4

P-STAR APPROACH TOWARDS MODELING INFLATION IN INDIA

4.1. Introduction

The evolution of monetary policy objectives in India since independence has been guided by both theoretical and practical considerations and follows the general guideline outlined in the preamble of Reserve Bank of India (RBI) Act 1935. According to RBI Act 1935 the Reserve Bank of India is entrusted to ensure the monetary stability in India. In this context the monetary stability is often understood to have a wider meaning encompassing multiple objectives such as price stability, sustainable growth and financial stability. The relative importance of a particular objective or objectives that guided the monetary policy differed from time to time depending on the prevailing conditions of the economy. For example, the focus of monetary policy in the early decades of post independence was to ensure adequate credit flows to priority sectors that are considered crucial for the economic growth. Later the prevalence of high and sustained inflation with growing unemployment during 70s brought price stability as a prominent objective of monetary policy. Further, increased integration with global financial system since 1990 brought new challenges and hence, maintaining stability in the financial sector also became an important objective of the central bank. Thus, at present monetary authorities in India
tries to maintain a balanced view regarding objectives of monetary policy and follow a sort of multiple indicator approach.

Even though, the monetary policy in India attends multiple objectives, maintaining low and steady inflation always remained as an important concern of RBI. Initiation of economic reforms since 1990 and consequent changes in the monetary policy framework increased the operational flexibility of central bank considerably. Moreover, the inflation rate also seems to be moderated since 1990 as the average inflation is lower and less volatile during this period compared to earlier decades. However, the liberalization and integration of financial markets also induced complexities in the dynamics of inflation. In this context, understanding the dynamics of inflation and its driving forces may provide useful insights for the conduct of monetary policy. This chapter attempts to examine the dynamics of inflation emphasizing role of monetary developments using monetary aggregates constructed using different aggregation procedures.

4.2. Trend and Pattern of Inflation in India

From a historical perspective inflation in India was always at moderate level with some exceptions which are mainly attributed to supply shocks such as oil price shocks, war etc. The descriptive statistics given in Table 4.1 and the plots of inflation in Figure 4.1 support this argument. The average inflation for the period from 1953 Q2 to 2009 Q2 is estimated to be 6.43 percent. At the same time, pattern of inflation exhibited considerable difference in each decade. For instance there is considerable fluctuations in the inflation rate during 1950s and 70s whereas it exhibits relatively stable trend since mid 80s compared to the previous decades.

The decade wise average inflation and the standard deviation (Table 4.1) give a detailed perspective on inflation since independence. According to the estimates, the average inflation rate was lowest (2.26 percent) during 1953 Q2 to 1960 Q1. However the variability of inflation is relatively higher during this period as indicated by the standard deviation of inflation which is estimated to be 7.13. Moreover, this period was characterized by both deflationary and inflationary episodes. For instance, the inflation rate was negative for the period from 1954 Q2 to 1955 Q4 with lowest being
minus 12.83 percent. The decline in price during this period is mainly attributed to higher agricultural production. However the inflation rose and exceeded 10 percent from 1956 Q2 to 1957 Q1 mainly due to increase in the investment demand as government emphasized a drive towards rapid industrialization in the second five year plan.

**Figure 4.1: Year–on-Year Percentage Change in WPI**

![Graph showing year-on-year percentage change in WPI]

The average inflation rate rose to 6.06 percent during 60s with a standard deviation of 4.84 which is lower than the preceding decade. Similarly the rate of inflation exhibited an increasing trend particularly from 1961 Q2 to 1967 Q4. The sustained increase in inflationary pressure during this period is due to the decrease in agricultural production and external shocks emanated from the two wars against China in 1962 and Pakistan in 1965. However bumper harvest in agriculture at the end of 60s brought down the inflationary pressure considerably since 1967 Q4.

The inflation rate fluctuated considerably during 70s; the volatility of inflation rate as measured by standard deviation is 8.56. In line with the increase in the international crude oil price in 1973-74, the domestic inflation overshot and reached 27.47 percent in 1974 Q4. The high inflation rate due to oil price shock prevailed during 1973-74 and 1974-75. Inflation rate decreased for brief period during 1975-76 but second oil price shock triggered another episode of high inflation during 1978-80.
Table 4.1: Descriptive Statistics of WPI Inflation in India (in %)

<table>
<thead>
<tr>
<th></th>
<th>Average Inflation</th>
<th>Standard Deviation</th>
<th>Maximum Inflation</th>
<th>Minimum Inflation</th>
</tr>
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<tbody>
<tr>
<td>1953 Q2 to 1960 Q1</td>
<td>2.26</td>
<td>7.13</td>
<td>15.66</td>
<td>-12.83</td>
</tr>
<tr>
<td>1960 Q2 to 1970 Q1</td>
<td>6.06</td>
<td>4.84</td>
<td>15.12</td>
<td>-2.34</td>
</tr>
<tr>
<td>1980 Q2 to 1990 Q1</td>
<td>7.63</td>
<td>3.76</td>
<td>19.14</td>
<td>2.08</td>
</tr>
<tr>
<td>1990 Q2 to 2000 Q1</td>
<td>7.76</td>
<td>3.47</td>
<td>15.42</td>
<td>2.64</td>
</tr>
<tr>
<td>2000 Q2 to 2009 Q2</td>
<td>5.26</td>
<td>3.13</td>
<td>15.42</td>
<td>0.74</td>
</tr>
<tr>
<td><strong>1953Q2 to 2009Q2</strong></td>
<td><strong>6.43</strong></td>
<td><strong>5.64</strong></td>
<td><strong>27.47</strong></td>
<td><strong>-12.83</strong></td>
</tr>
</tbody>
</table>
| 1985Q2 to 1998Q1  
(Monetary targeting)           | 7.75              | 3.02               | 15.42             | 3.44              |
| 1998Q2 to 2009Q2   
(Multiple indicator approach) | 5.13              | 1.98               | 10.45             | 0.74              |

The inflationary pressure sustained during 80s but with lesser variability. The average inflation rate during 80s is estimated to be 7.63 percent with a standard deviation of 3.47. The sustained inflationary pressure during this period is often attributed to automatic monetization of budgetary deficit which was 6.8 percent of GDP during 80s compared to 3.8 percent during 70s. Moreover the high budget and current account deficit in the 80s have resulted in Balance of payment problem and economic crisis in 1991. Hence, a package of macroeconomic stabilization program put in place to mitigate the economic crisis that caused substantial depreciation of Indian rupee vis-a-vis US dollar. Consequently, the inflation remained high in early 90s as the average inflation during 1990 Q2 to 1995 Q1 was above 10 percent level. Rise in fuel prices due to Gulf crisis in 1991 and monetary expansion due to increased capital flows mounted up the inflationary pressure during this period. However the inflation rate decreased since 1995 Q3. The average inflation rate (5.26%) and standard deviation (3.13) for the period 1995 Q3 - 2009Q3 are lower than the preceding four decades.

Even though the average inflation rate since 1953-54 is moderate with an average rate of 6.43 percent, the trajectory of inflation rate shows a shift since 1995-96. The average inflation during this period is not only lower but also has less variability compared to previous decades. This moderation in inflation rate is attributed to the improved fiscal monetary interface and also the reforms in
government security markets in mid 90s among other things. These reforms helped RBI to phase out the automatic monetization of fiscal deficit. From another perspective it can be argued that increased operation flexibility of RBI since the adoption multiple indicator approach has helped to maintain relatively stable prices. The inflation rate seems to be moderated under multiple indicator approach and the average inflation rate during the period is estimated to be 5.13 percent (Table 4.1). Note that the average inflation rate during monetary targeting regime is 7.75 percent. The variability of inflation rate too considerably decreased under multiple indicator approach as the standard deviation of inflation rate during this period is 1.98 compared to 3.02 under monetary targeting regime. Similarly, despite the shocks of different nature such as East Asian crisis, border tensions with Pakistan during May-June 1998 etc. the inflation rate continued to be at moderate level since the adoption of multiple indicator approach.

However it also has to be noted that the relatively low inflationary regime started before the introduction of multiple indicator approach in Aug 1998. Integration of the financial markets globally and market oriented reforms in India particularly complicated the conduct of monetary policy. Even though, present policy framework provide considerable operational flexibility to monetary authorities the increasing complexities throw new challenges. The difficulty to detect and contain inflationary pressure after the global financial crisis in 2008 has to be understood in this context. The inflation remained high even after an increase in the policy rate (repo rate) by 375 point basis between Jan 2010 and Oct 2011. Accurate assessment of inflationary pressure is necessary for timely monetary policy response.

Under multiple indicators approach both quantity and rate variable are used optimally by the monetary authorities but interest rate variables play more significant role in the conduct of monetary policy. However, the role of monetary impulses cannot be completely ignored in the propagation of inflationary pressure. Thus while modeling the dynamics of inflation monetary factors need to be accommodated. In this context this chapter attempts to understand the dynamics of inflation in India using P-Star model developed by Hallman, Porter, and Small (1991). Besides performance of both simple sum and currency equivalent monetary aggregates are
used in the empirical analysis to assess the impact of alternative monetary aggregation procedures.

4.3. Inflation Dynamics: A Brief Introduction to Prominent Theoretical Paradigms

Theoretical discourse in this respect provides a number of approaches in modeling inflationary process. This section reviews two prominent approaches that are popular in policy discourse namely quantity theory based P-star model and New Keynesian Phillips curve. The new Keynesian version of Philips curve become prominent since 90s and is considered to be the standard benchmark model. The underlying micro foundations of new Keynesian Philips curve emphasize the role of cost pressures in the short run dynamics of 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. Whereas, P-star approach is based on Quantity theory of money and it links the short run dynamics of actual inflation to the determinants of long run equilibrium price.

4.3.1. 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 output at the cost of higher inflation and vice versa. However, high rates of unemployment and inflation during 70s were inconsistent with the Phillips relation. In this respect Phelps (1967) and Friedman (1968) observed that the tradeoff between inflation and unemployment is not permanent. Moreover economy tends to maintain an unemployment rate consistent with microeconomic structure of the labor and product markets known as natural unemployment rate. A steady state of inflation prevails in the economy at the natural rate. Thus any deviation from natural rate will only induce a temporary increase or decrease in inflation. The unemployment would return to its natural level as the economic agents adjust their expectations about increase in prices. In other words, the
short run Phillips curve shifts as expectations about price changes. Hence, the absence of tradeoff between the unemployment and inflation in the long run the policy that tend to exploit this relation became dubious. In the long run, the policy makers have no choice regarding the unemployment rate other than natural unemployment rate.

Friedman-Phelps critique put forward two important propositions in modeling inflation (i) it distinguished between short run and long run tradeoff between inflation and output and (ii) it introduced expectations in price adjustment process. 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. While, the error in anticipated changes persisted for some time under adaptive expectation hypothesis, the rational expectation ruled out such possibility. In essence the short run tradeoff between output and prices arise due to price misperceptions or imperfect information on the part of price setters (Lucas 1972).

The Lucas (1972) and Sargent and Wallace (1975) propositions was based on the assumption that prices adjust instantaneously to any deviation from market clearing prices. However, as Gordon (1976) observes that empirical evidence for sluggishness in the price adjustment mechanism seriously undermines their arguments. Besides the high inflation during 70s due to oil price hikes indicated the role of supply shocks in modeling inflation. Accordingly Gordon (1977, 1982) proposed a modified version of Phillips curve building on Friedman-Phelps natural rate hypothesis with supply shocks popularly known as “triangle” model. As the name suggests the triangle model characterize the inflationary process on inertia, demand pressure and supply shocks. The empirical version of the triangle model of inflation ($\pi_t$) is given as follows

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

(4.1)
where the lagged inflation \((\pi_{t-1})\) captures inertia or nominal sluggishness not the inflation expectation alone, 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 such as oil prices hikes, changes in the relative price of imports etc. The excess demand is alternatively measured by the deviation of actual output from its potential.

Triangle model of inflation dominated the policy debates till the new Keynesian Phillips curve become prominent. The new Keynesian Phillips curve may be derived from a price setting behavior of monopolistically competitive firms. The monopolistic competitors are assumed to set price rather than quantities to maximize their profit. However, the choice of optimum price by each firm is constrained by frictions in price adjustment. The frictions in the price adjustment mechanism is theorized by new Keynesian models such as the staggered wage contract model by Taylor (1979, 1980), and Calvo (1983) as well as the quadratic price adjustment cost model by Rotemberg (1982). The new Keynesian Phillips can be derived incorporating any of these new Keynesian models that explain the frictions in the price adjustment (see Roberts (1995) for details). In this respect, the following section briefly describes the most commonly used formulation of new Keynesian Phillips curve using Calvo (1983) model following Gali and Gertler (1999).

Assuming that a random fraction of firms \((1-\theta)\) are expected to reset their prices, 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 \((p_t^*)\) as follows (all variables are expressed in logarithmic form)

\[
p_t = \theta p_{t-1} + (1 - \theta) p_t^*.
\]  

(4.2)

The optimum reset price \((p_t^*)\) by a representative firm in an imperfect market condition is chosen by maximizing its profits conditioned on Calvo type price adjustment mechanism. The optimum reset price \((p_t^*)\) may be expressed follows

\[
p_t^* = (1 - \theta \beta) \sum_{k=0}^{\infty} (\theta \beta)^k E_t \tilde{m} \bar{c}_{t+k},
\]  

(4.3)
where $\beta$ denotes subjective discount factor and $m\tilde{c}_t$ is the nominal marginal cost expressed as a deviation from its steady state level. According to equation 4.3 firms prices would be equal to weighted average of nominal marginal cost and will be fixed for certain time period. The new Keynesian Phillips curve may be obtained by combining equations 4.2 and 4.3 as follows

$$\pi_t = \beta E_t \pi_{t+1} + \frac{(1-\theta)(1-\theta\beta)}{\theta} (m\tilde{c}_t), \quad (4.4)$$

where $\pi_t$ denotes inflation measured as $(p_t - p_{t-1})$, $\beta$ and $\theta$ are subjective discount factor and price adjustment parameter as defined earlier. While $m\tilde{c}_t$ 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. As Gali and Gertler (1999) observes 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 write equation 4.4 as follows

$$\pi_t = \beta E_t \pi_{t+1} + \gamma (y_t - y_t^*), \quad (4.5)$$

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 new Keynesian Phillips curve could incorporate price rigidities into the model retaining rational expectation hypothesis and expectations are forward looking in nature. Consequently the inflation is assumed to depend on current and future economic conditions alone (Clarida, Gali, and Gertler 1999). The new Keynesian Phillips curve has strong micro theoretic foundation build in it. 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 that a fraction of firms are backward looking while setting the price. The hybrid version of new Keynesian Phillips curve may be expressed as follows

$$\pi_t = \beta^f E_t \pi_{t+1} + \beta^b \pi_{t+1} + \gamma (y_t - y_t^*), \quad (4.6)$$
where $\beta^f$ and $\beta^b$ are the coefficients of forward looking and backward looking components. Both primitive and hybrid versions of new Keynesian Philips curve as defined by equations 4.5 and 4.6 explains the dynamics of inflation to some measures of real activity. However, empirical studies failed to establish the short run link between output and inflation as predicted by the theory. Similarly, the inability to account the inflation persistence observed in the data by primitive new Keynesian Phillip curve as documented in Rudd and Whelan (2005) and the forward looking term in hybrid version of new Keynesian models found to play very limited role in explaining inflation dynamics. Notwithstanding the criticisms the new Keynesians models made significant contribution in understanding inflation dynamics and is widely used in empirical studies.

4.3.2. P-Star Models

P-star approach is based on Quantity theory of money and it links the short run dynamics of actual inflation to the determinants of long run equilibrium price. Under this approach the long run equilibrium price ($p^*$) is determined by current money supply, potential income and the equilibrium velocity. Under P-star model the actual price is assumed to adjust to the deviations from its long run equilibrium, In other words P-star model predicts whether inflation will rise, fall or unchanged as actual prices are below, above or at their equilibrium. Empirically this can be estimated as a reduced form equation that relates short-term changes in inflation to price gap which is defined as deviations from actual and equilibrium price. A brief exposition of the p-star is given below.

P-star model was first proposed by Hallman, Porter, and Small (1991) based on quantity theory money defined as

$$MV=PY,$$  \hspace{1cm} (4.7)

where $M$ is stock of money, $V$ stands of income velocity of money, $P$ denotes price level and $Y$ is the real output. Following equation 4.7 the long run equilibrium price can be can be specified given the stock of money ($M$) the level of potential real output ($Y^*$) and long run equilibrium value of velocity ($V^*$) as follows
\[ p^* = \frac{MV^*}{Y^*}. \]  \hfill (4.8)

Taking logarithmic transformation and denoting the transformed variables in lower case letters the equations 4.7 and 4.8 can be written as

\[ p = m + v - y, \]  \hfill (4.9)
\[ p^* = m + v^* - y^*. \]  \hfill (4.10)

Equation 4.10 states that “equilibrium price is equal to money per unit of potential output at equilibrium velocity” (Todter and Reimers 1994). Subtracting equation 4.10 from equation 4.9 we can express the deviation from actual price from its equilibrium level in terms of velocity gap and output gap as follows

\[ (p - p^*) = (v - v^*) - (y - y^*). \]  \hfill (4.11)

Having defined the price gap Hallman, Porter, and Small (1991) related inflation to lagged values of inflation and lagged price gap as follows

\[ \pi_t = \delta(p_{t-1} - p^*_{t-1}) + \pi_{t-1}; \quad \delta < 0 \]  \hfill (4.12)

Taking lagged inflation term to the left side of the equation we can arrive at a model for acceleration of inflation at time period \( t \) (\( \Delta \pi_t \)) as follows

\[ \Delta \pi_t = \delta(p_{t-1} - p^*_{t-1}); \quad \delta < 0 \]  \hfill (4.13)

According to equation 4.13, the inflation tends to accelerate if \( p_{t-1} < p^*_{t-1} \) and decelerate if \( p_{t-1} > p^*_{t-1} \). Thus the price gap can be used as a leading indicator of acceleration or deceleration of inflation. Further substituting equation 4.11 into equation 4.13 the acceleration of inflation (\( \Delta \pi_t \)) can be expressed as a function of output gap and velocity gap as follows

\[ \Delta \pi_t = \phi(v_{t-1} - v^*_{t-1}) - \gamma(y_{t-1} - y^*_{t-1}). \]  \hfill (4.14)

Thus a negative velocity gap (\( v_t < v^*_t \)) implies that current velocity is below its equilibrium level and it leads to an increased spending till the velocity reaches the
equilibrium level which tends to increase the inflation (Hallman, Porter, and Small (1991). Similarly a positive output gap \((y_t > y_t^-)\) implies that actual output is above its potential level and the excess demand pressure tend to increase the inflation until it reaches its potential. P-star models take monetary dynamics while modelling the dynamics of inflation as compared to new Keynesian models. In this respect, restricting coefficient of velocity gap equal to zero \((\varphi = 0)\) we can specify the output gap model similar to Phillips curve model as given in equation. 4.5 under certain assumptions.

P- Star models proposed by Hallman, Porter, and Small (1991) and its modified versions have been applied in empirical studies to understand the behavior of inflation using data from different countries. Hallman, Porter, and Small (1991) applied P-star model using quarterly US data for a period from 1955:1 to1988:4 and found that P-star model performs better in forecasting inflation. Similarly Hoeller and Poret (1991) estimated P-star model for 20 OECD countries and found that it tracks the inflation behavior of nine countries better than models based on output gap alone. Several studies pertaining to Euro Area examined P- star model and found significant evidence in support of P- star models [see for eg. Toèdter and Reimers 1994; Nicoletti-Altimari 2001; Gerlach and Svensson 2003; and Czudaj 2011]. These studies in the context of ‘Two pillar monetary policy’ followed by the European Central Banks emphasized the direct link between money and prices. Similarly, Gerlach and Svensson (2003) observed that price gap can be equated to the inverse of real money gap in the P- star model specifications. He found that real money gap along with output gap in P-star framework contains considerable information regarding future inflation.

However, only few studies have been done in the context of developing countries. In this respect Mujeri, Shahiduzzaman, and Islam (2009) estimated P-star model for Bangladesh and found empirical evidence in support of P Star models. In the Indian context, Nachane and Lakshmi (2002) estimated the \(P^*\) model using both annual and quarterly data for the period 1955 to 1990. They find supporting evidence for monetarist explanation of inflation as velocity gap models performed better compared to output gap model. However evidence for poor performance of output gap
models in their study may be attributed to use of unreliable data on output at quarterly frequencies.

In this context this study applies P-star model to study the inflation dynamics in India. An attempt is also made to assess the performance of various monetary aggregates such as simple sum and CE aggregates. Measurement error in the monetary aggregate may give misleading signals. For instance, Barnett and Chauvet (2011b) mentions that discrepancy in the prediction of US inflation using P-star model during 1991 and 1992 referred by Bernanke (2006) may be due to the use of simple sum M2. Most of the studies estimated P-star model using simple sum monetary aggregates. However, Reimers (2002) using divisia aggregates examined importance of money for future price movements in the Euro area using P-star framework. Empirical evidence emphasized role of money in predicting inflation irrespective of the method of aggregation. However Divisia aggregates performed relatively better compared to simple sum aggregates. Similarly, Mäki-Fränti (2007) also examined the performance monetary indicator constructed using Divisia and simple sum aggregates applying P-star methodology. The indicator based on Divisia monetary aggregate was found to outperform their simple sum counterparts.

4.4. Methodological Considerations

4.4.1. Specification of the Model

Following Hallman, Porter, and Small (1991) and Nachane and Lakshmi (2002) the econometric specification of P star model is given as follows:

$$\Delta \pi_t = \alpha_1 (\nu_{t-1} - \nu_{t-1}^*) - \alpha_2 (y_{t-1} - y_{t-1}^*) + \rho \pi_{t-1} + \sum_{i=j}^{q} y_j \Delta \pi_{t-j} + \varepsilon_t,$$

and $\varepsilon_t \sim iid$

An appropriate lag length (q) of lagged values of change in inflation will be decided to make the auto correlation free residuals. Further the lagged inflation term is included to account for incomplete adjustments. However specific models can be obtained from the equation 4.15 based on the assumption regarding inflation. If
inflation has unit root the model given by equation 4.15 can be reformulated as follows:

$$\Delta \pi_t = \alpha_1 (v_{t-1} - v_{t-1}^*) - \alpha_2 (y_{t-1} - y_{t-1}^*) + \sum_{i=j}^q y_j \Delta \pi_{t-j} + \epsilon_{1t},$$

and $\epsilon_{1t} \sim i.i.d$ (4.16)

Similarly, if inflation is a stationary variable the model can be expressed as follows:

$$\pi_t = \alpha_1 (v_{t-1} - v_{t-1}^*) - \alpha_2 (y_{t-1} - y_{t-1}^*) + \sum_{i=j}^q y_j \pi_{t-j} + \epsilon_{2t},$$

and $\epsilon_{2t} \sim i.i.d$ (4.17)

An appropriate econometric specification will be decided on the basis of time series properties of the inflation applying standard unit root tests\(^1\).

### 4.4.2. Estimation of Equilibrium Velocity and Potential Output

In order to estimate P-star model specified as either equation 4.16 or equation 4.17, we need to construct the equilibrium velocity ($v^*$) and potential output ($y^*$) series. Simplest way to construct equilibrium velocity ($v^*$) is to take the sample average assuming a velocity fluctuates randomly around a constant ($v_i = v^* + \epsilon_{lt}$) as in Hallman, Porter, and Small (1991)\(^2\). If velocity is assumed to follow deterministic trend then the equilibrium velocity can be constructed by fitting a linear trend ($v = \alpha_0 + \alpha_1 t$). However recent literature suggests that velocity may follow a stochastic rather than deterministic trend. In the presence of unit root a constant velocity or fitting linear trend to generate equilibrium velocity may be inappropriate and price gap from such series will be inconsistent with assumptions of P-star model. In this context, many studies tried to construct equilibrium velocity either using filters or modelling velocity based on money demand functions\(^3\). Following Hoeller and Poret (1991) this study

\(^1\) An appropriate specification can also be chosen by estimating the model given in equation 4.15 and then checking for the significance of coefficient of lagged inflation term ‘$\rho$’ as proposed by Hallman, Porter, and Small (1991).

\(^2\) Hallman, Porter, and Small (1991) also constructed a model based trend velocity for the sample period 1879-1954 even though he assumed constant velocity for the sample period 1955-1988. They observed that the long-run equilibrium velocity may depend on various factors such as real output, market interest rates and the structure of the financial system.

\(^3\) see Orphanides and Porter (1998) for a regression tree approach based on the short run relation between velocity and opportunity cost of money.
uses H-P filter to obtain equilibrium velocity. Similar methodology is used to obtain potential output in the absence of other reliable data on potential output.

4.5 Empirical estimation and Results

In order to estimate the P-star model this study used quarterly data from 1997 Q1 to 2009 Q2. Choice of sample period is constrained by the availability of Quarterly data on GDP. The quarterly inflation was estimated from wholesale price index. Similarly the velocity of each aggregate is estimated as a ratio of annualised nominal GDP to nominal money. Prior to estimation of velocity both the annualised nominal GDP and various aggregates were transformed into logarithmic scale. As mentioned in the previous section the equilibrium velocity ($v^*$) and potential output ($y^*$) is constructed using H-P filter method.

<table>
<thead>
<tr>
<th>Variables</th>
<th>ADF –test</th>
<th>PP Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Pi$</td>
<td>-0.32 (0.57)</td>
<td>-1.34 (0.16)</td>
</tr>
<tr>
<td>$\Delta \pi$</td>
<td>-6.90 (0.00)</td>
<td>-4.46 (0.00)</td>
</tr>
<tr>
<td>$(y-y^*)$</td>
<td>-2.75 (0.01)</td>
<td>-1.98 (0.04)</td>
</tr>
<tr>
<td>$(vcem1-vcem1^*)$</td>
<td>-2.84 (0.01)</td>
<td>-2.92 (0.00)</td>
</tr>
<tr>
<td>$(vm1-vm1^*)$</td>
<td>-3.29 (0.00)</td>
<td>-3.19 (0.00)</td>
</tr>
<tr>
<td>$(vcem2-vcem2^*)$</td>
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<td>-2.67 (0.01)</td>
</tr>
<tr>
<td>$(vm2-vm2^*)$</td>
<td>-2.59 (0.01)</td>
<td>-2.16 (0.03)</td>
</tr>
<tr>
<td>$(vcem3-vcem3^*)$</td>
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<td>-2.20 (0.03)</td>
</tr>
<tr>
<td>$(vm3-vm3^*)$</td>
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<td>-1.95 (0.04)</td>
</tr>
<tr>
<td>$(vcell-vcell^*)$</td>
<td>-2.96 (0.00)</td>
<td>-2.21 (0.03)</td>
</tr>
<tr>
<td>$(vII-vII^*)$</td>
<td>-3.38 (0.00)</td>
<td>-1.99 (0.04)</td>
</tr>
</tbody>
</table>

Figures in (#) are p values

In order to decide the appropriate econometric specification of P-star model we have first checked the stationary properties of inflation ($\pi$) by conducting Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests. The results of unit root tests for inflation, output gap and velocity gap are given in the Table 4.2. The unit roots tests indicate that inflation is a $I(1)$ process. Similarly the output gap ($y-y^*$) and the velocity gaps of various monetary aggregates are found to be stationary.
Since inflation has unit root we proceed to estimate the P-star model specified as follows\(^4\):

\[
\Delta \pi_t = \alpha_1 (\nu_{t-1} - \nu_{t-1}^*) - \alpha_2 (y_{t-1} - y_{t-1}^*) + \gamma_1 \Delta \pi_{t-j} + \epsilon_t. \tag{4.18}
\]

The above model is estimated using estimated velocity gaps of simple sum M1, M2, M3 and L1 along with the corresponding currency equivalent monetary aggregates (i.e. CE M1, CE M2, CE M3 and CEL1) for the sample period 1997 Q1 to 2009 Q2. In addition an output gap model (OG) is estimated excluding the velocity gap from the specification given in equation 4.18 for the sake of comparison.

The coefficients of output and velocity gap have expected sign. The Ljung-Box Q-statistics indicates that there is no significant residual serial correlation in the estimated models (Table 4.3). The coefficient of velocity gap is statistically significant except for the velocity gap of CE M1. However, most of the models reported insignificant coefficient for output gap. For models where in velocity of CE M1 is used the coefficients of both output gap and velocity gap is insignificant. Besides, the coefficients of output gap are significant only when we use the velocity gap derived from M2, L1, CEM3 and CE L1. Similarly, the coefficient of output gap in the output gap model (OG) is statistically insignificant. The empirical results also correspond to Nachane and Lakshmi (2002) who used p-star methodology to examine the inflation dynamics. Unlike in Nachane and Lakshmi (2002) the estimated coefficients of output gap in the models given in Table 4.3 have theoretically expected sign.

Further, all the coefficients of velocity gaps from monetary aggregates (Except CE M1) irrespective of aggregation method have significant and theoretically expected relation with change in inflation. Thus empirical evidence suggests that monetary dynamics do have a role in explaining the acceleration of inflation in India and both simple sum and currency equivalent aggregates performs equally good.

\(^4\) We have also estimated the equation including one period lagged inflation term (see foot note 2). The coefficient of lagged inflation term is statistically insignificant for all models which also justify our choice of model specification. The estimated coefficients of other variable were similar to those reported in table 4.3.
Table 4.3: Estimates of P-star Model

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>CE M1</th>
<th>M1</th>
<th>CE M2</th>
<th>M2</th>
<th>CE M3</th>
<th>M3</th>
<th>CE L1</th>
<th>L1</th>
<th>OG</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_1$</td>
<td>-0.16</td>
<td>-0.38*</td>
<td>-0.13*</td>
<td>-0.84*</td>
<td>-0.11*</td>
<td>-0.43*</td>
<td>-0.11*</td>
<td>-0.54*</td>
<td>--</td>
</tr>
<tr>
<td>$\alpha_2$</td>
<td>0.39</td>
<td>0.17</td>
<td>0.49</td>
<td>0.82*</td>
<td>0.67*</td>
<td>0.54</td>
<td>0.67*</td>
<td>0.67*</td>
<td>0.15</td>
</tr>
<tr>
<td>$\gamma_1$</td>
<td>0.35*</td>
<td>0.25</td>
<td>0.38*</td>
<td>0.26*</td>
<td>0.35*</td>
<td>0.34*</td>
<td>0.30</td>
<td>0.32</td>
<td>0.39*</td>
</tr>
<tr>
<td>$\bar{R}^2$</td>
<td>0.17</td>
<td>0.24</td>
<td>0.19</td>
<td>0.29</td>
<td>0.24</td>
<td>0.21</td>
<td>0.20</td>
<td>0.24</td>
<td>0.14</td>
</tr>
<tr>
<td>$Q(2)$</td>
<td>0.51</td>
<td>0.66</td>
<td>0.48</td>
<td>0.31</td>
<td>0.43</td>
<td>0.79</td>
<td>1.11</td>
<td>0.67</td>
<td>1.40</td>
</tr>
<tr>
<td></td>
<td>(0.78)</td>
<td>(0.72)</td>
<td>(0.79)</td>
<td>(0.86)</td>
<td>(0.81)</td>
<td>(0.67)</td>
<td>(0.58)</td>
<td>(0.72)</td>
<td>(0.49)</td>
</tr>
<tr>
<td>$Q(4)$</td>
<td>6.21</td>
<td>5.95</td>
<td>8.66</td>
<td>6.56</td>
<td>8.88</td>
<td>6.81</td>
<td>9.28</td>
<td>6.37</td>
<td>11.19</td>
</tr>
<tr>
<td></td>
<td>(0.18)</td>
<td>(0.20)</td>
<td>(0.07)</td>
<td>(0.16)</td>
<td>(0.06)</td>
<td>(0.15)</td>
<td>(0.06)</td>
<td>(0.17)</td>
<td>(0.02)</td>
</tr>
<tr>
<td>$Q(8)$</td>
<td>7.39</td>
<td>7.15</td>
<td>10.95</td>
<td>7.88</td>
<td>11.22</td>
<td>8.45</td>
<td>11.48</td>
<td>8.00</td>
<td>12.68</td>
</tr>
<tr>
<td></td>
<td>(0.50)</td>
<td>(0.52)</td>
<td>(0.20)</td>
<td>(0.45)</td>
<td>(0.19)</td>
<td>(0.39)</td>
<td>(0.18)</td>
<td>(0.43)</td>
<td>(0.12)</td>
</tr>
</tbody>
</table>

* indicate significance level at 5%. ; Figures in (#) are p values.

Table 4.4: Forecasting Performance of P-star Models

<table>
<thead>
<tr>
<th>Criteria</th>
<th>CE M1</th>
<th>M1</th>
<th>CE M2</th>
<th>M2</th>
<th>CE M3</th>
<th>M3</th>
<th>CE L1</th>
<th>L1</th>
<th>OG</th>
</tr>
</thead>
<tbody>
<tr>
<td>in-sample</td>
<td>RMSE</td>
<td>0.014</td>
<td>0.014</td>
<td>0.014</td>
<td>0.013</td>
<td>0.014</td>
<td>0.014</td>
<td>0.014</td>
<td>0.015</td>
</tr>
<tr>
<td></td>
<td>MAE</td>
<td>0.011</td>
<td>0.011</td>
<td>0.012</td>
<td>0.011</td>
<td>0.012</td>
<td>0.011</td>
<td>0.012</td>
<td>0.013</td>
</tr>
<tr>
<td></td>
<td>Obs</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
<td>48</td>
</tr>
<tr>
<td>out of sample</td>
<td>RMSE</td>
<td>0.025</td>
<td>0.022</td>
<td>0.024</td>
<td>0.022</td>
<td>0.023</td>
<td>0.024</td>
<td>0.023</td>
<td>0.023</td>
</tr>
<tr>
<td></td>
<td>MAE</td>
<td>0.019</td>
<td>0.018</td>
<td>0.020</td>
<td>0.019</td>
<td>0.021</td>
<td>0.021</td>
<td>0.020</td>
<td>0.020</td>
</tr>
<tr>
<td></td>
<td>Obs</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

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4.5.1. **Forecasting Performance**

The forecasting ability of models was examined using both in-sample and out-of-sample forecast. In-sample forecasts allow us to investigate the forecasting performance of the models estimated for the whole sample period. Out-of-sample forecasting performance was carried out by estimating each model recursively, beginning with the period 1997 Q1 to 2007 Q1, and introducing successively a new quarter at each recursion. The one period ahead forecast, made at each stage are then noted and compared with the corresponding actual observation. In order to evaluate the forecasting performance of models this study used Root Mean Square Error (RMSE) and mean absolute error (MAE) criteria. Given the actual series \((y_t)\) and its forecasted value \((y_t^f)\) from a particular model, the Root mean squared error (RMSE) and mean absolute error (MAE) for \(H\) number of periods over which forecasts are being compared may be defined as:

\[
RMSE = \sqrt{\frac{\sum_{t=1}^{H} (y_t^f - y_t)^2}{H}}, \tag{4.19}
\]

and

\[
MAE = \frac{\sum_{t=1}^{H} |y_t^f - y_t|}{H}. \tag{4.20}
\]

The results of forecasting evolution is summarised in Table 4.4

The forecasting performance of models with both velocity gap and output gap perform relatively better than the output gap model according to the Table 4.4. The results indicate that the aggregation procedure doesn’t make much difference in the forecasting performance of the model. The results in general indicate that monetary developments are important in predicting changes in inflation. However unavailability of reliable data on GDP prior to 1996-97 is a major limitation for this. The small sample size limited the use of an alternative methodology. The study may be extended as more data is available and use a better methodology to get more insights into the dynamics of inflation in India.
4.6. Conclusion

This study examined the role of monetary developments in a P-star framework using quarterly data form 1997 Q1 to 2009 Q2. In order to assess the performance of alternative monetary aggregates the model was estimated using measures of velocity gap from simple sum and CE monetary aggregates. Following Hallman, Porter, and Small (1991) the reduced form equation is estimated that relates the changes in inflation to output gap and velocity gap. H-P filter was used to obtain equilibrium velocity and potential output series. The forecasting ability of models was also examined using both in sample and out of sample forecast. In order to evaluate the forecasting performance of models this study used Root Mean Square Error (RMSE) and mean absolute error (MAE) criteria.

Results from P-star models shows that monetary factors do contain information regarding changes in the information as the coefficient with respect to velocity gap is significant and have correct sign. CE aggregates performs as good as simple sum aggregates in predicting the movements in inflation. The in-sample and out-of-sample forecasting performance gives similar results with respect to CE and simple sum aggregates. However the methodology applied in this chapter doesn’t allow for arriving at decisive conclusions on the applicability of P-star model vis-a-vis its alternatives as well to assess the usefulness of aggregation theoretic monetary aggregates. The unavailability of reliable data on real output at quarterly frequency considerably limited the sample size. With an extended sample size it is possible to use alternative methodologies to generate potential output and equilibrium velocity such as Kalman filter instead of H-P filter and use advanced forecasting methodology.