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INFERRING INDIA'S POTENTIAL GROWTH AND POLICY STANCE

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Abstract

We propose an alternative method to infer potential growth, and use it to derive the Indian monetary policy stance based on estimated linear and Markov switching policy rules. We define growth to reach potential if a second round pass through of supply shocks to inflation occurs. Growth reached potential only in 2007-08 when growth exceeded 9 percent. Conventional measures of potential growth support the conclusions. Estimates with a two-variable Vector Auto Regression show multiple supply shocks, not second round effects, largely explain inflation. A one percent underestimate of potential output leads to a 25 basis point rise in policy rates.

Keywords: Potential growth, demand and supply shocks, Markov switching policy rules.

JEL Classification: E22; E32; E52

1. Introduction

The paper develops an alternative method to infer potential growth, and uses it to derive the Indian monetary policy stance based on estimated linear and Markov switching policy rules. Most monetary policy regimes respond to output gaps and to deviations of inflation from some target value. An incorrect measure of potential growth, and therefore the output gap, can lead to policy over- or under-correction.

The difference of unemployment from the natural level at which there is no inflation; or the difference of output from potential or full-employment output; or of output growth from potential growth or growth of full-employment output, are alternative measures of the cyclical output gap. Since emerging markets (EMs) tend to have higher and more volatile transitional growth, a growth based measure is most useful for short term macroeconomic policy. Long-run potential output for an EM can be defined as full employment at the productivity level that can

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deliver a middle-income level. While this may be kept in mind as a long-term target, the potential growth relevant for calculation of the output gap is the growth rate that does not create macroeconomic imbalances such as accelerating inflation. Long-run potential output may be relatively constant, but potential growth, which depends on volatile components (like investment), fluctuates more.

Studies measuring potential output for AEs dominate the literature, using either simple univariate trends or multivariate techniques where a measure of potential output is extracted from a number of variables organized in some theoretical framework. This could be a production function, or a simpler output-capital ratio, or a more complex dynamic stochastic general equilibrium (DSGE) or structural vector autoregression (SVAR) model. A third set of techniques are stochastic filters such as the Hodrick-Prescott (HP) or the Band-Pass filter. Time series measures of potential growth apply filters to separate trend or persistent changes from transitory ones, but tend to be mechanical, and give too much weight to end points. Production function based measures are neglect macroeconomic information and require detailed data such as on labour participation, hours and unemployment, which may not be available in an EM. Ongoing structural change in EMs also makes application of these methods difficult. For example, these methods underperformed even in advanced economies(AEs) after structural changes due to the global financial crisis.[3] De Masi (1997), who also studies developing countries, uses univariate trends and HP filters for these countries.

Bordoloi et. al. (2009), estimated potential growth for India using HP filter, Band-Pass filter, BN decomposition, unobserved component model and SVAR for the period 1998-2007. They mention they do not use DSGE and production function approaches because of lack of conceptual clarity and data respectively. They find unobserved component models to be most efficient for estimation of quarterly potential output based on a series of comparison tests. Their potential growth estimates range between 8 and 10 percent for 2007, with their preferred method giving an estimate of above 9 percent.

The macroeconomic aggregate supply relation implies if inflation is constant growth is close to its potential. Svensson and Woodford (2003) suggested inflation can be used to infer potential output for an AE. Sustained above target core inflation may indicate excess demand, implying output has reached potential. Rungcharoenkitkul (2012) uses this relation to infer potential growth in Cambodia. Volatile headline inflation due to temporary commodity price shocks does not, however, affect potential growth. Since prices rise more easily than they fall, core inflation itself can also reflect pass through of cost pressures from a temporary supply shock rather than excess demand. A first round pass through may not reflect excess demand. Moreover, more prices are set in a backward-looking manner in EMs and administered prices make the problem more severe.

Transient supply shocks are frequent in EMs. Second round pass through makes their contribution to inflation high and sustained. This is turn implies the economy has hit its non-inflationary growth potential. We define growth to reach potential if such a second round pass through of supply shocks to inflation occurs, and infer potential growth using this definition.

3 Adnan and Khan (2008), Cotis et. al (2005) and Dupasquieret. al (1999) offer surveys.

Examples of second round pass through are high food inflation that raises wages since food is still a large share of the consumption basket. The Indian administered price mechanism, and other governance failures that raise average costs, also tend to prevent any fall in price, and impart an upward bias to costs and prices after a supply shock (Goyal 2012a, b).

The contribution of supply shocks to inflation, which is required for the measure, is estimated using the method of Blanchard and Quah (1989) as applied to the Indian economy by Goyal and Pujari (2005). We test for the appropriate identification—whether long-run aggregate supply (AS) is vertical or horizontal—and find Indian data validates the latter. The estimates of supply and demand shocks are used to determine the periods when Indian output growth hit its potential. The idea of inflation persistence is used to define potential growth: positive contribution of structural supply shocks, above a threshold, and sustained over two years implies output has reached its potential. The results show multiple supply shocks occurred over 2008-2011, but there was no sustained second round pass through during this period. Real wages did rise, but there must also have been some rise in productivity.

We also present more conventional measures for India, using the HP and the polynomial filter, and deriving factors of production based potential growth measures from an underlying aggregate production function. These support the macro-based measure applied in this paper. Neither labour nor capital is a constraint on production in the longer-run for a populous economy in transition. Other analysis also shows supply may be elastic, but subject to upward shocks, as supply shocks raise costs of production for infra-marginal output also (Goyal, 2011). The entire supply curve shifts as costs rise at all levels of production.

Next, estimated Taylor rules are used to show the effect of underestimating output gaps on policy rates and macroeconomic outcomes. Since Taylor rule coefficients are low both on estimation and from optimizing behaviour for such an EM (Goyal and Tripathi, 2012),they imply sharp changes in policy rates should be avoided. The large cumulative movements in policy rates after the global financial crises may partly explain adverse Indian macroeconomic outcomes.

The rest of the paper is as follows: section 2 explains and applies the structural vector autoregression (SVAR) methodology to test for the appropriate identification, section 3 estimates supply shocks and derives potential growth using the restriction identified, section 4 compares the result to potential growth inferred from production function and stochastic filter approaches and section 5 estimates Taylor rules and applies the implied output gap to assess policy outcomes. Section 6puts together the main results and draws out implications for policy. Detailed test results are in two appendices.

2. Estimating Demand and Supply Shocks from an SVAR Model

A bivariate output-price SVAR is used to decompose inflation rate time-series into two components, one due to aggregate demand (AD) and the other due to aggregate supply (AS) shocks. The long-run Blanchard-Quah (1989) type restrictions do not restrict the short-run behaviour of the economy. There are potentially an infinite number of paths, generated by different demand and supply shocks, which the economy could follow while satisfying the restrictions. Therefore the estimated demand and supply shocks can be used to test further hypotheses, on which identification valid, as is done in this paper.

The identifying restriction, which is validated is a horizontal long-run AS curve, that is, an AS shock has no long-run impact on output. Dynamic properties of the estimated model turn out to be consistent with the predictions of such an AS-AD framework.

Such an identifying restriction also validates the use of a bivariate VAR. A two-equation small-sized VAR implies only two shocks driving the economy can be identified. So it must be feasible to aggregate multiple underlying shocks into two classes of shocks. Both shocks are assumed to be mean-zero serially uncorrelated and uncorrelated with each other.[4] Faust and Leeper (1994) showed the conditions under which such an aggregation is appropriate is if the underlying multiple shocks affect the variable of interest in the same fashion. The horizontal AS gives a natural classification into two classes of structural demand and supply shocks in line with the original reduced form shocks. The shocks, in the AD equation (1) affect the output gap directly, and are demand type shocks. Reduced form shocks, which enter the AS equation (2), affect inflation directly and so are supply-type shocks.

$$x_t = \alpha_1 x_t + \alpha_2 \left(i_t - \pi^e_{t+1}\right) + \varepsilon_{1t} \qquad \text{... (1)}$$

$$\pi_t = \beta_1 \pi^e_{t+1} + \beta_2 x_t + \varepsilon_{2t} \qquad \text{... (2)}$$

where x_t is the potential gap, π_t is inflation, π^e_{t+1} is expected inflation and ε_{1t} and ε_{2t} are random shocks. So the two equation VAR is better justified under this identification.

In the conventional identification where an AD shock has no long-run impact on the level of output, Mio (2002) finds, as we do, that AS shocks have persistent effects on inflation which is not consistent with the identification imposed. He surmises the AD shock must be also picking up sectoral price effects since aggregate prices rise with sectoral prices. This makes it necessary to increase the number of series, in order to separately identify the relevant shocks. For example, including oil as well as non-oil price shocks. Goyal and Singh (2007) test for the correct identification, expanding the SVAR to include oil price inflation, but the AS identified is similar.

2.1 Methodology and Results

Writing a variant of (1) and (2) in matrix form we have the reduced form VAR equation, $Z_t = (\Delta Y_t, I_t)$, in stationary variables, where Y_t stands for output and I_t stands for inflation. It is written as:

$$Z_t = u + \sum_{k=1}^{n} \varphi_k Z_{t-k} + \varepsilon_t \quad , \quad \varepsilon_t : \text{Reduced form residuals} \qquad \text{... (3)}$$

$$\hat{\Omega} = (1/T) \sum_{t=1}^{t} \varepsilon_t \varepsilon_t^{'} \qquad \text{... (4)}$$

Step 1: We convert it into the Wald form, to get the structural residuals:

$$(I - \sum_{k=1}^{n} \varphi_k B^k) Z_t = u + \varepsilon_t \qquad \text{... (5)}$$

[4] The covariance matrix of these two shocks is assumed to be a diagonal matrix with two rows and two columns.

$$Z_t = (I - \sum_{k=1}^{n} \varphi_k B^k)^{-1} u + (I - \sum_{k=1}^{n} \varphi_k B^k)^{-1} \varepsilon_t \quad ... (6)$$

$$Z_t = c + \psi(B)\varepsilon_t \quad ... (7)$$

Step 2: Identification using long run restrictions

$$Z_t = c + \Psi(1)u_t \quad ... (8)$$

$$\begin{pmatrix} \Delta Y_t \\ I_t \end{pmatrix} = c + \begin{pmatrix} \Psi_{11}(1) & \Psi_{12}(1) \\ \Psi_{21}(1) & \Psi_{22}(1) \end{pmatrix} \begin{pmatrix} u^y \\ u^i \end{pmatrix} \quad ... (9)$$

Where u^y is the structural demand shock and u^i is the structural supply shock.

Note that $\Psi(1)$ is a long run matrix. If the supply curve is vertical (VSC) (used in Blanchard and Quah (1989)): $\Psi_{11}(1)$ =0. In the VSC, the restriction is that demand shock does not affect output growth in the long run. However, this does not imply that demand shocks do not affect growth in the short run.

If the supply curve is horizontal (HSC): $\Psi_{21}(1)$ =0. In the HSC, the restriction is that demand shocks do not affect inflation in the long run. This, however, does not mean that demand shocks do not affect inflation in the short run.

2.1.1 Testing VSC versus HSC

Goyal and Pujari (2005)tested to see which restriction is valid for the Indian economy by applying tests summarized below.

If the VSC is the correct identification:

1. Impact of demand shocks on output should die down by the medium run
2. Supply shocks should have little sustained impact on price levels
3. Demand shocks should account for the major part of inflation
4. Supply shocks should affect long run output

If the HSC is the correct identification:

1. Impact of demand shocks on price levels should die down by the medium run
2. Supply shocks must form the major part of inflation
3. Demand shocks have a sustained long run impact on output levels
4. Supply shocks should have little sustained long run impact on output

Their dataset was from January 1971 to July 2004 and their results supported the HSC. We run the test for monthly data extending from May 1990 to December 2012. Since levels were I (1), our VAR was estimated with stationary log differences. That is difference of log monthly IIP (index of industrial production) giving growth and, difference of log WPI (wholesale price index) giving inflation.

Our results (details reported in the Appendix)also imply a high elasticity of long run supply cannot be ruled out, because supply shocks have a large impact on inflation and demand shocks have a large and persistent effect on output. This confirms the horizontal supply curve continues to be more applicable to the Indian case. Since this is the case, we use the HSC to estimate supply shocks needed to infer potential growth in the next section. Goyal and Pujari (2005) focused specifically on identification of the long run aggregate supply curve for India. For us this is only the first step. After the identification we calculate the relative contribution of demand and supply shocks to inflation, and then use these to infer the potential growth.

3. Estimating Supply Shocks for Calculating Potential Growth

After establishing that long run AS curve in India is horizontal, we proceed by identifying contribution of AD and AS shocks to inflation. For the calculation of potential growth we repeat the estimation above, for the period 1990:May-2011:December, with the index of industrial production (IIP) and WPI (manufacturing), since the latter is not contaminated with volatile commodity prices, and so better captures the second round effect of supply shocks such as commodity prices on manufacturing prices.[5] Inflation here is annualized inflation. Log differences of the two indices were found to be I(0).

Results with the HSC identifying restriction are given below.

Table 1. Forecast error variance decomposition (FEVD) output growth (IIP)

Step	*Std Error*	*Demand*	*Supply*
1	0.01571417	99.955	0.045
4	0.01756536	98.558	1.442
8	0.01770914	97.378	2.622
12	0.01802833	95.955	4.045
20	0.01883941	94.760	5.240

Table 2. Decomposition of variance for WPI (manufacturing) and inflation (INFL)

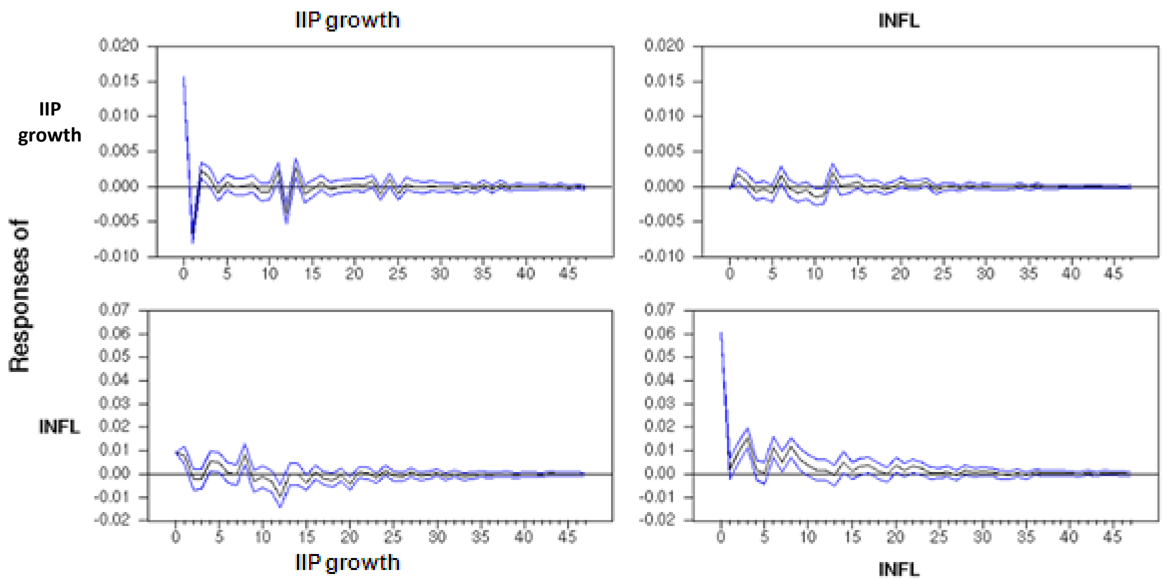
Step	*Std Error*	*Demand*	*Supply*
1	0.06138321	2.369	97.631
4	0.06466658	3.871	96.129
8	0.06626072	4.957	95.043
12	0.06824755	6.619	93.381

The FEVDs show demand shocks dominate for output growth and supply shocks for inflation, consistent with the HSC identification.

5 Estimations were also done for the quarterly frequency using GDP, which is not available at the monthly frequency. These are available on request. Since the monthly frequency is more relevant for policy, only that is reported here.

3.1 Impulse Responses

The impulse responses are also consistent with the underlying HSC, AD-AS framework. Output growth shows a strong positive response to a demand shock, while the response of inflation is weak. The effect of a supply shock is just the reverse—a strong positive effect on inflation of an adverse supply shock and a weak effect on output growth (Figure 1). The reduced form supply shock enters the AS equation and raises price.



The x-axis plots number of periods and y-axis plots the magnitude of responses; 95% confidence intervals are shown

Figure 1. The impulse response to a one standard deviation demand (top panel) and supply (bottom panel) shock.

3.2 Estimating Supply Shocks from the Historical Decomposition

Inflation at time t is assumed to be solely explained by the cumulative impact of AS and AD shocks from the infinite past up to time t. The first term on the right-hand side of equation (10) represents the inflation rate explained by AS shocks, and the second term of equation (10) represents the inflation rate explained by AD shocks.

$$I_t = c + \sum_{j=0}^{\infty} \Psi_{21}(j) u^y(t-j) + \sum_{j=0}^{\infty} \Psi_{22}(j) u^i(t-j) \qquad \text{... (10)}$$

Each of the coefficients represents the dynamic response, that is, the impulse response, of inflation to each of the two structural shocks at time t + i. The contribution to inflation of each type of shock is calculated using the historical decomposition technique. Given a time series, historical decomposition divides it into two parts: baseline forecasts, and deviations from such forecasts.

The deviations are also called innovations to the variables. The historical decomposition is used with SVAR models to quantify the deviations from the baseline forecast into contribution due to different shocks. For example, consider our bivariate VAR(1) model Z_t:

$$Z_t = \Phi_1 Z_{t-1} + \varepsilon_t ,$$

Following forecasting principles we have:

$$Z_{t+r} = \Phi_1 Z_{t+r-1} + \varepsilon_{t+r}$$

Backward substitution:

$$Z_{t+r} = \underbrace{\Phi_1^s Z_t}_{\substack{\text{Baseline} \\ \text{Forecast}}} + \underbrace{\sum_{j=1}^{s} (\Phi_1^j B^j) \varepsilon_t}_{\substack{\text{accumulation of} \\ \text{shocks (reduced from} \\ \text{residuals)}}}$$

To convert reduced form residuals into structural residuals,

$$Z_{t+r} = \Phi_1^s Z_{t+r-1} + [\sum_{j=1}^{s} (\Phi_1^j B^j) B_0^{-1}] u_t$$

Figure 2 and 3 report historical decomposition of inflation for the periods 1991-95 and 1995-2011 respectively.

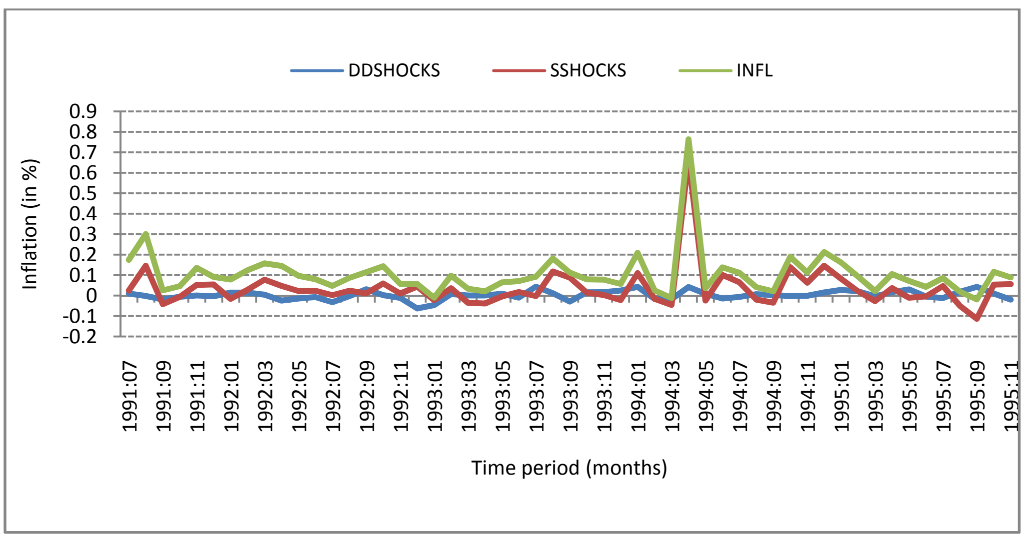


Figure 2. Inflation and its drivers 1991-95

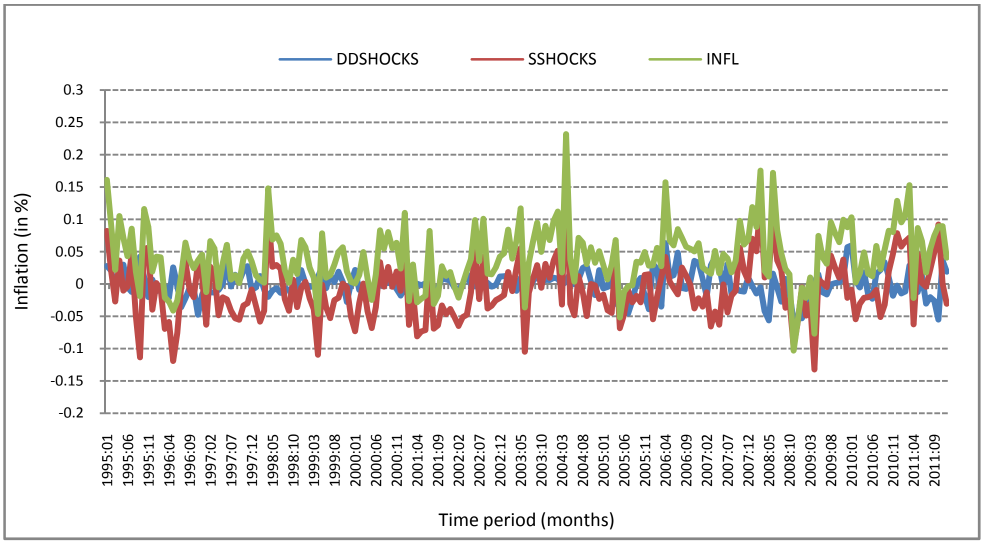


Figure 3. Inflation and its drivers 1995-2011

The historical decomposition shows supply shocks account for a large share of inflation.[6] Supply-shocks were countercyclical, that is they tended to reduce inflation during high growth periods such as 1995-96 and 2003-07. Adverse supply shocks tended to coincide with oil price spikes. The only period when supply shocks were sustained for a two-year stretch was 2007-08 showing growth had reached its then potential of 9percent. Demand shocks did not contribute much to inflation except in 2006-07 and in 2010. Positive supply shocks and negative demand explain the combination of low growth and high inflation in 2008 and 2011. The supply shocks in this period included high international oil prices, the failure of rains in 2009, and fluctuating global risk which drove periodic rupee depreciation.

3.3. Deriving Potential Growth

A simple inference from persistently high inflation since 2007 could imply growth was at potential. But volatile headline inflation must first be excluded. Core inflation can also reflect cost shocks. It is if initial supply shocks are sustained into a second round that growth hits its potential, and must be curtailed. Figure 4 gives the estimated shocks driving inflation in 2010 and 2011. The large positive supply shocks over the end of 2010 to early 2011 can be explained by the new plateau oil prices reached after the Arab spring. The sharp exchange rate depreciation following the escalating Euro debt crisis was probably responsible for the peak in supply shocks towards the end of 2011.

There were multiple supply shocks, but they were not sustained, suggesting that a wage price spiral had not set in. Either second round pass-through had not reached a sufficient magnitude, or productivity increases made it possible to absorb wage increases. A useful measure of potential output, under frequent supply shock conditions, is when such pass-through

[6] The decomposition of output into demand and supply shocks, also done, shows as expected, that demand shocks dominate under the HSC identification and supply shocks under the VSC. It is available on request.

is high enough to sustain supply shocks at above 5 per cent. Cost shocks can raise inflation even if supply response is elastic. Oil shocks, wages rising in response to high food prices, since food is a large share of the consumption basket, poor systems and governance, are all sources of such an upward creep (see Goyal, 2012b).

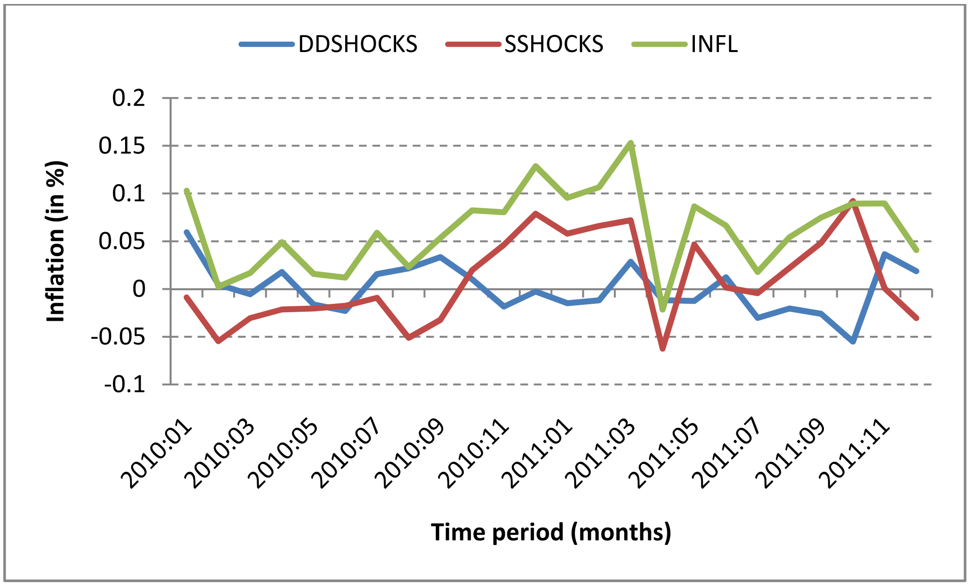


Figure 4. Inflation and its drivers 2010-11

If markets clear perfectly and prices and wages are flexible, then a fall in one price balances a rise in another with no effect on the aggregate price level. But prices and wages rise more easily than they fall. So, a rise in a critical price raises wages and therefore other prices, generating inflation. Some relative prices, among them food prices and the exchange rate, have more of such impact. The exchange rate also matters because of dependence on oil imports and since international food prices now influence domestic prices. That India's bout of high inflation started with the jump in world food prices in 2007, and was sustained by the large depreciation in 2008, favours such an explanation. But even so, the estimated supply shocks show second round effects were not large enough to sustain the supply shocks. Rather, multiple primary shocks pushed up inflation, in specific months in 2010-11 (Figure 4). The next section infers potential growth from more conventional methods.

4. Production Function and Stochastic Filter Approaches

For comparative purposes we also infer potential growth from first, input variables such as the potential availability of both labour and finance considering an implicit aggregate production function (Goyal 2012a),second, from capital-output and savings ratios, and third using the HP and polynomial filters

4.1 Labour

Youthful entrants to the Indian labour force are expected to be 12 million per year over the 2010s. Absorbing these alone would require a 10 percent growth rate with an employment elasticity of 0.25. In addition, some of the below poverty line population of around 300 million has to transfer to higher productivity employment.[7] Since the labour market is heterogeneous it is difficult to get one number, but international estimates of India's unemployment are 10.8 percent in 2010, rising from 6.8 in 2008.[8] The National Sample Survey round of 2009-10 shows it to be over 20 percent for those with a degree or diploma. A survey based estimate (GOI, 2012) showed aggregate unemployment to be only 3.8percent on the usual status approach, which classifies only those who cannot even get part-time or temporary work as unemployed. Since the informal labour market provides such jobs and the poor cannot afford to be unemployed in the absence of unemployment insurance, this figure tends to be low. But even under usual status, unemployment of graduates and those with higher degrees was ten percent. So while labour is not a constraint on growth, high growth is required to absorb labour available.

4.2 Finance

Rapidly growing Asian economies generally had high savings rates. This is consistent with research showing lagged savings lead growth. The Indian savings/gross domestic product (GDP) ratio peaked at 36.4 percent in 2007-08 but fell to30.8 percent in the slower growth following the global financial crisis (GFC)—there is a structural rise in savings, but savings also fluctuate with growth. If 2-4 percent of GDP is a safe level of the current account deficit (CAD) and the incremental capital output ratio (ICOR) is 4.5, the upper limit of capital availability (40 percent of GDP) gives 8.9 percent rate of growth. Lower limits of the GDP ratios, 30 for savings and 2 for CAD, give 7.1 percent potential growth.

Infrastructure spending is expected to rise from 6 to 9-12 percent of GDP, if one trillion dollars is spent over the next five years. A CAD of about 3 percent implies only one-quarter of this, or 250 billion dollars, can come from foreign savings. The bulk still has to come from domestic resources. Moreover, the volatile risk-on risk-off capital flows after the GFC, created problems in financing even a CAD of 3 percent. So increasing the share of stable foreign financing, and improving the financial intermediation of domestic savings are required.

4.3 Productivity and Organization

There are improvements in productivity. Large Indian firms have become globally competitive. Some systems and institutions have improved. But considerable improvement in governance is required. Many strokes of the pen reforms are possible, for example in the power sector. Unreliable power supply forces the use of expensive captive generation raising costs of production. The range for potential growth can shift up if rising productivity reduces the ICOR. For example, with an ICOR of 4 the range would be 10 to 8 percent.

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7 In comparison the unemployment impact of the Global Financial Crisis in advanced countries was only about 22.5 million.

8 Source: CIA factbook https://www.cia.gov/library/publications/the-world-factbook/

4.4 Demand

There are many sources of demand. Young people setting up new homes and equipping them creates demand, as does spending on infrastructure. Rural demand can support industry; domestic demand can compensate for slower export growth and vice versa. Although there is a trend increase in demand, interest elasticity has increased, making demand more vulnerable to cyclical tightening. Investment has become more volatile since it is now largely private investment. A fall in this component of demand also adversely affects supply, reducing trend growth.

Even so, diversity in sources of growth, a demographical advantage, network effects, having crossed a threshold, cautious liberalization and strengthening of institutions all suggest catch-up growth is possible for India. Labour is the only non-produced factor of production. Persistent unemployment raises the natural rate of unemployment—it becomes more difficult for those long unemployed to re-enter the labour force. A process of transition has the reverse effect on labour markets, making it easier for those in part-time and low productivity jobs to shift to better jobs. The only restraint is how fast capital can be organized to provide the jobs. So investment can become a critical medium-run constraint, and create volatility in potential growth.

4.5 The Output Gap

The output gap graphed in figure 5 is the GDP growth minus potential output growth in the case of ICOR based potential growth. It is measured as output gap = [(GDP actual-GDP potential)/GDP potential] for HP filtered output and polynomial output.

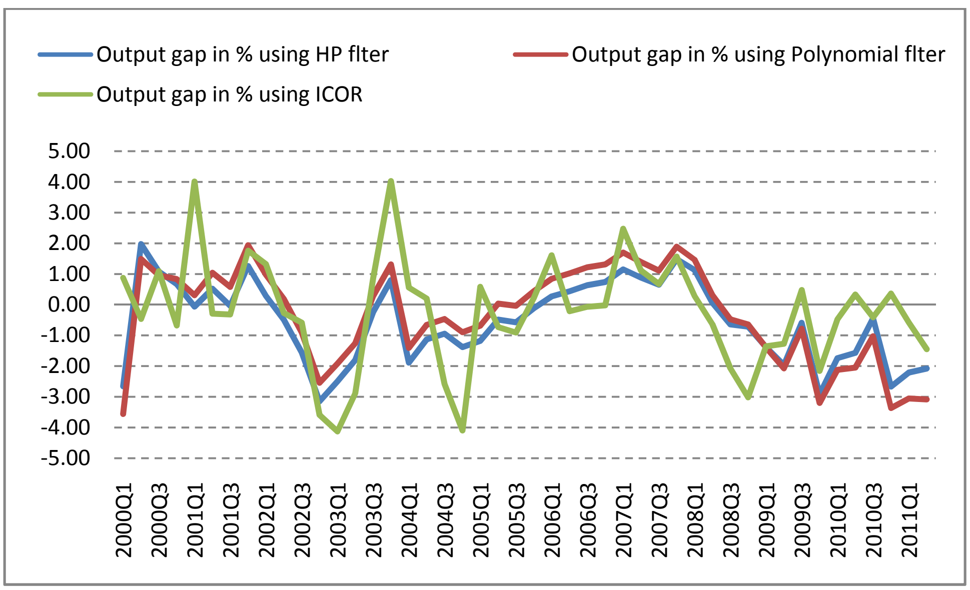

Figure 5. Measures of output gap

Total domestic and foreign savings as a ratio of GDP at market prices divided by the ICOR[9] gives the rate of growth of capital. This is one approximation to potential growth.

Figure 5 shows output was below potential from 2008 for the output gap using all three methods—HP and Polynomial filter based estimates of potential output and ICOR based estimates of potential growth. The lowest estimate (ICOR based) gives an output gap of -1 in 2011Q1, while the HP filter gives an output gap of -2, supporting the results from our SVAR model.

5. Estimated Taylor Rule

An incorrect output gap affects the policy stance. We quantify the effect using estimated Taylor rules. Goyal and Tripathi (2012) estimated a Taylor rule of the standard form where the short policy rate was regressed on the deviation of output from potential and on inflation. The constant captured the inflation target and the real interest rate. A lagged interest rate was included to capture policy smoothing.

The data was at quarterly frequency from 2000Q2 to 2011Q2, for the call or money market rate, GDP, wholesale price index (WPI), and non-food manufacturing goods WPI. GDP and WPI series were de-seasonalized using the X-12 ARIMA procedure. Wholesale Price Index (WPI) was defined as headline inflation and core inflation was defined as non-food, manufacturing goods inflation. Output gap was calculated as the percent deviation of real GDP from a target, or trend real GDP given by the HP filter. All the variables (growth rate and inflation terms) were in percentages. Year-on-year inflation was measured using annual percentage change

Unit root tests showed the variables to be stationary. The equations were estimated using ordinary least squares regression with Newey-West variance-covariance matrix, in order to correct for both autocorrelation and heteroskedasticity.

The two estimated equations with headline inflation and core inflation (t-values in brackets) were:

(1) Headline inflation

$$r_t = \underset{(2.71)}{1.85} + \underset{(5.24)}{0.58 r_{t-1}} + \underset{(2.83)}{0.156 \pi_t} + \underset{(3.12)}{0.32 y_t}$$

(2) Core inflation

$$r_t = \underset{(2.96)}{2.12} + \underset{(5.21)}{0.59 r_{t-1}} + \underset{(2.06)}{0.126 \pi_t} + \underset{(2.93)}{0.29 y_t}$$

The estimated rules capture the RBI's preferences over the period, but do not imply that it necessarily followed a policy rule—estimation rule could be capturing average behavior resulting from optimization. The relatively low coefficients reflect the lags and rigidities in an EM. In the typical mature market Taylor Rule, the coefficient on inflation exceeds unity so that the interest rate rises as much or more than inflation. Goyal and Tripathi (2012) show that, given typical lags in an EM, the system is stable even with such low coefficients, under optimization that includes smoothing. They find optimization does better than following a rule.

9 The ICOR taken from the Planning Commission is estimated at 4.6 over 1999-2002, falls to 3.6 over 2003 to 2006, and rises to 4.5 after that.

Although demand had risen in March 2011, when the policy rate was 6.75 (Figure 4) by 2011 (September), when the policy rate was 8.25 and core inflation was about 10, equation (2) gives a policy rate of 7.95 if the output gap was -1 and 8.15 if the output gap was +1. Instead the policy rate was raised to a peak of 8.5 in October. The rate of growth slumped to 7 percent (with manufacturing at 2.7) so the output gap was probably larger than 1. Results are similar using headline inflation and equation (1). The equations estimate the RBI's average behavior over the decade when the policy rate came to be actively used. It is possible if behavior changed and the weight on inflation was higher when inflation was high, with some weight on output—since inflation targeting was never strict. To test if the weight on inflation rose in high inflation periods, we estimate a Markov regime switching Taylor Rule.

5.1 Regime Switching Monetary Policy Rule

Diagnostic checks supported a rule with end of quarter call money rate (using the rate of the last month of the quarter), inflation (both headline and core), output gap (using HP filter) and change in exchange rate out of the large number of policy rules estimated. Call money rate at end of quarter was taken to tackle the issue of endogeneity. All the variables were found to be stationary except CMR which was trend stationary. It was detrended before estimation. Although the variables and the data set (1998Q2 - 2011Q4) were slightly expanded compared to (Goyal and Tripathi, 2012), the coefficients estimated were similar, showing values much below unity.

Linear policy rules (standard errors in parentheses):

1. Headline inflation

$$r_t = \underset{(0.59)}{-1.07} + \underset{(0.12)}{0.248}r_{t-1} + \underset{(0.10)}{0.179}\,\pi_t + \underset{(0.21)}{0.577}x_t + \underset{(0.084)}{0.172}\Delta ex_t$$

2. Core Inflation

$$r_t = \underset{(0.493)}{-0.67} + \underset{(0.130)}{0.248}r_{t-1} + \underset{(0.10)}{0.140}\,\pi_t + \underset{(0.22)}{0.57}x_t + \underset{(0.084)}{0.187}\Delta ex_t$$

However, any conclusion regarding possible interest rate should be made keeping in mind that call money rate was detrended at the beginning. The trend must be added back to arrive at a comparable call money rate value.

$$r_t = 7.87 - 0.0420t$$

In 2011-12 Q2, when repo rate was 8.125percent (average of the quarter), inflation was about 9.35percentand exchange rate depreciation close to 2.35percent, equation (1) implied policy rate should have been 7.63percent with output gap (+1) and 6.49percent with output gap (-1) in 2011-12 Q3. Rather it was increased to a peak of 8.5percent.

But the weight attached to inflation could change under different inflation episodes; the RBI could be expected to give a higher weight to inflation when it is high. The BDS (Brock, Dechert and Scheinkman) test[10] on the estimated residuals (see Appendix B), establishes non-linearity implying Markov switching (MS) policy rules need to be estimated. Therefore we estimate such non-linear policy rules that allow coefficients to change, and chose the one which satisfies

[10] The test was first devised in 1987 to detect the presence of non-linearity in a series.

diagnostic checks proposed by Breuing et. al. (2003) (see Appendix B).The regime switching monetary policy rule chosen was:

$$r_t = \alpha + \beta_1 r_{t-1} + \beta_2^{st}\ \pi_t + \beta_3 x_t + \beta_4 \Delta ex_t ; st \in (0,1)$$

CMR responds to inflation differently in the two regimes. However weights/ response to other variables remain the same. Only the error variance and the coefficient of inflation switched between regimes (Table 3).

Table 3. MS regressions for the two states

	State 1	*State 2*
Constant	-0.805***	-0.805***
Call money rate (-1)	0.74***	0.74***
Inflation (headline)	0.13***	0.19
Output gap	0.12*	0.12*
Exchange rate	0.097**	0.097**
Error variance	0.28***	11.92***
Probability	0.92	0.75
Expected time periods	12.76	4.01

Maximum likelihood =-82.03

MS results suggest that State 1, with a lower but significant inflation coefficient, existed for 1998-99, 2000-2006 and then from 2009 onwards. An increase in 1percent inflation increased interest rate by 13 basis point on an average. State 2 existed intermittently for 2007 and parts of 2008. This was the tail end of a period of 9 percent growth when inflation rose sharply after international food and oil price shocks. The weight attached to inflation was higher but was insignificant, maybe because of the inability to effectively sustain the higher weight on inflation as output was adversely affected. The high error variance implies other omitted variables affected outcomes. The estimated rule is unable to capture behavior adequately over this period. But the higher coefficient on inflation suggests the sharp repo cuts as the GFC set in, taking the repo to 4.75 and the reverse repo to 3.25 (this was the effective rate since liquidity injections kept the call money rate at this level, Figure 7) by April 2009 may have been too much, especially since food price inflation remained in double digits.

Even if we assume State 2 inflation coefficient was the operative one, the policy rate should have been 8.12 percent in 2011-12 Q3 with output gap (+1) and 7.88 with output gap(-1). This was still way below the actual policy rate of 8.5percent.

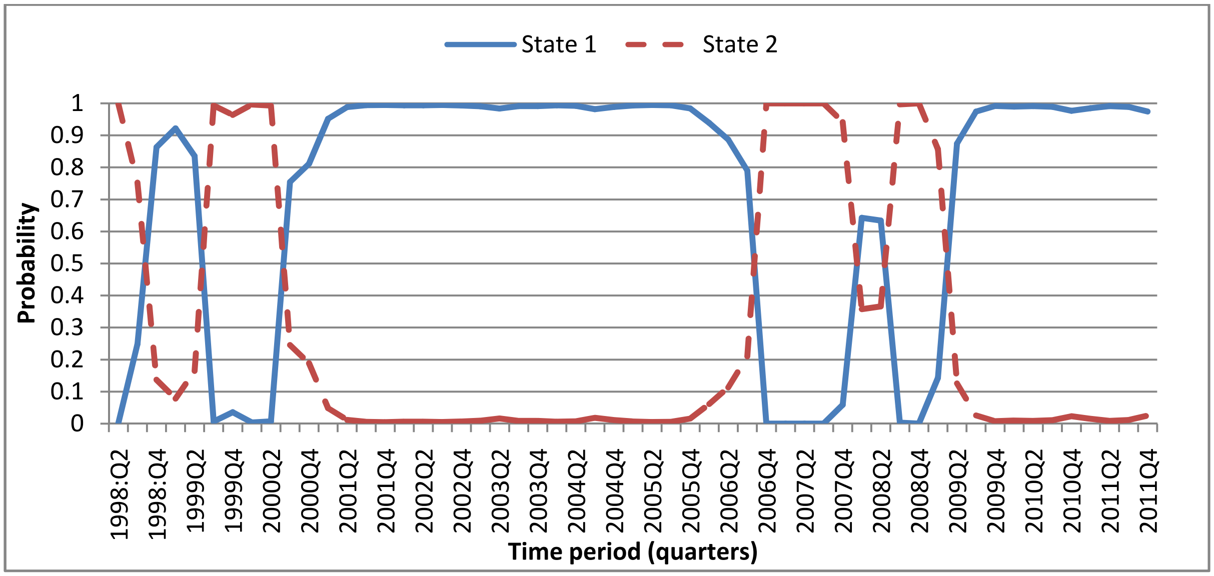

Figure 6. The two states for headline inflation

In 2008-09 and in 2011, there was overcorrection compared to past RBI behavior. A sustained slowdown ensued, lasting well into 2013. Underestimating potential growth can explain some excessive monetary tightening. From the estimated TRs, a difference of one percent point in the estimated output gap would give about a 25 basis points difference in the policy rate. But even though growth falls in a slowdown, it does not necessarily imply potential growth has fallen.[11] The Reserve Bank of India estimated potential growth at about 8 percent in 2011using non-inflationary past trend growth as a measure. Using filtered past trend growth would lower potential further to 7 percent, while the peak labour-financial resource based measure would range between7.5-9 percent. The supply shock based measure indicates output was below potential in 2011.

6. Conclusion

If estimated supply shocks are persistent, and inflation remains high, it implies second round pass through is under process so output must be at or above potential. This innovative method enables us to derive a measure of potential growth that draws on both theory and the structure of the Indian economy. The supply shocks are estimated using the restriction of elastic longer run aggregate supply, in a time series model. Structure, theory and tests support the restriction. Purely data based techniques to estimate potential growth have inherent limitations—they depend on periods and smoothing techniques adopted. Therefore such an alternative measure is useful.

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[11] Use of the HP filter to measure potential has been criticized because it gives too much weight to end points.

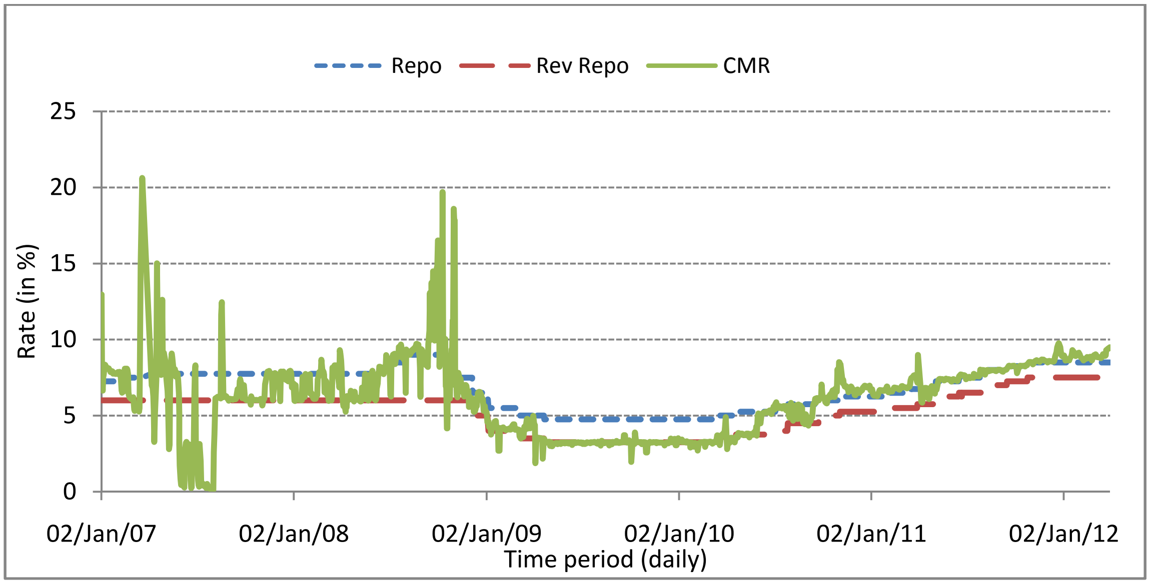

Figure 7. Policy and call money rates

The estimates show supply shocks largely explain inflation. Both this exercise and the ICOR based analysis find output to be at potential only in the years 2007-08 when growth rates exceeded 9 percent. The period 2010-11 had a few peaks, but no sustained excess of output over potential, implying inflation was due to multiple supply shocks, rather than sustained second round effects.

These results are qualitatively robust to alternative choices for the price variable, assumptions for the lag length of VAR, and the use of quarterly data. Other input-based methods also support the estimated potential growth.

With a high elasticity of supply, reducing demand does lower firms' ability to pass through price increases, but it entails a large output sacrifice for a small effect on prices. Innovative ways to reduce costs are required. In general, prices tend to rise more easily than they fall. So monetary policy should let first round effects of cost shocks pass through, but react just sufficiently to anchor inflationary expectations and prevent second round effects from rising wages and prices. Estimated policy rules, even allowing for more weight on inflation under high inflation regimes, show overcorrection in 2008 and in 2011, so that stabilization was ineffective. Incorrect estimates of potential growth can contribute to excessive tightening. As interest rates rise investment falls, further lowering short-term potential growth. Estimated policy rules suggest a one percent underestimate can imply a 25 basis point rise in policy rates. Reaching potential output in an EM during a catch-up phase may imply exceeding past peak growth rates, but the absence of second round pass through indicates potential output is not exceeded. Rise in investment and productivity are the enabling factors. Accurate assessment of potential output can contribute to the fine-tuning required for supportive monetary policy.

Policy rates are assessed against estimated Taylor rules, which capture past behavior. The coefficients, and response to both inflation and output gaps, are lower than they are in mature markets. Other studies also get similar coefficients. Goyal and Tripathi (2012) show more lags and rigidities in EMs make such a low response optimal. The Markov regime-switching Taylor rules are imprecisely estimated and do not satisfactorily capture policy hardening when inflation crosses a threshold (RBI, 2011), so more work needs to be done. Also the structural importance of food prices suggests policy should tighten more and quickly when food inflation rises to anchor inflationary expectations, but other research suggests the natural rate of a low per capita income economy is lowered when there is a shock to the consumption of the poor (Goyal, 2011). Again more research is required to clarify these issues.

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Appendix A: Testing HSC versus VSC identifications

The FEVD and Impulse Response for HSC and VSC estimated using log differences of monthly IIP and WPI, with 14 lags and a constant, are given below. IIP proxies for output, since the latter is not available at a monthly frequency.Monthly inflation is multiplied by 12 to give annual inflation.

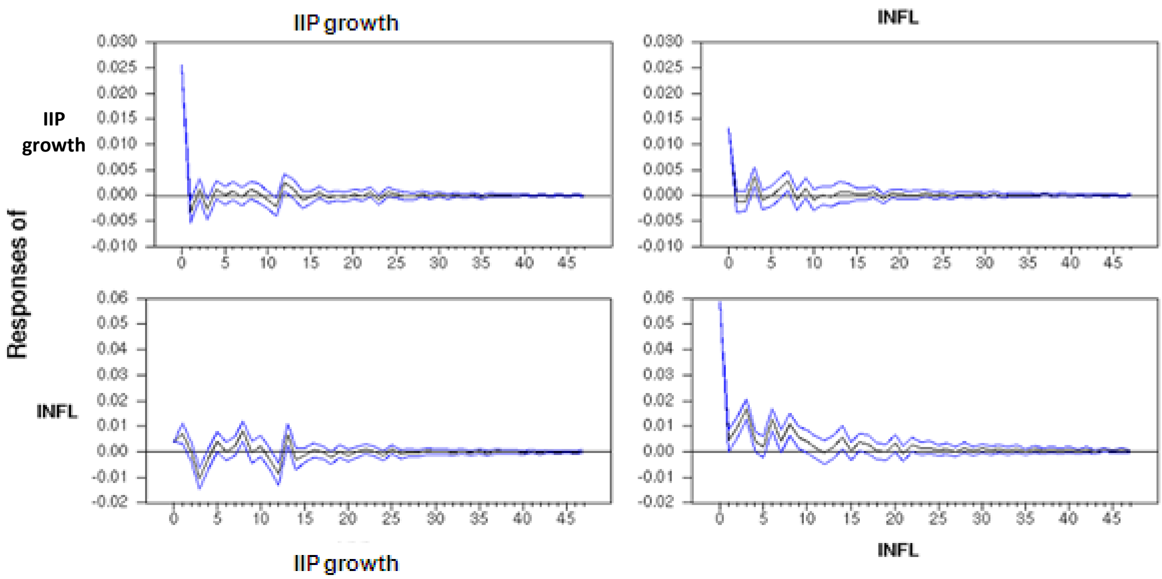

Figure A1: HSC impulse response to a one standard deviation demand (top panel) and supply (bottom panel) shock along with 95% confidence intervals[12]

The impulse response shows the response of IIP growth to a demand shock and of inflation to a supply shock dominates, consistent with the identification imposed.

Table A1. FEVD: Decomposition of Variance for IIP growth

Step	*Std Error*	*Demand*	*Supply Shocks*
1	0.02889375	78.850	21.150
4	0.02949477	77.877	22.123
8	0.02971310	76.936	23.064
12	0.02988825	76.793	23.207

[12] The X-axis plots number of periods and y-axis plots the magnitude of responses.

Table A2. Decomposition of Variance for WPI inflation

Step	*Std Error*	*Demand*	*Supply Shocks*
1	0.0590	0.390	99.610
4	0.0635	4.371	95.629
8	0.0652	4.824	95.176
12	0.0670	6.331	93.669

The FEVD shows supply shocks had a large impact on inflation and the large effect of demand shocks on growth was persistent, as is to be expected if the supply curve is elastic.

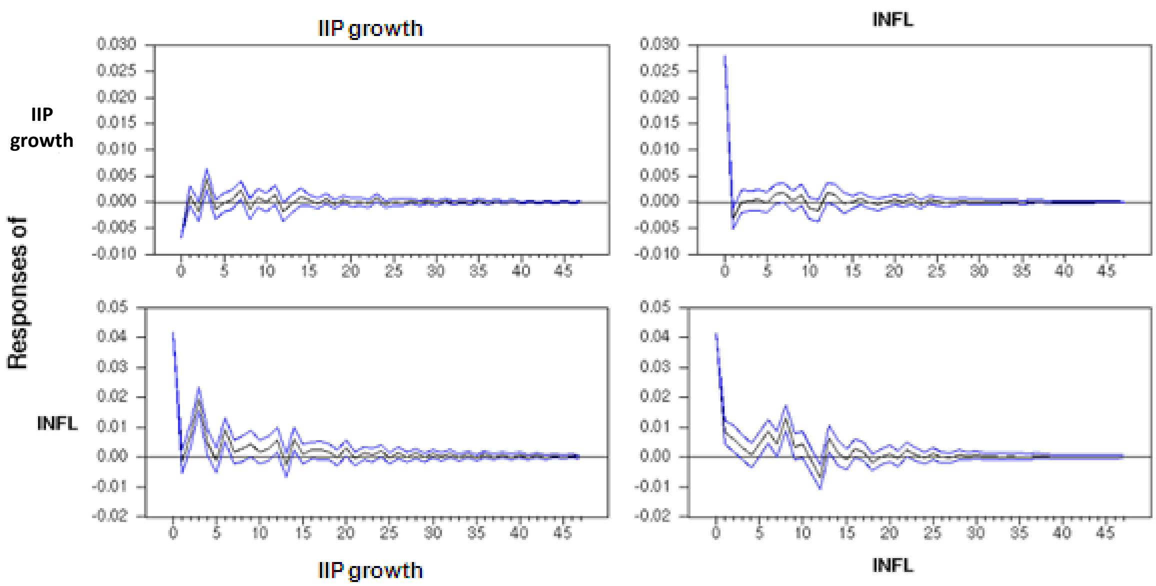

Figure A2. VSC: The impulse response to a one standard deviation demand (top panel) and supply (bottom panel) shock along with 95% confidence intervals. X-axis plots number of periods and y-axis plots the magnitude of responses.

The impulse response shows the response of IIP growth to a supply shock dominates but both demand and supply shocks affect inflation equally, which is not consistent with the VSC identification imposed.

Table A3. FEVD: Decomposition of Variance for IIP growth (Monthly VSC)

Step	*Std Error*	*Demand*	*Supply Shocks*
1	0.02889270	5.730	94.270
4	0.02949372	8.318	91.682
8	0.02971206	9.033	90.967
12	0.02988720	9.422	90.578

Table A4. Decomposition of Variance for WPI inflation

Step	*Std Error*	*Demand*	*Supply Shocks*
1	0.05901127	50.329	49.671
4	0.06354152	54.276	45.724
8	0.06522304	54.059	45.941
12	0.06701236	52.017	47.983

The FEVD shows supply shocks had a large and sustained impact on inflation, so demand shocks do not account for the major share of inflation, and demand shocks have a rising and persistent effect on output growth. These results are not consistent with an inelastic long-run supply curve.

Appendix B: Diagnostic checks for Markov switching policy rules

Breunig et. al. (2003) suggests formal as well as informal tests to test if the model is correctly specified. The procedures are based on a comparison of the 'sample' properties of the data with the 'population' characteristics suggested by the model.

(a) Hypothesized model is estimated by maximum likelihood

(b) These coefficients are then used to simulate a large set of pseudo-observations. It is assumed that this set is large enough so that there is no error attached to the simulation process. These observations are interpreted as the 'population' implied by the simulation process

(c) 'Sample' and 'Population' are tested against each other on 5 grounds: mean, variance, probabilities (P1 and P2) and quadrants

i. P1 is probability of observing a contraction after an expansionary period and vice-versa for P2.

ii. Qi's are defined based upon combinations of high/low volatility with high/low growth. Define $z=y-\mu$, then Q1= $[z > 0; |z|< \sigma]$, Q2=$[z < 0; |z| < \sigma]$,Q3=$[z <0;|z| > \sigma]$ and Q4=$[z > 0; |z| > \sigma]$.

Table B1. Diagnostic checks table

	Data Sample	*Simulation Population*	*t-stat Sample=Population*
Mean	2.10	1.22	1.48
Variance	17.98	12.84	2.36
P1	0.20	0.154	0.883
P2	0.418	0.3013	1.066
Q1	0.2407	0.2092	0.7393
Q2	0.4074	0.5653	2.92
Q3	0.1852	0.1139	1.76
Q4	0.1667	0.1116	1.78

t-stats are calculated after correcting for auto-correlation using Newey west covariance matrix.

The diagnostic checks show that the MS model is a good fit. All the tests are insignificant at 1percent level expect for Q2 which is insignificant at 0.25percent.

Linear Rules

Headline Inflation

Table B2. Ljung-Box Q stats for auto-correlation

	Lag 10	*Lag 20*
Residuals	10.503	15.207
Squared residuals	16.58	18.44

Core inflation

Table B3. Ljung-Box Q stats for auto-correlation

	Lag 10	*Lag 20*
Residuals	10.675	13.84
Squared residuals	18.19	19.62

These tests suggest that autocorrelation is insignificant at 5percent at lag 10 and 20.

Tests to detect non-linearity

BDS test checks for null of independently and identically distributed residuals versus the alternative of non-linearity.BDS test was performed using fraction of standard deviations as a method of choosing distance between two residuals with value 0.7 and 5000 bootstrapped simulations. Cusum test of squares tests for instability in parameters.

Table B4. Headline inflation BDS test

Dimension	*BDS Statistic*	*Std. Error*	*z-Statistic*	*Normal Prob.*	*Bootstrap Prob.*
2	0.036701	0.011048	3.322025	0.0009	0.0118
3	0.029604	0.011749	2.519730	0.0117	0.0514
4	0.020583	0.009380	2.194258	0.0282	0.0852

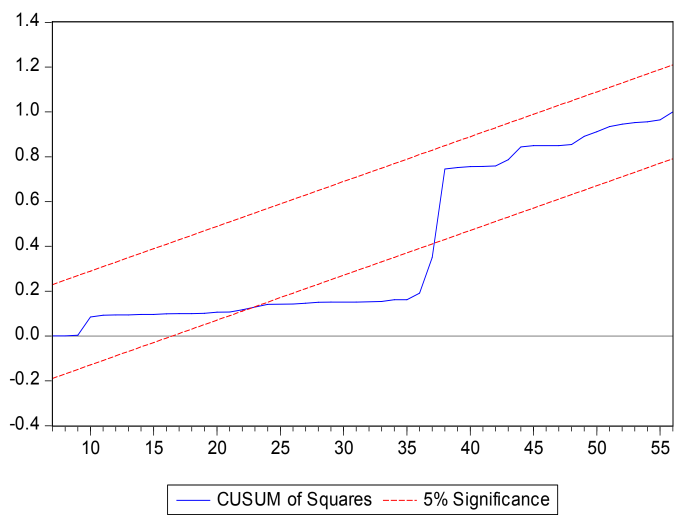

Figure B1. Cusum test of squares, headline inflation.

Plots test statistic (S_t)against the pair of 5 percent critical lines.[13] X-axis plots time period and y-axis plots the statistic value.

♦♦♦

[13] Movement outside the critical lines suggests parameter or variance instability