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Abstract

Simultaneity issues as well as incorrect measurement of shocks and of the cyclical variable bias estimated slopes of the Indian aggregate supply curve (AS). Our initial Generalized Method of Moments estimation, based on a filtered output gap variable and including supply shocks, also gives an unrealistic downward sloping AS. But we find measures of asymmetries in price changes outperform traditional measures of supply shocks. Estimation using marginal costs as a proxy for the output gap gives a positive coefficient that reduces in size on including our comprehensive supply shock variable, implying the correct AS has a small positive slope, but is subject to multiple shifts. The semi-structural specification, closer to firms' actual decisions, gives estimates of structural parameters such as degree of price stickiness and extent of forward-looking price adjustment. The results more correctly separate shocks from cyclicality, help to interpret India's growth and inflation experience, and have implications for policy.

Keywords: Indian aggregate supply, slope, shocks, firms' price-setting, marginal costs

JEL Code: E31, E32

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1. Introduction

An ongoing debate on the shape of the Indian aggregate supply curve (AS) raises interesting econometric and policy issues. We take systematic steps to improve the estimation. On correcting for endogeneity we still get an unrealistic negative slope. On adding better variable definitions, we get a positive slope, but on using a better measure of supply-shocks the slope decreases in size. The result that the Indian AS is relatively flat, but subject to frequent shifts, suggests the output cost of disinflation can be high, but the way to moderate it is to address the factors causing shifts of the curve.

A supply shock is defined as a sudden change in price and output, resulting from a shift of the aggregate supply curve (AS). For example, since oil price changes are unrelated to the cyclical variable they are best measured as shock variables augmenting the AS. The slope of the AS shows how inflation changes with the output gap during the cycle. Identification problems as well as measurement of shocks and of the cyclical variable bias the estimated slope. Our use of Generalized Method of Moments (GMM) estimation to address identification issues, and more careful measurement of the relevant variables, gives a more robust estimation of the slope.

The output sacrifice from a policy induced reduction in aggregate demand depends on this slope. Correct estimation is important, therefore. If the output gap[1] coefficient is zero, the AS is vertical and there is no tradeoff between inflation and growth. A policy tightening will reduce inflation, without affecting growth. If forward-looking firms or workers factor in a future price rise and the economy is close to excess capacity, the expectation augmented AS can be vertical even in the short-run. But a standard short-run AS, derived from the classical Phillips curve in which wages rise as unemployment falls, has a positive slope. A monetary tightening then decreases inflation, but at the cost of slower output growth. Now there is a tradeoff since an output sacrifice is required to reduce inflation.

The New Keynesian economics (NKE) literature derives an upward sloping short-run AS (Gali and Gertler, 2000) from firms' maximization of expected profits. Potential output is obtained from optimal marginal cost, closer to firms' actual decisions, making it a better

[1] 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, are alternative measures of the cyclical output gap.

measure of the cyclical variable. The NKE literature suggests if price setting is forward-looking there is no short-run tradeoff for a demand shock that raises output transiently above potential even if the AS slope is positive. Policy tightening will just keep output at potential. But under a supply shock there is an output sacrifice. Tightening has to reduce output below potential to moderate the inflationary impulse. The sacrifice is low if the AS has a steep slope since a small fall in output will lead to a large fall in inflation. But an almost flat AS implies a large fall in output will be required for a small fall in inflation. The slope is an empirical question this paper seeks to address.

But there are two problems in estimating the slope. First, that of identifying the AS, since under generalized rational expectations all variables enter demand and supply equations. And second, correct measurement of variables.

The negative slope found in early estimations of the Indian AS (Dholakia, 1990) may merely reflect the scatter of equilibrium outcomes. Later research that controlled for supply shocks found a positive slope (Paul 2009). Even so, the approximations used to measure supply shocks, which included international oil price hikes, and indices of monsoon failure, were crude, as were the measures of the output gap. Supply shocks prominent in India's inflation dynamics included exogenous exchange rate, financial, administered price and wage rate changes that raised costs for firms at all levels of output. Therefore a comprehensive measure that includes different types of supply shocks is required.

We (i) extract supply shocks from firms' asymmetric response to large compared to small shocks (ii) obtain a better measure of the output gap from disaggregated industrial data, and (iii) estimate the short-run AS with both monthly and yearly data, using GMM estimation that ensures the lagged variables used as instruments are uncorrelated with forecast errors. These variables capture the information available at the time expectations are formed.

The initial estimation based on an HP-filtered monthly IIP (Index of Industrial Production) output gap variable, gave a negative coefficient for the output gap, like the early estimations although our supply shock variable outperformed another measure based solely on oil price shocks. Attempts to reproduce earlier estimations that found a positive slope by controlling for supply shocks showed those estimations to be fragile. But using marginal costs derived from yearly disaggregated wage and output data, as the measure of output gap, gave a positive coefficient. The early downward sloping AS, therefore may have been due to errors in variables. Moreover, the slope reduced in size on including the robust supply shock estimate, implying the true AS has a small positive slope, but is subject to multiple shifts. The semi-structural specification derived from firms' behavior also gave estimates of structural parameters such as the period of time after which firms adjust prices[2].

The remainder of the paper is structured as follows: Section 2 reviews the literature, section 3 explains the identification and measurement issues, section 4 gives the method used to estimate supply shocks, section 5 develops and estimates a NKE type AS using standard aggregate measures of the output gap, section 6 refines the estimation to include marginal cost based measures of the output gap, before section 7 concludes.

2. Literature Review

Early Indian studies found, first, a negative relationship between inflation and the output gap. Second, they found supply shocks from monsoon failures and global crude oil prices largely explained inflation. This literature is surveyed in Paul (2009), who himself got a positive coefficient for the output gap for the time period (1956 - 2007) after controlling for supply shocks such as paucity of rainfall, oil prices, and liberalization, and estimating the AS for industry only in a crop not a fiscal year. He concludes a Phillips curve type of trade-off between output gap and inflation exists in the Indian industrial sector, as it does in developed countries.

Singh et.al (2010) also estimated inflation as a function of the output gap and a supply shock. They derived the output gap using a non-linear Kalman filter with quarterly Gross Domestic product (GDP) between 1996 and 2005. Their results confirm a Phillips curve exits in India when supply shocks are taken into consideration. Dua and Guar (2010) also used quarterly GDP between 1996 and 2005. After controlling for agricultural shocks and imported inflation through exchange rates, they found a positive relation between the output gap and inflation. In these papers also, dummy variables or indices of rainfall are the proxies used for supply shocks. Goyal and Pujari (2005) test the validity of a vertical versus a horizontal restriction for the Indian AS. The vector autoregression based estimation supports the latter and gives an

[2] The estimations further develop earlier work reported in Tripathi and Goyal (2013), which was focused on examining the impact of relative price changes on aggregate prices.

estimate of supply shocks. The paper pointed to the importance of measuring and controlling for supply shocks in order to correctly identify the AS.

3. Identification and Measurement

Simultaneity bias is inherent in an aggregate demand-supply system. Consider a simple stylized downward-sloping demand and an upward-sloping supply curve. If a variable shifts only one of the functions, the shifting function will then identify the other. Without a subset of variables that change supply while leaving demand unchanged, or vice versa, only a scatter of market equilibrium points will be estimated.

Technology may be the primal source of shocks for supply and preferences may be the primary source of shocks for demand, but with model-based rational expectations, variables affecting supply also influence demand. In a systemic perspective, there is no variable that can be excluded from demand or supply, in order to identify the other (Sims 1980).

In addition, least squares attenuation bias, that is, incorrect measurement of a single variable, biases its estimated coefficient towards zero if the variance of the measurement error is positive. The direction of the bias is not known in a multiple variable regression. If a significant variable is omitted, or measurement is so poor it amounts to an omitted variable, it also biases the coefficients of the other variables in the regression, depending on the correlation between the two variables.

3.1. Identifying the AS from Indian growth and inflation outcomes

Table 1, which gives decadal deviations from average growth and inflation rates, shows above trend inflation to be generally associated with below trend growth in India. The observed correlation between the output gap and inflation is negative. Simple AS estimation using the underlying data points would give a negatively sloped AS curve, even though the equilibrium points xyz in inflation output-gap space come from an AD-AS structure (Figure 1) with a positively sloped AS.

Shifts of an AS with a steep positive slope along a downward sloping demand curve also generate negatively correlated $xy'z'$ (Figure 2). In Figure 1, xyz give the equilibrium points not the AS, while in Figure 2 $xy'z'$ identify the AD not the AS curve. The AD-AS curves tend to shift together since supply shocks are normally accompanied by demand contractions. So the equilibrium outcomes in Figure 2, xyz, which take account of shifts in both the AD-AS curves, would show no change in inflation. But these outcomes do not replicate negative Indian growth inflation correlations (Table 1), suggesting the Indian AS is unlikely to be steep like that in Figure 2.

Table 1: GDP growth and inflation: Inverse correlation (Average annual decadal deviations from pre- and post-1990 averages)

	Real GDP growth	WPI inflation
1970-71 to 1979-80	-1.4	0.8
1980-81 to 1989-90	1.3	-0.6
1990-91 to 1999-00	-0.7	1.1
2000-01 to 2009-10	0.8	-1.6
2010-11 to 2013-14	-0.3	1.0

Note: Deviations before 1990 are taken from the pre-1990 average growth of 4.3 and inflation of 8.6. After 1990 the averages from which deviations are taken are 6.5 for growth and 7 for inflation respectively.
Source: Calculated with data from www.rbi.org.in

It has recently been argued the Indian AS curve may be backward bending because distortions from inflation reduce effort. RBI (2011 Box 11.4, pp.32) and Pattanaik and Nadhanael (2013) estimate the inflation threshold where such negative effects kick in to be about 5 per cent. But in the theoretical arguments for such a curve, effort decreases with output only after unemployment falls below some critical threshold (Figure 3 shows the output corresponding to the minimum unemployment rate or MUR). Given India's large population and limited high productivity employment, unemployment is unlikely to be near such a minimum rate.

Moreover, if the economy were operating on the backward bending region, as in Figure 3, a contraction in demand should raise output and reduce inflation along $xy'z'$. But in the Indian experience, policy tightening led to falling growth and sticky or rising inflation. Moreover, if supply shocks are also present, the negative correlation disappears in this case along the equilibrium outcomes xyz (Figure 3) where inflation and growth rise together. Again this does not replicate Indian outcomes suggesting a backward bending AS is unlikely.

Since only a structure such as in Figure 1 fits the stylized facts, robust estimation that controls for supply shocks should also identify such a flat AS. Our estimations in the sections below corroborate this.

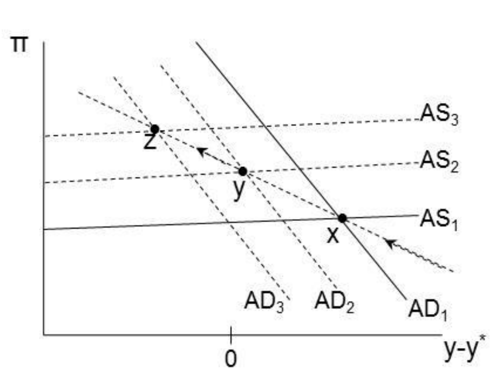

Figure 1: Almost flat AS

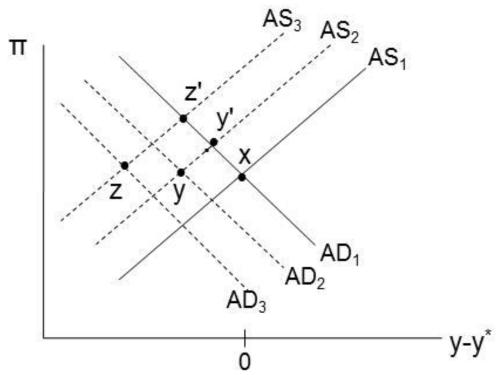

Figure 2: AS with a positive slope

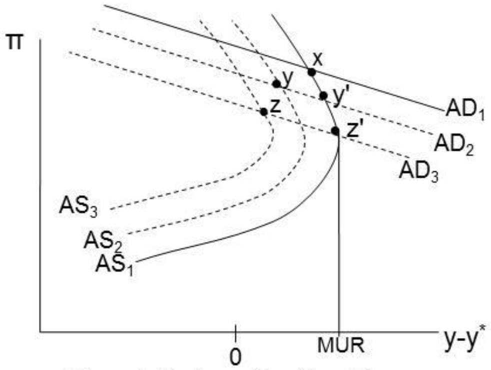

Figure 3: Backward bending AS

Source: Authors

4. A General Measure of Supply Shocks

Changes in certain relative prices, such as those of oil or food, often underlie supply shocks. According to standard theory, however, changes in the relative prices of some goods should have no effect on the price level, since it is monetary not real factors that affect aggregate price. In an economy with a constant money supply, some prices may rise but others should fall, so the average price level remains constant.

But relative prices can affect the aggregate price level if relative prices like food influence wages. Or major administered price like oil rise but rarely fall. Or prices are sticky downwards or, firms respond more to large shocks so they have a disproportionately large impact on the price level (Ball and Mankiw, 1994).

In the NKE framework, a firm adjusts its price towards its desired relative price only if the change exceeds the menu cost—or cost of changing a price. If a few firms want large price increases, while most firms want small decreases, the upper tail of the price distribution would be larger than the lower tail. Prices are raised but not lowered, and the overall price level increases. Conversely, if the distribution of desired adjustments is skewed to the left, decreases dominate, and the price level falls.

Since its variance and skewness determine the size of the tails of the distribution of relative price changes, these can be used to estimate supply shocks. A weighted average of relative price movements that are greater in absolute value than some cut off X (Ball and Mankiw 1995) is a parsimonious measure of the relevant asymmetry, which captures both the direct effect of skewness and the magnifying effect of variance on inflation:

$$AsymX = \int_{-\infty}^{-x} rh(r)dr + \int_{x}^{\infty} rh(r)dr \tag{1}$$

AsymX measures the positive mass in the upper tail of the distribution of price changes minus the negative mass in the lower tail, where *r* is an industry relative price change (log industry inflation rate minus the mean of all industry log inflation rates) and *h(r)* is the density of *r*, and the tails are defined as relative price changes greater than X per cent or smaller than -X per cent. AsymX is zero for a symmetric distribution of relative price changes, positive when the right tail is larger than the left tail and negative when the left tail is larger.

In the empirical estimation we take X=10 per cent. Asym10 captures large shocks by giving full weight to price changes above 10 per cent and zero weight to other price changes. The resulting series exhibit large fluctuations over time. Some of the extreme observations correspond to well-known oil shocks. For example, Asym10 is large and positive during the years 1974, 1980, 1990 and 2004.

The distribution of Indian industrial inflation[3] in 1974 and 2006 is skewed to the right, implying an increase in the overall price level; 1984 gives a left skewed distribution, implying a fall in the price level. A more or less symmetric distribution in 2000 indicates a low effect on the price. The first two years correspond to oil price shocks. There is

[3] To obtain average change, each industry is weighted as in the wholesale price index (WPI). The weights capture the relative share of industries in the reference year.

considerable variation in the distribution of price changes over the years. Administered prices, including agricultural support prices and minimum wages, that tend to be revised upwards rather than downwards, often by large amounts, imply the skew is more likely to be positive. A measure of supply shocks based only on oil price increases or on rainfall would miss these other more chronic types of supply shocks[4].

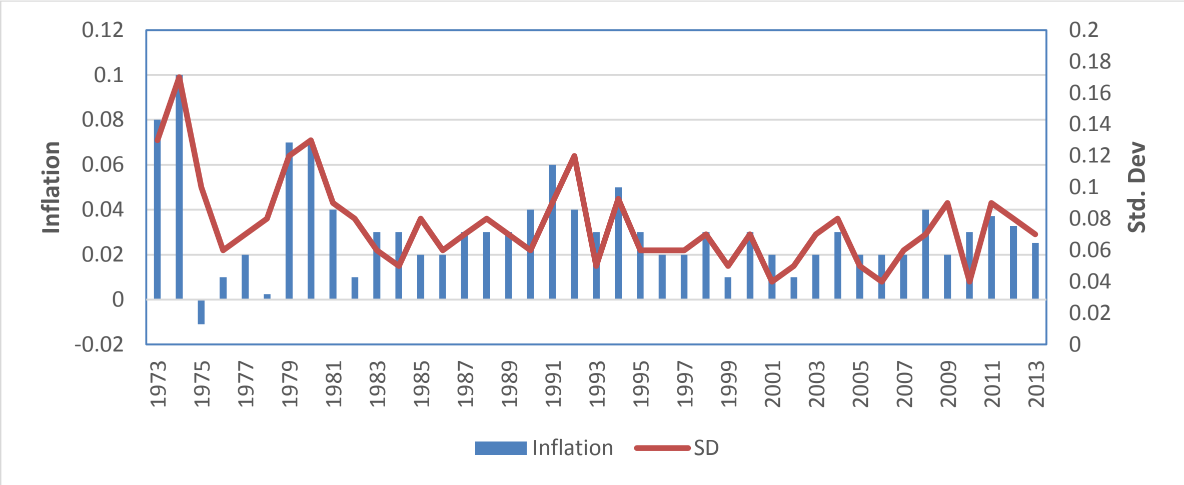

Figure 4: Plot of Inflation and Standard Deviation
Source: Drawn using data from www.rbi.org.in

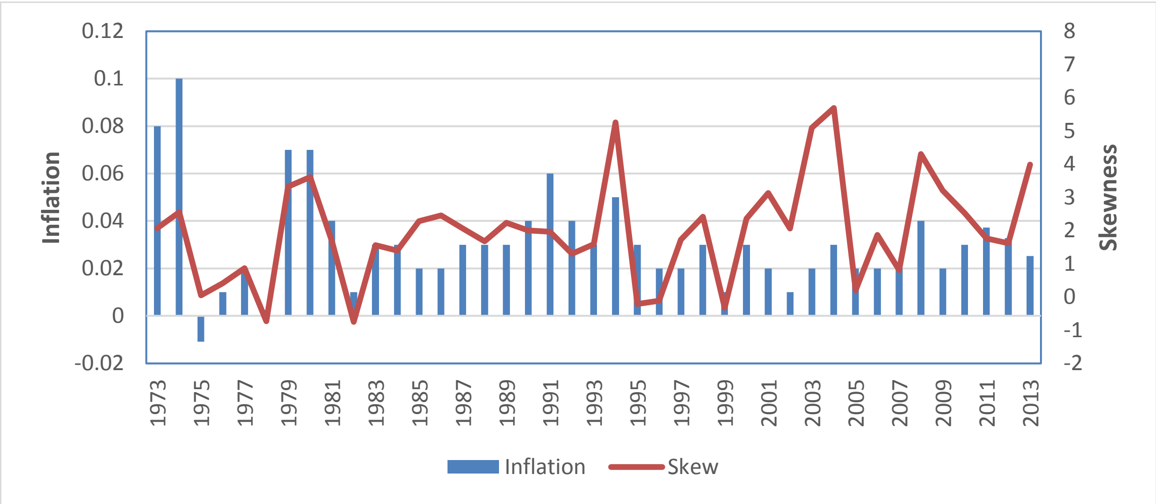

Figure 5: Plot of Inflation and Skewness

Source: Drawn using data from www.rbi.org.in

[4] See Goyal (2012) for a discussion of these chronic cost push factors in India, and Tripathi and Goyal (2013) for more detailed analysis of asymmetric price changes.

Figure 4 and 5 graph inflation, with the standard deviation and the skewness respectively, calculated from the log wholesale price index (WPI) for each year. They demonstrate the contribution of skewness and variance respectively to inflation. The skew is largely positive.

5. New Keynesian Aggregate Supply

A large literature takes the Phillips curve (PC) as the starting point for the analysis of the dynamics of inflation. The New-Keynesian Phillips curve provides a micro founded formulation of inflation that is consistent with rational expectations, since it is derived from firms' setting of optimal prices. The term New-Keynesian aggregate supply (NKAS), however, is more appropriate for our analysis since the dependent variable for the PC was unemployment but the NKAS has the output gap as its argument.

Following the Calvo (1983) model, a random fraction (1 − θ) of firms are assumed to reset their price p^*_t in each period, implying an evolution of the (log) price level:

$$p_t = \theta p_{t-1} + (1-\theta)p_t^* \tag{2}$$

Assuming an imperfectly competitive market structure where a firm sets its price as a fixed markup over marginal cost, the optimal reset price is:

$$p_t^* = (1-\beta\theta)\sum_{k=0}^{\infty} \beta\theta^k E_t\left\{mc_{t+k}^n\right\} \tag{3}$$

Where β is the firm's discount factor and mc^n_t is a firm's nominal marginal cost. Since price is likely to be fixed over some period, a firm sets price equal to the weighted average of expected future nominal marginal costs. In the limiting case of perfect price flexibility (θ=0), the firm simply adjusts its price proportionately to the movements in the current marginal cost. The future affects current prices when there is price rigidity (θ>0).

Let $\pi_t \equiv p_t - p_{t-1}$ denote the inflation rate at *t*, and mc_t the per cent deviation of the firm's real marginal cost from its steady state value. The equations (2) and (3) can be combined to yield a NKAS of the form:

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

Under relatively general conditions, aggregate real marginal cost is proportional to the gap between output and its potential level.

$$mc_t = kx_t = k\left(y_t - y_t^*\right) \tag{5}$$

With this assumption, the NKAS becomes:

$$\pi_t = \beta E_t \pi_{t+1} + \lambda x_t \tag{6}$$

Where $\lambda = k\frac{(1-\theta)(1-\beta\theta)}{\theta}$. As with the traditional PC, inflation depends positively on the output gap and a "cost push" term that reflects the influence of expected inflation, $E_t\{\pi_{t+1}\}$ as opposed to $E_{t-1}\{\pi_t\}$earlier. Inflation now depends on the discounted sequence of future output gaps. This can be seen by iterating equation (6) forward:

$$\pi_t = \lambda \sum_{k=0}^{\infty} \beta^k E_t\{x_{t+k}\} \tag{7}$$

Standard econometric models that include lagged inflation, can be interpreted as the NKAS if the lags are understood as proxies for expectations. But the lags are not ad-hoc and enter in a more theoretically consistent way in the NKAS as compared to the original PC.

The NKAS implies a central bank can control inflation due to excess demand without cost by committing to keep the output close to its potential level in the future—firms would then not set higher prices, that once raised persist for some time. There is a tradeoff, however, between output and inflation variability under supply shocks. Raising the policy rate and reducing output below potential can reduce inflation. The action is more effective, however, if the coefficient on the output gap is large; with a flat AS a large output sacrifice is required for a small reduction in inflation.

After adding supply shocks to Eq. (6) we get the expectations augmented AS shown below (Gordon, 1977):

$$\pi_t = \beta E_t \pi_{t+1} + \lambda x_t + shock_t \tag{8}$$

5.1 Methodology and data

Equation (6) and (8) are estimated, with both monthly and annual data. Both give an estimate of the short-run AS but at different frequencies. Industry level data used to estimate *mc*, which is a more robust measure of the output gap, was available only at a yearly frequency, making it necessary to use yearly data also.

Our aim is to extract the AS from an underlying AD-AS system. Under rational expectations a system of equations is always overidentified. The variables exceed the number of parameters to be estimated as all the variables and lags are present in each equation. Since the error term is correlated with the independent variables in each equation, instrument variables that are correlated with the independent variables but uncorrelated with the residual error are required. In dynamic models, lagged variables, which are not correlated with prior period errors, are obvious candidates. The number of such orthogonality or moment conditions is larger than the number of parameters, so minimizing the sum of squares finds the unique element of the parameter space that sets linear combination of the expected cross products of the unobservable disturbances and observable instrument variables equal to zero (Hansen, 1982). This gives the required unique solution. Normally, weights used are inversely proportional to the variances of the individual moments. An additional benefit of using sample moments is they do not depend on the distribution of the error term, which is normally unknown in rational expectation models.

GMM can also be used to estimate an expected variable based on a number of lagged variables thus mimicking the actual broad-based determination of rational expectations. The instruments used to proxy expected future inflation were: interest rate, exchange rate depreciation, oil price inflation and older lags of inflation[5]. The use of disaggregated price and wage data makes better measurement and better instruments available. Per unit fuel consumption was used as an additional instrument for industry level data.

In equation (8), to make a comparison between a traditional supply shock and our estimated Asym10 we also used a “net oil price increase” (NOPI) transformation, as proposed by Hamilton (1996a). This equals the percentage increase in oil prices over the previous year’s high if that is positive, and zero otherwise.

The monthly data set is for 1971M4 to 2014M4; yearly data for 1990 to 2012. The HP detrended series of the index of industrial production (IIP) was taken as a measure of monthly output gap[6]. Price and interest rate series were collected at both frequencies. The wage bill and value of output for 35 manufacturing industries (three digit NIC code[7]) was sourced from ASI data to calculate the proxy for marginal cost. Prices were taken from the disaggregated wholesale price index (WPI), using a concordance table from the Economic and Political Weekly, to calculate each industry's inflation. For all India estimation WPI all commodities was used.

[5] Paul (2009) uses one lag of inflation as a proxy for expected inflation, implying expectations are formed adaptively.

[6] Continuous series for WPI and IIP with base year 2004-05 were constructed by splicing.

[7] Data spanning 1990 to 2012 falls under 4 different NIC classification years: 1987, 1998, 2004 and 2008. Various concordance tables were used to get continuous time series.

The WPI series were from the Office of Economic Adviser, Government of India; crude oil prices in US dollar per barrel were from International Energy Agency; data on call money rate as an instrument of monetary policy and IIP were from Reserve Bank of India website. Hamilton's NOPI creates a series which is similar to other measures of oil price shocks until 1986 (when price increases were infrequent they usually set new annual highs), but filters out many of the small choppy movements since then. It also explicitly rules out effects from price decreases. The monetary policy variable (Monpol) was calculated as change in call money market rate. In all regressions, the left hand side variable is the log change in WPI. All the variables were found to be stationary using the ADF test.

5.2 Estimation of the monthly aggregate supply curve

We first estimate monthly NKAS with and without supply shocks and also test the performance of Asym10 compared to a traditional measure of supply shocks. The GMM estimates of equation (6) are given in Table 2 (column 1) and of equation (8), with different measures of supply shocks, in columns 2, 3 and 5. For purposes of comparison with earlier studies, the standard AS, with inflation lags instead of expected inflation, is also estimated by OLS and reported in column 4. More lags were tried but were dropped because they were insignificant.

Table 2: Estimation of monthly AS with an alternative measure of shocks

Inflation					
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Expected inflation	1.08 (0.00)**	1.07 (0.00)**	1.08 (0.00)**		0.75 (0.00)**
Inflation (lag 1)				1.28 (0.00)**	0.59 (0.00)**
Inflation (lag 2)				0.32 (0.00)**	0.11 (0.08)*
Output gap	-0.024 (0.08)*	-0.021 (0.01)**	-0.023 (0.09)*	-0.09 (0.07)*	-0.04 (0.06)*
NOPI		0.051 (0.02)**	0.048 (0.25)	0.0019 (0.05)**	0.0027 (0.23)
Monpol		0.068(0.06)*	0.039 (0.37)	0.005 (0.02)**	0.0028 (0.17)
Asym10			0.291 (0.00)**	0.016 (0.012)**	0.05 (0.00)**
R^2	0.89	0.88	0.90	0.92	0.90
D.W.	1.75	1.83	1.76	2.03	2.09
B.P.	1.84 (0.17)	2.32 (0.12)	2.0 (0.19)	0.03 (0.82)	2.56 (0.19)
J test	1.81(0.41)	1.04(0.59)	1.58(0.45)		2.02(0.34)

[a] *Note*: P-values are in brackets; ** significant at 5%; *significant at 10%. D.W. close to 2 indicates the absence of serial correlation in errors. Breusch Pagan (B.P.) tests the null of homoskedasticity. Hansen's J tests over-identifying restrictions in GMM estimations.

Source: Authors' estimation.

The estimations shows Asym10 explains inflation significantly and is a better proxy for shocks as NOPI becomes insignificant or very low in the presence of Asym10. J test[8] statistics, given in last row of Table 2, are not too large implying that instruments used are appropriate and are independent of error processes. The Monpol variable also becomes insignificant or very low when supply shocks are correctly measured. The coefficient of the output gap remains negative despite the inclusion of supply shock variables, whether only expected inflation (column 1-3) or only lagged inflation (column 4), or a mixture (column 5) enters the AS. Previous estimations that found the slope to be positive with lagged inflation and a measure of supply shocks included, therefore, may not be robust[9].

Inflation also depends on its own lagged values in the data, which an AS with purely forward-looking variables does not capture. Moreover, not all agents have rational expectations. The standard NKAS estimated is the "hybrid" variant which gives a measure of the residual inertia in inflation that is otherwise left unexplained. Backward-looking behavior is likely to be especially important in a developing economy, which has many types of rigidities including administered prices.

The hybrid AS is derived including some firms that follow simple behavioral rules (Gali and Gertler, 2000). This generates inertia in inflation. A fraction of firms set prices using a backward-looking rule of thumb. Although each firm still adjusts its price in any given period with fixed probability $1-\theta$ as in equation (2), out of those changing their prices in period t, a fraction $1-\omega$ of the firms are "forward-looking", and set prices optimally. The remaining firms are backward-looking and use a simple rule of thumb that is based on the recent history of aggregate price behavior. The rule has the following two features: first, there are no persistent deviations between the rule and optimal behavior; that is in steady-state the rule is consistent with optimal behavior. Second, the price in period t, given by the rule, depends only on information dated t-1 or earlier.

If p^f_t denotes the price set by forward-looking firm at *t* and p^b_t the price set by backward-looking firm. Then the index of newly set prices in period *t* is given by:

[8] The Hansen J statistic is a test of over identifying restrictions in GMM estimation. It thus tests the validity of the instruments. It is zero for any exactly-identified equation, and positive for an over identified equation. The null hypothesis of the test states that all instruments are uncorrelated with the errors.

[9] For example, Paul (2009) finds a positive coefficient on the current output gap when he uses an additional lagged output gap variable. Tripathi and Goyal (2013) find a positive coefficient on a lagged output gap variable. The current output gap also turns positive when more inflation lags are included, even though those lags are insignificant.

$$p_t^* = (1-\omega)p_t^f + \omega p_t^b \qquad (9)$$

Forward-looking firms continue to behave exactly as in the baseline model described by equation (3). But backward-looking firms obey a rule of thumb given by:

$$p_t^b = p_{t-1}^* + \pi_{t-1} \qquad (10)$$

That is, a firm sets its price equal to the average price set in the t-1 period, with a correction for inflation. It may also reflect the use of lagged inflation in a simple way to forecast current inflation. This leads to a hybrid AS including inflation lags, which is reported in column 5 of table 2.

But the negative yet significant output gap coefficient is still at odds with the theory. Other problems are, when equation (6) of NKAS, which relates inflation to the next period expected inflation and output gap, is solved forward, we get that inflation should equal a discounted stream of expected future output gap (7). Thus, the model predicts that higher inflation should lead increase in output relative to trend. There is little evidence of such a pattern, however.

The NKE literature has, therefore, argued the measure of the output gap used is flawed. Traditional output gap measures are criticized on the grounds that naive detrending procedures assume potential GDP evolves smoothly over time. In theory, however, a number of shocks can affect potential output, which could fluctuate significantly from period to period. Using marginal cost, the variable that directly enters firms' decisions, would capture these. But this data is only available at the yearly frequency. Therefore we next estimate the yearly NKAS with a marginal cost proxy obtained from Indian industry level data.

6. Yearly NKAS Estimation: Industry level analysis

The theoretical model that underpins the NKAS, equation (4), predicts that it is real marginal cost that drives inflation. It has been estimated using empirical proxies for marginal cost. Gali and Gertler (2000), Gali, Gertler and Salido (2001) and Shapiro (2007) propose using real average unit cost, or labor's share of income, to measure real marginal cost. Cost minimization implies the firm's real marginal cost will equal the real wage divided by marginal product of labor. Assuming a Cobb Douglas production function gives a simple empirically implementable approximation. Let A_t denote technology, K_t denote capital, and N_t denote labor. Then output Y_t is:

$$Y_t = A_t K_t^a N_t^\beta \qquad (11)$$

Real marginal cost is ratio of the real wage (W/P) to the marginal product of labor $(\delta Y/\delta N)$.

$$MC_t = \frac{W_t}{P_t}\frac{1}{\delta Y_t/\delta N_t} \tag{12}$$

Solving for $\frac{1}{\delta Y_t/\delta N_t}$ from the production function and substituting, gives:

$$MC_t = \frac{W_t N_t}{\beta P_t Y_t} \tag{13}$$

Denoting per cent deviation from the steady-state by lower case letters, the real marginal cost can be written as:

$$mc_t = w_t + n_t - p_t - y_t \tag{14}$$

The AS estimated using marginal cost (14), as the output gap variable, is given in Table 3:

Table 3: NKAS: Industry level estimation

Inflation				
	(1)	(2)	(3)	(4)
Expected Inflation	1.06 (0.00)**	0.91(0.00)**	1.01 (0.00) **	0.85 (0.01) **
Marginal cost	0.089(0.02)**	0.034(0.02)**	0.07 (0.03) **	0.08 (0.05) **
NOPI			0.16 (0.00)**	0.05 (0.23)
Monpol			0.13(0.00)**	0.08 (0.35)
Asym10		0.048(0.01)**		0.05 (0.01) **
R-square	0.65	0.72	0.72	0.72
J test	2.12(0.58)	2.80(0.42)	5.49(0.23)	8.83(0.11)

[a] *Note*: ** significant at 5%; p-values in brackets.
Source: Authors' estimation.

All the coefficients are significant in column (1), (2) and (3). Hansen's J test shows that instruments used and model estimates are valid. The slope coefficient, with *mc* used instead of IIP as the output gap, is now correctly signed. It is positive, and the coefficient is significantly different from zero. But when the supply shock variable, Asym10, is added to the estimation (column 2), the slope decreases. Monpol and NOPI both became insignificant (column 4) suggesting that Asym10 is a better proxy for supply shocks. When supply shocks are correctly measured (column 4) the policy shock variable Monpol becomes insignificant. Since Monpol captures policy induced demand shocks, this implies that it is the supply curve being estimated and not equilibrium outcomes affected by both demand and supply variables.

Combining equations (9) and (10) with equation (2) gives the hybrid AS curve that also includes lagged inflation:

$$\pi_t = a_f E_t\{\pi_{t+1}\} + \gamma mc_t + a_b \pi_{t-1} + e_t$$

Where:

$$\phi = \theta + \omega[1 - \theta(1-\beta)]$$
$$a_f = \beta\theta\phi^{-1}$$
$$a_b = \omega\phi^{-1}$$
$$\gamma = (1-\omega)(1-\theta)(1-\beta\theta)\phi^{-1}$$

The coefficients are explicit functions of three structural model parameters: θ, the degree of price stickiness; ω, the degree of backwardness in price settings, and the discount factor β. The empirical estimation of the hybrid AS is:

Table 4: Hybrid AS: Industry level estimation

Inflation				
	(1)	(2)	(3)	(4)
Expected inflation	0.69(0.05)**	0.73(0.03)**	0.69 (0.01)**	0.83(0.02)**
Marginal cost	0.19(0.02)*	0.029(0.06)**	0.25 (0.02)**	0.08(0.04)**
NOPI			0.10 (0.00)**	0.02 (0.77)
Monpol			0.07 (0.05)**	0.02 (0.35)
Lagged inflation	0.21(0.01)**	0.30 (0.02)**	0.33(0.00)**	0.31 (0.06)*
Asym10		0.027 (0.02)**		0.05 (0.06)*
R square	0.65	0.64	0.67	0.62
J test	6.5(0.12)	5.4(0.17)	6.01(0.18)	5.5(0.17)

[a] *Note*: ** significant at 5%; *significant at 10%; p-values in brackets.
Source: Authors' estimation.

Instruments used are valid. Coefficient of log of marginal cost comes in with right sign. On adding supply shocks the size of the coefficient falls significantly, suggesting the correct AS is almost flat but subject to shifts captured by the Asym10 variable. In all the estimations, though Asym10 comes in with small coefficients it is always significant. Its inclusion continues to make NOPI and Monpol insignificant (column 4).

The final estimated AS of column (2) Table 4 is also used to get estimates of structural parameters. The parameter θ is 0.516. The parameter ω is 0.34. That is, 34 per cent of industries are backward-looking in price setting. The parameter β comes out to be 0.96.

7. Conclusion

Measurement of variables and identification strategies impact estimated coefficients in any regression. We show the estimated slope of the AS is sensitive to the method of estimation and to the measurement of the supply shocks and the output gap variable. Measures of asymmetries in price changes capture a large fraction of the shifts in the AS due to supply shocks. These variables outperform traditional measures of supply shocks, such as the changes in the relative prices of food and energy.

When our asymmetry measures are included, the coefficients on energy prices are either close to zero, or are statistically insignificant. In contrast, the inclusion of the traditional measures of supply shocks has little effect on the size or significance of the asymmetry variables, implying our variables are better measures of supply shocks than are the traditional variables. Particular price shocks such as food and energy matter because, together with propagation mechanisms such as administered prices, they induce positive skew in the distribution of price changes. So the shocks themselves are unsatisfactory proxies, and their use in previous studies on the AS may have biased estimated coefficients.

When supply shocks are correctly measured, coefficients on monetary policy, which is a demand variable, becomes insignificant, implying that it is the supply curve that is being estimated and the regressions are not reproducing equilibrium outcomes affected by both demand and supply variables.

Better measurement of both supply shocks and of the output gap variable, reduces the size of the coefficient on the output gap. The final estimated AS has a small positive slope, but has significant shift variables. One rationale for such an aggregate supply curve is if wage negotiations, and therefore firm costs, respond more to supply shocks, such a food prices, than to cyclical factors, so costs rise at all levels of output during supply shocks.

If supply shocks are frequent, and there is a negative correlation between growth and inflation observed in Indian data, then simple regressions may estimate a downward sloping demand curve along which the supply curve shifts, thus explaining the negative slope obtained in early studies, and the incorrectly high slope coefficient for the AS obtained in later estimation that introduced supply shocks.

Our results also show that an average Indian firm changes prices about once in a year. Half of the firms reset their prices in any period, and 66 per cent of firms are forward-looking in their price setting. The share of firms with forward-looking behavior exceeds those with backward-looking behavior.

These estimated real and nominal price rigidities imply that a sharp policy response to a rise in expected future excess demand can prevent the 66 per cent of forward-looking firms from raising prices. Since the higher prices set would persist for about a year, policy that anchored inflation expectations would reduce persistence of inflation. This is without any cost to output since inflation is reduced by reducing future, not current, output gaps.

However, about 34 per cent of firms are backward-looking, so there would be some inflation persistence and lagged effects of policy rate changes. Moreover, once supply shocks are correctly estimated, the AS has only a mild upward slope. So there is a large output cost in reducing demand in response to a supply shock, with little effect on inflation. Policy may allow the price level effect of a temporary supply shock without tightening. But it should consider other alternatives such as better communication, and supply-side actions to anchor inflation expectations. For example, a temporary appreciation can neutralize a supply shock. In addition, demand tightening may shift down the supply curve to the extent it reduces a second round rise in wages. This is a topic for further research. Monetary policy continues to be highly effective, but optimal stabilization may require the use of unconventional methods.

IMF (2013) shows evidence the AS has become flatter in advanced economies in recent years, implying reduced responsiveness of inflation to economic slack. They attribute this partly to the better anchoring of inflation expectations. In an emerging market like India, the slope may be low for more traditional reasons of excess capacity. But frequent shocks raise costs at all levels of output as inflation respond more to extraneous shocks like food prices rather than to cyclical factors. Credible anchoring of inflation expectations can act on some of these responses such as rise in wages. It requires complimentary reform of the administered price mechanisms and other factors that tend to raise costs and propagate shocks. This would moderate the impact of relative price shocks on aggregate prices, which lead to frequent shifts of the AS.

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