WP-2019-026

Correlated Shocks, Hysteresis, and the Sacrifice Ratio: Evidence from India

Ashima Goyal and Gagan Goel

Indira Gandhi Institute of Development Research, Mumbai
August 2019

Correlated Shocks, Hysteresis, and the Sacrifice Ratio: Evidence from India

Ashima Goyal and Gagan Goel

Email(corresponding author): ashima@igidr.ac.in

Abstract

In an emerging market subject to frequent shocks output sacrifice from disinflation depends not only on the Phillips curve slope but also on shifts in demand and supply. Introducing shocks and correlations between shocks in a Kalman filter based estimation, the slope flattens, correlation between permanent output shocks (supply) and output gap (demand) shocks is negative and a new decomposition of output between trend and output gap shocks is obtained. The flat supply curve is robust to parameter changes, and business cycle turning points are tracked well, but the decomposition varies. More stable inflation expectation and rise in forward-looking behaviour increases volatility of trend growth and reduces the output gap. Inflation targeting had such effects in India. Estimated sacrifice ratio varies with the period and method, but it rises to 6.7 over 2011-17 if such hysteresis is included. Simultaneous equation estimation corroborates the results. In the estimation period, inflation targeting affected expectations but not inflation.

Keywords: Sacrifice ratio; Phillips curve slope; correlated demand and supply shocks; hysteresis

JEL Code: E32, E52, E31

Acknowledgements:

The paper further develops Gagan Goel's IGIDR M.Phil thesis. Helpful comments from annonymous referees, Jayati Sarkar, Subrata Sarkar and Abhishek Kumar and secretarial assistance from Reshma Aguiar are acknowledged.

Correlated Shocks, Hysteresis, and the Sacrifice Ratio: Evidence from India

August 8, 2019

1 Introduction

Low and stable inflation has been part of monetary policy goals all over the world. But disinflationary policy to reduce inflation is expected to have costs in the form of lower output and employment. The sacrifice ratio (SR) is defined as the short-run output loss due to reducing inflation.

A trade off between output and inflation in the short run is empirically observed primarily in advanced economies. The aggregate supply or Phillips curve (PC) gives the rise in unanticipated inflation (expected inflation subtracted from actual inflation), as a function of the difference of output from its potential level. The SR depends on the slope of the Phillips curve. For advanced economies, there is some evidence the PC has flattened (IMF 2013) raising the SR.

In emerging economies, supply-side constraints imply frequent shifts in the PC[1]. Correlated demand shifts can occur if forward-looking behaviour adjusts private demand or if policy responds to supply shocks. This can further impact supply. Our objective is to estimate the SR in the presence of such correlations in demand and supply shocks that can affect trend output and therefore have persistent effects. Sacrifice ratio is then measured on an adjustment path consisting of a series of shifting equilibria from one long run equilibrium to another (Zhang, 2005 and Hofsetter, 2008).

Emerging economies growth is volatile compared to advanced economies. So it requires more careful disentangling of trend output from the cyclical component. If the cycle affects the trend, demand shocks can create persistent effects or hysteresis. In the literature, generally Hodrick and Prescott (HP) or Band-Pass filters are used to disentangle these components. These filters smooth out either the trend component or the cyclical component of output. Potential or trend output and expected inflation are not observed time series but they are required for estimating the PC and SR accurately. Trend and cyclical component are unobservable components of observed output. A Kalman filter (KF) allows a stochastic trend, correlation between trend and cycle, as well as other unobservables to be extracted using available data. We therefore estimate the SR using the KF technique, following BN (Basistha and Nelson, 2007).

Figure 1 shows the output sacrifice for a pure demand shock and for a demand shock in the presence of a supply shock. The top panel shows a large output sacrifice from a fall in demand if

[1]There is evidence of a flat aggregate supply curve with multiple supply shocks for India (Goyal and Tripathi, 2015; Goyal 2011).

the aggregate supply curve (or PC) is flat. The bottom panel shows the output sacrifice would be even larger if a supply shock follows a demand shock or a demand shock follows a supply shock, while the change in inflation depends on the size of the supply shock. If consumption is reduced after an adverse supply shock, output falls while prices rise. This could happen if forward looking agents reduce demand following a supply shock, or if monetary or fiscal policy contracts. Growth rates could also be affected, as supply contracts further.

A leftward shift of aggregate demand (AD) following contractionary policy to reduce inflation after a cost shock would add to a contraction in demand from forward-looking households. A negative correlation between AD and aggregate supply (AS) shocks follows. Moreover, firms may expect higher interest rates from contractionary monetary policy and thus higher input cost, which induces further leftward shift of the AS curve. So, forward-looking behaviour would accentuate correlations between inflation, trend and output gap. This was the Indian experience after external shocks in the 1970s, 2011 and in 2018. Temporary supply shocks triggered sustained periods of lower growth. Goyal and Kumar (2018) show policy induced demand shocks shifted the AS curve to the left in 2011[2].

Therefore a SR calculated only using slopes and not shifts in the AS and AD curves would be an underestimate. Taking account of shifts and correlations, or using a simultaneous equation structure rather than a single equation PC, would give a more correct estimate of the SR or change in output accompanying a fall in inflation[3].

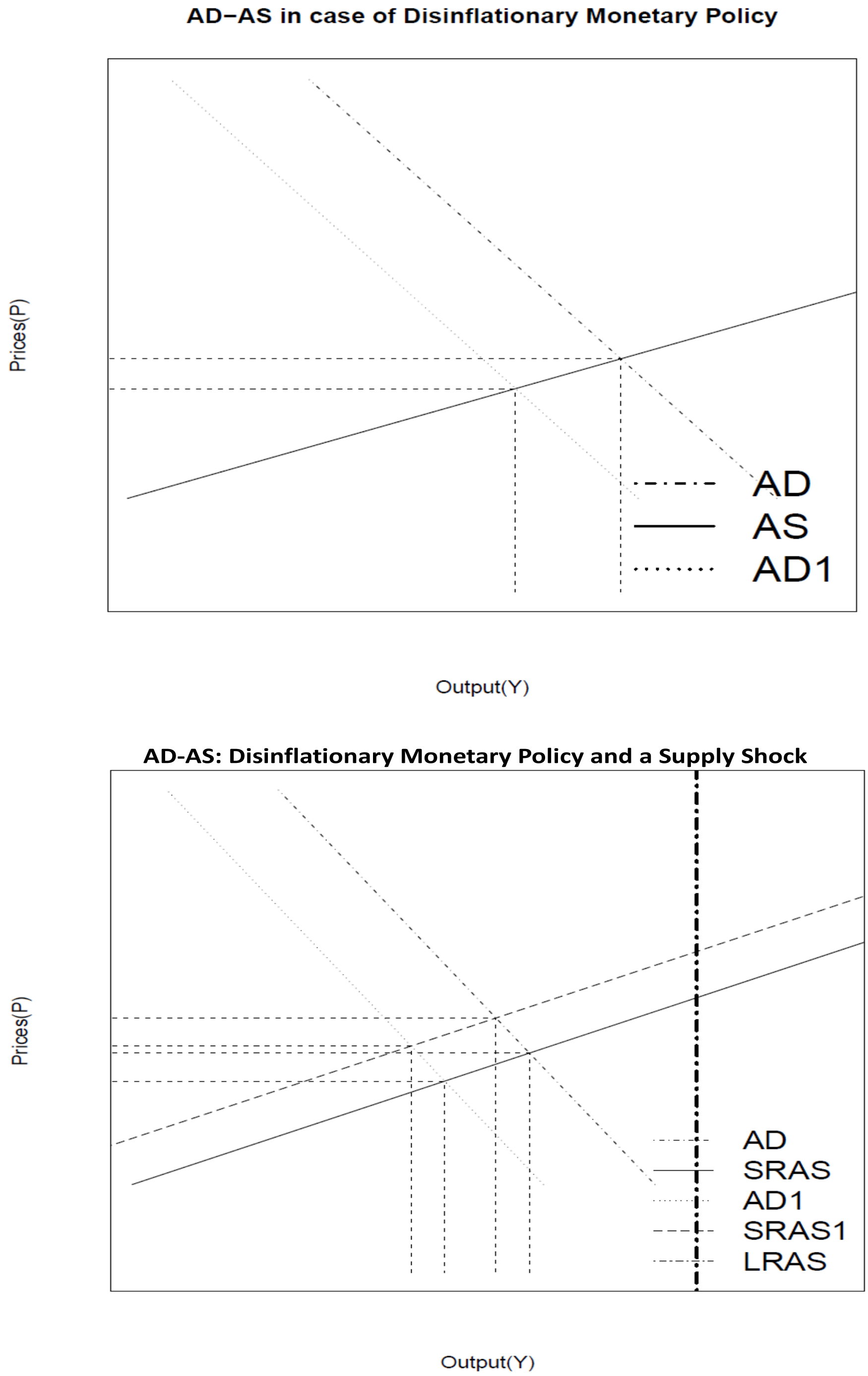
Emerging economies differ from advanced economies in many aspects of their economic structure. We take account of two major differences that can be expected to affect the SR—frequent supply shocks and their correlation with demand shocks. Second, how this affects the volatility of trend growth and therefore persistence of demand shocks.

Results from the KF estimations are: The slope of the PC flattens, the correlation between permanent output (supply) shocks and output gap (demand) shocks is estimated to be negative and a new decomposition of output between trend and output gap shocks is obtained. While the flat supply curve is robust to parameter changes and business cycle turning points are tracked well, the level of the output gap changes. A fall in volatility of inflation expectations and rise in forward-looking behaviour increases the volatility of trend growth and reduces the output gap. There are indications of such effects after monetary-fiscal policy tightened in 2011 and inflation targeting was adopted in 2013. The output sacrifice from an estimate that includes persistent growth effects is larger (6.7 over 2011-17) for the post global financial crisis (GFC) disinflation compared to the literature and our own initial episode based estimates. The implication for policy is that structural reforms, such as the adoption of inflation targeting, that impose large demand shocks, should be carefully implemented to minimize such shocks. The analysis implies demand shocks will have more persistent effects to the extent forward-looking behaviour increases and inflation expectations become less volatile.

[2]They allow for multiple high and low growth equilibria. Persistent low growth shifts the long-run AS leftward. Shifts in AS and AD are due to lagged endogenous variables, expectations as well as policy shocks. The correlation between all three components is negative. BN also estimate a negative correlation between permanent and gap shocks for the UK.

[3]Just as Goyal and Tripathi (2015) find correctly measuring supply shocks reduces the AS slope.

Figure 1: Impact of demand and supply shocks on output and inflation



There are many variables that affect inflation and output. Therefore, apart from the minimal unobserved component model we also, (following Gorden and King, 1982) estimate a hybrid between an structural vector autoregression (SVAR) and a traditional dynamic simultaneous equation structure. This allows us to add a number of exogenous variables to the few identified endogenous variables. The process again reduces the slope of the AS compared to single equation estimates such as Chinoy et. al (2016). It also supports the negative relationship between productivity and the output gap that is a major result of the KF model. Inflation targeting (IT) may have increased the volatility of potential growth, but it did not have any effect on inflation itself in the period of SVAR estimation, after controlling for supply shocks.

Section 2 presents a literature review. Section 3 gives stylized facts including preliminary results from an episode based estimation of the SR. Section 4 has details of data, methodology and results for a state space and for a simultaneous equation model, before Section 5 concludes. An Appendix at the end reports tests and details on estimations.

2 Literature Review

The most frequently used methods of calculating the SR are broadly: Variants of a PC model, including extensions to SVAR, and the disinflation episode method.

Okun (1978) initially estimated the SR using a simple formulation of a Phillips curve. Gordon and King (1982) used a simultaneous equation model and introduced structural parameters to disentangle supply and demand shocks. They included several other channels of monetary influence on the inflation process and observed the dynamic pattern of prices and output. Simultaneous equation method can give more insights on the SR by isolating the monetary shock from other shocks such as supply shocks, and controlling for endogenous responses. They showed the relationship between SVAR and estimating traditional dynamic simultaneous equations system.

VAR models emerged as an alternative to traditional large-scale dynamic simultaneous equation models, since dynamic restrictions in regression models were often ad-hoc. It was necessary to discard empirically implausible exogeneity assumptions, even while modelling all endogenous variables jointly rather than one equation at a time. The success of such VAR models as descriptive tools and to some extent as forecasting tools is well established. But their ability to differentiate between correlation and causation, in contrast, has remained contentious. Structural interpretations of VAR models impose additional identifying assumptions based on institutional knowledge, economic theory or other extraneous constraints on the model responses. Only after decomposing forecast errors into structural shocks that are mutually uncorrelated and have an economic interpretation can we assess the causal effects of these shocks on the model variables.

To identify structural shocks, Gorden and King (1982) specified an inflation equation with restrictions as follows:

$$p_t = \gamma_0 + \gamma_1(L)p_{t-1} + \gamma_2(L)x_t + \gamma_3(L)z_t + \epsilon_t \tag{2.1}$$

Here each L in parenthesis indicates that the set of coefficients is allowed to be a polynomial in the lag operator. Each component of the z vector is defined to equal zero when a particular supply shift is absent, allowing a zero value for the sum of the x_t output gap term, with the constant term to be interpreted as a 'no-shock natural rate' situation compatible with steady inflation ($p_t = p_{t-1}$). Instead of the natural weighted unemployment rate commonly used in such estimations, they used log output ratio, $\tilde{Q}_t$, and included 13 variables to calculate the output and price effects of a monetary deceleration for the U.S. economy. The endogenous variables are arranged in an order that treats the food-energy price effect and relative price of imports as 'most exogenous' and allows the inflation rate and effective exchange rate to be influenced by current innovations in each of the variables listed above them. The advantage of their hybrid method is that variables that were endogenous could be modelled with the full VAR lag structure, but exogenous, dummy and other context specific variables could also be introduced.

Cecchetti (1994) also extended this analysis arguing that SVAR could account for the unique contribution of a monetary shock on the SR and give a measure of disinflation cost. Cecchetti and Rich (2001) extended the previous study with new SVAR models, though these were criticized for assuming a linear relationship through all the phases. Filardo (1998) introduced non-linearity in the Phillips curve by assuming different slope coefficients of the output gap in different phases of the economy. Other extensions include estimating the impact of international competitiveness and cross country aspects (Belke and Boeing, 2014).

Ball (1994) introduced an episode-specific method to measure SR. He first identified disinflation episodes and then calculated SR for every episode. He interpreted SR as the output cost of reducing inflation by one point through an aggregate demand contraction. But his method ignored supply side shocks and persistent impacts of disinflation. It was modified by Zhang (2005) who used the HP filter to capture persistence effects, and by Hofsetter (2008) who accounted for hysteresis in the disinflationary process as did Ball (2014) and Belke (2018). Hysteresis is well explored in the literature but its effects through correlated shocks is not. We concentrate on estimating the latter.

Moreover, HP filter imposes smoothness but not determinism on the trend. Although this statistical method is attractive because of its simplicity, its shortcomings are well documented. Results are not model based making the economic interpretation doubtful. Nor are they able to capture structural changes. Additional shortcomings specific to the HP filter are: (i) it is difficult to identify the appropriate value of the detrending parameter λ and (ii) this technique is susceptible to what is often referred to as end-point bias caused by the asymmetry inherent in the filter at the extreme points of a time series. This problem can be partially corrected by extending the data sample with projections before running the filter. Hamilton (2017) also explains why HP filter is not appropriate to disentangle trend shocks from cyclical ones, which is our focus in this paper.

In the Indian context, RBI (2002) made an early attempt to calculate the SR. Estimating a PC with annual data, they found a SR of 2%. Subsequently, Kapur and Patra (2003) estimated the SR for India using annual data for the time period 1971 to 2001. With the help of a short-run supply curve and using different specifications, their calculated SR was in the range of 0.5 to 4.7. They found the SR differed depending upon the inflation measure, sample period and specifications used in the estimations.

Dholakia (2014) calculated SR for annual data using dynamic aggregate supply and demand approach, and found it to be in the range of 1.8 to 2.1 during the disinflation period and 2.8 for the inflationary period. Durai and Ramachandran (2013) used episode method for the estimation of the sectoral SR. Using annual data for the time period 1950-51 to 2009-10, they found a negative SR in the range of -0.1 to -2% for the farm sector and a positive SR of 0.7 for the non-farm sector. The negative SR in the agricultural sector offsets the SR in the non-farm sector to give an overall low SR.

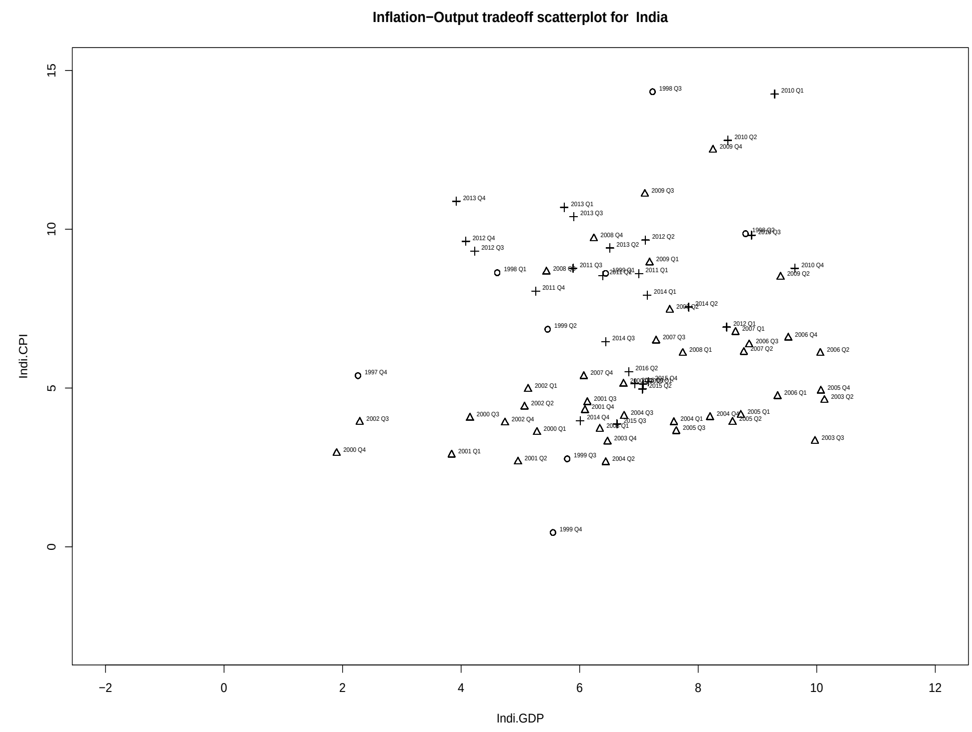
Dholakia and Virinchi (2017) tried to estimate short and long-run SR using quarterly data. They used both the regression approach and the episode method. The SR varies from 1.7 to 3.8 depending upon the inflation measure and method used in the calculation. Mitra et al. (2015) also estimated SR for two different conditions of the economy as in Dholakia (2014) but used a different methodology. With the help of both direct method and a time varying ARDL framework, they estimated a SR of 2.7 during the expansionary period and 2.3 in the contractionary period.

There are estimates of the Phillips curve for India (Paul, 2009, Singh et al., 2011, Kotia, 2013, Goyal and Tripathi, 2015). But the implications of correlated demand and supply shocks are yet to be explored.

3 Stylized facts

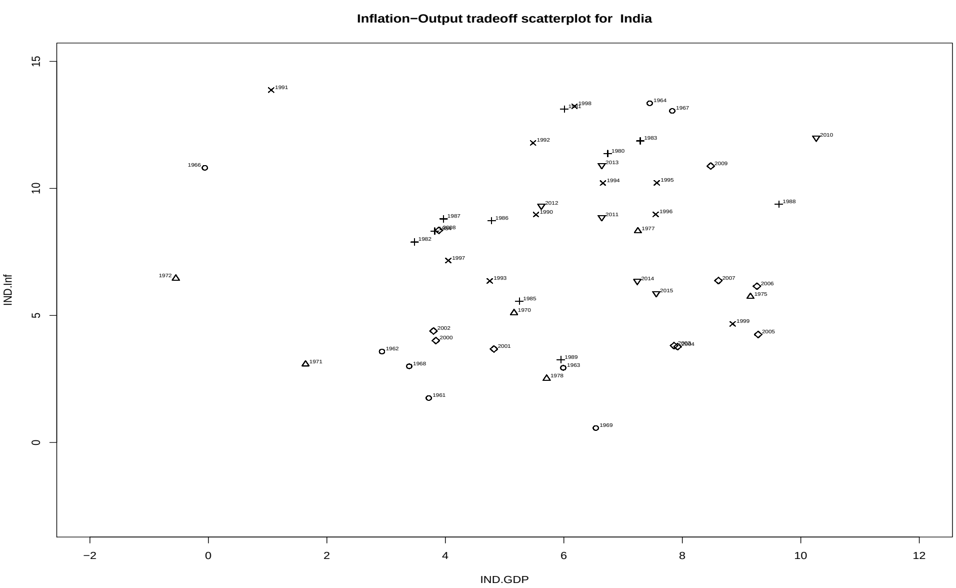
3.1 Scatter-Plot of Output and Inflation

Figure 2: Indian inflation - output trade off, quarterly data



A simple scatter plot of Indian inflation and growth (figures 2 and 3) does not reveal any consistency in the overall pattern across decades. Quarterly data indicates a backward bending relationship between observed output growth and inflation. While for the recent decade, a negative relationship seems to exist, the 2000s show a backward bending trend with high growth in 2003-05. Annual data, however, does not support this pattern. It seems to be positive with high standard deviations. Further investigation is required to derive a trade-off, if any, between output and inflation. We next estimate Ball's (1994) episode-based SR with both annual (Table 1) and quarterly (Table 2) data.

Figure 3: Inflation - output trade off, annual data



3.2 Ball's Episode Based Method

This is a non- parametric approach for estimating SR. It proceeds as follows. First, trend inflation is defined as a centred 9 quarter (3 year) moving average of actual inflation for quarterly (annual) data; trend inflation in quarter t is average of inflation from $t-4$ through $t+4$. Second, 'peaks' and 'troughs' in trend inflation, where peak is a quarter in which trend inflation is higher than its previous 4 quarters and following 4 quarters, and similarly for trough, are identified. Third, disinflation episodes in which trend inflation falls substantially are identified. Fourth, sum of output gap, that is, the difference of actual output and potential output is calculated for the episodes. Assumptions made to calculate potential output are as follows: Output is at its trend or natural level at the start of a disinflation episode, which is at an inflation peak. Output is again at its trend level 4 quarter after an inflation trough while trend output grows log-linearly between two points when actual and trend output are equal. Numerator of SR is sum of deviation between log actual output and the fitted line. Finally, SR is calculated as a ratio of sum of output losses (deviation between actual output and potential output) over change in trend inflation over an episode: $\frac{Y_t - Y_p}{\pi^t - \pi^p}$ where Y_t is actual log output and Y_p its 'full employment' or trend level, and π^t is trough and π^p is peak inflation.

This method assumes only demand affects inflation and disinflation does not change the trend

Table 1: Episode-based estimate of sacrifice ratio for India (annual data)

Peak inflation	Length	Δ in trend core π%	Sum output gap%	Sacrifice ratio
1965	5	-6.3	-66.1	10.5
1972	5	-9.1	13.3	-1.5
1981	6	-3.4	-23.0	6.8
1992	10	-6.6	23.6	-3.6
2010	6	-4.3	2.4	0.55

level of output, that is, there is no hysteresis. The denominator would always be negative as trough inflation would always be less than peak. But SR can be negative, as is found in some episodes in Table 1, if inflation trough is less than peak as an adverse supply shock fades, while actual output stays above the measured potential as aggregate demand contraction is less. This seems to be the case before the nineties liberalizing reforms. Inflation is trend core inflation extracted from the WPI. In the quarterly estimates (Table 2), which do not cover the period of negative annual estimates, SR is always positive. It is especially high in the high growth 2000s where potential output would be assumed to be high in Ball's method. We next turn to model based refinements that give a better estimate of output gaps and allow for possible hysteresis.

Table 2: Episode-based estimate of sacrifice ratio for India (quarterly data)

Peak inflation	Length	Δ trend core π%	Sum output gap %	Sacrifice ratio
Q4 1996	5	-5.8	-5	0.78
Q4 1998	16	-7.1	-22	3.12
Q3 2003	9	-1.6	-12	7.29
Q1 2007	10	-1.5	-16	10.41
Q3 2010	9	-9.4	-3	0.33
Q3 2013	8	-9.9	-2	0.21

4 Model based measures

4.1 Unobserved Component Model

Estimating output gap and allowing for hysteresis to measure SR requires distinguishing the business cycle component (output gap) from the trend component (potential output) in observed real GDP. Basistha and Nelson (2007) point out the literature on this can be broadly categorized into two groups, statistical and economic. Of the two major sub-categories of statistical approaches to the decomposition of output one imposes smoothness on either the trend or on the cycle. The other does not impose prior smoothness on either component, at least directly, but uses a time series model to let the data speak for itself. The latter require identification of a stochastic trend component, a long horizon forecast with a unit root. The trend may or may not be correlated with the cycle. Merging of economic with statistical approaches has led to multivariate unobserved component models. A bivariate KF state-space estimation of the PC can obtain unobservables such as the output gap and thus decompose output into stochastic trend and cyclical shocks, while drawing on information in both inflation and output. If trend and cycle shocks are correlated demand shocks can have persistent effects. We set out the basic model in the next section.

4.1.1 Kalman Filter Estimation

Measurement Equation

$$\pi_t = \tilde{\pi}_t + \delta g_t \tag{1}$$

$$Y_t = P_t + g_t \tag{2}$$

State Equation

$$\tilde{\pi}_t = \beta_0 + \beta_1 . \varphi . \pi_t^{se} + \beta_2 \left(\tilde{\pi}_{t-1} + \delta g_{t-1}\right) + \epsilon_{\pi,t} \tag{3}$$

$$P_t = \mu + P_{t-1} + \epsilon_{p,t} \tag{4}$$

$$g_t = \phi_{g1} g_{g-1} + \phi_{g2} g_{t-2} + \epsilon_{g,t} \tag{5}$$

Measurement equations (1) and (2) relate each of observed inflation, π_t, and output Y_t to state variables. But $\tilde{\pi}$, the part of inflation not related to the gap, is itself treated as a state variable. It is assumed to be partially observed through lagged inflation as well as some measure of inflation expectations, π_t^{se}, in Equation (3). β_1 is the forward looking operator while β_2 is the backward looking operator determining inflation. Error associated with this equation, $\epsilon_{\pi t}$, is a composite of unobserved variables that play a role in expected inflation and of a direct supply shock.

The hybrid New Keynesian PC (NKPC) is recovered by substituting Equation (3) in Equation (1). One variable of our interest is δ, the slope parameter of the PC. This is constrained to be positive and to lie between 0 and 1. The lower is δ, the flatter is the PC, and thus lower is the impact of the output gap on inflation.

Equation (2) is an identity where observed output is equal to permanent component of output, P_t, and cyclical component, g_t. Here, Y_t is in logs, and so is the permanent component, P_t. The cyclical component g_t can be negative, so it cannot be taken in logs. It is, therefore, difference of log of observed and potential output. Potential or trend output are other names of the permanent component, which we use interchangeably.

Of the other two state variables, the trend component, P_t, is assumed to follow a random walk, and as it is in logs, μ is an average growth rate (Equation 4). In Equation (5) g_t is assumed to follow an AR (2) model. Since it is a cyclical component, it should be stationary, satisfying the condition that sum of ϕ_{g1} and ϕ_{g2} is less than 1. State equations specify laws of motion for unobserved or state variables.

The three shocks are defined as $\epsilon_{\pi,t} \sim N(0, \sigma_\pi^2), \epsilon_{p,t} \sim N(0, \sigma_p^2), \epsilon_{g,t} \sim N(0, \sigma_g^2)$. The variances and 3 covariances are among the parameters to be estimated using maximum likelihood, while the

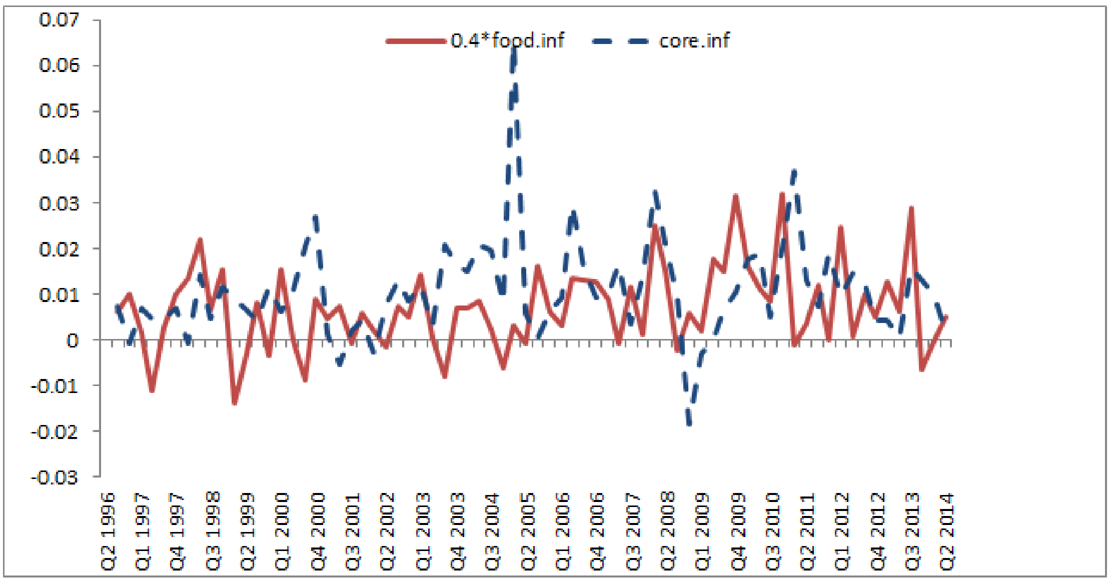
KF produces estimates of the unobserved components $\tilde{\pi}_t, g_t$ and P_t. Estimations are done with and without covariance terms to observe how bringing in correlations between shocks impacts underlying structural parameters. Treating both g_t and $\tilde{\pi}_t$ as unobservables implies the KF estimate of g_t is consistent with the behaviour of inflation. This is a valuable measure of g_t for an emerging economy, which has unemployed resources, so that the only restraint on output comes from inflation.

4.1.2 Data and Parameter Restrictions

We use quarterly Indian time-series over 1996:2 to 2017:1 taken primarily from the Reserve Bank of India (RBI) database. Output is the log of deseasonalised real GDP in 2005 prices. Inflation is core inflation calculated from log difference of wholesale price index (WPI) non-food and non fuel manufacturing components. Core inflation is stationary at 1% level of significance by Phillips - Perron test and 10% level of significance by ADF test (Appendix Table A1). Log output is non-stationary.

Time series on survey expectations are not available for India. RBI (2014) finds commodity inflation to be the best explanatory variable for household inflation expectations. Low per capita incomes and a large share of food in the consumption basket in India during this period made food inflation a good proxy for inflation expectations. We found deseasonalised food inflation to give the best fit in the recent period among food inflation, fuel inflation, and weighted or simple average of fuel and food inflation as a proxy for forward looking expectation. We tried one, two, and four quarter moving average of food inflation. Food inflation is a stationary series at 1% level of significance by Phillips Perron test (Appendix Table A1). We introduce a smoothing parameter, φ, multiplying inflation expectations in Equation (3). This reduces the volatility of food inflation and therefore of inflation expectations. Fig. 4 provides the graph of the core-inflation and smoothed food inflation using parameter, φ. We found 0.4 to be the best fit as smoothing parameter.

Figure 4: Inflation and inflation expectation



We have 84 observations that we use to estimate 12 parameters and extract 3 state variables.

Given that we estimate a linear state space model with only few observations available, constraining some parameters is required to ensure convergence. Many studies in this area use theoretically or empirically motivated restrictions on the parameter space, especially so in KF based output gap estimations.

We constrained δ to be positive. To ensure long run neutrality β_1 and β_2 sum to 1. Since g_t series is assumed to follow an AR(2) stationary process, ϕ_{g1} and ϕ_{g2} sum to less than 1.

Given the unique structure of this model, there is no pile up problem. The latter generally arises in maximum likelihood estimation of innovations linking two non-stationary unobserved variables. But in this setup, there is only one non-stationary unobserved variable, P_t. Also, there is no measurement error in observation equation.

4.1.3 Estimation of Benchmark Specifications and Output Gaps

Benchmark estimations are in Table 3. The estimate of trend growth rate is around 1.7% quarterly, which implies trend growth rate of around 7% annually. The estimated response of inflation to the gap is 0.0001, indicating a flat-sloped Phillips curve. The estimates also show negative correlation between the gap or cycle shock and shocks to the permanent (or trend) component (ρ_{Pg}), a positive correlation between the permanent shock and the inflation shock ($\rho_{\pi P}$) and a negative correlation between the inflation shock and the gap shock ($\rho_{\pi g}$)[4]. The sum of AR coefficients of 0.846 implies any impact on output gap would be persistent, as can be seen in impulse responses (Figure A.1 in the Appendix).

Table 3: The parameter estimates with all unrestrained covariances, and smoothing parameters 0.4 (Benchmark I, BI), and 1 (Benchmark II, BII)

The trend drift, the Phillips curve slope, and the autoregressive coefficients					
	BI $\varphi = 0.4$	BII $\varphi = 1$		BI	BII
μ	0.017	0.018	ϕ_{g1}	1.113	1.112
δ	0.0001	0.0001	ϕ_{g2}	-0.265	-0.266
Non-gap coefficients of the Phillips curve					
β_0	0.012	-0.028			
β_1	0.992	0.992			
β_2	0.008	0.008			
Standard deviations and correlations of shocks					
σ_π	0.054	0.106	$\rho_{\pi g}$	-0.458	-0.449
σ_p	0.001	0	$\rho_{\pi p}$	0.015	0.022
σ_g	0.002	0.01	ρ_{pg}	-0.615	-0.606

Fig. 5 shows smoothed estimates of the output gap and trend growth. The top panel imposes constraints restricting all correlations[5] to be between 0 and -1 and in the bottom Benchmark I (BI) panel there are no restrictions. The estimates of the gap pick India's recession and boom periods

[4]Signs are the same as in BN. Goyal and Kumar (2018) also estimate a negative correlation between demand and supply shocks.

[5]This increases variation in output gap and reduces that in the trend compared to the BI case of no restrictions– σ_p is lower at 0.0008 and σ_g is higher at 0.006 than the BI values of 0.001 and 0.002 respectively (Tables 3 and 4).

quite efficiently. For instance, mid-1990s boom, recession post east Asian crisis, boom starting in 2003, GFC in 2008, V-shaped recovery and again a prolonged slump after the GFC and also a recovery in 2016. Since the volatility of trend output is higher in the lower panels with unconstrained ρs, the changes in output gap are smaller, but more frequent especially in the post 2012 period of demand contractions that harmed supply conditions.

Figure 5: Smoothed measures of the output gap and the trend output growth for food inflation smoothing of 0.4, no constraints on ρs as Benchmark I (BI)

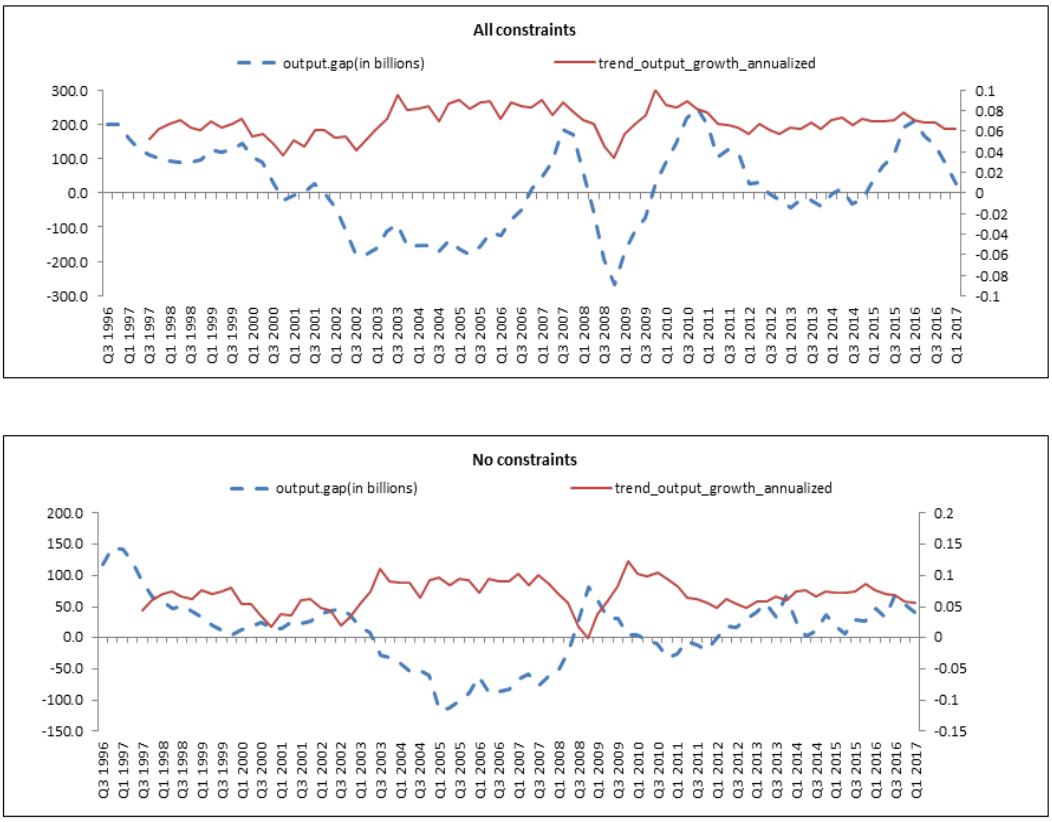


Figure 5 BI shows a moderately big size of the random walk component in the trend output fluctuations, as does the estimate of the standard deviation of the random walk component as compared to standard deviation of the output gap shock. In Table 3 σ_P is approximately five times higher than σ_g for BI. Impulse responses shown in Appendix Figure A.1, show the trend component rises sharply with output. But in BII σ_p goes to zero and all the variation goes to the cyclic component. The other parameters in BI and BII are similar.

4.2 Robustness Checks

Table 4: Parameter estimates under different scenarios

Scenarios/ Parameters	No ρ_s	No $\rho_{\pi g}$ $\rho_{\pi P}$ $\varphi = 1$	No $\rho_{\pi P}$ $\varphi = 1$	All ρs unconstrained $\varphi = 1$ BII	$\rho_{Pg} \in (0, -1)$ $\rho_{\pi g} \in (-1, 0)$ $\varphi = 1$	$\rho_{Pg} \in (-1, 0)$ $\rho_{\pi g} \in (-1, 0)$ $\rho_{\pi P} \in (0, 1)$ and $\varphi = 0.4$	$\rho_{Pg} \in (0, -1)$ $\rho_{\pi g} \in (-1, 0)$ and $\varphi = 0.4$	All ρs unconstrained $\varphi = 0.4$ BI	$\rho_{Pg} \in (0, -1)$ $\rho_{\pi g} \in (-1, 0)$ and $\varphi = 0.8$	Structural break $2014Q1 - 2017Q1$ BI
μ	0.017	0.017	0.018	0.018	0.018	0.017	0.017	0.017	0.017	0.015
δ	0.008	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
β_0	-0.015	0.026	0.011	-0.028	-0.026	0.012	0.012	0.012	-0.013	-0.158
β_1	0.569	0.992	0.992	0.992	0.992	0.992	0.992	0.992	0.992	0.993
β_2	0.431	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008
ϕ_{g1}	1.101	1.108	1.11	1.112	1.11	1.118	1.113	1.111	1.111	1.101
ϕ_{g2}	-0.275	-0.266	-0.267	-0.266	-0.267	-0.253	-0.258	-0.265	-0.265	-0.272
σ_π	0.065	0.097	0.059	0.106	0.098	0.054	0.054	0.054	0.081	0.171
σ_p	0.008	0.01	0	0	0	0.008	0.008	0.01	0.008	0.004
σ_g	0.004	0.008	0.01	0.01	0.009	0.006	0.006	0.002	0.006	0
ρ_{pg}	0	-0.61	-0.615	-0.606	-0.266	-0.267	-0.267	-0.615	-0.266	-0.603
$\rho_{\pi g}$	0	0	-0.458	-0.449	-0.169	-0.17	-0.17	-0.458	-0.169	-0.451
$\rho_{\pi p}$	0	0	0	0.022	0.019	0	0.019	0.015	0.019	0.017
Log likelihood	-366.114	-330.89	-371.407	-324.246	-329.041	-379.701	-379.758	-379.071	-345.802	-37.015

Estimations were performed with and without covariances in the state variance - covariance matrix and other changes in order to examine the robustness of underlying structural parameters. Four models were estimated for covariances, one with no covariances, then including correlation between trend and cyclical shock, then adding correlation between inflation shock and cyclical shock and then including also correlation between inflation shock and permanent shock. Other estimations varied the parameter φ, placed restrictions on the covariances, allowed for a structural break in inflation and introduced lagged g in the PC as another channel of hysteresis. We also tried some other approximations as the proxy for inflation expectations, reported above[6]. Since a feature of the Indian economy in our period of analysis was sharp movements in, and divergences between different measures of inflation, testing for and introducing a structural break in inflation was also tried.

Table 4 presents the results from some of these simulations. Smoothed estimates of trend output growth and output gap are shown in figures 5 and 6. Some observations are: (i) Inclusion of correlation ρ_{pg}, between trend and gap component of output, lowers[7] the output elasticity of AS, δ, implying a higher SR. (ii) The effect of inflation expectations on inflation, β_1, increases while the effect of lagged inflation, β_2, decreases, as soon as ρ_{pg} is introduced. Thus introducing the correlation gives a more correct measure of the impact of expectations on inflation. (iii) Negative $\rho_{\pi g}$ implies negative supply shocks that raise inflation decrease demand, reducing the output gap and negative ρ_{pg} implies a shock that reduces P tends to raise g. (iv) AS slope, δ, and inflation parameters, β_1 and β_2, remain the same irrespective of variations in other parameters, after the introduction of ρ_{pg}. (v) ϕ_{g1} and ϕ_{g2} change very little in different smoothing specifications. (vi) The σs and ρs are sensitive to changes in φ and to restrictions on ρs. Volatility of the permanent component of output σ_p rises as φ falls or the volatility of inflation expectations falls; for $\varphi < 1$, σ_p rises as ρs rise indicating more forward-looking behaviour; σ_π(volatility of inflation) rises with φ but falls if ρs and especially $\rho_{\pi p} = 0$. If $\sigma_p = 0$ all the volatility goes to the cyclic component and there are no stochastic shocks to trend growth. (vii) Introducing a structural break in inflation[8] changes only σ_π and β_0 without affecting any of the major parameters or inferences above. The results are therefore robust to non-linearities or breaks in inflation.

The simulations establish δ and β coefficient values are robust once the correlation ρ_{pg} is introduced. The signs of the correlations are also robust as are the shape and turning points of the output gap, which capture the Indian macroeconomic cycle well. But the covariances and σs vary with the imposition of constraints on the covariances and the food inflation smoothing parameter φ. This makes the stochastic trend growth rate and the level of the output gap vary across simulations.

Higher absolute values of ρs, where they are unconstrained, imply more forward-looking behaviour, since that is one cause of correlated shocks. Food inflation and the smoothing parameter together proxy expected inflation. The value 0.4 for the food smoothing parameter, gives the least RMSE for deviation of expected inflation from actual inflation, and so is chosen as BI. The maxi-

[6]Results are available on request.

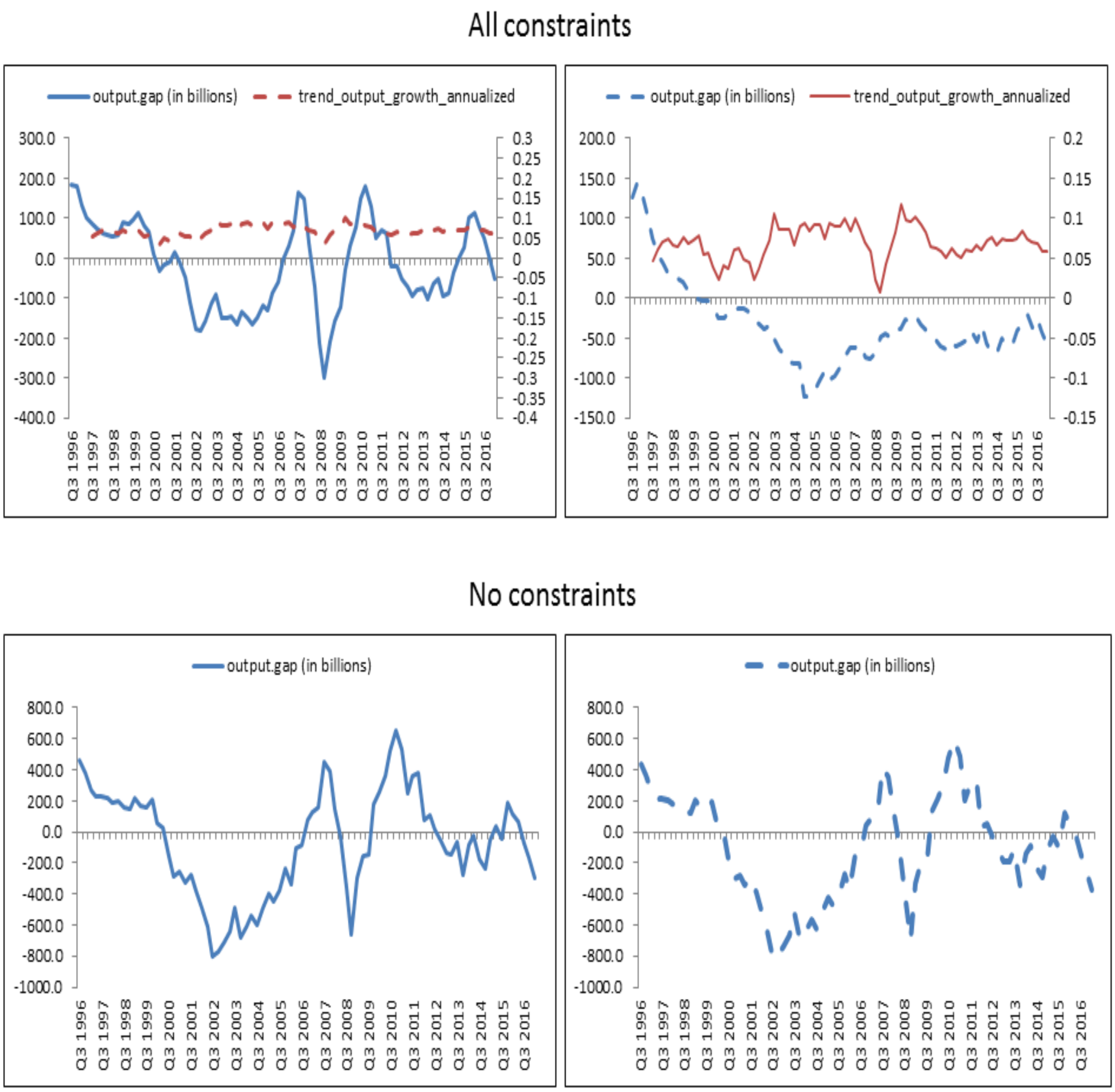
[7]Goyal and Tripathi (2015) also find better measurement of variables gives a better estimate of slope.

[8]Tests show a structural break in inflation in 2014 so the last column in Table 4 gives a separate estimation for the period after that.

mum likelihood, however, is the highest for $\varphi = 1$ all ρs unconstrained, although the difference is not much. This is chosen as BII, since it sends all the stochastic variation to output gaps and is therefore useful to measure SR.

Below we see the difference in trend cycle decomposition first, as φ falls reducing the volatility of inflation expectations. Second, for each φ as forward-looking behavior reduces when constraints are imposed on ρs. Figures 5 and 6 show simulations with constraints in the unit space on correlations (top panel) and with no constraints (bottom panel) for food smoothing parameters 0 .4 (Figure 5), 0.8 and 1 (Figure 6).

Figure 6: Smoothed measures of the output gap and the trend output growth for smoothing of 0.8 (LHS) and 1 (RHS). Bottom RHS Benchmark II



For 1: No constraints on ρs (BII): Volatility of potential growth is zero (standard deviation 0), there are sharper changes in the output gap, which is more negative (-400bn) in the end. All constraints: Volatility of potential growth is high (standard deviation 2), the output gap is negative ever since 2000, reaching -60 bn at the end of the period.

For 0.8: No constraints: Volatility of potential growth is zero (standard deviation 0), the output gap is negative (-300 bn) in the end. All constraints: Volatility of potential growth is low (standard deviation 1), there are sharper changes in the output gap, which is negative at the end of the period.

For 0.4: No constraints (BI): Volatility of potential growth is high (standard deviation 2), the output gap is positive in the end of the period. Constraints (0, -1) on ρs: Volatility of potential growth falls (standard deviation 1), there are sharp changes in the output gap, which is positive in the end.

When σ_p is low, σ_g is high; σ_p rises with higher absolute values of ρs but falls with φ. Therefore, potential output fluctuates less when inflation expectations are volatile and if expectations are less forward-looking (correlations are constrained), or if policy does not impose demand shocks in response to supply shocks. In these conditions, therefore, output gap fluctuates more. The output variation in any period is distributed over g or P in the model simulations.

So in BII $\varphi = 1$ no constraints (Figure 6 bottom RHS) all the variation goes to g and there is none in P. Unconstrained higher absolute ρs indicate more forward-looking behaviour. BI with $\varphi = 0.4$, represents the case of less volatile expectations, and $\varphi = 1$ BII volatile inflation expectations. Post-inflation targeting India is probably closer to BI. BII, however, gives a straigthforward measure of output sacrifice as the sum of output gaps since the stochastic variation in P is zero with all the variation going to g. When P changes, it has to be multiplied by future growth to correctly calculate output sacrifice, which is difficult.

The simulations also allow us to conclude since correlations are non-zero for India, there is some degree of forward-looking behaviour, apart from other sources of correlation. Obtaining the exact decomposition between trend and gap changes requires better inflation expectation data. But better anchoring of inflation expectations will reduce the volatility of the cyclic component and increase that of trend growth. Indian growth volatility has been high in the period of IT ranging from 8.2 to 5.8% quarterly growth. As correlations rise with more forward-looking behaviour policy needs to contract demand less in response to a supply shock. This could mitigate growth volatility.

4.3 Sacrifice Ratio

The slope of the PC affects the SR. The above estimates give a flat PC, which implies a high SR. But the final SR also depends on shifts of the curves and persistent changes in trend output growth. Since supply shocks make it difficult to identify disinflation based only on inflation we also estimate SR for periods of policy tightening, defined as a rise in Repo rates, and using the simulation BII to calculate output sacrifice (as sum of output gaps) for unsmoothed core and headline WPI inflation (Table 5).

The SR was negative in the 2000s tightening because although the output gap became negative inflation rose with supply shocks (rising oil and food prices). This contrasts with the high positive SR obtained for this period by the episode method (Table 2). The excessive post GFC stimulus was inadequately reversed so output exceeded potential although inflation fell. The post 2011 period, which included IT saw positive SR varying between 1 to 1.72. The cost in falling output gaps from sustained tightening over Q3 2011 to Q1 2017 was 6% from BII, which sends all the stochastic variations to the output gap but fall in trend growth also has to be added to the SR. The average

Table 5: Monetary tightening and BII based sacrifice ratio with core and headline inflation

Monetary tightening	Length in quarters	Sum of % Δ in output gap Benchmark II	% Δ in core inflation	% Δ in headline inflation	Sacrifice ratio: Core inflation	Sacrifice ratio: Headline inflation
Q2 1998-Q1 2002	16	-10	-8.5	-4.45	1.16	2.21
Q4 2005-Q3 2008	8	-2	3.75	6.25	-0.55	-0.33
Q2 2010-Q1 2012	8	14	-10.11	-2.45	-1.39	-5.72
Q3 2013-Q4 2014	5	-4	-10	-6.7	0.42	0.63
Q3 2011-Q1 2017	22	-6	-6.35	-3.71	1.00	1.71

annual growth in this period fell to 7% compared to 8% over 2003-2011 in BI. The output lost through lower growth minus the largely positive output gap over this period was 25% giving a SR for core inflation of 4 and of 6.7 for headline inflation. Therefore, the SR that includes hysteresis effects on growth is larger. Some of this growth loss was due to prolonged tight financial conditions as IT was adopted while the country was on a fiscal deficit reduction path under fiscal responsibility legislation. The negative ρ_{pg} and inverse relation of σ_p and σ_g in the simulations suggest demand contractions reduce supply, lowering potential output. Enders and Hurn (2007) find SRs to be higher when the direction of causality is from demand to supply shocks.

One reason for the large actual growth fluctuations of this period could be demand contractions in the context of better anchoring of inflation expectations since our analysis suggests this would increase the impact of demand shocks on potential output.

4.4 Simultaneous Equation Model

Our KF model is parsimonious, leaving out many variables that affect Indian inflation. Chinoy et. al. (2016) in estimating the single equation PC below to understand Indian inflation dynamics, introduced a large number of such variables:

$$\pi_t = \Sigma_1^n \tau_n \pi_{t-n} + \theta D_{nr} + \alpha(x-x^*)_{t-1} + \beta w_{t-1} + \gamma MSP_{t-1} + \delta Rain_t + \Sigma_1^n \rho_n GF_{t-n} + \tau X_{t-1} + u_t \quad (6)$$

Where π_{t-n} are lagged inflation; D_{nr} is dummy for new regime since 2014 Q1 when IT was announced although it was informally adopted since 2013; w_{t-1} and MSP_{t-1} are wages and minimum support prices respectively. $Rain_t$ is a dummy variable taking value 1 if monsoon is below average, else 0. GF is global food prices while X_{t-1} contains global crude inflation and INR/USD exchange rate.

But a single equation format neglects endogeneity associated with output gap, trend output shock or productivity shock and monetary policy or interest rate shock. So, we include a number of India specific and dummy variables as above while removing endogenity by using a simultaneous equation framework following Gorden and King (1982). The introduction of additional relevant variables adds to the minimal unobserved component model, gives further insights on the SR, and serves as a robustness check on earlier results.

4.4.1 Data, Model and Results

Table 6: Data definitions and sources

Endogenous variable	Definition	Variable name in the analysis	Data source
Adjusted nominal GNP growth	Change in log (GDPMP at constant prices)	y	RBI
Output ratio	Log (actual level of output/trend level of output)	Q	RBI, Authors calculation
Productivity growth	Based on growth in total factor productivity, yearly estimates to quarterly (same for each quarter in same year)	PROD	The conference Board, Total Economy Database
Fixed weight GNP deflator	WPI inflation	P	RBI
Interest rate	Repo rate	i	RBI
Exogenous variable	**Definition**	**Variable name in the analysis**	**Data source**
Adjusted money supply growth	Change in log (Broad money ($M3$))	mg	RBI
Change in effective minimum wages	Change in log(Minimum wages)	MIN_W	Indiastat
Change in effective social security payroll tax	Change in MSP	MSP	Indiastat
Dummy for below average rainfall	Rainfall below 85%, dummy takes value 1 else 0	rain	Indiastat
Dummy for new regime of inflation targetting	Since Year $2014Q$, dummy takes value 1 else 0	Dn regime	Authors' calculation
Global crude price inflation	Fuel (Energy) Index, 2005 = 100, includes Crude oil (petroleum), Natural Gas, and Coal Price Indices	GC	IMF
Global food price inflation	Food Price Index, 2005 = 100, includes Cereal, Vegetable Oils, Meat, Seafood, Sugar, Bananas, and Oranges Price Indices	GF	IMF
Food-energy price effect	WPI inflation - core inflation	PFF	RBI
Change in relative price of imports	Inflation in Value of Imports, Cost including Freight (CIF)	PIM	IMF-IFS
Real effective exchange rate	Change in INR/SDR	EX	RBI

Data definitions and respective sources are given in Table 6. First, individual equations were estimated to select variables and identify endogenous and exogenous variables. We found no causal impact of inflation and its lag on MSP or minimum wages. They were exogenous mostly explained by own lags and so was the case with exchange rate. For endogenous variables, the AIC criterion suggested one lag. Since order condition is not met in that scenario, we stick to R^2 criterion and economic theory to select the final equation structure. Appendix tables A3 and A4 show individual regression equations for inflation and productivity respectively. The regression with highest R^2 is chosen for further simultaneous equation estimation. Selected regressions are summarised in Table A5 where a blank implies that the variable is not present in the equation, and numerals in the bottom half give the number of lags of endogenous variables included.

There are four equations to be estimated simultaneously with quarterly data running from 1996 Q2 to 2017 Q1. First is the inflation equation, determined by output gap and productivity while controlling for other exogenous variables. Second equation is for output gap affected by interest rate and money growth rate, and its lags. Third equation is the Taylor's rule, with interest rate responding to lags of output gap and of inflation. Fourth equation is for productivity growth explained by minimum support prices, minimum wages, lag of output gaps and its own lags. Tests of residuals show use of OLS is consistent. The hybrid between simultaneous equations and SVAR conserves degrees of freedom since exogenous variables do not come in with lags. Diagnostic tests are satisfactory.

Summarized results, giving the sum of significant coefficients, are shown in Table 7. Response of P to Q is 0.31 as opposed to 0.52 in the Chinoy et. al. (2016) single equation specification with HP filter. Thus correcting for the simultaneity bias reduces the output elasticity of inflation indicating the correct AS is flatter. Policy dummy for inflation targeting turns out to be insignificant after controlling for more shocks and including productivity as compared to their specification. Results confirm a negative relationship between productivity and output gap shocks. The regression of productivity on output gap is negative. Increase in minimum wages marginally decreases productivity. The aggregate demand and Phillips curve coefficients have the same signs as those obtained in the KF model, while cost shocks, especially food and energy prices, shift up the Phillips curve. The Taylor rule suggests interest rates are more persistent and respond positively to change in inflation and to output gap. Output gap is only affected by its own lags and is highly persistent, as suggested by KF results as well. Detailed simultaneous equation results are shown in Table 8. Figure A2 gives some tests of residuals.

Table 7: Summarized results of simultaneous equation model

Endogenous variable	Pre-determined variable	Sum of current and lagged co-efficients
P	Constant	0
P	MIN_W	0
P	MSP	0
P	P	-0.44
P	PFF	0.32
P	PIM	-0.02
P	Q	0.31
P	PROD	-0.003
P	mg	-0.01
Q	Constant	0
Q	Q	0.95
Q	i	-0.00019
i	Constant	0.66
i	i	0.88
i	P	13.82
i	Q	21.64
PROD	Constant	0
PROD	MIN_W	-0.00025
PROD	PROD	0.87
PROD	Q	-40.94
PROD	MSP	0.00074

Table 8: Simultaneous equation regression result with P, Q, i and PROD as endogenous variables

VARIABLES	P	Q	i	PROD
L.P	-0.154			
	(0.160)			
L2.P	-0.0158			
	(0.125)			
L3.P	0.0512			
	(0.103)			
L4.P	-0.264***			
	(0.0999)			
L5.P	-0.187***			
	(0.0671)			
L6.P	-0.126			
	(0.0939)			
L7.P	0.135**			
	(0.0657)			
L8.P	-0.126**			
	(0.0576)			
Q	0.796**			
	(0.356)			
L.Q	-0.486**	1.383***	21.64***	71.10**
	(0.244)	(0.134)	(6.799)	(29.17)
PROD	-0.00342**			
	(0.00134)			
PFF	0.306***			
	(0.0196)			
L.PFF	0.0549			2.136
	(0.0421)			(1.881)
L2.PFF	0.0125			-0.621
	(0.0332)			(1.917)
L3.PFF	-0.0622*			
	(0.0370)			
L4.PFF	0.0787**			
	(0.0374)			
PIM	-0.0214***			
	(0.00587)			
L.PIM	-0.00134			
	(0.00669)			

L2.PIM	-0.000700		
	(0.00705)		
L3.PIM	0.00712		
	(0.00587)		
L4.PIM	-0.00744		
	(0.00557)		
Dnregime	-0.00226		
	(0.00403)		
L.MSP	-5.67e-06		0.000695
	(3.89e-06)		(0.000855)
L.MIN_W	5.30e-05*		0.00283
	(3.19e-05)		(0.00328)
L2.MIN_W	-0.000163***		-0.00211
	(3.06e-05)		(0.00322)
L3.MIN_W	0.000143***		0.00995***
	(3.52e-05)		(0.00319)
L4.MIN_W	-2.55e-05		-0.0102***
	(3.23e-05)		(0.00289)
mg	0.000732	0.00365	
	(0.00728)	(0.0102)	
L.mg	-0.0131*	0.00790	
	(0.00700)	(0.0102)	
EX	0.0105		
	(0.0376)		
L.EX	-0.0358		
	(0.0398)		
L2.EX	0.0373		
	(0.0312)		
GC	0.00810		
	(0.00764)		
L.GC	0.00316		
	(0.00751)		
L2.GC	0.00990		
	(0.00784)		
L2.Q		-0.429*	-145.3***
		(0.223)	(44.88)
L3.Q		-0.0879	84.56**
		(0.217)	(42.44)
L4.Q		0.0261	-51.30*
		(0.132)	(26.24)

L2.mg	0.00954		
	(0.0103)		
L3.mg	0.00555		
	(0.0101)		
i	0.000420		
	(0.000969)		
L.i	-0.00335**	0.882***	
	(0.00151)	(0.0515)	
L2.i	0.00316**		
	(0.00160)		
L3.i	-0.000110		
	(0.00155)		
L4.i	-0.00101		
	(0.000885)		
P		13.82***	
		(3.890)	
L.PROD			0.800***
			(0.0807)
L4.PROD			-0.224**
			(0.104)
L5.PROD			0.297***
			(0.103)
L8.PROD			-0.0762
			(0.0639)
MSP			0.00175*
			(0.000919)
MIN_W			-0.00341
			(0.00249)
L2.MSP			-0.000664
			(0.000840)
L3.MSP			-0.00268***
			(0.000808)
L4.MSP			0.00167**
			(0.000777)
L3.EX			
L4.EX			
GF			

Constant	-0.0213	0.00510	0.657*	0.268
	(0.0721)	(0.00369)	(0.384)	(0.378)
Observations	59	59	59	59
R-squared	0.946	0.909	0.863	0.847
Parameters	35	13	3	20
Chi-squared	1102.09	602.95	374.50	332.04

Notes: Standard errors in parentheses. Dnregime is a dummy variable equal to 1 for the period 2014Q1 - 2017Q1 and 0 for all other quarters. Inflation targetting was adopted in India in 2014 Q1. The log-likelihood of the model is 478.3436; AIC and BIC are -806.6871 and -650.8718 respectively. *** p<0.01, ** p<0.05, * p<0.1

5 Conclusion

In an emerging market subject to frequent supply shocks and to correlated shifts in demand, the SR depends not only on the slope of the supply curve but also on shifts in supply and demand curves. On embedding a variety of shocks and correlations between shocks in a Kalman filter based maximum likelihood estimation of a New Keynesian Phillips Curve with Indian data, the slope of the Phillips curve flattens. The correlation between permanent output shocks (supply) and output gap (demand) shocks is estimated to be negative. While the flat supply curve is robust to parameter changes, and business cycle turning points are tracked well, the level of the output gap and volatility of trend growth does change. More forward looking behaviour and fall in inflation expectation volatility increases the volatility of trend growth and reduces that of the output gap. Indian growth rates have been more volatile after the adoption of inflation targeting. The SR that includes such hysteresis then would rise.

A methodological innovation was to use the simulation that sends all the stochastic variation to the output gap to estimate the SR, as well as the simulation with the best approximation for inflation expectations. The first had volatile inflation expectations. It gave a low steady rate of growth and a larger output gap. Food inflation with a smoothing parameter was used as a proxy for unobserved inflation expectations. A food inflation smoothing parameter calibrated at 0.4, gave the least RMSE for deviation of expected inflation from actual inflation. This simulation had smaller output gaps and larger trend variation. The SR calculated from it was higher because of persistent effects on growth.

A simultaneous equation estimation of the Phillips curve corroborates the dominance of supply shocks, reduction in AS slope under better estimation and the correlation between the output gap and productivity. The hybrid SVAR allowed exogenous, dummy and other context specific variables to be introduced while modelling endogenous variables with the full VAR lag structure. The introduction of additional relevant variables than can be added in the minimal unobserved component model, served as a further robustness check on the KF results and gives more insights on the SR. Supply shocks had a large impact on inflation while the coefficient of the output gap was lower and policy dummy for inflation targeting was insignificant. Correcting for simultaneity bias reduces the output elasticity of inflation and introducing productivity and more shocks as controls reduces the impact of inflation targeting on inflation as compared to earlier single equation specifications. Results confirm a negative relationship between productivity and output gap shocks as the regression of productivity on output gap has a negative coefficient. Other coefficients had the same signs as those obtained in the KF estimates.

Flat sloped aggregate supply curve and correlated shocks partly due to forward-looking behaviour, suggest monetary-fiscal policy, which responds to temporary shocks, will result in lower trend growth. The SR that includes the output loss from lower growth is larger than that calculated from the episode method. Inflation targeting may have increased forward-looking behaviour, thus increasing the growth loss from tighter policy, even if it did not have an appreciable impact on inflation itself in the period of estimation, after controlling for supply shocks. There was a sharp reduction in oil prices in 2014.

Indian pre-reform growth rates were low and stable since financial markets were underdeveloped and forward-looking behaviour low. Post-reform growth volatility is higher. Our analysis suggests this may be partly due to more forward-looking behaviour. Supply shocks are still a source of volatility although their relative size is moderating. To the extent forward-looking agents adjust to these shocks policy makers need to do less. The large policy reactions to supply shocks that were standard in the pre-reform period need to be moderated now.

References

Ball, L. M. 2014. 'Long-term damage from the great recession in OECD countries,' NBER Working Paper 20185, National Bureau of Economic Research, Cambridge/MA, May.

Ball, L. M. 1994. 'What determines the sacrifice ratio?' in Monetary Policy, ed. N. G. Mankiw, Chicago: University of Chicago Press, pp. 155-188.

Basistha, A. and C. Nelson. 2007. 'New measures of the output gap based on the forward-looking New Keynesian Phillips Curve,' Journal of Monetary Economics, 54 (2), 498-511.

Belke, A. 2018. 'Secular stagnation, unemployment hysteresis and monetary policy in EMU: Scratches but not scars?,' Economist's Voice, https://doi.org/10.1515/ev-2018-0034.

Belke, A. and M. Boeing. 2014. 'Sacrifice ratios for Euro area countries: New evidence on the costs of price stability,' Australian Economic Review 47 (4), 455-471.

Burns, A. F. and W. C. Mitchell. 1946, 'Measuring business cycles,' National Bureau of Economic Research, Inc.

Cecchetti, G. S., and R. W. Rich. 2001. 'Structural estimates of the US sacrifice ratio,' Journal of Business and Economics Statistics, 19 (4), 416-27.

Cecchetti, G. S. 1994. Comment in N. G.Mankiw (ed.), Monetary Policy. Chicago: University of Chicago Press, pp. 188-93.

Chinoy, S., P. Kumar and P. Mishra. 2016. 'What is responsible for India's sharp disinflation?' Chapter 13 in Ghate, Chetan and Kletzer, Kenneth M. (Eds.) Monetary Policy in India: A Modern Macroeconomic Perspective, pages 425-452. Springer: India.

Dholakia, R. H. 2014. 'Sacrifice ratio and cost of inflation for the Indian economy,' IIMA Working Papers WP 2014-02-04, Indian Institute of Management Ahmedabad, Research and Publication Department.

Dholakia, R. H. and K. S. Virinchi. 2017. 'How costly is the deliberate disinflation in India? Estimating the sacrifice ratio,' Journal of Quantitative Economics, 15 (1), 27-44. March.

Durai, S. R. S. and M. Ramachandran. 2013. 'Sectoral effects of disinflation: Evidence from India,' Macroeconomics and Finance in Emerging Market Economies, 6:1, 77-87, DOI: 10.1080/17520843.2012.728236.

Enders, W. and S. Hurn. 2007. 'Identifying aggregate demand and supply shocks in a small open economy,' Oxford Economic Papers, 59 (3), 411-429.

Filardo, A. 1998. 'New evidence on the output cost of fighting inflation,' Economic Review, Federal Reserve Bank of Kansas City, issue Q III, 83 (3).

Gordon, R. J. and S. R. King. 1982. 'The output cost of disinflation in traditional and vector autoregressive models,' Brookings Papers on Economic Activity, Economic Studies Program, The Brookings Institution, 13 (1), 205-244.

Goyal, A. 2011. 'A general equilibrium open economy model for emerging markets: Monetary policy with a dualistic labor market,' Economic Modelling, 28(2), 1392-1404.

Goyal, A. and A. Kumar. 2018. 'Active monetary policy and the slowdown: Evidence from DSGE based Indian aggregate demand and supply,' The Journal of Economic Asymmetries. 17: 21-40. June. DOI: https://doi.org/10.1016/j.jeca.2018.01.001.

Goyal, A. and S. Tripathi. 2015. 'Separating shocks from cyclicality in Indian aggregate supply,' Journal of Asian Economics, 38, 93-103.

Hamilton, J. D. 2017. 'Why you should never use the Hodrick-Prescott filter,' NBER Working Papers 23429, National Bureau of Economic Research, Inc.

Hofstetter, M. 2008. 'Disinflation in Latin America and the Caribbean: A free lunch?' Journal of Macroeconomics, 30 (1), 327-45.

IMF (International Monetary Fund) 2013. 'The dog that did not bark: Has inflation been muzzled or was it just sleeping?' In World Economic Outlook: Hopes, Realities, Risks.

Kapur, M., and M. D., Patra. 2003. 'The Price of Low Inflation,' RBI Occasional Papers, 21 (2 and 3), 191-233. Monsoon and Winter, 2000.

Kotia, A. 2013. 'An unobserved components Phillips Curve for India: Re-examining output inflation dynamics in India,' Working Paper, Oxford University.

Mitra, P. D. Biswas and A. Sanyal. 2015. 'Estimating sacrifice ratio for Indian economy- A time varying perspective,' RBI Working Paper Series No. 01. Available at https://rbi.org.in/scripts/PublicationsView.aspx?id=16404.

Okun, A. M. 1978. 'Efficient disinflationary policies,' American Economic Review, 68, 348-352.

Paul, B.P. 2009. 'In search of the Phillips curve for India,' Journal of Asian Economics, 20, 479-488.

RBI (Reserve Bank of India). 2014. 'Report of the expert committee to revise and strengthen the monetary policy framework,' (Chairman: Urjit Patel).

RBI (Reserve Bank of India). 2002. 'Growth, inflation and the conduct of monetary policy,' chapter 5 in Report on Currency and Finance 2000-2001.

Singh, B. K., A. Kanakaraj, and T. Sridevi. 2011. 'Revisiting the empirical existence of the Phillips Curve for India,' Journal of Asian Economics, 22, 247-258.

Taylor, J.B. 1983. 'Union wage settlements during a disinflation,' America Economic Review, 73 (5), 981-93.

Virmani, V. 2004. 'Estimating output gap for the Indian economy: Comparing results from unobserved-components models and the hodrick-prescott filter,' IIMA Working Papers WP 2004-04-02, Indian Institute of Management Ahmedabad, Research and Publication Department.

Zhang, L. 2005. 'Sacrifice ratios with long-lived effects,' International Finance, 8 (2), 231-62.

Appendix

Table A.1: Unit root test - ADF and PP test for Log-output, core inflation and food inflation

Variable	Augmented Dicky Fuller Test		Phillips-Perron Unit Root Test	
	statistic	p.value	statistic	p.value
log_output	-2.23	0.48	-8.64	0.61
Core_inflation	-3.15	0.10	-59.70	0.01
food_inflation	-3.06	0.14	-87.00	0.01

Table A.2: : Unit root test - ADF and PP test for Q, PROD, i and core inflation

Variable	Augmented Dicky Fuller Test		Phillips-Perron Unit Root Test	
	statistic	p.value	statistic	p.value
Prod	-3.409	0.013	-3.658	0.0065
i	-3.176	0.0261	-2.467	0.128
Q	-3.590	0.008	-2.957	0.0433
coreinf	-6.868	0.000	-6.863	0.000

Figure A.1: Impulse responses of output gap shock, trend component shock and inflation shock

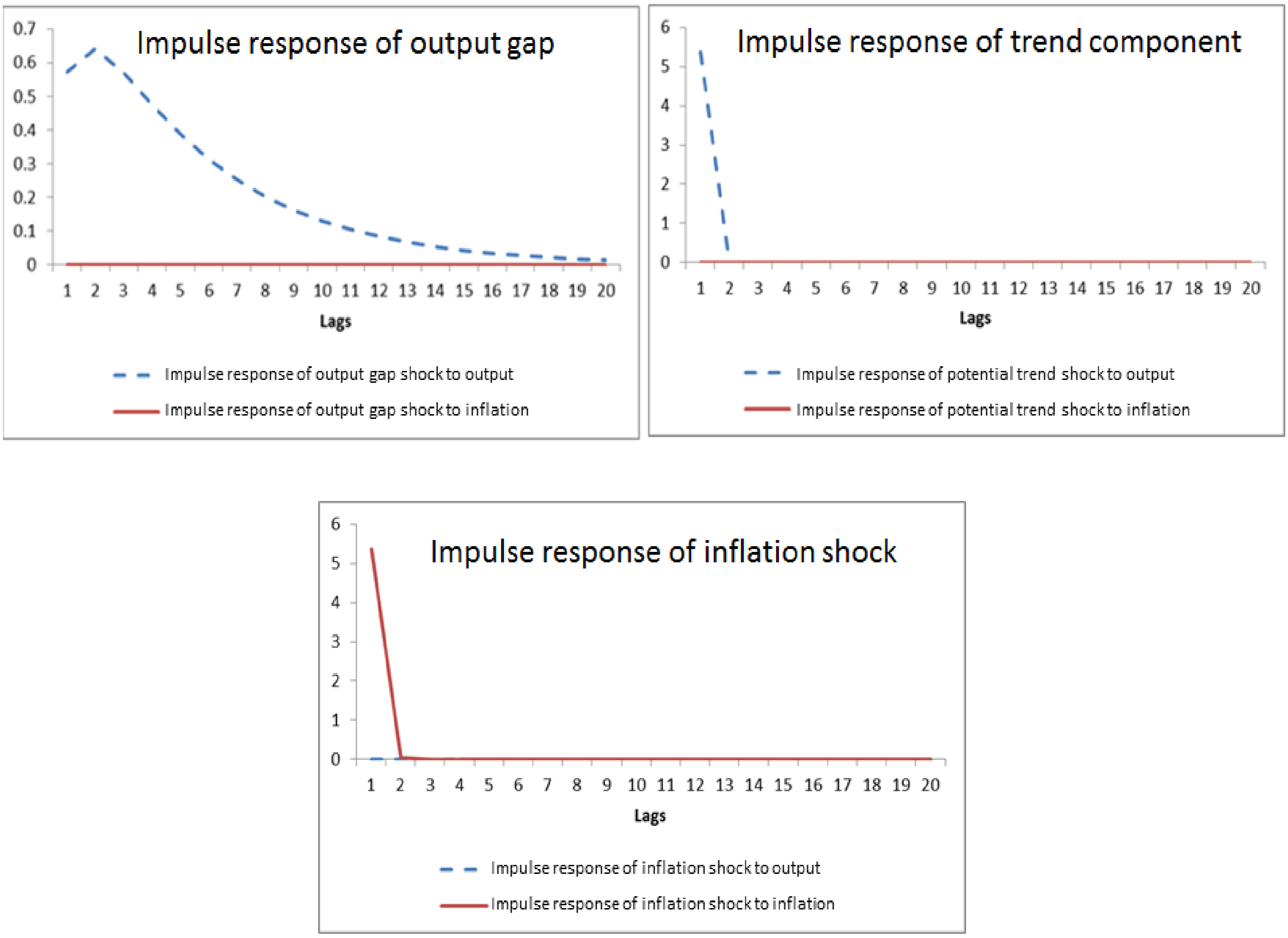


Table A.3: Regression results for **inflation** with different specifications

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
VARIABLES	P	P	P	P	P	P	P	P	P
L.P	0.00920	-0.0257	-0.00472	0.0325	0.0186	0.0426	-0.0395	-0.0386	-0.136
	(0.146)	(0.147)	(0.143)	(0.142)	(0.148)	(0.162)	(0.165)	(0.168)	(0.195)
L2.P	-0.179	-0.103	-0.0732	-0.0274	-0.0458	0.0282	-0.0931	-0.0912	-0.142
	(0.147)	(0.153)	(0.146)	(0.152)	(0.158)	(0.181)	(0.166)	(0.171)	(0.179)
L3.P	0.0696	0.0422	0.0541	0.0101	0.00330	0.111	0.0396	0.0365	-0.0321
	(0.102)	(0.101)	(0.0965)	(0.0956)	(0.102)	(0.176)	(0.167)	(0.176)	(0.190)
L4.P	0.0674	0.0778	0.0859	0.0962	0.0891	0.173	0.0644	0.0668	0.0247
	(0.104)	(0.103)	(0.101)	(0.104)	(0.107)	(0.182)	(0.172)	(0.178)	(0.181)
L5.P				-0.207**	-0.207**	-0.198*	-0.128	-0.126	-0.121
				(0.0981)	(0.1000)	(0.112)	(0.102)	(0.106)	(0.113)
L6.P				-0.0508	-0.0429	-0.0408	-0.00509	-0.00422	-0.0439
				(0.0960)	(0.0989)	(0.120)	(0.112)	(0.115)	(0.138)
L7.P				0.0730	0.0694	0.0737	0.151	0.153	0.126
				(0.0986)	(0.102)	(0.132)	(0.124)	(0.129)	(0.133)
L8.P				-0.155	-0.135	-0.105	-0.164	-0.164	-0.215*
				(0.0947)	(0.102)	(0.117)	(0.112)	(0.113)	(0.127)
Q	-0.0818	-0.101	-0.177	-0.234	-0.190	-0.188	-0.282	-0.284	-0.302
	(0.373)	(0.382)	(0.366)	(0.357)	(0.379)	(0.401)	(0.383)	(0.389)	(0.426)
L.Q	-0.0613	0.0167	0.0943	0.226	0.182	0.164	-0.0225	-0.0169	-0.0408
	(0.379)	(0.387)	(0.373)	(0.372)	(0.391)	(0.423)	(0.405)	(0.420)	(0.441)
PROD	4.24e-05	0.000293	0.000373	9.71e-05	8.68e-05	0.000263	-0.000186	-0.000142	-0.00101
	(0.00111)	(0.00113)	(0.00110)	(0.00113)	(0.00117)	(0.00131)	(0.00119)	(0.00138)	(0.00155)
PFF	0.291***	0.293***	0.293***	0.282***	0.283***	0.285***	0.282***	0.281***	0.260***
	(0.0364)	(0.0349)	(0.0345)	(0.0344)	(0.0352)	(0.0369)	(0.0332)	(0.0347)	(0.0405)

L.PFF	0.0139	0.0178	0.0119	-0.00507	-0.00181	0.00113	0.0460	0.0462	0.0429
	(0.0543)	(0.0546)	(0.0533)	(0.0536)	(0.0553)	(0.0597)	(0.0598)	(0.0608)	(0.0639)
L2.PFF	0.0911*	0.0776	0.0743	0.0362	0.0391	0.0290	0.0690	0.0692	0.0699
	(0.0512)	(0.0520)	(0.0507)	(0.0542)	(0.0557)	(0.0588)	(0.0538)	(0.0546)	(0.0587)
L3.PFF						-0.0409	-0.0211	-0.0198	-0.00544
						(0.0601)	(0.0568)	(0.0607)	(0.0646)
L4.PFF						-0.0368	0.00269	0.00214	0.0137
						(0.0630)	(0.0588)	(0.0602)	(0.0620)
PIM	-0.0141	-0.0142	-0.0167*	-0.0166*	-0.0152	-0.0201*	-0.0176*	-0.0176*	-0.0218**
	(0.00923)	(0.00937)	(0.00897)	(0.00891)	(0.00938)	(0.0108)	(0.00971)	(0.00988)	(0.0106)
L.PIM	-0.00557	-0.00604	-0.00343	-0.000678	-0.00209	-0.00123	0.00170	0.00193	0.00497
	(0.0109)	(0.0110)	(0.0106)	(0.0107)	(0.0112)	(0.0120)	(0.0112)	(0.0119)	(0.0132)
L2.PIM	0.00684	0.00804	0.00694	0.00960	0.0105	0.0109	-0.00493	-0.00498	-0.00432
	(0.00834)	(0.00859)	(0.00836)	(0.00935)	(0.00971)	(0.0124)	(0.0121)	(0.0123)	(0.0143)
L3.PIM						0.00323	0.00496	0.00486	0.00593
						(0.0121)	(0.0112)	(0.0114)	(0.0119)
L4.PIM						-0.00616	-0.00567	-0.00560	-0.00282
						(0.0108)	(0.00980)	(0.0100)	(0.0106)
Dnregime	-0.00216	-0.00145	-0.00117	-0.00617	-0.00604	-0.00555	-0.00494	-0.00477	-0.00659
	(0.00681)	(0.00659)	(0.00650)	(0.00682)	(0.00696)	(0.00731)	(0.00655)	(0.00712)	(0.00867)
L.MSP		-7.28e-06	-7.67e-06	-7.15e-06	-7.12e-06	-6.90e-06	-1.38e-05**	-1.36e-05*	-1.62e-05**
		(6.16e-06)	(6.09e-06)	(6.10e-06)	(6.21e-06)	(6.60e-06)	(6.81e-06)	(7.80e-06)	(7.32e-06)
L.MIN_W		-3.41e-06	4.34e-07	9.51e-06	7.21e-06	6.21e-06	-3.30e-05	-3.44e-05	-2.99e-05
		(2.40e-05)	(2.29e-05)	(2.41e-05)	(2.52e-05)	(2.84e-05)	(5.50e-05)	(5.95e-05)	(5.78e-05)
L2.MIN_W							-0.000135*	-0.000135*	-0.000130*
							(6.65e-05)	(6.77e-05)	(6.84e-05)
L3.MIN_W							0.000145**	0.000144**	0.000145**
							(5.82e-05)	(5.91e-05)	(5.99e-05)

L4.MIN_W									3.72e-05	3.81e-05	4.20e-05
									(4.79e-05)	(5.05e-05)	(4.96e-05)
mg	-0.00273	-0.00388	-0.00429			-0.00418	-0.00392	-0.00368	-0.0245*	-0.0246*	-0.0248*
	(0.00916)	(0.0109)	(0.0106)			(0.0103)	(0.0107)	(0.0113)	(0.0121)	(0.0125)	(0.0126)
L.mg		-0.00138	-0.00261			-0.00332	-0.00266	-0.00354	-0.0261*	-0.0262*	-0.0254*
		(0.0106)	(0.0104)			(0.0101)	(0.0104)	(0.0111)	(0.0129)	(0.0132)	(0.0134)
EX	-0.00131	-0.00404	0.0341**			0.0267	0.00281	0.0112	0.0429	0.0415	0.0401
	(0.0391)	(0.0403)	(0.0167)			(0.0173)	(0.0426)	(0.0485)	(0.0455)	(0.0506)	(0.0478)
L.EX	0.0529	0.0510					0.0288	0.0240	-0.0364	-0.0360	-0.0437
	(0.0579)	(0.0594)					(0.0607)	(0.0730)	(0.0684)	(0.0696)	(0.0725)
L2.EX	-0.00522	-0.00924					-0.00253	-0.00886	0.0461	0.0471	0.0590
	(0.0418)	(0.0422)					(0.0420)	(0.0512)	(0.0486)	(0.0516)	(0.0517)
MSP	-4.63e-06										
	(6.24e-06)										
MIN_W	-1.70e-05										
	(2.61e-05)										
rain										0.000374	
										(0.00562)	
gc											0.0105
											(0.0113)
L.gc											-0.00295
											(0.0129)
L2.gc											-0.00228
											(0.00942)
Constant	-0.180**	-0.144*	-0.130*			-0.0967	-0.106	-0.0955	-0.195**	-0.195**	-0.203**
	(0.0800)	(0.0745)	(0.0670)			(0.0698)	(0.0766)	(0.0874)	(0.0869)	(0.0884)	(0.0920)
Observations	68	68	68			68	68	68	68	68	68

R-squared	0.764	0.767	0.761			0.794	0.796	0.802	0.855	0.855	0.861

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table A.4: Regression results for **productivity** with different specifications

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
VARIABLES	PROD	PROD	PROD	PROD	PROD	PROD	PROD
L.PFF	-1.430	-1.151	-0.166	0.699	1.321	1.924	1.588
	(2.590)	(2.710)	(2.637)	(2.614)	(2.736)	(2.532)	(2.536)
L2.PFF	1.292	1.120	1.284	1.033	1.577	2.214	2.250
	(2.572)	(2.686)	(2.600)	(2.592)	(2.689)	(2.560)	(2.576)
L.PROD	0.870***	0.877***	0.937***	1.009***	0.970***	0.795***	0.677***
	(0.131)	(0.143)	(0.0994)	(0.104)	(0.116)	(0.123)	(0.143)
L4.PROD	-0.131	-0.164	-0.236	-0.269*	-0.244	-0.174	-0.199
	(0.133)	(0.140)	(0.148)	(0.146)	(0.149)	(0.138)	(0.144)
L5.PROD			0.170	0.220	0.225	0.240*	0.201
			(0.147)	(0.147)	(0.147)	(0.138)	(0.145)
L8.PROD			-0.136	-0.159*	-0.115	-0.0582	-0.000904
			(0.0914)	(0.0918)	(0.107)	(0.102)	(0.111)
MSP	-0.000234	-0.000360	0.000159	0.00145	0.000829	0.000215	-0.000247
	(0.000494)	(0.00128)	(0.00132)	(0.00142)	(0.00162)	(0.00150)	(0.00157)
MIN_W	0.000950	-8.34e-06	-0.000209	0.00102	0.000659	0.000610	0.000482
	(0.00159)	(0.00178)	(0.00175)	(0.00323)	(0.00328)	(0.00309)	(0.00315)
L.MSP		0.00116	0.00116	0.000937	0.000830	0.00117	0.000975
		(0.00119)	(0.00116)	(0.00120)	(0.00121)	(0.00112)	(0.00112)
L2.MSP		-1.06e-05	-9.20e-05	0.000231	0.000204	-0.000219	-1.39e-05
		(0.00118)	(0.00116)	(0.00118)	(0.00119)	(0.00112)	(0.00113)
L3.MSP		0.000728	0.000594	5.30e-05	0.000163	0.000636	0.000591
		(0.00118)	(0.00116)	(0.00120)	(0.00121)	(0.00115)	(0.00115)
L4.MSP		-0.00154	-0.00184	-0.00204	-0.00151	-0.000866	-0.000266
		(0.00124)	(0.00127)	(0.00129)	(0.00145)	(0.00134)	(0.00147)
L.MIN_W				-0.00192	-0.00180	-0.000635	0.000297
				(0.00423)	(0.00425)	(0.00401)	(0.00403)
L2.MIN_W				-0.000800	-0.00115	-0.00154	-0.00109
				(0.00414)	(0.00418)	(0.00390)	(0.00396)
L3.MIN_W				0.00762*	0.00745*	0.00530	0.00394
				(0.00428)	(0.00430)	(0.00402)	(0.00415)
L4.MIN_W				-0.00859**	-0.00690	-0.00640	-0.00629
				(0.00363)	(0.00421)	(0.00393)	(0.00420)
L.Q					-14.85	52.77	50.26
					(18.51)	(33.52)	(37.27)
L2.Q						-104.5**	-89.72
						(51.64)	(56.75)
L3.Q						68.29	42.78
						(50.85)	(58.89)

L4.Q						-52.50*	-9.319
						(30.23)	(54.99)
L5.Q							-53.13
							(54.20)
L6.Q							27.62
							(56.93)
L7.Q							8.019
							(53.29)
L8.Q							-34.52
							(31.81)
L2.PROD	-0.00823	0.0518					
	(0.174)	(0.181)					
L3.PROD	0.0316	0.0265					
	(0.179)	(0.184)					
Constant	0.366	0.292	0.377	-0.0417	-0.238	-0.571	-0.558
	(0.410)	(0.430)	(0.439)	(0.516)	(0.573)	(0.545)	(0.547)
Observations	68	64	64	64	64	64	64
R-squared	0.700	0.726	0.738	0.768	0.771	0.821	0.840

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Figure A.2: Histogram and Jarque-bera test for normality of residuals of inflation, output gap, interest rates and productivity equation respectively.

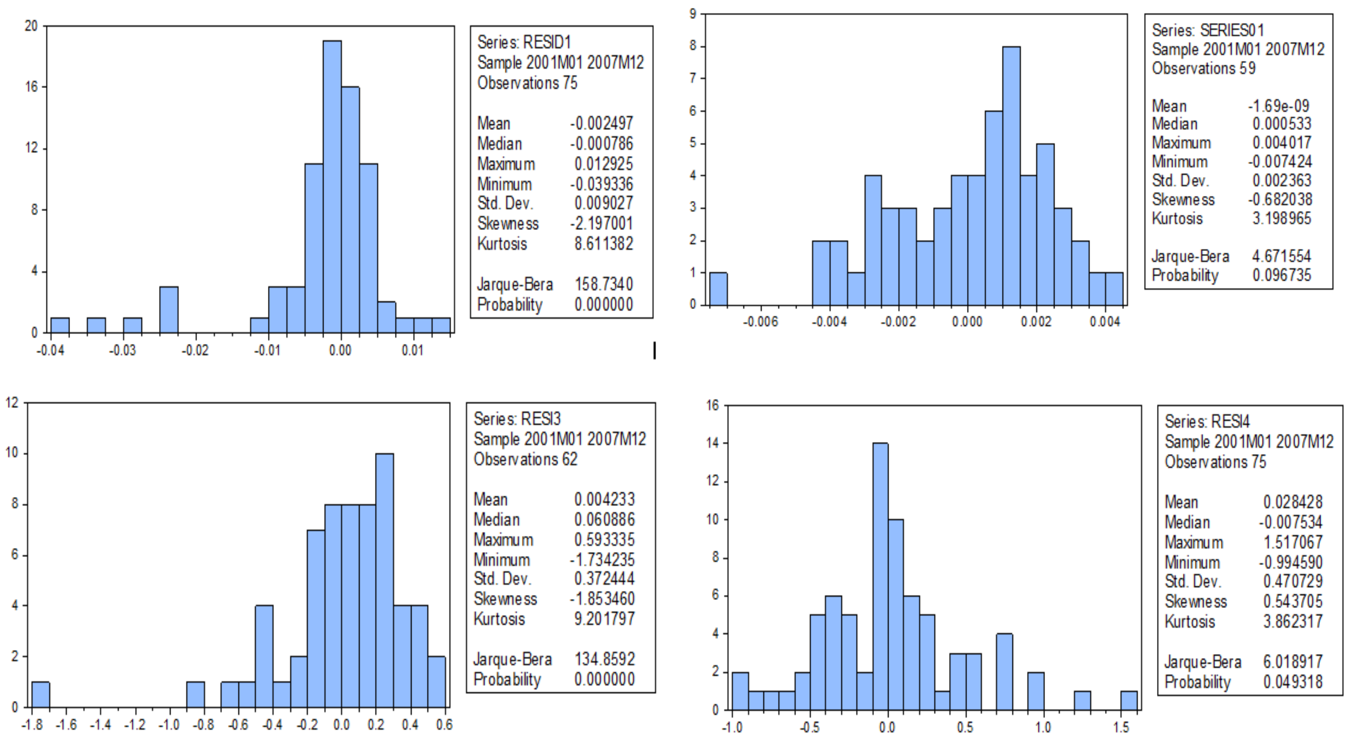


Table A.5: : Equations of the Model

VARIABLES	P	Q	i	prod
Current Endogenous				
P			1	
Q	1			
PROD	1			
i		1		
Current Exogenous				
Dnregime	1			
EX	1			
gc	1			
mg	1	1		
MIN_W				1
MSP				1
PFF	1			
PIM	1			
Lagged Endogenous				
P	8			
Q	1	4	1	4
PROD				1, 4, 5, 8
i		4	1	
Lagged Exogenous				
EX	2			
gc	2			
mg	1	3		
MIN_W	4			4
MSP	1			4
PFF	4			2
PIM	4			