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AN UNOBSERVED COMPONENTS PHILLIPS CURVE FOR INDIA

Re-examining output inflation dynamics in India

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This paper reassesses the inflation-output dynamics of the Indian economy and estimates a Phillips curve (PC) for India. Instead of modelling the PC using the usual autoregressive dependent lag (ARDL) model, an unobserved components (UC) model is used in which the lagged inflation term of the ARDL models is replaced with an unobserved random walk. Using the UC framework has many advantages. It facilitates the use of the Kalman (1960) filter instead of having to depend on the ad-hoc Hodrick-Prescott filer to compute output gap. Furthermore, its time varying parameters capture the Phillips curve dynamics better than an ARDL model with fixed parameters. I find evidence of a robust Phillips curve relation for India, even without explicitly controlling for supply shocks. This is a novel finding and stands in stark contrast to existing literature which is at best, sceptical of any PC like relationship for India. The baseline PC model is then extended by incorporating various supply shocks. These results hold important information for the central banker as they change the context of monetary policy from a state of agnosticism about the Phillips curve for India to a state where such a relation is firmly established.

1. INTRODUCTION

Non- inflationary growth is one of the main aims of economic policy. The Maastricht Treaty, for instance, identified price stability as the primary objective of the Eurosystem[1]. The main objective of the Reserve Bank of India (RBI), is "…formulation and implementation of monetary policy with the objectives of maintaining price stability…[and] to promote economic growth…"[2]. Therefore, a thorough understanding of inflation and output dynamics is indispensable for effective monetary policy formulation.

This paper tries to reassess the inflation-output dynamics of the Indian economy and estimates a Phillips curve (henceforth PC) for India. Instead of modelling the PC using the usual autoregressive dependent lag (ARDL) model, an unobserved components (UC) model is used in which the lagged inflation term of the ARDL models is replaced with an unobserved random walk. Using the UC framework has many advantages. It facilitates the use of the superior Kalman (1960) filter instead of having to depend on the ad-hoc Hodrick-Prescott filer to compute output gap. Furthermore, its time varying parameters capture inflation and output gap dynamics better than a fixed parameter ARDL model.

Using quarterly data on GDP and WPI inflation (1996 Q1- 2013 Q3), I estimate an Unobserved Components Phillips curve for India on the lines of Harvey (2011) and find evidence of a robust Phillips curve relation for India, *even without explicitly controlling for supply shocks*. This is a novel finding and stands in stark contrast to existing literature which is at best, sceptical of any PC like relationship for India. The baseline PC model is then extended by incorporating various supply shocks. This greatly improves the fit of the model and provides a useful inflation forecasting tool. These results hold important information for the central banker as they redefine the context of monetary policy from a state of agnosticism about the Phillips curve for India to a state where such a relation firmly established.

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[1] European Union, Protocols of the Treaty on European Union and the Treaties Establishing the European Communities, Treaty of Maastricht , Chapter II, Article 2, 7 February 1992 (http://www.eurotreaties.com/maastrichtext.html) [accessed 5 April 2013]

[2] Reserve Bank of India: Functions and Working , Government of India (http://rbidocs.rbi.org.in/rdocs/Content/PDFs/FUNCWWE080910.pdf) [accessed 5 April 2013]

§2 and §3 provide a review of the PC literature, with the latter expounding exclusively on the Indian economy. §4 deals with supply shocks in the Indian context, followed by some data limitations in the next section. §6 provides a general unobserved components (UC) model, variants of which are used to model the PC in §7. §8 summarises the results and reports robustness checks. §9 concludes and briefly discusses policy implications.

2. THE STORY OF THE PHILLIPS CURVE

The relationship between inflation and unemployment has always been at the centre of economic thinking. It is popularly believed that it was Phillips (1958) who first suggested that the rate of change of unemployment can explain the rate of change of money wages. However, earlier accounts date back at least to Fisher (1926) who interpreted the relation in the opposite direction of causality. He wrote, rather colourfully, that, "…facts and theory both indicate that in the 'dance of the dollar' we have the key, or at any rate a very important key, to the major fluctuations in employment."[3] In fact, Humphry's (1985) survey of the history of the PC provides even earlier references of PC-like relationships, dating back to Hume's (1752) classic essays "On Money" and "On Interest", and the works of Thorton (1802).

Samuelson and Solow (1960) first coined the term 'Phillips curve' and suggested a trade-off between inflation and unemployment which could be used by the government to lower unemployment at the cost of higher inflation by pursuing Keynesian expansionary policies. Friedman (1968) and Phelps (1967, 1968) however, believed that in the long run, unemployment cannot be lowered below the "natural rate" which is consistent with accurate inflation expectations. The 1970s episode of stagflation vindicated their view. Lucas (1972, 1973) and Sargent and Wallace (1975, 1976) steered the rational expectations revolution which led to the 'policy ineffectiveness proposition', implying a vertical PC. It invited criticism owing to its reliance on the controversial joint hypothesis of full market clearing and imperfect information.

The Friedman-Phelps-Lucas theories relied on the fact that agents obtain complete information about the aggregate price level with a lag. However, information on prices is published on a monthly basis and one should expect agents to learn from their past mistakes, and form future

[3] Fisher, I. (1926). "Statistical Relation between Unemployment and Price Changes, A." International Labour Review 13: pp792.

expectations more accurately. Therefore, as Gordon (2011) points out, their theory cannot explain multi-period business cycles of longer than one month. Furthermore, empirical tests for the policy ineffectiveness proposition were a failure (as illustrated by Gordon (1982) and Mishkin (1982)).

The breakdown of these models gave way to what Gordon (2011) calls the bifurcation of the PC theory into two divergent paths post 1975: First was the Keynesian[4] or inertial approach which explicitly included supply shock variables like prices of food and fuel, productivity growth etc. Gordon *et. al.* (1977) came up with the econometric implementation of this model and called it the 'Triangle Model' signifying the interplay of demand, supply shocks and inertia. It was specified as

$$\pi_t = (lags\ of\ \pi_t) + \beta(U_t - U_t^N) + z_t + \varepsilon_t \qquad \ldots(1)$$

where π_t is inflation, inertia is captured by past lags of π_t (backward looking); $U_t - U_t^N$ measures deviation of unemployment from its natural rate or the unemployment gap (alternatively output gap could be used) and z_t captures supply shocks.

At the other end, the forward looking theories used price flexibility and the ability of expectations to jump in response to (anticipated) policy changes to model the PC. This led to the emergence of literature which formulated a game between agents and policy makers, where one could distinguish between a rule based and a discretionary policy framework (see Kydland and Prescott (1977)).

The more recent micro-founded New Keynesian PC (NKPC) literature is specified as

$$\pi_t = \alpha E_t \pi_{t+1} + \beta(U_t - U_t^N) + \varepsilon_t \qquad \ldots(2)$$

where $\alpha E_t \pi_{t+1}$ captures forward looking expectations. Unlike equation (1), supply shocks are relegated to the error term. It allows for policies to have short run impact on unemployment because of frictions like the ones modelled for instance, by Taylor's (1980) staggered wage

[4] This approach is Keynesian because it does not micro-found inertia as is done in new Keynesian theories which were presented first by Fischer (1977) and Taylor (1980).

contracts, Akerlof and Yellen's (1985) rule of thumb pricing strategies, or Calvo's (1983) staggered prices amongst others.

Though theoretically compelling, the NKPC has not performed well empirically (see Gordon (2011)). Ball (1994) explores the puzzling 'deflationary boom' implication of the NKPC, and how it is contrary to the costly disinflations experienced by post-war economies. Furthermore, since the NKPC does not contain lagged inflation terms, the only source of inflation persistence is the output gap, which is unable to capture the autocorrelation in inflation data.

In response to these criticisms, Galí and Gertler (1999) introduced a "hybrid" NKPC which had both forward and backward looking elements:

$$\pi_t = \alpha\pi_{t-1} + (1-\alpha)E_t\pi_{t+1} + \beta(U_t - U_t^N) + \varepsilon_t \qquad \ldots(3)$$

where variables assume their usual meanings.

It is empirically an improvement over the NKPC, but as Rudd and Whelan (2005 and 2007) and Gordon (2011) find, most of the fit comes from the backward looking component. This raises further questions about the reliability of a forward looking set up like the NKPC.

Future research should focus on search of a better model to capture inflation persistence. Recently, there has been some convergence of opinion about modelling persistence by a time varying random walk component (see Stock and Watson (2007), Cogley and Sargent (2008) and Harvey (2011)). This paper expounds on this specification (see §6.2) and finds that it fits Indian data well.

3. LITERATURE ON INDIA

Most early literature on the PC for India argues that it simply does not exist. One of the strongest denials came from Dholakia (1990), who said that, a serious trade-off between inflation and unemployment in India is "*imaginary*", implying a horizontal PC with Keynesian-type short run price rigidities. Rangarajan (1983) concluded that "*contrary to general belief, industrial output* *has grown faster in periods of small price increases than in periods of high price increases*"[5]. Similarly, Chaterji (1989) finds that industrial prices are closely tied to costs and relatively impervious to demand pressures. Ghani (1991) evaluated the role of rational expectations in price setting behaviour and postulated a negative relationship between output and inflation. Studies based on VAR-type modelling (Rangarajan and Arif (1990) and Das (2003)) have the same puzzling conclusions. More recently Virmani (2004) used an unobserved component PC both on the lines of Knutter (1994) and Domenech and Gomez (2006), and finds that contrary to theory, output gap enters the PC equation with a negative coefficient. Others who have argued for the lack of a meaningful PC relationship in India include Bhattacharya and Lodh (1990), Balakrishnan (1991), Callen and Chang (1999), Nachane and Laxmi (2002), and Brahmananda and Nagaraju (2002) and Srinivasan et. al. (2006).

In light of this overwhelming literature against the existence of the PC for India, this paper finds that there is in fact, a clear positive relationship between inflation and output gap, which could be useful for policy makers. Though there are some recent studies (see next section) which have touched upon this view, they suffer from several shortcomings. This paper improves upon these and provides a parsimonious model to capture inflation-output gap dynamics in India.

3.1 LIMITATIONS OF THE INDIAN LITERATURE

The present literature has the following limitations (the first two are also mentioned in Kapur (2013)). First, since quarterly GDP estimates are available only from 1996Q1 in India (see §5 for details), most studies are based on annual data. This fails to capture short run inflation dynamics and persistence, and is less important for policy purposes. Moreover, annual studies span as many as three to four decades (in order to get sufficient number of observations). Such long term studies must take into account the various structural breaks that the Indian economy has undergone through the years (economic liberalisation, 1960s bank nationalisation etc.). Unfortunately, this treatment is unsatisfactory in most studies.

Second, to get around the unavailability of quarterly data, it has become popular to proxy GDP by the monthly Index of Industrial Production (IIP). However, since the industrial sector

[5] Rangarajan, C. (1983). Conflict between employment and inflation.
Employment policy in a developing country-a case study Robinson, Macmillan.

constitutes only 19 per cent of the Indian economy[6], this approach is plagued with specification errors. Moreover, comparing the 'IIP-gap' to aggregate economy-wide inflation rate (as has been done in most studies) makes little sense, as the latter spans agricultural and services sectors as well. With the notable exceptions of Kapur (2013) and Dua and Gaur (2009), most studies have relied on IIP data to report a positive inflation-output gap relation. These include Callan and Chang (1999), Srinivasan *et.al.* (2006), Paul (2009) and Mazumder (2011) amongst others. This paper uses quarterly GDP data from 1996 Q1, published by the Indian Central Statistical Organization to capture fully the demand pressures in the economy.

Third, to the best of the author's knowledge, *all* published studies (with the exception of Virmani (2004) and Singh *et. al.* (2011)) use the Hodrick Prescott (HP) (1997)[7] filter and detrended GDP so obtained as an estimate of output gap. However, uncritical use of the HP filter can be shown to be spurious for the following reasons, particularly in the context of a developing country like India (see Singh *et.al. (2011))*.

i. The occurrence of regular and volatile shocks to stochastic trends in emerging economies led Aguiar and Gopinath (2004) to suggest that in such countries 'the cycle is the trend'. The applicability of the HP filter in such a context is questionable (see Ozbek and Ozlle (2005)).

ii. The HP filter may prove inefficient even for developed economies. Mise *et. al.* (2005) point to the suboptimality of the HP filter at the end points. (also see Harvey and Trimbur (2008) and Harvey and Delle Monache (2009).

iii. Harvey and Jaeger (1993) conclude that "the HP filter may create spurious cycles and/or distort unrestricted estimates of the cyclical component… [and] lead to misleading conclusions being drawn on the relationship between short-term movements in macroeconomic time series"[8].

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[6] Handbook of Indian Statistics, RBI. Data for 2011-12. (http://dbie.rbi.org.in/DBIE/dbie.rbi?site=home) [accessed 5 April 2013]

[7] The HP filter carries out the trend-cycle decomposition of a series x_t through solution of the constrained minimisation problem:

$\underset{[x_t^*]_{t=1}^{T}}{min} \sum_{t=1}^{T}(x_t - x_t^*)^2 + \lambda \sum_{t=2}^{T-1}[(x_{t+1}^* - x_t^*) - (x_t^* - x_{t-1}^*)]^2$; $\lambda > 0$, were λ controls the smoothness of the estimated trend component and x_t^* is the trend growth in x_t.

[8] Harvey, A. C. and A. Jaeger (1993). "Detrending, stylized facts and the business cycle." Journal of applied econometrics **8**: pp246.

iv. Lastly there is no guarantee that the standard values of the smoothing parameter (λ) i.e., 14400, 1600 and 100 for monthly, quarterly and annual data respectively, which are based on their suitability for US GDP data are as suitable for Indian data. Therefore, the choice of λ leaves a window of ambiguity.

The importance of a good measure of trend cannot be over emphasised and has profound policy implications. With the HP filter underperforming on so many counts, the present literature stands exposed. A more efficient way to detrend macroeconomic data is to set up a state-space estimation framework under which efficient Kalman (1960) filtering techniques can be employed to obtain smoothed estimates of unobserved components. This is discussed in §6.

Fourth, *all* studies in the Indian context have relied on lagged inflation terms to capture inflation persistence in an Autoregressive Distributed Lag (ARDL) model. As Harvey (2011) points out, an ARDL model such as

$$\pi_t = \mu_t + \alpha\pi_{t-1} + \varepsilon_t, \qquad \varepsilon_t \sim NID(0, \sigma_\varepsilon^2), \qquad t = 1, \ldots\ldots, T \qquad \ldots(4)$$

imposes the dynamics of the inflation gap on core inflation. This can be seen by iterating forward the core inflation term in the following equivalent equation:

$$\pi_t = (1 - \alpha L)^{-1}\mu_t + (1 - \alpha L)^{-1}\varepsilon_t, \qquad t = 1, \ldots\ldots, T \qquad \ldots(5)$$

Therefore, as in Harvey (2011), I model inflation as a driftless random walk instead of relying on past lags of inflation. This can easily be incorporated into state space framework as discussed in §6.2.

Fifth, as Figure 3 in §6.2 reveals, inflation and output gaps, lead each other at different points of time. Thus, for example, while output leads inflation in 2008-09, the same is not true for 2010-13. Therefore, as pointed out by Harvey (2011), in such situations, using a time invariant model fails to capture these dynamics. A time varying UC model is thus employed here.

Lastly, authors have estimated ARDL models without a systematic model selection procedure. This results in variables entering with lags at odd lengths. Furthermore, criticisms of data mining can well be levied on such specifications. Barely any of the studies deal with this important aspect explicitly. Use of out of sample extrapolative prediction tests is crucial in such a context but absent from most studies. A brief treatment of this issue is presented in §8.

To sum up, this paper attempts to improve upon these limitations to uncover the PC for India.

4. A BRIEF NOTE ON SUPPLY SHOCKS

If there is one issue that all the studies on the Indian PC echo in unison, it is the indispensability of controlling for supply shocks. The apparent elusiveness of the PC in India is often blamed on them. Such shocks have also played an important role in explaining the upward sloping unemployment-inflation PC of the 1970s in industrialized countries.

I focus on food prices, global commodity prices (oil and non-oil) and movements in the exchange rate as these particularly plague India. However, this paper disproves the idea that controlling for supply shocks is a necessity for arriving at a meaningful PC for India (a recent study by Kapur (2013), provides similar evidence but with a very different model). Having said this, controlling for supply shocks does still provide a better fit to the model. Diagnostics and predictive tests also give better results.

Before moving to the UC models, a brief discussion of supply shocks is presented below.

4.1 Food Prices: India is still an agrarian economy in many respects. Even today over 60 per cent of the labour force is employed in this sector[9], and unlike in the case of developed economies, food in India still constitutes a large chunk of consumption expenditure. Cumulatively (primary plus manufactured), food items command a weight of 24 per cent[10] in computation of the Wholesale Price Index (WPI). As of 2012 only about 35 per cent[11] of crop land in India was artificially irrigated making food production heavily dependent on rainfall and vulnerable to droughts. Moreover, episodes of hoarding are not uncommon and have been

[9] Prime Minister Manmohan Singh's McKinsey Quarterly Interview, The McKinsey Quarterly, 2005 Special Edition: Fulfilling India's promise. (http://pmindia.gov.in/interview-details.php?nodeid=2) [accessed 5 April 2013]
[10] WPI Compilation Manual (page 21-35), Office of Economic Advisor to Commerce Ministry, Government of India. Available online at (http://www.eaindustry.nic.in/WPI_Manual.pdf). [accessed 5 April 2013]
[11] World Development Indicators, World Bank Organization (2008-12) (http://data.worldbank.org/indicator/AG.LND.IRIG.AG.ZS). [accessed 5 April 2013]

responsible for jacking up food prices overnight. The supply side volatilities in the food market must be adequately controlled for so that output (demand-side) and inflation dynamics to be clearly exposed.

4.2 Global commodity prices: About 24 per cent of India's energy consumption is met by oil, 70 per cent of which is imported[12]. The Indian economy is therefore extremely sensitive to global oil price movements. Notwithstanding the heavily subsidized oil prices (by public sector oil marketing companies), episodes of high global oil inflation do ultimately seep into domestic inflation, albeit with a lag. Furthermore, the recent indication by the present dispensation to reduce petroleum subsidies promises to only quicken this pass through in future. Since international oil prices are not tightly linked to domestic demand, price movements in these goods is considered as a supply shock for the economy.

4.3 Exchange rate movements: The Indian rupee depreciated significantly (by almost 10 per cent) vs. the US dollar in July- September 2012. Exchange rate dynamics can considerably add to the import bill, with a quick pass through into domestic inflation.

These supply shocks are incorporated into the UC Phillips curve in §7.2.

5. SOME DATA LIMITATIONS

Before proceeding to the model, some limitations of the data are presented. Firstly, no continuous time series is available for unemployment in India. The only available unemployment data comes from the National Sample Survey Organization (NSSO) through surveys which are conducted once every two to five years. Hence, one cannot estimate the conventional PC with unemployment gap as in equation (1) and (2). The natural response is to use the output gap specification instead. The Central Statistical Organisation started releasing quarterly GDP data only in 1996. Therefore the scope of this study is Q1 1996-Q3 2012.

[12] Country Analysis Briefs, India, International Energy Agency (http://www.eia.gov/cabs/india/Full.html) [accessed 5 April 2013]

Secondly, unlike most countries, India does not have an aggregated index of consumer prices (CPI). There are four CPIs all targeted at different population groups but an all India CPI is not available. Therefore, WPI inflation is used in this study. This is the headline inflation in India used by the RBI for policy making. A list of data sources is provided after the bibliography.

6. TREND CYCLE DECOMPOSITION IN AN UNOBSERVED COMPONENTS FRAMEWORK

An unobserved components model using state space time series is considered for the PC. This section presents a brief overview of a general UC model. The next section applies variants of this model to obtain (i) the output gap, (ii) the inflation gap and (iii) the unobserved components PC.

A structural time series model is set up in this section (see Harvey (1989) or Harvey and Jaeger (1993) for a concise account of state space models). Consider the following trend-cycle decomposition:

$$y_t = \mu_t + \gamma_t + \psi_t + \varepsilon_t, \qquad \varepsilon_t \sim NID(0, \sigma_\varepsilon^2), \qquad t = 1, \ldots\ldots, T \qquad \ldots(6)$$

where y_t is the observed series (say, log of GDP), μ_t is the trend, γ_t is the seasonal, ψ_t is the cyclical and ε_t is the irregular component.

The trend is a local linear trend given by

$$\begin{aligned} \mu_t &= \mu_{t-1} + \beta_{t-1} + \eta_t, \qquad \eta_t \sim NID(0, \sigma_\eta^2), \\ \beta_t &= \beta_{t-1}, + \zeta_t, \qquad \zeta_t \sim NID(0, \sigma_\zeta^2), \end{aligned} \qquad t = 1, \ldots\ldots, T \qquad \ldots(7)$$

where β_t is the slope component and the normal white noise disturbances are independent of each other.

The stochastic seasonal component, γ_t is based on a trigonometric formulation given by

$$\gamma_t = \sum_{j=1}^{[\frac{s}{2}]} \gamma_{j,t} \qquad \ldots(8)$$

where each $\gamma_{j,t}$ is generated by

$$\begin{bmatrix} \gamma_{j,t} \\ \gamma_{j,t}^* \end{bmatrix} = \begin{bmatrix} \cos\lambda_j & \sin\lambda_j \\ -\sin\lambda_j & \cos\lambda_j \end{bmatrix} \begin{bmatrix} \gamma_{j,t-1} \\ \gamma_{j,t-1}^* \end{bmatrix} + \begin{bmatrix} \omega_{j,t} \\ \omega_{j,t}^* \end{bmatrix} \quad \begin{matrix} j = 1, \ldots, \left[\frac{s}{2}\right], \\ t = 1 \ldots T, \end{matrix} \quad \begin{matrix} \omega_t \sim NID(0, \sigma_\omega^2), \\ \omega_t^* \sim NID(0, \sigma_\omega^2), \end{matrix} \qquad \ldots(9)$$

where $\gamma_j = 2\pi j/s$ is the frequency, in radians, and the seasonal disturbances ω_t and ω_t^* are mutually and serially uncorrelated (with common variance, as above).

The stochastic cycle, ψ_t is specified as

$$\begin{bmatrix} \psi_t \\ \psi_t^* \end{bmatrix} = \rho_\psi \begin{bmatrix} \cos\lambda_c & \sin\lambda_c \\ -\sin\lambda_c & \cos\lambda_c \end{bmatrix} \begin{bmatrix} \psi_{t-1} \\ \psi_{t-1}^* \end{bmatrix} + \begin{bmatrix} \kappa_t \\ \kappa_t^* \end{bmatrix} \quad t = 1, \ldots\ldots, T, \quad \begin{matrix} \kappa_t \sim NID(0, \sigma_\kappa^2), \\ \kappa_t^* \sim NID(0, \sigma_\kappa^2), \end{matrix} \qquad \ldots(10)$$

where λ_c is frequency, in radians, in the range $0 \le \lambda_c \le \pi$; ρ_ψ is the dampening factor, with $0 < \rho_\psi \le 1$, and the disturbances κ_t and κ_t^* are mutually and serially uncorrelated (with common variance, as above). The period of the cycle is equal to $2\pi/\lambda_c$. For computing the output gap, this value is fixed at 20 quarters (five years), which is the length of a typical business cycle (Koopman *et. al.* (2007)). [Fixing the period of cycle to 20 seems controversial but the results are not altered in a significant manner if the data is allowed to determine the length of the cycle]

The reduced form of the model is an Autoregressive Moving Average ARMA (2,1) process with complex roots for the autoregressive part. The model is assumed to be Gaussian and the hyperparameters $(\sigma_\varepsilon^2, \sigma_\eta^2, \sigma_\zeta^2, \sigma_\kappa^2, \lambda_c, \rho_\psi)$ are estimated using Maximum Likelihood. Estimates of trend, cyclical, seasonal, and irregular components are given by a smoothing algorithm in Koopman *et. al.* (2007).

Different specifications of the trend can give a whole class of structural time series models (see Appendix 1 of Harvey (1989) for a summary). The most general is the local linear trend model specified in equation (7) above. If $\sigma_\zeta^2 = 0$, it reduces to a random walk with drift. Moreover, if $\sigma_\eta^2 = 0$, but $\sigma_\zeta^2 > 0$, the trend is an integrated random walk. If $\sigma_\eta^2 = \sigma_\zeta^2 = 0$, we get a deterministic trend i.e., $\mu_t = \mu_0 + \beta t$. Lastly, if there is no slope component and $\sigma_\eta^2 > 0$ we get a driftless random walk trend given by $\mu_t = \mu_{t-1} + \eta_t$.

6.1 OUTPUT GAP

Like Harvey (2011), log of GDP is explained by a trend cycle decomposition (equation 11) in which trend (or potential) GDP (y_t) is modelled as an integrated random walk: μ_t (with stochastic seasonal (γ_t) and cyclical (ψ_t) components). The estimates of the cyclical component which are calculated by the Kalman filter give us the output gap. Thus we have

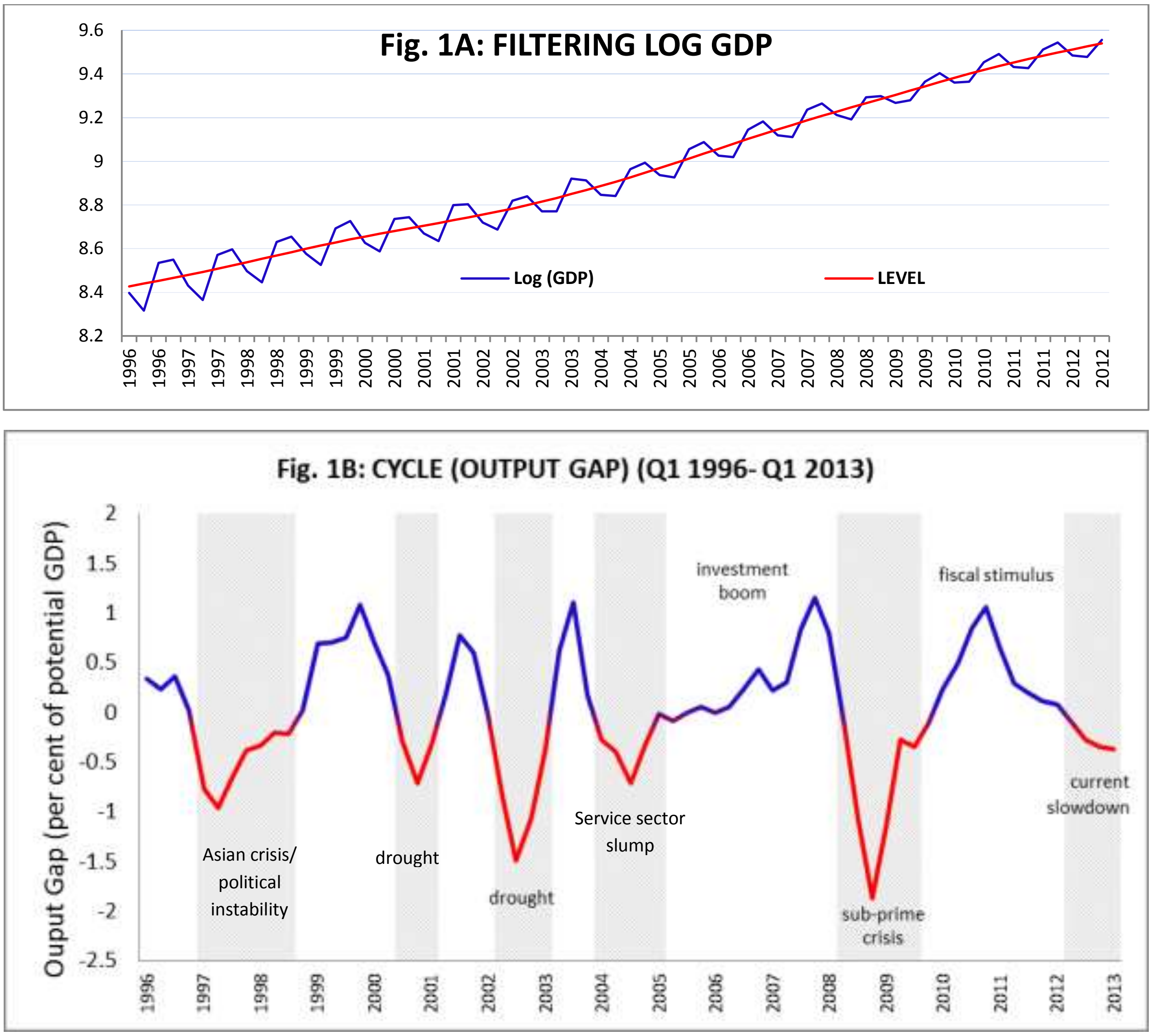
$$\begin{aligned} y_t &= \mu_t + \psi_t + \gamma_t + \varepsilon_t, & t &= 1,\ldots\ldots,T \\ \mu_t &= \mu_{t-1} + \beta_{t-1} & \zeta_t &\sim NID(0, \sigma_\zeta^2), \\ \beta_t &= \beta_{t-1}, + \zeta_t, \end{aligned} \qquad \ldots(11)$$

where variable assume their usual meanings. However, unlike Harvey (2011) a 'balanced cycle model' as suggested by Harvey and Trimbur (2003) is used, where, ψ_t=$\psi_t^{(k)}$. A second order cycle is used here ($k = 2$):

$$\begin{bmatrix} \psi_t^{(2)} \\ \psi_t^{*(2)} \end{bmatrix} = \rho \begin{bmatrix} \cos\lambda & \sin\lambda \\ -\sin\lambda & \cos\lambda \end{bmatrix} \begin{bmatrix} \psi_{t-1}^{(2)} \\ \psi_{t-1}^{*(2)} \end{bmatrix} + \begin{bmatrix} \psi_{t-1}^{(1)} \\ \psi_{t-1}^{*(1)} \end{bmatrix} \qquad t = 1,\ldots\ldots,T, \qquad \ldots(12)$$

Such higher order cycles result in smoother cycles and lead to more pronounced cut-offs of the band-pass gain function at both ends of the range of business cycle frequencies centred at λ. Figure 1. shows the estimated components of the trend and cycle from the above specified UC model. . Interestingly, the output gap results (Fig. 1B) are consistent with the booms and slow-downs that have characterized the Indian economy over the past two decades.

Fig. 1: Log (GDP) and its decomposition into stochastic level and cyclical components.



The diagnostic tests of state space time series models are based on residuals, which should satisfy the following properties (in decreasing order of importance[13]):

1. Independence
2. Homoskedasticity
3. Normality

[13] See chapter 8, section 8.5 of Commandeur and Koopman (2007) for a discussion on these tests: I use the Box-Ljung test for serial correlation which is based on residual autocorrelation of the first q lags. The test statistic is distributed as χ^2 with $(q-p-1)$ degrees of freedom where p is the number of hyperperameters to be estimated. For verifying homoskedastocity of the residuals, the H statistic is used which tests whether the variance of the residuals in the first third part of the series is equal to the variance of the residuals corresponding to the last third part of the series. This is tested employing a two tailed test against an F-distribution with (h, h) degrees of freedom. h is the nearest integer to $(n-d)/3$, where n= number of observations, d= number of diffuse initial elements. Normality of residuals is tested against the Bowman-Shenton statistic which is based on the third and fourth moments of the residuals and has a χ^2 distribution with 2 degrees of freedom.

The model comfortably satisfies all these diagnostic tests as reported in Table 1.

I wish to point out here that Virmani (2004) also used a UC model to compute output gap. He used Clark's (1987) model of the trend comprising of random walk plus a fixed drift and the cycle being an autoregressive component of order two. However instead of using the CSO's official GDP data, he used quarterly GDP estimates which had been interpolated from annual data. I found that Clark's (1987) specification does not fit Indian data well.

TABLE 1: Diagnostic Tests for the GDP Model

Diagnostic	Test	Value	Critical value	p-value
Independence**	Box-Ljung Q(q)	9.7542	10.6446	0.1354
	r(1)	0.10141		
	r(q)	0.05001		
Homoskedasticity**[14]	1/H(20,20)	1.02794	2.4645	0.4757
Normality**	Bowman-Shenton	0.38912	4.6052	0.8232

* INDICATES THAT NULL HYPOTHESIS IS NOT REJECTED EVEN AT10% LEVEL OF SIGNIFICANCE

6.2 INFLATION

This section fits a UC model to Indian WPI inflation data (per cent change in WPI year-on-year). This is done solely to compare inflation gap with the output gap (estimates of the inflation and output cycles) which will motivate the PC. UC models do well to capture inflation persistence by a random walk trend component. Two specifications were tried: the first uses a random walk with drift and the second uses a driftless random walk to model trend inflation (μ_t). The latter was chosen based on a range of diagnostic tests as well as goodness of fit criteria. Harvey (2011) also uses this specification. It also has legitimacy in macroeconomic literature (see Cogley et. al. (2008) who argue that 'A consensus has emerged that trend inflation is well approximated by a driftless random walk'). The superiority of this specification to an autoregressive specification has already been mentioned in §3.1.

[14] $If\ H < 1, as\ it\ is\ here, we\ test\ whether\ (1/H) < F_{h,h}$

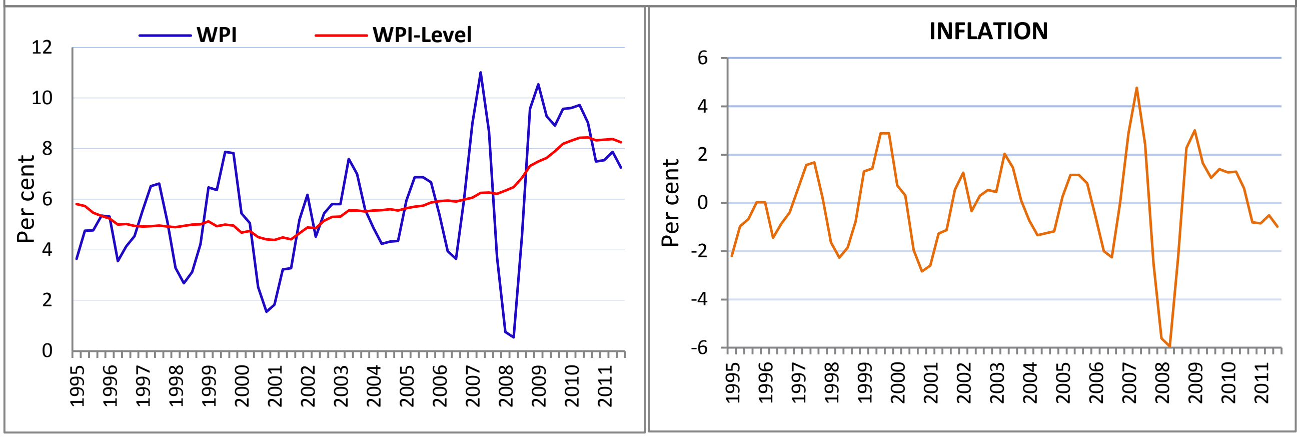
Thus, we have:

$$\pi_t = \mu_t + \psi_t + \gamma_t + \varepsilon_t, \qquad \varepsilon_t \sim NID(0, \sigma_\varepsilon^2),$$
$$\mu_t = \mu_{t-1} + \eta_t, \qquad \eta_t \sim NID(0, \sigma_\eta^2), \qquad t = 1, \ldots\ldots, T \qquad \ldots(13)$$

where variables assume their usual meaning.

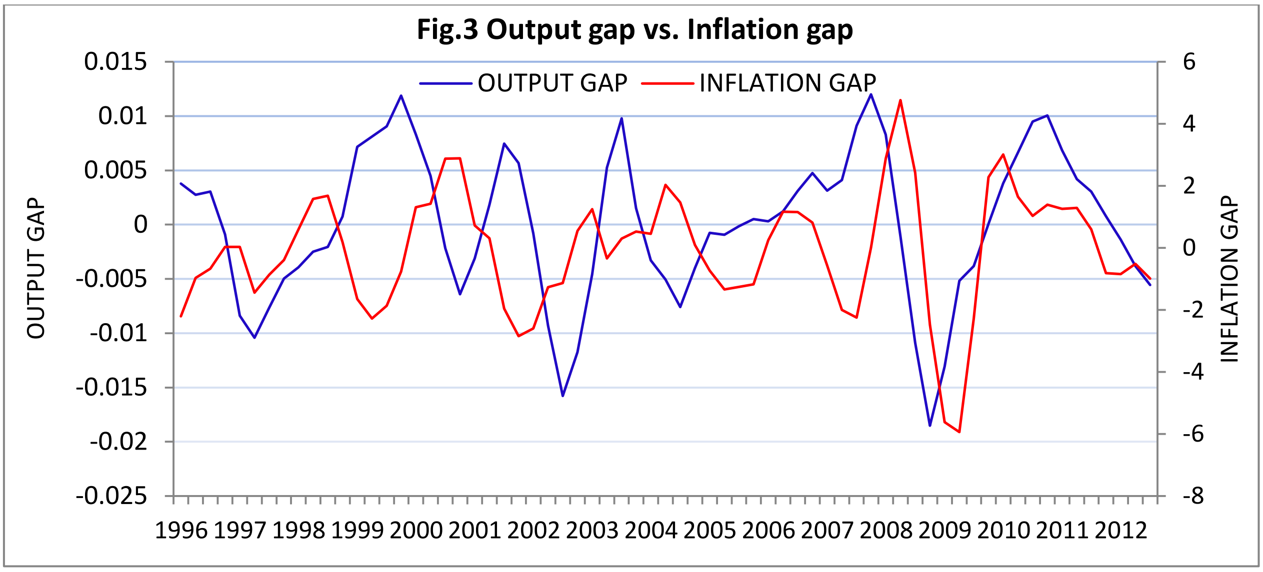
Note that ε_t and η_t are mutually and serially uncorrelated disturbances. The seasonal component is deterministic[15] and the cyclical component is as specified in equation (10). Like in the case of output gap in §6.1, σ_ε^2 collapses to zero so that the cycle is smoother than detrended inflation. Fig. 2 graphs the trend and cyclical components.

FIG. 2: WPI inflation and its decomposition into stochastic level and cyclical components



The diagnostics are not entirely satisfactory. But this is not surprising because no explanatory regressors have been used. The purpose of estimating equation (13) was to obtain the inflation cycle solely for comparison with the output gap in Fig. 3, therefore the results are not reported. Figure 3 shows that output and inflation lead each other at different times. Therefore, as discussed in §3.1, a model with time varying dynamics should do better than conventional models with time invariant parameters. Moreover, note that movements in the two variables are more synchronized toward s the end of the sample (more on this later).

[15] The variance of the seasonal component was insignificantly different from zero as reported In Koopman *et. al.* (2007)



7. MODEL SPECIFICATION: THE UNOBSERVED COMPONENTS PC

Two specifications are discussed:

A. A parsimonious 'pure' PC with output gap as the only explanatory variable.

B. An 'extended' PC with controls for food, oil, and non-oil commodity price and exchange rate shocks built in.

7. 1 THE PURE PC

The unobserved components PC is specified as

$$\pi_t = \mu_t + \gamma_t + \psi_t + \beta_1 OG_t + \varepsilon_t, \qquad \varepsilon_t \sim NID(0, \sigma_\varepsilon^2), \qquad t = 1, \ldots\ldots, T, \qquad \ldots(14)$$

where OG_t is the stationary output gap as estimated in §6.1, and can enter the equation with lags. This is akin to the backward looking PC (with the unobserved random walk term having replaced the lagged inflation term) and, under some conditions, it can also be interpreted as forward looking (see Harvey (2011) for detailed derivations).

The above formulation may look theoretically opaque at first but has a very straightforward interpretation. In the long run, actual output equals potential output, such that, $OG_t = 0$. This implies that μ_t measures trend inflation. This is intuitive. When actual output equals potential, inflation is equal to its “trend” value, which by definition, is the level of inflation consistent with the long run potential level of output.

7.2 THE EXTENDED PC

Supply shock controls are added to equation (14) to obtain the extended PC. The controls have been taken from Kapur (2013). Most other papers use similar controls for supply shocks.

7.2.1 Food price shocks: $rain_t$

To control for supply side pressures on food prices, the variable $rain_t$ is used. It measures per cent deviation in actual rain from normal rainfall during the month of July. Rainfall in the month of July is critical as this is when the kharif crop is sown. A deficiency in rainfall in July should adversely affect food prices with a lag.

7.2.2 Global commodity price shocks: $croil_t$ and $nfuel_t$

Variation in international crude oil prices - $croil_t$ is used as a control for oil price shocks and variation in global non-fuel commodity prices - $nfuel_t$ to accommodate supply pressures from non-oil commodities which have seen considerable volatility in recent years (especially metals). Data for both these variables has been taken from the International Monetary Fund (IMF)

7.2.3 Controlling for price of import

Movements in the exchange rate of the Indian Rupee should also be controlled for. Depreciation in the Rupee may increase price of imports without requisite demand pressure. Like Kapur (2013), the Nominal Effective Exchange Rate (NEER: variation (y-o-y) in the 36-currency trade-weighted nominal effective exchange rate index of the Indian rupee complied by the RBI) is used here.

The extended PC is thus as follows:

$$\pi_t = \mu_t + \gamma_t + \psi_t + \beta_1 OG_t + \beta_2 Rain_t + \beta_3 Croil_t \qquad t = 1,\ldots\ldots,T$$
$$+\beta_4 NFUEL_t + \beta_5 NEER_t + \varepsilon_t \qquad \varepsilon_t \sim NID(0, \sigma_\varepsilon^2), \qquad \ldots(15)$$

where variables assume their usual meanings. The regressors can enter with lags.

8. ESTIMATION AND RESULTS

Estimation was done on the STAMP package of Koopman *et. al.* (2007). Models are fitted for the period 1997Q1- 2012Q3. Results and diagnostics are shown in Table 2 and Table 3 respectively.

8.1 THE 'PURE' PC

The pure PC model suggests that output gap enters the PC equation contemporaneously with a positive coefficient of 1.73 which is significant at 5% level. This implies that one per cent rise in output gap (i.e., a one per cent rise in deviation of actual GDP above trend) raises inflation by 1.73 percentage points.

It should be underscored that at this stage none of the supply shocks have been incorporated. The pure PC model is therefore an incomplete model of inflation. However, it is reported here to emphasize an important and novel finding, namely that *rising output gap adds to inflation, even without controlling for any of the supply shocks that the Indian economy is subjected to*.

In all previous studies (with exception to Kapur (2013)) on the Philips curve for India, authors have found the output gap coefficient insignificant or even negative- unless supply shocks are comprehensively dealt with. In fact, the vagaries of supply shocks to the Indian economy have widely been cited as the main reason for the apparent unobservability of a PC relationship in the Indian economy. The results above clearly show that this is not the case- even after ignoring supply shocks altogether, a significant positive relationship between output gap and inflation can be uncovered by an unobserved components model.

TABLE 2: Estimated Equations for Quarterly Changes in the WPI 1997:Q1 to 20012:Q3			
Dependent variable: Annualized sequential growth rate of WPI			
Variable		MODEL	
		PURE PC	EXTENDED PC
Parenthesis contain t- values	OG_t	**1.73***	**2.490****
		(2.44)	(3.72)
	$Rain_{t-2}$	-	**-0.13****
			(-3.28)
	Oil_{t-2}	-	**-0.03****
			(-2.96)
	Oil_{t-4}	-	**0.03****
			(3.54)
	$Nfuel$	-	**0.06***
			(2.43)
	$NEER$	-	**-0.49****
			(-4.41)
	$NEER_{t-2}$	-	**0.59****
			(4.64)
	$NEER_{t-4}$	-	**-0.64****
			(-4.82)
** Significant at 1 percent level; * Significant at 5 percent level			

Past studies have made supply shocks a "scapegoat" that is used as an excuse for the apparent absence of a Phillips curve for India. However, the blame laid elsewhere- perhaps in the flawed dynamics of ARDL modelling and the uncritical use of the HP filter to compute output gap.

8.2 THE 'EXTENDED' PC

The Pure PC model can be improved further by incorporating supply shocks. The Extended PC model does just that by estimating equation 15 above.

The first thing to note is the positive and significant coefficient of 2.49 against contemporaneous output gap. Its value is larger than the one in the Pure PC model. This is not surprising as supply shocks are now sieved out of the equation. A one per cent rise in output gap (i.e., a one per cent rise in deviation of actual GDP above trend) raises inflation by 2.49 percentage points.

Secondly, results show that deficiency in rainfall in July has adverse impact on inflation. A 10 per cent deficiency in rainfall in July raises inflation by 130 basis points.

Thirdly, global commodity prices significantly impact inflation as well. International crude oil prices appear with a lag of two and three quarters-perhaps reflecting the slow pass through of international price volatility into Indian inflation owing to the administered price mechanism for petroleum in India. The sum of these lagged coefficients is 0.004 implying that a 10 percent rise in international crude prices raises inflation in India by 4 basis points with a lag of three quarters. This value is puzzlingly low. However, controlling for oil price shocks can be tricky, given the staggered and discontinuous petroleum price movements in India. This remains a limitation in the paper. However, this is a standard and one of the least controversial ways of dealing with oil price shocks and thus has been followed nonetheless. Global non-fuel commodity prices have a quick pass through and impact inflation contemporaneously. A 10 per cent rise in non-fuel commodities increases inflation by about 6 basis points. Lastly, $NEER_t$ is significant contemporaneously and at lag two and four quarters - adding up to -0.55. It is negative as expected- one per cent depreciation (decrease in NEER) in the exchange rate causes the inflation rate to rise by 50 basis points.

The two models can be compared using two goodness of fit criteria which are particular to UC models. The predictive error variance (PEV) is the basic goodness of fit measure and it is the variance of the residuals in steady state. It corresponds to the variance of disturbance of the reduced ARMA model.

Table 3 reports that PEV for the Pure model 11.571 as compared to 5.915 of the Extended model implying that the latter gives a much better fit (which is not surprising as it incorporates supply shocks). The appropriate coefficient of determination for seasonally adjusted data in UC models is

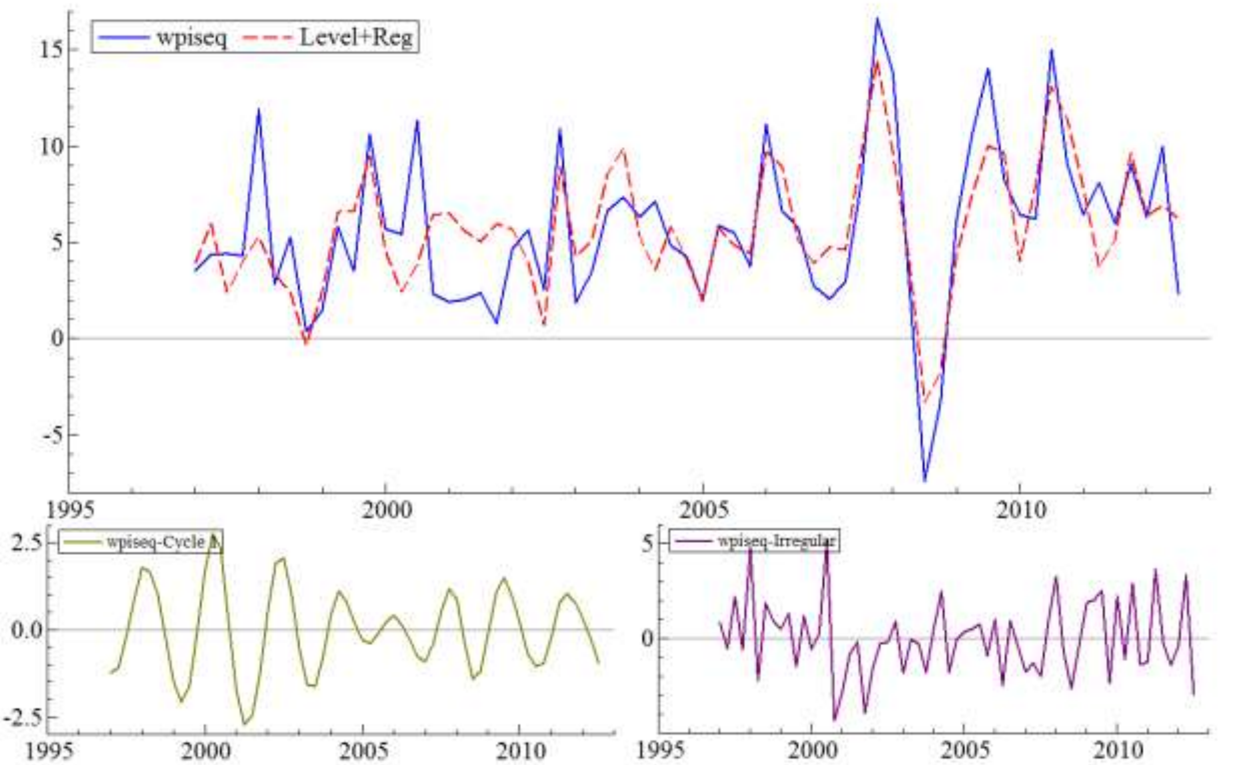
$$R_s^2 = 1 - \left({}^{SSE}/_{SSDSM}\right),$$

where SSE is the residual sum of squares and SSDSM is the sum of squares of first differences around the seasonal mean. Once again, the Extended model outperforms the Pure model and with $\boldsymbol{R_s^2} = .70$.

TABLE 3: DIAGNOSTIC TESTS		
	PURE PC	**EXTENDED PC**
Std.error	3.40	2.43
PEV	11.57	5.92
R_S^2	0.32	0.70
Normality	3.92 (4.61)	0.12 (4.61)
H(h,h)	1.32** (1.77)	0.89** (1.85)
DW	2.08	1.98
r(1)	-0.08	-0.02
r(q)	0.03	-0.07
Q(q,q-p)	10.58** (10.65)	3.30** (9.24)
AIC	2.97	2.10
**INDICATES THAT NULL HYPOTHESIS IS NOT REJECTED EVEN AT10% LEVEL OF SIGNIFICANCE		
PARANTHESIS CONTAIN 10 PER CENT CRITICAL VALUES		

Figure 5 plots the actual inflation vs. the fitted values as well as the cyclical and irregular components from the Extended model.

Fig. 5: Components in model relating inflation to output gap and supply shock controls



The diagnostic tests (see Table 3) for both the Pure and Extended PC model are very comfortably satisfied. The null hypotheses of independence, homoskedasticity and normality of errors are not rejected at even ten per cent level of significance. These results are encouraging and suggest a robust Phillips curve for India.

As a last check of robustness, multi-step ahead (extrapolative), out of sample predictive tests are reported for both the Pure (Fig. 6 (a)) and the Extended models (Fig. 6 (b)). These are easily conducted on Koopman *et. al.* (2007), where the post sample size of 7 (one tenth of the total sample) is used. The results are satisfactory (predictions are within 2 root mean squared error bands of actual values as shown) and most importantly, should allay all fears of data mining. Use of such out of sample extrapolative prediction tests is crucial in empirical studies but unfortunately absent from most other studies on the Indian Phillips curve

Fig.6a :Multi-step predications, conditional on output gap estimated from full sample in Pure PC model

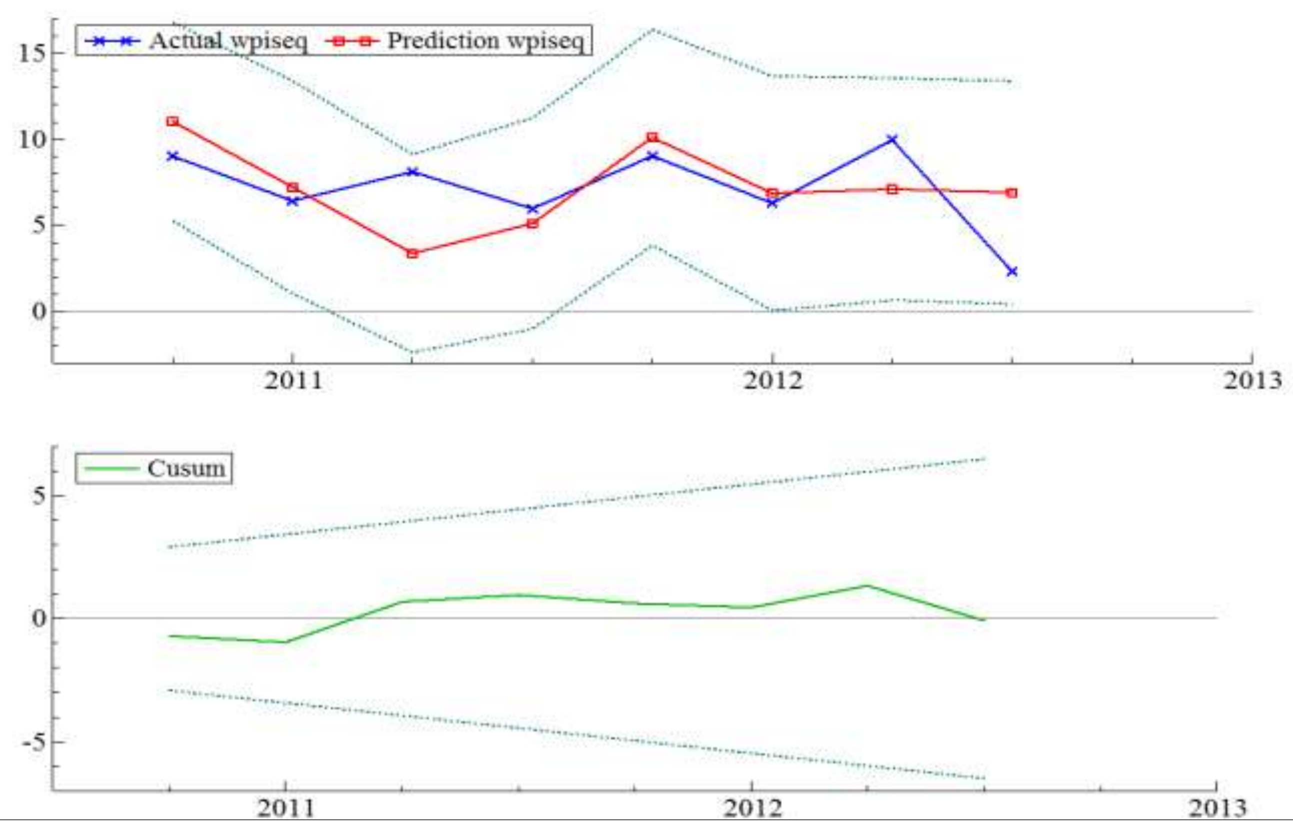
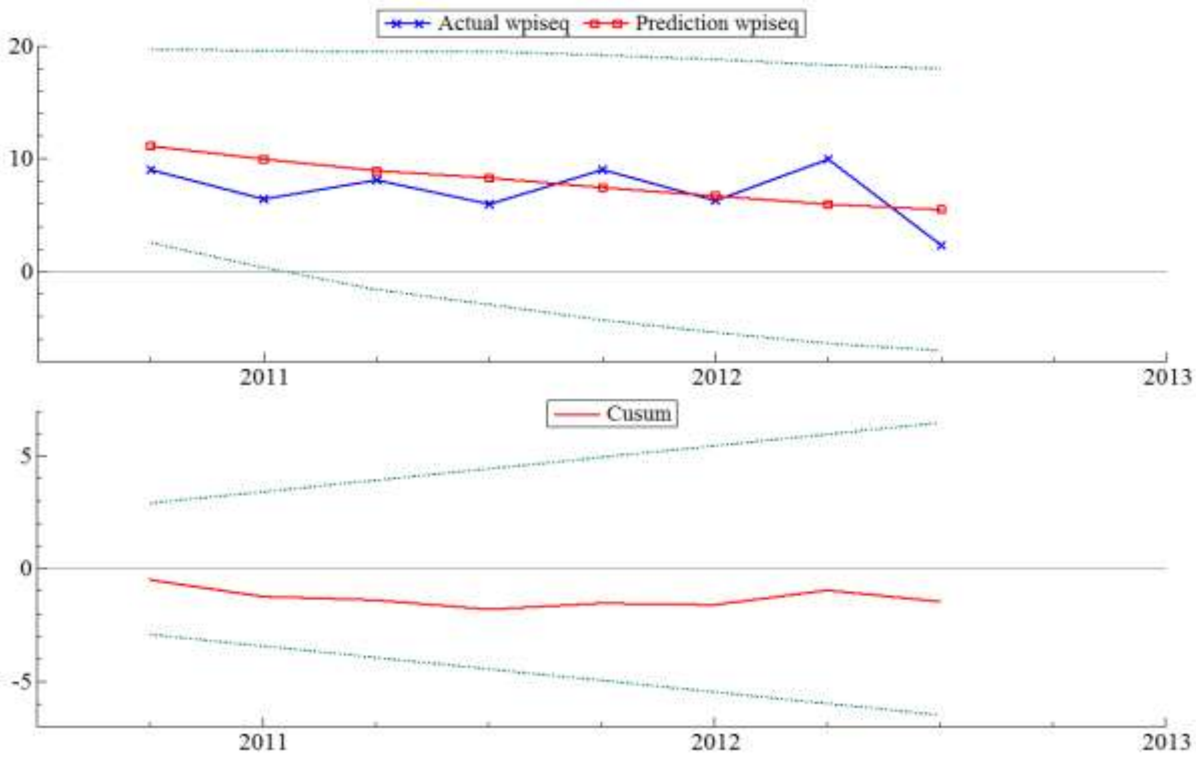


Fig.6b: Multi-step predications, conditional on output gap and supply shocks estimated from full sample in Extended PC model



9. CONCLUSION

In this paper I undertook the task of estimating the Phillips curve for India amidst vast literature which dismisses that any such relationship between inflation and output gap exists. Not only is this pessimism unfounded, this paper also shows for the first time, that even without controlling for supply shocks, one can arrive at a positive relationship between these two variables in India, providing perhaps the strongest support in favour of a Phillips curve for India.

An unobserved components model was used to improve upon the standard ARDL specifications. Furthermore, the econometric implementation of the of the PC was enhanced by using the Kalman filter as opposed to the HP filter; using quarterly aggregate GDP and inflation data rather than narrower and more convenient proxies like IIP and NFMI; by using a time variant model to better capture short run dynamics and lastly, by carrying out multi-step (extrapolative) prediction tests to allay fears of data mining.

I discuss in detail how India is different from industrialized economies in that it is frequently hit by rather persistent supply shocks. Therefore, it is only natural to want to purge the Phillips curve from these extraneous influences. This is done in a systematic way by controlling for food, fuel and non-fuel commodity prices as well as the exchange rate. Special care was taken to overcome the data limitations presented in § 5.

A comparison of the inflation and output gaps in Figure 3 shows an unmistakable relationship between output gap and inflation gap, especially towards the end of the sample. Based on this motivation, two UC Phillips curves were estimated. The first ignored supply shocks and relied solely on output gap to explain inflation. The highly significant and positive output gap coefficient in such a specification is a novel finding. Due to the conventional wisdom (see § 3) that in India output gap doesn't enter inflation dynamics in any meaningful way, this finding has profound implications for monetary policy. Further investigation on this line is desirable.

The second models took explicit account of supply shocks. The results show an improvement over the Pure PC specification which did not explicitly control for these shocks. The overall fit is better and so are the diagnostics and predictive tests. A one per cent rise in output gap raises inflation by 2.49 percentage points.

***

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DATA SOURCES

VARIABLE	SOURCE	WEBSITE
Gross Domestic Product at Factor Price and Constant Prices (i.e., Real GDP at factor price)	Central Statically Organization, Ministry of Statistics and Programme Implementation, Government of India	http://mospi.nic.in/Mospi_New/site/home.aspx
Nominal Effective Exchange Rate	Handbook of Statistics in the Indian Economy: Database on Indian Economy (Reserve Bank of India)	http://dbie.rbi.org.in/DBIE/dbie.rbi?site=home
Wholesale Price Index	Office of the Economic Adviser to the Government of India, Ministry of Commerce and Industry	http://eaindustry.nic.in/
Rainfall data for $\boldsymbol{Rain_t}$	Indian Meteorological Department	www.imd.gov.in
Global commodity inflation	International Monetary Fund	