equilibrium level, respectively.

The traditional quantity theory relation is given as follows:

$$MV=PY, \tag{7}$$

where M is stock of money, V is income velocity of money, P is aggregate price level and Y is real output.

The long run equilibrium price for a given the stock of money, the level of potential real output (Y^*) and long run equilibrium value of velocity (V^*) can be specified as follows:

$$P^* = \frac{MV^*}{Y^*}. \tag{8}$$

Alternatively, in log form, equation (7) and (8) can be written as:

$$p = m + v - y, \tag{9}$$

$$p^* = m + v^* - y^*. \tag{10}$$

Equation (10) states that equilibrium price is equal to money per unit of potential output at equilibrium velocity (Todter and Reimers 1994).

By subtracting equation (10) from (9), we can express the deviation of actual price from its equilibrium level in terms of velocity gap and output gap as follows:

$$(p - p^*) = (v - v^*) - (y - y^*). \tag{11}$$

Having defined the price gap, Hallman et. al. (1991) related inflation to lagged values of inflation and lagged price gap as follows:

$$\pi_t = \delta(p_{t-1} - p^*_{t-1}) + \pi_{t-1} ; \qquad \delta < 0. \tag{12}$$

According to equation (12), the inflation rises if $p_{t-1} < p_{t-1}^*$ and falls if $p_{t-1} > p_{t-1}^*$. Further substituting equation (11) into (12), inflation can be expressed as a function of output gap and velocity gap as:

$$\pi_t = \varphi(v_{t-1} - v_{t-1}^*) - \gamma(y_{t-1} - y_{t-1}^*) + \pi_{t-1}. \tag{13}$$

The above specification has been used by number of empirical studies in the literature. The disadvantage of such specification is that in its empirical evaluation, it requires measures of long-run equilibrium velocity and the potential output. Alternatively, as demonstrated in Svensson (2000), and Gerlach and Svensson (2003), the P-star model given in equation (12) can be written as:

$$\pi_t = \alpha(\widetilde{m}_{t-1} - \widetilde{m}_{t-1}^*) + \pi_{t-1}, \tag{14}$$

where $\widetilde{m}_{t-1} - \widetilde{m}_{t-1}^*$ is the real money gap and $\widetilde{m}_{t-1} = m_{t-1} - p_{t-1}$, where m_{t-1} is the nominal money stock.

The long run equilibrium real money stock can be defined in terms of potential output and long run equilibrium velocity using equation (10) as follows:

$$\widetilde{m}_{t-1}^* = y_{t-1}^* - v_{t-1}^*, \tag{15}$$

where $\widetilde{m}_{t-1}^* = m_{t-1} - p_{t-1}^*$, rearranging this in terms of long run equilibrium price we get :

$$p_{t-1}^* = m_{t-1} - \widetilde{m}_{t-1}^*. \tag{16}$$

This expression is equivalent to equation (10). Further, this implies that

$$p_{t-1} - p_{t-1}^* = -(\widetilde{m}_{t-1} - \widetilde{m}_{t-1}^*). \tag{17}$$

Hence, by substituting price gap with real money gap in equation (12), we can arrive at equation (14). Readily available high frequency data on money supply makes such specification more amenable to empirical analysis. Moreover, the advantage of estimating the P-star model in terms of real money gap establishes a direct link between money and inflation as emphasised by the quantity theory. It can be easily shown that the P-star specification augmented by supply shocks is equivalent to estimating the new Keynesian Philips curve as given in equation (5) (Gerlach and Svensson, 2003).

MEASUREMENT OF VARIABLES

The study uses monthly data for the sample period from April 1993 to August 2014. The sample selection is dictated by the availability of consistent time series data on all the variables used in empirical estimation. The inflation rate is measured as month to month change in wholesale price index: $\pi_t = \ln(P_t) - \ln(P_{t-1})$.[4] The measure of real M3 money stock used in the study differs from what is reported by the Third Working Group on Money Supply (RBI, 1998) for the reason that we need to exclude certain minor components of monetary aggregates for the sake of constructing the corresponding Divisia M3 money stock.

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[4] Blejer (1983) argued that the price change measured over longer time horizon will not reflect frequent small price changes occurring in an economy.

In this regard, the measures of simple sum and its Divisia counterpart excludes call/term borrowings of financial institutions and certificate of deposits issued by the commercial banks, because interest rates on these two components witnessed high volatility during the sample period.[5] Further details regarding the components of monetary aggregates and interest rates used in the construction of the Divisia monetary aggregates are given in the Appendix A.

The data on monetary components (m_{it}) is seasonally adjusted using X-12 ARIMA method. The growth rate of Divisia quantity index is defined as:

$$\ln(M_t) - \ln(M_{t-1}) = \sum_{i=1}^{n} s_{it}^* \left(\ln m_{it} - \ln m_{it-1}\right) \tag{18}$$

where $s_{it}^* = 0.5(s_{it} + s_{it-1})$ is the average expenditure shares of two adjacent periods, $s_{it} = q_{it} m_{it} / \sum q_{it} m_{it}$ is the expenditure share of ith asset and q_{it} is the user cost (Barnett, 1978) of ith asset defined as: $q_{it} = (R_i - r_{it})/(1 + R_i)$ with r_{it} being the rate of return on i^{th} asset and R_t being the return on a benchmark asset that does not provide monetary services. Theoretically, it is a rate of return on a benchmark asset that provides no liquidity services and is used to transfer wealth from one period to another. In practice, it is either proxied by the rate of return on a least liquid asset/long maturity assets or maximum rate of return among a range of assets.[6] Following Barnett and Spindt (1982),

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[5] The call rate and the interest rate on certificate of deposits were as high as 35 percent during some periods and such wild fluctuations in interest rates affects the calculation of benchmark rate. Moreover, these monetary candidates constitute very negligible proportion of M3 money stock; hence, there is not much loss arising out of their exclusion.

[6] See Barnett (2003) and Anderson and Jones (2011) for further discussion on the issues involved in calculating rate of return on benchmark assets.

the benchmark rate of interest (R_t) is chosen as the maximum rate among a set of market rates such as prime lending rate (PLR) of SBI, yield on long-term government securities (r_{gs}) and the rate of return on components M3 and is given as:

$$R_t = Max\{r_{i,t}(i = 1,2,3, \ldots n), r_{gs,t}, BPLR_t\}. \tag{19}$$

The real simple sum and Divisia aggregates are obtained by deflating them with wholesale price index. The real money gap for both simple sum ($\widetilde{m}_{t-1} - \widetilde{m}_{t-1}^*$) and Divisia M3 ($d\widetilde{m}_{t-1} - d\widetilde{m}_{t-1}^*$) is measured as the difference between the observed money stock and its long term trend component, which is obtained using H-P filter.

Following Kapur (2013), we use variety of supply shock measures while estimating the model to ensure that the results are robust. In this regard, we consider world non-fuel commodity inflation, relative price change of food, energy, food and energy and crude oil price inflation. The measure of output gap is constructed as the difference between the index of industrial production (IIP) and its long run equilibrium level estimated using H-P filter. As output gap from IIP is considered an imperfect measure of demand pressure, we also constructed an alternative measure of output gap defined as deviation of real GDP from potential output.[7]

The monthly data on wholesale price index, food and fuel prices, components of monetary aggregates, interest rates, yield on long-term government securities, IIP and GDP are collected from the *Handbook of Statistics on Indian Economy* published by Reserve bank of India (RBI).

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[7] We have used the interpolation technique developed by Denton-Chollette (1971) to interpolate quarterly GDP to obtain monthly time series data on GDP.

The interest rate on time deposits and benchmark prime lending rate of State Bank of India (SBI) are obtained from SBI on request. The time series data on non-fuel commodity price and crude oil prices is obtained from the International Financial Statistics published by the International Monetary Fund.

ECONOMETRIC METHODOLOGY

Based on the discussions earlier, we estimated the following P-star model with real money gap:

$$\pi_t = c + \alpha\pi_{t-1} + \gamma(\tilde{m}_{t-1} - \tilde{m}^*_{t-1}) + \delta Z_{t-1} + \varepsilon_t \qquad (20)$$

where $\varepsilon_t \sim iid$, c, α, γ and δ are the parameters to be estimated and Z_{t-1} capture the influence of supply shocks on aggregate inflation.

Next, we model the inflation using the following Phillips curve specification:

$$\pi_t = c_1 + \alpha_1\pi_{t-1} + \gamma_1(y_{t-1} - y^*_{t-1}) + \delta_1 Z_{t-1} + \varepsilon_{1t}, \qquad (21)$$

Where $\varepsilon_{1t} \sim iid$, $y_{t-1} - y^*_{t-1}$ is the deviation of real output from its potential level and γ_1 and δ_1 respectively capture the impact of output gap and supply shocks on inflation.

EMPIRICAL RESULTS AND DISCUSSION

To estimate the P-star model and the Philips curve relationship, we used the specification given in equation (20) and (21), respectively. Further,

we estimated the P-star model using the simple sum and Divisia real money gap measures to examine whether Divisia monetary aggregate has an edge over its sum counterpart in explaining inflation. Before proceeding to empirical analysis, we examine the time series properties of all the variables under consideration. To this end, we used Augmented Dicky Fuller (ADF) and Phillip-Perron (PP) unit root tests. The results obtained from these tests indicate that all the variables follow $I(0)$ process.

Next, we estimate the P-star and Philips curve models using Ordinary Least Squares method and the results are presented in Table 1. Column 2 of the Table gives the results for model-1, which uses real money gap from Divisia aggregates. Similarly, in column 3, we present the results obtained from the model-2 wherein real money gap from simple sum aggregates is used. In column 4, results obtained from model 3 which uses Philips curve specification are presented.[8]

The results suggest that the coefficient associated with lagged inflation is statistically significant in all the three models implying some persistence in the inflation. Also, the results suggest that the coefficient associated with supply shock measure (Z_{t-1}) proxied by world non-fuel commodity inflation is statistically significant with expected sign in all the three models.[9] Similarly, the coefficient associated with real money gap also turns out to be significantly different from zero in both model-1 and 2. These results suggest that monetary dynamics does have a crucial role

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[8] We present results from the model wherein output gap is constructed from IIP. We also estimated the model where output gap is constructed from monthly GDP. The results obtained from both the specifications were identical.

[9] We have also used alternative measures of supply shocks such as relative price inflation of food, relative price inflation of fuel, relative price inflation of food and fuel and movements in international crude oil inflation. However, the coefficients with respect to all these supply shock measures were found to be statistically insignificant.

in explaining inflation. These results are consistent with the findings of Nachane and Laskshmi (2002). It is interesting to note that the coefficient with respect to Divisia real money gap (in model-1) is greater than the coefficient associated with its simple sum counterpart (in model-2) indicating that the theoretically admissible monetary aggregates contain additional information about inflation.

However, in model-3, the coefficient with respect to output gap turns out to be statistically insignificant. This result suggests that the aggregate demand pressure measured as output gap fail to explain the fluctuations in aggregate inflation. Similar results were reported by Bhattacharya and Lodh (1990) and Virmani (2004) in the Indian context. Recently, Paul, 2011; Singh *et. al.*, 2011 and Kapur, 2013 attributed these theoretically inconsistent results to unavailability of reliable output gap and supply shock measures. In addition, the estimates of adjusted R-squared ($\overline{R}^2$) provided at the end of the Table 1, indicate that the models estimated with alternative real money gap measures have an edge over Philips curve model in explaining inflation. Overall, the empirical results obtained from P-star models indicate that the monetary developments seem to explain significant proportion of fluctuations in inflation.

Table 1: Estimated Coefficients of the Inflation Model

	Model-1	Model-2	Model-3
Constant	0.035** (7.618)	0.036** (7.595)	0.037** (7.682)
π_{t-1}	0.396** (6.906)	0.389** (6.761)	0.354** (5.989)
Z_{t-1}	0.041** (3.453)	0.046** (4.034)	0.059** (5.135)
$d\tilde{m}_{t-1} - d\tilde{m}^*_{t-1}$	1.029** (4.240)		
$\tilde{m}_{t-1} - \tilde{m}^*_{t-1}$		0.838** (3.823)	
$y_{t-1} - y^*_{t-1}$			-0.027 (-0.174)
$\overline{R}^2$	0.31	0.30	0.26
Q(2)	0.42 [0.81]	0.54 [0.77]	1.16 [0.56]
Q(4)	6.08 [0.19]	4.61 [0.56]	2.61 [0.62]
Q(8)	11.03 [0.15]	9.54 [0.32]	6.95 [0.54]

Note: ** denotes 5% level of significance. Figures in (#) and [#] are t statistics and p values respectively. The Ljung-Box Q statistics indicate that the entire three models are free from autocorrelation.
Source: Estimated by authors.

Forecasting Performance

The forecasting performance of the alternative models is examined using out-of-sample forecast. The forecasting analysis is carried out by estimating each model recursively, beginning with the period April 1993 to August 2012 and incorporating successively a new data point to the sample. In the first stage, we compare the inflation forecasts obtained from the Philips curve model with the P-star model. In the second stage, we compared the forecasting performance of competing P-star models estimated with Divisia (model-1) and simple sum (model-2) real money

gap measures. In order to evaluate the forecasting performance of these models, the *h* period ahead forecast made at each stage, is compared with the corresponding actual observation. For this purpose, we compare the estimates of mean square error (MSE) and mean absolute error (MAE) obtained from each model.

In this regard, we used Diebold–Mariano (1995) predictive accuracy test statistic (DM) to examine whether the estimates of MSE (and MAE) obtained from P-star models are significantly different from the estimates of MSE (MAE) obtained from Philips curve model. In the second stage, the MSE (MAE) obtained from a model with simple sum real money gap is compared with the model wherein Divisia real money gap measure is used. In Table 2, the DM statistic for one month to five month ahead forecasts obtained from model-3 and model-1 and 2 are compared. The results indicate that the estimates of MSE obtained from the models wherein real money gap measures are used are significantly lower than the MSE obtained from the output gap model. The DM statistics based on MAE also gives similar inference. In particular, the DM statistics (based on MAE) in favour of Divisia real money gap measure is found to be statistically significant at 10% level except for three month ahead forecasts. Similarly, the DM statistics in favour of simple sum real money gap is found to be significant for one, two and five period ahead forecasts. Thus, the results clearly indicate that the real money gap contains more useful information than the output gap for forecasting inflation.

Table 2: Out-of-Sample Forecast Comparisons - Output vs Real Money Gap Model

Forecast Horizon	Model-3 vs Model-1		Model-3 vs Model-2	
	MSE	MAE	MSE	MAE
h=1	*3.05(0.00)*	1.84(0.06)	2.89(0.00)	2.09(0.04)
h=2	3.13(0.00)	1.84(0.07)	2.88(0.00)	2.00(0.04)
h=3	2.21(0.03)	1.32(0.18)	2.22(0.03)	1.65(0.10)
h=4	2.71(0.01)	1.84(0.07)	2.53(0.01)	1.94(0.52)
h=5	2.80(0.00)	1.74(0.08)	2.51(0.01)	1.78 (0.07)

Note: We present Diebold–Mariano forecast accuracy comparison tests of output gap model against real money gap modelsThe null hypothesis is that the two forecasts have the same mean squared error(MSE)/mean absolute error(MAE). Positive values indicate superiority of real money gap model. Figures in(#) are p-values.
Source: Estimated by authors.

Table 3: Out-of-Sample Forecast Comparisons-Simple Sum vs Divisia Money Gap Model

Forecast Horizon	Model 2 vs Model 1	
	MSE	MAE
h=1	2.23(0.03)	0.41(0.68)
h=2	2.40(0.02)	0.57(0.57)
h=3	1.48(0.14)	0.07(0.94)
h=4	2.02(0.04)	0.63(0.53)
h=5	2.14(0.03)	0.77(0.44)

Note: We present Diebold–Mariano forecast accuracy comparison tests of simple sum against Divisia real money gap model. The null hypothesis is that the two forecasts have the same mean squared error(MSE)/mean absolute error(MAE). Positive values indicate superiority of Divisia real money gap model. Figures in(#) are p-values.
Source: Estimated by authors.

Further, in Table 3, we compare the forecasting accuracy of the alternative P-star models estimated with Divisia and simple sum money gap measures. The results suggest that the MSE from Divisia money gap measure is statistically significantly lower than the MSE obtained from simple sum monetary aggregates. Thus, the results indicate that the P-star model estimated with Divisia real money gap measure performs

better than the model with simple sum real money gap measures in forecasting inflation.

Evidence from VAR Model

In this section, we have examined the dynamic relationship between inflation, real money and output gap using a vector autoregression (VAR) model. To this end, three different versions of VAR models are estimated. In each model, inflation and a measure of supply shock appear as common variables while output gap, simple sum money gap and its Divisia counterpart are alternatively used.[10] The VAR model is estimated using two lags as advocated by conventional lag selection criteria and having the order of the variables as supply shocks, output gap and inflation. To examine the dynamic response of inflation due to the shocks in other variables in the VAR model, we estimated the respective orthogonalized impulse responses of inflation from each model. Moreover, to complement the results, we decompose the forecast error variance of inflation obtained from each VAR model. In particular, we determine the extent to which inflation is affected by the three structural innovations at different forecast horizons.

In Figure 1, we present the plots of accumulated impulse-response coefficients of inflation for a one standard deviation shock in the output gap, simple sum real money gap and Divisia real money gap obtained from the respective VAR models. The dashed line indicates the response of inflation to a shock in the output gap obtained from the VAR model where output gap is used. The solid line denotes the response of inflation to a shock in the simple sum real money gap which is obtained from the model where simple sum money gap measure is used. Similarly, the response of inflation to the shocks in Divisia real money gap,

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[10] Based on the results from presented earlier, we used a measure of supply shock defined as world non-fuel commodity inflation.

obtained from the model wherein Divisia money gap is used, is indicated by the dotted line in the Figure. It is evident from the Figure that the response of inflation to the shocks in simple sum and Divisia money gap measure is relatively larger at each period than to a shock in the measure of output gap. Also, the shocks in money gap measures seem to have a long term impact on inflation as the impulse response coefficients rise till 12 months. These results indicate that the shocks in real money gap play a predominant role in explaining inflation. Moreover, consistent with the findings of previous section, the response of inflation to a shock in Divisia real money gap is larger than its response to a shock in simple sum money gap at each period; implying that theoretically admissible monetary aggregate has an edge over its simple sum counterpart in explaining the dynamics of inflation.

Figure 1: Impulse-Response of Inflation

Legend: $(\tilde{m}_{t-1} - \tilde{m}^*_{t-1})$, $(d\tilde{m}_{t-1} - d\tilde{m}^*_{t-1})$, $(y_{t-1} - y^*_{t-1})$
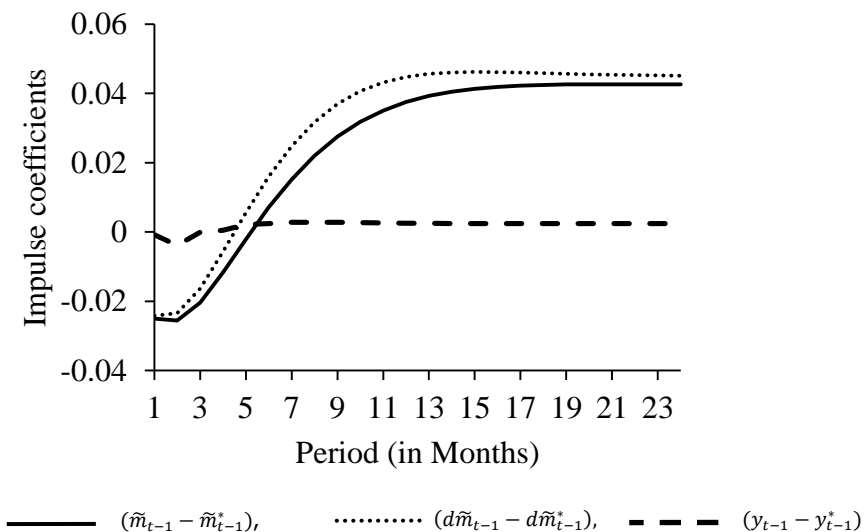
Further, in Table 4, we present the results regarding the decomposition of forecast error variance of inflation obtained from each VAR model. [11] Here, we present the proportion of forecast error variance of inflation explained by only Divisia real money gap, simple sum real money gap and the real output gap obtained from the respective models. It can be seen from the second and third columns the Table that the forecast error variance of inflation obtained from the models, wherein alternative money gap measures were used, is increasingly explained by the shocks in simple sum and Divisia money gap measures. However, the model where the measure of output gap is used, the forecast error variance of inflation is not much explained by the shocks in the output gap. For instance, in the model wherein simple sum real money gap measure is used, 25.64% of forecast error variance of inflation is explained by shocks in simple sum money gap at one month forecast horizon and it increases to 30.36% at 15 months forecast horizon.

In the model where Divisia money gap is used, the proportion of forecast error variance of inflation explained by shocks in Divisia money gap is 24.37 and 32.42% at 1 and 15 months horizons, respectively. However, in the model with output gap, the forecast error variance of inflation explained by the shocks in output gap measure turn out to be less than 1% at each forecast horizon. More importantly, it is evident from the results that the shocks in Divisia real money gap explain a greater proportion of variability of inflation at each forecast horizon than the simple sum money gap. These results indicate that the shocks in Divisia real money gap predominantly explain the variability of inflation at each horizon whereas the shocks in real output gap do not seem to account for a significant impact. These evidences suggest that the Divisia money gap measure contains more information about the fluctuations in

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[11] The respective proportions attributed to inflation and the supply shock in each model can be obtained from authors.

inflation as compared to the information content of the output gap measure. Hence, the measure of money gap obtained from Divisia money has an edge over output gap in forecasting inflation. This evidence from decomposition of forecast error variance of inflation corroborate the findings presented earlier.

Table 4: Decomposition of Forecast Error Variance of Inflation

Forecast Horizon (in Months)	Due to shocks in		
	$\widetilde{m}_{t-1} - \widetilde{m}_{t-1}^*$	$d\widetilde{m}_{t-1} - d\widetilde{m}_{t-1}^*$	$y_{t-1} - y_{t-1}^*$
1	25.64	24.37	0.03
3	21.67	21.68	0.70
6	27.33	29.51	0.75
9	29.90	32.15	0.75
12	30.33	32.42	0.75
15	30.36	32.42	0.75
24	30.36	32.42	0.75

Source: Estimated by authors.

We also examined the relevance of alternative supply shock measures by estimating the VAR model with inflation, Divisia real money gap and the five alternative measures of supply shock.[12] These five measures of supply shocks include: world non-fuel commodity inflation (WNEI) relative price inflation of food (RPFD), relative price inflation of fuel (RPFU), relative price inflation of food and fuel (RPFF) and movements in international crude oil inflation (OI). The five VAR specifications were estimated using these measures of supply shock alternatively. The impulse response function of inflation corresponding to the innovations in each supply shock is provided in the Appendix B. The plots of impulse-response coefficients of inflation indicate that the response of inflation is greater for the innovations in the world non

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[12] The VAR models with simple sum money gap and output gap were also estimated in this context. However, similar inferences can be drawn from the results.

energy inflation (WNEI). However, it is evident that the impact of each supply shock on inflation is transitory in nature as the respective impulse response coefficients become quite flat soon after 3 months. These results are consistent with the findings reported earlier.

CONCLUSION

This study uses P-star model to examine the role of money in explaining inflation in India using the data for the sample period from April 1993 to August 2014. In particular, we compare the performance of traditional Phillips curve approach against P-star model in forecasting inflation. Moreover, the study estimates P-star model using the alternative measures of money such as simple sum and Divisia M3, to examine the relevance of aggregation theoretic monetary aggregates in explaining inflation. The empirical results indicate that P-star model with real money gap has an edge over traditional Phillips curve approach in forecasting inflation. More importantly, we found that the P-star model estimated with Divisia real money gap performs better than its simple sum counterpart. These empirical findings suggest that the changes in growth rate of money play a crucial role in explaining inflation in India.

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Appendix A

Monetary Components and Corresponding Interest Rate Proxies

Monetary components (x)	Interest rates (r)
Currency with the public	Zero
Demand deposits (demand deposits with banks + other deposits with the RBI)	Implicit rate of demand deposits (r_{DD}) $= r_T(1-[BR/DD])$; where r_T is 91 days treasury bill rate, BR is Bank reserve held against demand deposits and DD is demand deposits [Kelin (1974)]
Term deposits with the contractual maturity of up to and including one year with banks	Interest rate on one year term deposits of SBI
Term deposits with the contractual maturity of over one year	Maximum Interest rate of term deposits with the contractual maturity of over one year of SBI

Source: Paul and Ramachandran (2011).

Appendix B

Impulse Response of Inflation to Shocks in Alternative Measures of Supply Shocks
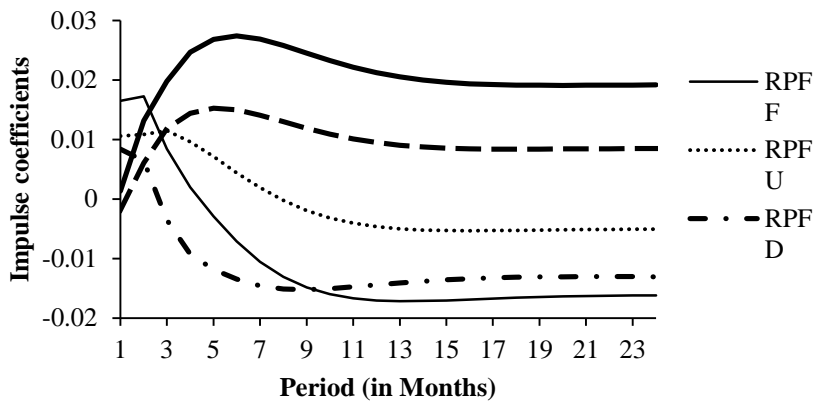
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