WP-2011-026

Relative Prices, the Price Level and Inflation: Effects of Asymmetric and Sticky Adjustment

Shruti Tripathi and Ashima Goyal

Indira Gandhi Institute of Development Research, Mumbai
October 2011
http://www.igidr.ac.in/pdf/publication/WP-2011-026.pdf

Relative Prices, the Price Level and Inflation: Effects of Asymmetric and Sticky Adjustment

Shruti Tripathi and Ashima Goyal
Indira Gandhi Institute of Development Research (IGIDR)
General Arun Kumar Vaidya Marg
Goregaon (E), Mumbai- 400065, INDIA
Email (corresponding author): ashima@igidr.ac.in

Abstract

The paper examines how relative price shocks can affect the price level and then inflation. Using Indian data we find: (i) price increases exceed price decreases. Aggregate inflation depends on the distribution of relative price changes—inflation rises when the distribution is skewed to the right, (ii) such distribution based measures of supply shocks perform better than traditional measures, such as prices of energy and food. They moderate the price puzzle, whereby a rise in policy rates increases inflation, and are significant in estimations of New Keynesian aggregate supply, (iii) an average Indian firm changes prices about once in a year; the estimated Calvo parameter implies half of Indian firms reset their prices in any period, and 66 percent of firms are forward looking in their price setting. The implication of these estimated real and nominal price rigidities for policy are drawn out.

Keywords:

WPI, NKPC, asymmetric, stickiness, size, frequency, inflation

JEL Code:

E31, E12, C26, C32

Acknowledgements:

We thank Reshma Aguiar for help with the word processing.

Relative Prices, the Price Level and Inflation: Effects of Asymmetric and Sticky Adjustment

Shruti Tripathi and Ashima Goyal

1.1 Introduction

Many studies have examined data underlying nationally-representative consumer and producer price indices from national statistical agencies. A smaller set of studies have focused on micro level data for a subset of manufacturing industries. They offer many insights on price setting, price stickiness and determinants of inflation in the short run, which have direct consequences for the conduct of monetary policy.

In this paper, the focus is on price setting in India and its responses to shocks. Klenow and Malin (2010), found that one of the features of price setting in developing countries are more frequent price changes reflecting higher inflation rate existing in the country. We try to test this hypothesis using non parametrical approach and examine the link between frequency and size of price changes. When a firm experiences a shock to its desired relative price, it changes its price only when the change in price is large enough to cover the cost of the process of change. It implies that firms may respond to large shocks and not to small shocks. This hints that distribution of desired changes in relative price may have a role to play in determining average price level.

Results in the literature[1] are: First, individual prices change at least once a year. The frequency is closer to twice a year in the U.S. versus once a year in the Euro Area. Second, goods differ significantly in how frequently their prices change. At one extreme are goods whose prices change at least once a month (food, energy), and at the other extreme are services that change prices much less often than once a year. Such heterogeneity makes mean price durations much longer than median durations. Third, goods with more cyclical qualities

[1] See Alvarez et.al (2008), Goldberg-Hellerstein (2009), Bunn and Ellis (2009), Gautier (2008), Fabiani et.al (2005), and Blinder (1998).

(cars and apparel) exhibit greater micro price flexibility than goods that doesn't show much cyclicality. Durables prices as a whole change more frequently than nondurables and services. Fourth, the timing of price changes is little synchronized across products. In the US most movements in inflation (from month to month or quarter to quarter) are due to changes in the size rather than the frequency of price changes. In countries with more volatile inflation, such as Mexico, the frequency of price changes has shown more meaningful variation. Fifth, changes in price level are positively related to the skewness of relative price changes. Suppose, for example that the distribution of desired changes in relative prices are skewed to the right. In this case a few firms desire a large price increase, which gets balanced with small price decreases by most of the firms. However, due to existence of menu cost, firms respond more quickly to a large change in price then to a small change. Desired increases occur more quickly than desired decreases. Hence, the price level rises in the short run.

We found average price increase over time is greater than average price decrease. While price increase is around 10 percent price decrease is less than 5 percent. This suggests that the positive rate of inflation in India might be driven by much higher price increases compared to price decreases. It takes around one year for the Indian market to change the price of the products which implies both real and nominal rigidities in the market.

We also found changes in the price level are positively related to skewness of relative price changes. Results suggest that the asymmetry variable is a better measure of supply shocks than the traditional variables. Traditional variables performed well in earlier studies because they were acting as proxy for asymmetries. The results also suggest that the relationship between asymmetries and inflation holds across all time period.

The paper has three main sections. The first on price stickiness and the second on asymmetric behavior of prices and the third on estimation of Phillips curve for India. The last, section four, concludes and draws out some implications.

2. Price Stickiness

There are two theories regarding the correlation between frequency and size of price change. The majority of price setting models predict a negative correlation between the frequency and size of price changes. If prices are rigid and change less often, the size of price change tends to be larger, as the new optimal price is likely to be further from the original price (Mankiw, 1985). In contrast, Rotemberg (1982) argues that in case of convex costs of price adjustment, the frequency and size of price changes will exhibit positive correlation. To supplement this literature from a developing country's perspective, this paper studies the relationship between frequency and size of price change non-parametrically using Indian disaggregated WPI data.

2.1 Data Set

The data set contains the wholesale price index (WPI) records of 90 products collected at monthly frequency by the Office of Economic Adviser, Government of India from M4 1971 to M4 2010.

2.2 Measuring Frequency and Size of Price Changes

To define frequency of price changes and the duration of a single price spell formally we follow Horvath (2011). Let p_{it} be the price of product *i* at time *t*.

Then we define:

$$x_{it} = \begin{cases} 1 \; if \; p_{it} \neq p_{it-1} \\ 0 \; if \; p_{it} = p_{it-1} \end{cases} \tag{1}$$

As a result, the product-specific frequency of price changes, μ, is computed as:

$$\mu_i = \frac{1}{T} \sum_{t=1}^{T} x_{it} \tag{2}$$

T

he frequency of price changes is calculated as the ratio of price changes in the month to the number of observations for which the price of the particular product is available.

The product-specific size of price increases, λ_i, is computed as:

$$\lambda_i = \frac{1}{T} \sum_{t=1}^{T} \theta_{it} \left(\frac{p_{it} - p_{it-1}}{p_{it-1}} \right) \; where \; \theta_{it} = \begin{cases} 1 \; if \; p_{it} > p_{it-1} \\ 0 \; if \; p_{it} \leq p_{it-1} \end{cases} \tag{3}$$

Similarly, the product-specific size of price decreases

$$\gamma_i = \frac{1}{T} \sum_{t=1}^{T} \delta_{it} \left(\frac{p_{it} - p_{it-1}}{p_{it-1}} \right) \; where \; \delta_{it} = \begin{cases} 1 \; if \; p_{it} < p_{it-1} \\ 0 \; if \; p_{it} \geq p_{it-1} \end{cases} \tag{4}$$

That is, the size of price changes is calculated as the percentage increase (decrease) of the price of a particular item in the month *t* compared to the price of the same item in the month *t-1*, conditional on the occurrence of a price change (i.e. zero percent price changes are not included).

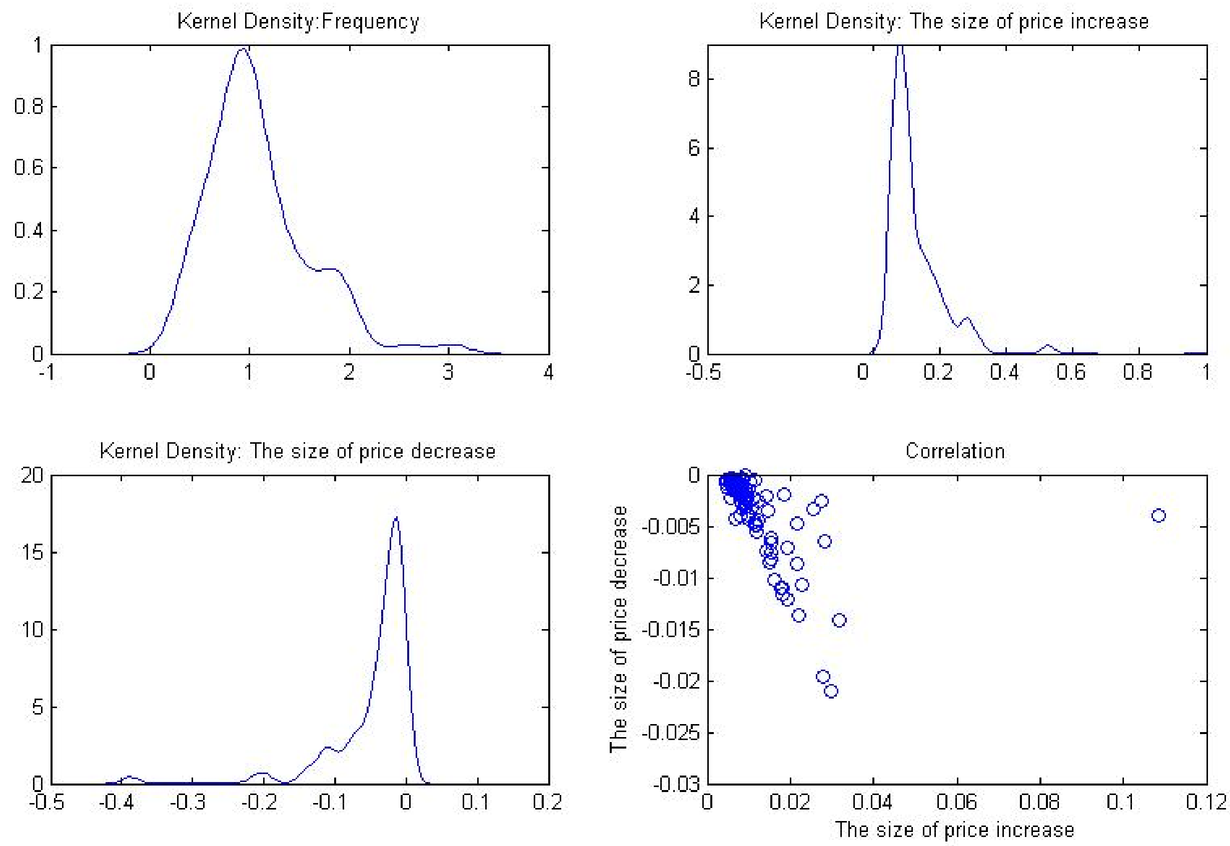

Figure 1: Frequency and Size of Price Changes

Figure 1 gives descriptive statistics on frequency of price changes, size of price increase, size of price decrease and correlation between sizes of price increase vis-à-vis decrease. The first three figures give the kernel density for the frequency and price increase and decrease. Y-axis gives density values and x-axis gives the points at which these density values are evaluated. Kernel density estimation is a non-parametric way of estimating the probability density function of a random variable.

The result represented by the first graph indicates the most common frequency of price change is around one, so the typical price changed in about one year during the sample period, reflecting price rigidity in the Indian market.

The second graph gives kernel density for the size of price increase. Conditional on frequency of price change, the result suggests that the magnitude of the price increase is around 10 percent. The magnitude of price decrease, given by the lower left graph, is much lower, slightly less than 5 percent.

According to the Kernel density graph price falls are more frequent but lower in magnitude. On the other hand frequency of price increase is lower but the magnitude is higher. The result may be due to bi-annual sales in the Indian consumer products market. But price increases only when the magnitude is large enough to cover menu cost.

The last part of Figure 1 gives the correlation between the magnitude of price increases and decreases. It indicates high correlation between the two. In value terms it comes to -0.865. This result may point to the pricing method followed at the retail level. It is possible price decreases with temporary sales, and prices increase with the end of sales as well as with positive inflation.

The correlation value between frequency of price change and the size of price increase was found to be highly significant (0.22 with t-value = 2.076), while the correlation value between frequency of price change and the size of price decrease turned out to be insignificant (-0.16 with t-value = -1.43). This means that if there is a change in prices, there is a higher probability of price rise. Our finding is in confirmation with the literature for developing countries[2].

The main findings of this section are: average price increase over time is greater than average price decrease. While price increase is around 10% price decrease is less than 5%. This suggests that the positive rate of inflation in India might be driven by much higher price increases compared to price decrease. Prices of Indian products are changed in around one year which implies both real and nominal rigidities in the market.

[2]In a study for Brazil price increases are less frequent after a period of exchange rate appreciation and more frequent when inflation is higher; in periods of high economic activity; and when macroeconomic uncertainty is higher (Barro et.al. 2009). Duration of price spells is just above 6 months. In a study for Hungary the mean duration of prices is 8 months. The average size of increases is 11.2 percent, and the average size of decreases is 8 percent (Gabriel and Reiff 2008). However, Medina et.al (2007) found, that at a firm level, prices are adjusted on average every three months.

3. Asymmetric Price Changes

3.1 The distribution of price change

To give an initial sense of asymmetries, Figure 2 presents histograms of log industry price changes for four years. In constructing these histograms, each industry is weighted as in the WPI. Here weights are taken as a proxy for relative importance of industries in the reference year.

Figure 2 shows considerable variation in the distribution of price changes. While 1974 and 2006 show a distribution skewed to the right, implying an increase in the overall price level, 1984 gives a left skewed distribution. In this case, the lower tail is larger than the upper tail implying a fall in the price level. However the distribution in 2000 is more or less symmetric. In this case, firms or industries with desired change in the upper tail of distribution raise their price and those in the lower tail lower their price, so the effect on the price level is low. The first two years correspond to OPEC shocks oil prices rose in both the years.

It is also noticeable that the number of products changing price was much higher in 2006, at around 60, compared to the number changing prices in 1974 (little more than 40). In the earlier period oil prices were administered and other prices were also controlled, so fewer industries may have felt the need to adjust their prices during a supply side shock than in the more recent period.

Table A1 in the Appendix presents the inflation, standard deviation and skewness of the log wholesale price index for each year. The table reflects the scenarios given by the four year example of Figure 2. The skewness of price changes varies over time, and it varies together with the inflation rate. Years of negative skewness (1978, 1982, 1995, 1996, 1999) coincides with years of decreasing inflation whereas years of positive and high value skewness tend to be years of high inflation.

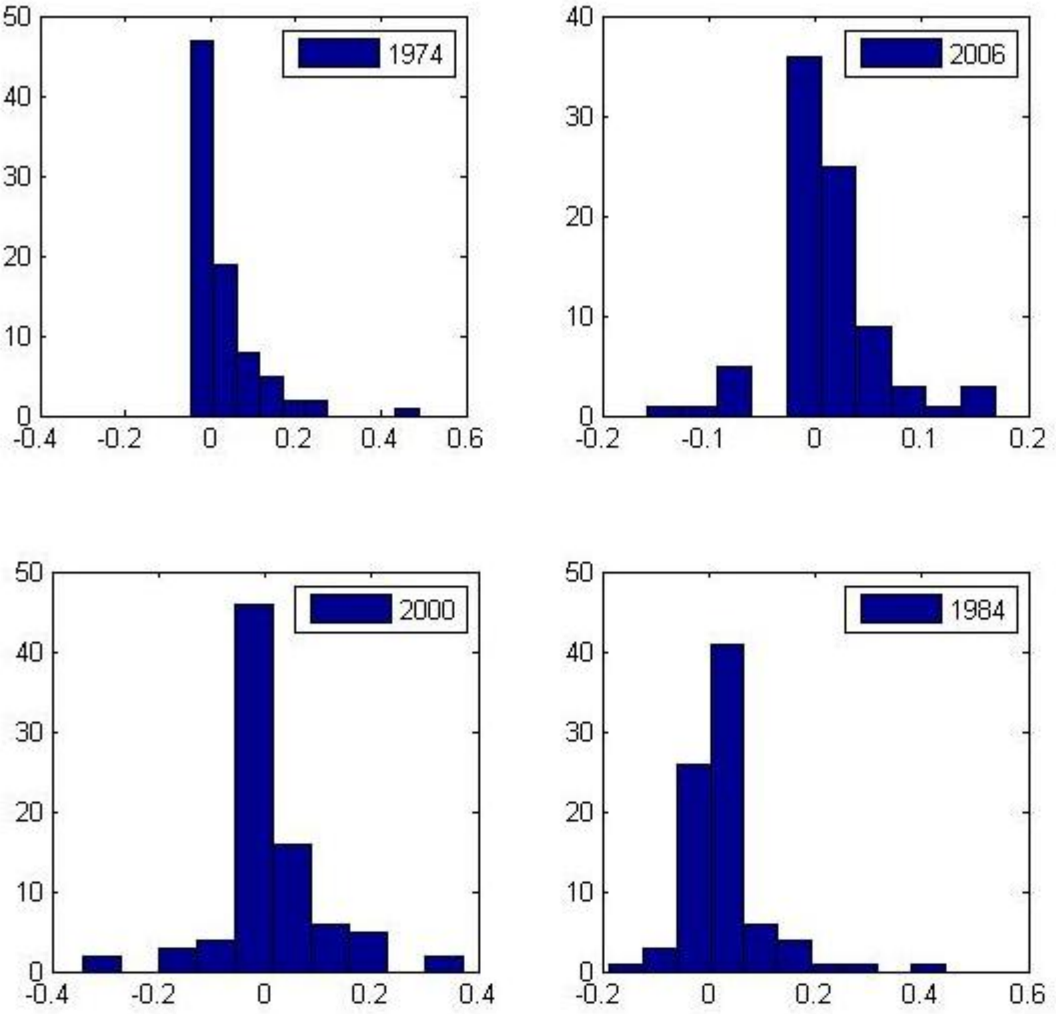

Figure 2: Histogram of Log of Wholesale Price Changes for Four Years

3.2 Data Set

The data set contains the wholesale price index (WPI) collected at monthly frequency by the Office of Economic Adviser, Government of India from M4 1971 to M4 2010. Crude oil prices in US dollar per barrel for the same period was taken from International Energy Agency and data on call money rate as an instrument of monetary policy was taken from Reserve Bank of India website.

3.3 Estimating Inflation

We now turn to more systematic analysis of the data and test whether skewness and variance have inflationary effect on price change. It's been well documented that inflation in any period depends on demand and supply shocks and monetary policy changes. So, we estimate a benchmark model which includes oil price shock as supply shock, monetary policy variable as affecting demand, and lagged inflation, to capture persistence. Then sequentially we introduce standard deviation, skewness, interaction term and all variables together and attempt to confirm the relationship between inflation and skewness.

In the literature, a number of transformations have been suggested as a proxy for an oil price shock[3]. A final transformation for oil shocks was proposed by Hamilton (1996a), who also advocated an investment-uncertainty transmission mechanism. He argued that "[i]f one wants a measure of how unsettling an increase in the price of oil is likely to be for the spending decisions of consumers and firms, it seems more appropriate to compare the current price of oil with where it has been over the previous year rather than during the previous quarter alone (p.216)". Specifically, his "net oil price increase" (NOPI) transformation equals the percentage increase over the previous year's high if that is positive, and zero otherwise. This 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.

In our estimation we use Hamilton's definition of oil price shock. For monetary policy variable (Monpol) change in call money market rate is taken. In all regressions, the left hand side variable is the log change in WPI[4]. Tables 1 and 2 test the inflationary effect of the variance and skewness in relative price changes. Table 1 presents results using un-weighted moments of relative price changes or moments with equal weighting of all prices and Table 2 uses weighted moments. That is each component is weighted as in the official WPI calculation. (Specifically, each component's price change is weighted by the "relative importance" of the industry in 1993-94). Column 1 is benchmark equation that uses only lagged inflation to explain current inflation. Columns 2 to 4 introduce the standard deviation of relative price changes, the skewness and both variables together. Columns 5 and 6 add the

[3] Mork (1989) defined oil price as the producer price index for crude oil. To construct a proxy for oil shock he simply set values less than zero (price decreases) equal to zero in log differences of PPI. Ferderer (1996) examined the hypothesis that oil prices affect the economy via a sectoral shifts transmission mechanism as in Lilien (1982) and Loungani (1986), whereby oil price changes in either direction induce costly sectoral reallocations of resources, or via an investment-uncertainty mechanism (Bernanke (1983) and Pindyck (1991)), whereby increased uncertainty increases the option value of waiting and leads to delayed investment. His proxy for the sectoral shifting and uncertainty that oil prices generate is a weighted within-month standard deviation of daily spot prices of different petroleum products.

[4] All the variables were found to be stationary using the ADF test. The estimation method was OLS.

interaction between the standard deviation and skewness. All the regressions also include lagged inflation to capture persistence, NOPI and the monetary policy variable.

Skewness is a measure of the asymmetry of the probability distribution of a real-valued random variable. The skewness value can be positive or negative, or even undefined. Qualitatively, a negative skew indicates that the tail on the left side of the probability density function is longer than the right side and the bulk of the values (possibly including the median) lie to the right of the mean. A positive skew indicates the tail on the right side is longer than the left side and the bulk of the values lie to the left of the mean. A zero value indicates that the values are relatively evenly distributed on both sides of the mean, typically but not necessarily implying a symmetric distribution.

These regressions confirm the relation between skewness and inflation and its contribution to R^2. The standard deviation turns out to be insignificant, but the two moments interact positively. Standard deviation magnifies the effect of skewness. When both weighted moments and their interaction are included there is significant increase in R^2 (centered). Table 1 and 2 also brings out the price puzzle.

The coefficient of Monpol is consistently positive. The frequent positive relationship between the interest rate and inflation in empirical estimations is known as the “price puzzle” (Bernanke and Blinder (1992) and Sims (1992)). It is a puzzle because an unexpected tightening of monetary policy (that is, an unexpected increase in the policy rate) is expected to be followed by a decrease in inflation so that the coefficient of the interest rate in an equation for inflation should be negative. However, we see a decline in coefficient of Monpol after the inclusion of a variable (SD, Skewness) representing asymmetric behavior of prices and thereby capturing some effects of supply shocks. In the literature the price puzzle normally disappears when supply shock variables are introduced, since these tend to raise prices. Here it does not disappear with NOPI, but is considerably reduced with skewness variable, suggesting skewness is better measure of supply shocks. In view of this impact we next develop another more robust measure of asymmetry.

Table 1: Inflation and Distribution of Price Changes						
	Dependent Variable: Inflation (unweighted measures of dispersion)					
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	0.021(0.005)**	0.017(0.007)**	0.019(0.006)**	0.007(0.007)**	0.012(0.005)**	0.004(0.007)*
Lagged inflation	0.375(0.154)**	0.268(0.120)**	0.323(0.156)**	0.429(0.150)**	0.505(0.148)**	0.428(0.105)**
Standard deviation		0.017(0.167)		0.17(0.109)		0.178(0.112)
Skewness			0.007(0.002)*	0.041(0.001)**	0.047(0.004)*	0.005(0.004)*
Skew*SD					-0.004(0.044)	-0.016(0.156)
NOPI	0.003(0.00)**	0.003(0.00)**	0.003(0.00)**	0.003(0.00)**	0.003(0.00)**	0.003(0.00)**
Mon pol	0.007(0.01)*	0.007(0.01)*	0.002(0.01)*	0.002(0.01)*	0.004(0.01)*	0.001(0.01)*
R^2	0.52	0.55	0.59	0.61	0.65	0.73
D.W.	1.766	1.738	1.828	1.795	1.801	1.804
Breusch-pagan	0.21(0.645)	0.47(0.49)	0.39(0.53)	0.41(0.52)	0.44(0.51)	0.28(0.62)

Note: Standard errors in the brackets; ** significant at 5%; *significant at 10%. If the errors are white noise, D.W. will be close to 2. Breusch Pagan tests the null of homoskedasticity.

Table 2: Inflation and Distribution of Price Changes						
	Dependent Variable: Inflation (Weighted measures of dispersion)					
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	0.021(0.005)**	0.017(0.007)**	0.019(0.006)**	0.007(0.007)**	0.012(0.005)**	0.004(0.007)*
Lagged inflation	0.375(0.154)**	0.268(0.130)*	0.323(0.156)**	0.429(0.150)**	0.505(0.148)**	0.428(0.105)**
Standard deviation		0.017(0.167)		0.17(0.109)		0.178(0.112)
Skewness			0.007(0.002)*	0.041(0.001)**	0.047(0.004)*	0.005(0.004)*
Skew*SD					-0.004(0.044)*	-0.016(0.156*
NOPI	0.003(0.00)**	0.003(0.00)**	0.003(0.00)**	0.003(0.00)**	0.003(0.00)**	0.003(0.00)**
Mon pol	0.007(0.01)*	0.001(0.01)*	0.007(0.01)*	0.002(0.01)*	0.007(0.01)*	0.007(0.01)*
R^2	0.52	0.55	0.60	0.68	0.73	0.78
D.W.	1.766	1.738	1.828	1.795	1.801	1.804
Breusch-Pagan	0.3(0.85)	0.40(0.53)	0.34(0.56)	0.68(0.41)	0.56(0.29)	0.91(0.33)

3.4 Alternative Measure of Asymmetry

Ball and Mankiw (1995) measure of asymmetry is a weighted average of relative price movements that are greater in absolute value than some cut off X. That is their measure is:

$$AsymX = \int_{-\infty}^{-x} rh(r)dr + \int_{x}^{-\infty} rh(r)dr \qquad (5)$$

Where r is an industry relative price change (an industry inflation rate minus the mean of industry inflation rates) and h(r) is the density of r. Loosely speaking, AsymX is the change in the aggregate price level caused by price changes of industries whose relative price changes by more than X. Here the focus is on the case of X=10 percent. The resulting series for AsymX exhibits large fluctuations over time. Some of the extreme observations correspond to well-known oil shocks; for example AsymX is large and positive during the year 1974, 1980, 1990 and 2004.

Table 3 examines whether this asymmetry variable explains movements in inflation by regressing inflation on lagged inflation and AsymX = 10 percent, in the presence of variable tracking supply side shocks in form of NOPI and the policy response Monpol.

Table 3: Alternative measure of Asymmetry

	Dependent Variable: Inflation (Weighted measures of dispersion)	
	(1)	(2)
Constant	0.025(0.002)**	0.024(0.003)**
Lagged inflation	0.046(0.021)*	0.044(0.031)*
AsymX	0.003(0.00)**	0.003(0.00)**
NOPI		0.001(0.77)
Monpol		0.004(0.72)
R^2	0.75	0.77
D.W.	1.86	1.66
B.P.	0.82(0.15)	0.63(0.32)

Note: Standard error in brackets

Fundamentally, the theory says that inflation depends on the size of tails of the distribution of changes in relative prices. Here the effort is to test this theory with a single variable-one that takes care of both skewness and variance. It was found that AsymX explains inflation significantly and is a better proxy for shocks as NOPI turns insignificant in the presence of

AsymX. That the Monpol variable is also insignificant suggests the dominance of supply shocks for inflation.

Main Findings:

- Changes in the price level are positively related to skewness of relative price changes. Which leads to inflation in following way: suppose, for example, the distribution of desired changes in relative prices is skewed to the right. In this case, few firms would like to make large increases in price, which gets balanced by small desired decreases by other firms. Since firms respond more quickly to large shocks than to small shocks, the desired increase occurs more quickly. Thus the average price rises in the short run.
- The result suggests menu cost models of price adjustment.
- These results suggest that an asymmetry variable is a better measure of supply shocks than the traditional variables. Traditional variables performed well in earlier studies because they were acting as proxy for asymmetries.
- The results also suggest the relationship between asymmetries and inflation holds across all time periods. In contrast, energy prices affect inflation only when they have major effect on asymmetries.

4. Estimation of the Phillips Curve

A large literature on the dynamics of inflation takes the Phillips curve as the starting point of the analysis. In the Phillips curve literature, inflation depends on past inflation, on supply shocks and on a measure of the business cycle such as the output gap, or marginal cost, or unemployment. From this outlook the above regression is like an estimated Phillips curve, with the omission of a business cycle variable. To relate this study with the Phillips curve literature, we estimate a Phillips curve for India on the basis of various definitions and then modify it to include supply shocks. However the supply shock included in the estimation would not be the traditional variables defining supply shock but the AsymX as defined above.

Data used for estimation of the Phillips curve are WPI, IIP, Interest rates (CMR), exchange rate and oil prices at monthly frequency. The period of estimation was from 1986M5 to 2010M12. Data is mainly taken from Reserve Bank of India (RBI) website. All variables were converted into logs and first differenced except for interest rate. IIP was taken as a measure of output gap and hence the HP detrended series of IIP were taken.

4.1 The Traditional Phillips Curve:

The Friedman-Phelps description of the Phillips curve was predicated on the assumption that expectations about inflation evolved over time as a result of actual past experience— that is, that expectations were formed adaptively. In empirical evaluations of the hypothesis, therefore, researchers used a distributed lag of past inflation rates to proxy for expectations, and then tested whether such proxies received a coefficient of unity:

$$\pi_t = 1.260\pi_{t-1} - 0.269\pi_{t-2} + 0.017y_{t-1} + e_t$$

All the coefficients were significant. The output term enters significantly with a positive sign. Sum of coefficients on lagged inflation does not differ significantly from unity.

When we include the variable representing asymmetric changes in price (AsymX), the equation changes to:

$$\pi_t = 1.210\pi_{t-1} - 0.28\pi_{t-2} + 0.013y_{t-1} + 0.004AsymX + e_t$$

Criticism:

This form of Phillips curve strategy was criticized in two remarkable papers by Sargent (1971) and Lucas (1972). For these economists, the treatment of expectations implicit in estimates of above equation was deficient in that it was inconsistent with forward looking rational behavior. Sargent argued (at the time) the U.S. inflation process appeared to be mean-stationary, so it was quite reasonable for the public to formulate inflation expectations in a manner that was consistent with mean-reversion. Thus, forcing the distributed lags on past inflation to sum to one was inconsistent with the forecasts that a rational agent would make, and would lead to empirical estimates of sum of coefficients to be less than one even if the hypothesis were correct. In Lucas's almost simultaneous analysis, the central bank pursues a monetary policy in which money growth (and hence inflation) is mean stationary, so reduced-form regressions for inflation would yield values of sum of coefficients less than one even though agents had rational expectations and the economy by construction did not manifest a long-run tradeoff between output and inflation.

4.2 The New Phillips Curve

Lucas and Sargent's introduction of rational expectation into the field of economic modeling made the traditional Philips curve obsolete. The challenge was then to demonstrate that persistent effects of nominal disturbances can be obtained in a rational expectations framework. By far the most popular formulation, the new-Keynesian Phillips curve, is based on Calvo's (1983) model of firms' random price adjustment. This formulation has several advantages, but most important of all is that it provides micro founded formulation of inflation output tradeoff that is consistent with rational expectations. This model assumes that in each period a random fraction $(1 - \theta)$ of firms reset their price, while all other firms keep their prices unchanged. Thus, the evolution of the (log) price level is given by:

$$p_t = \theta p_{t-1} + (1-\theta)p_t^* \tag{6}$$

Where p^*_t is the price chosen by those who can reset their prices. Assuming an imperfectly competitive market structure such that, absent any frictions, firms would set their price as a fixed markup over marginal cost, a firm's optimal reset price is determined by:

$$p_t^* = (1-\beta\theta)\sum_{k=0}^{\infty}\beta\theta^k E_t\{mc_{t+k}^n\} \tag{7}$$

Let β be the firm's discount factor, and mc^n_t is a firm's nominal marginal cost. In other words, firms take into account that their prices will likely be fixed over some period by setting their price equal to a weighted average of expected future nominal marginal costs. Note that in the limiting case of perfect price flexibility (θ=0), the firms simply adjust its price proportionately to the movements in the current marginal cost. The future becomes relevant only 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 percent deviation of the firm's real marginal cost from its steady state value. The equations (6) and (7) can be combined to yield a new-Keynesian Phillips curve (NKPC) of the form:

$$\pi_t = \beta E_t \pi_{t+1} + \frac{(1-\theta)(1-\beta\theta)}{\theta}(mc_t) \tag{8}$$

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

$$mc_t = kx_t = k(y_t - y_t^*) \tag{9}$$

With this assumption, the NKPC becomes:

$$\pi_t = \beta E_t \pi_{t+1} + \lambda x_t \tag{10}$$

Where $\lambda = k.\frac{(1-\theta)(1-\beta\theta)}{\theta}$. This model of inflation has several appealing features. As with the traditional Philips curve, inflation depends positively on the output gap and a "cost push" term that reflects the influence of expected inflation. A key difference is that it is $E_t\{\pi_{t+1}\}$ as opposed to $E_{t-1}\{\pi_t\}$ that matters. As a consequence, inflation depends exclusively on the discounted sequence of future output gaps. This can be seen by iterating equation 10 forward, which yields:

$$\pi_t = \lambda \sum_{k=0}^{\infty} \beta^k E_t\{x_{t+k}\} \quad (11)$$

Implications:

While standard econometric models include lagged inflation, these lags are often understood to be proxying for expectations, so the NKPC bears some resemblance to the original Phillips model. However, the strength of this statistical correlation is likely to vary across monetary policy regimes: In periods when the Central Bank (CB) has little credibility, the public may formulate its inflation expectations based on actual recent inflation performance, rather than on the public statements of the CB. By contrast, if the CB maintains a credible inflation target, then recent lagged values of inflation may play only a small role in the formulation of expectations.

Probably the most important implication of the NKPC model is that there is no "intrinsic" inertia in inflation, in the sense that there is no structural dependence of inflation on its own lagged values. Instead, inflation is determined in a completely forward-looking manner. The idea that there is considerable inertia in inflation, and hence that it is difficult to reduce inflation quickly, does not hold in this framework. According to the NKPC, the CB can costlessly control inflation due to excess demand by committing to keep the output close to its potential level in the future, although there is a tradeoff between output and inflation variability under supply shocks.

To estimate equation (10) we used Generalized Methods of Moments (GMM)[5] which removes any simultaneity bias in a single equation. The instruments used to proxy expected future inflation were; interest rate, exchange rate depreciation, oil price inflation and older lags of inflation.

[5]In the GMM technique valid instruments take care of the problem of endogeneity in explanatory variables when the data distribution function is not known, so maximum likelihood estimation is not applicable

$$\pi_t = 1.06E_t\{\pi_{t+1}\} - 0.034y_t + e_t$$

We found that all coefficients turned out to be significant. However, coefficient of output gap comes in with wrong sign. Statistic for J test for over identification is 6.633(0.084) (the null hypothesis that the model is "valid"). F test for weak instruments 271.5 (0.00) (null hypothesis instruments are weak).

In the presence of AsymX the equation changes to:

$$\pi_t = 1.06E_t\{\pi_{t+1}\} - 0.031y_t - 0.003AsymX_t + e_t$$

Problem with this approach:

When equation (10) of NKPC, 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 (11). Thus, the model predicts that higher inflation should lead increases in output relative to trend. In fact, however, there is little evidence of such a pattern in the literature and data. The coefficient associated with the output gap is negative and significant, which is at odds with the theory.

These poor results suggest two possible interpretations: Either the rational-expectations NKPC provides a bad description of inflation, or else this particular measure of the output gap is flawed. Perhaps unsurprisingly, the latter explanation has proven popular in recent years with proponents of the model. Typically, these researchers criticize traditional measures of the output gap on the grounds that naive detrending procedures assume that potential GDP evolves smoothly over time. In theory, however, changes in potential output will be affected by any number of shocks, and so could fluctuate significantly from period to period.

1.3 NKPC Estimation: Industry level analysis

The theoretical model that underpins the NKPC, equation (8), predict that it is real marginal cost that drives inflation. In recent years this workable model of NKPC has been estimated using empirical proxies for marginal cost. In particular Gali and Gertler (2000), Gali, Gertler and Salido (2001) and Shapiro (2007) have proposed using real average unit cost to measure real marginal cost. This proxy is labor's share of income.

Let's assume that existing technology takes form of Cobb Douglas function. Let A_t denote technology, K_t denote capita; and N_t denote labor. Then output Y_t is given by:

$$Y_t = A_t K_t^{\alpha} N_t^{\beta} \tag{12}$$

Real marginal cost is then given as ratio of the wage rate to the marginal product of labor.

$$MC_t = \frac{W_t}{P_t} \frac{1}{\delta Y_t / \delta N_t} \tag{13}$$

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

$$MC_t = \frac{W_t N_t}{\beta P_t Y_t} \tag{14}$$

Denote percent deviation from the steady state by lower case letters, the real marginal cost can be written as:

$$mc_t = w_t + n_t - p_t - y_t \tag{15}$$

The data we use is yearly for India over the period 1990 to 2008. We use data for prices, interest rate, fuel consumption, wages (total value = W*N**),** value of output and quantity for 35 manufacturing industries (three digit NIC code)**.** While marginal cost proxy is calculated form ASI data, prices are taken as WPI prices at disaggregated level. The resulting estimated equation is given by:

$$\pi_t = 1.04 E_t\{\pi_{t+1}\} + 0.085 mc_t + e_t$$

All coefficients are significant. Coefficient of log of marginal cost comes in with right sign. J test for over-identification is 7.911(0.063) (the null hypothesis is the model is "valid") Instruments used were per unit fuel consumption, interest rate, lags of inflation and exchange rate.

In presence of AsymX:

$$\pi_t = 1.25 E_t\{\pi_{t+1}\} + 0.025 mc_t + 0.005 AsymX_t + e_t$$

The mc_t coefficient is now correctly signed. It is positive, and coefficient is significantly different from zero. However, the model fails to fully capture the empirical dependence of inflation on its own lagged values. The so-called "hybrid" variant of the NKPC, is the standard NKPC estimated in the literature.

4.4 Hybrid Phillips Curve

Hybrid Phillips curve became popular as it dealt with the issue of apparent inertia in inflation. To do so, Gali and Gertler (2000), extended the basic Calvo model to allow a fraction of firms to use a backward looking rule of thumb to set prices. By doing so they claim to obtain a measure of the residual inertia in inflation that NKPC leaves unexplained.

In the paper, they continue to assume that each firm is able to adjust its price in any given period with fixed probability 1-θ as given by equation (1). They also assume that out of those which are changing their prices in period t, there exist two types of firm. A fraction 1-ω of the firms are "forward looking", they set prices optimally, given the constraints on the timing of adjustments and using all the available information to forecast marginal costs. The remaining firms are backward looking firms; they use a simple rule of thumb that is based on the recent history of aggregate price behavior.

Let p^f_t denote 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:

$$p_t^* = (1-\omega)p_t^f + \omega p_t^b \tag{16}$$

Now, forward looking firms behave exactly as in the baseline Calvo model described by equation (7). But backward looking firms obey a rule of thumb which has 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.
Therefore the backward looking firms follow the rule given by:

$$p_t^b = p_{t-1}^* + \pi_{t-1} \tag{17}$$

Which states that a firm set its price equal to the average price set in the t-1 period, with a correction for inflation. It also reflects that lagged inflation is used in a simple way to forecast current inflation.

Combining all the above expressions with equation (6) gives us the hybrid Philips curve

$$\pi_t = \boldsymbol{\alpha}_f E_t\{\pi_{t+1}\} + \gamma mc_t + \boldsymbol{\alpha}_b \pi_{t-1} + e_t$$

Where:

$$\phi = \theta + \omega[1 - \theta(1 - \beta)]$$

$$\alpha_f = \beta\theta\phi^{-1}$$

$$\alpha_b = \omega\phi^{-1}$$

$$\gamma = (1 - \omega)(1 - \theta)(1 - \beta\theta)\phi^{-1}$$

In this specification, all the coefficients are explicit functions of three model parameters: θ, which measures the degree of price stickiness; ω, measures the degree of backwardness in price settings and the discount factor β.

The empirical version of the hybrid Philips curve is estimated as

$$\pi_t = 0.69E_t\{\pi_{t+1}\} + 0.27mc_t + 0.28\pi_{t-1} + e_t$$

Coefficient of log of marginal cost comes in with right sign. J test for over-identification 0.218 (0.896) (the null hypothesis is that the model is "valid"). Sum of coefficients on both lagged and lead inflation does not differ significantly from unity.

Structural estimates:

The parameter θ is estimated to be about 0.516. The parameter ω is estimated to be about 0.34 that is 34 percent of the prices setting industries are backward looking. The parameter β came out to be 0.96

Final form of NKPC with AsymX:

$$\pi_t = 0.77\{\pi_{t+1}\} + 0.21mc_t + 0.25\pi_{t-1} + 0.004AsymX_t + e_t$$

In all the above mentioned cases, though AsymX comes in with small coefficients but has always been significant. We interpret the coefficients on the asymmetry variable as showing how this variable shifts the short run inflation and some output gap or marginal cost measure. However, there are two fundamental problems that we can attribute to using the labor income share as our proxy for real marginal cost: firstly, the labor share of income is countercyclical, whereas theory suggests marginal cost should be procyclical; and second, the assumption used in order to obtain the labor income share as the proxy for real marginal cost is overly restrictive.

Conclusion

The paper examines different ways in which relative price shocks affect the price level and then inflation. Using India data we found evidence that: Average price increase over time is greater than average price decrease. While price increase is around 10 percent price decrease is less than 5 percent. It takes around one year for Indian markets to change price of the products implying both real and nominal rigidities in the market. Changes in the price level are positively related to skewness of relative price changes. There is evidence for menu cost models of price adjustment.

The results also suggest that the asymmetry variable is better measure of supply shocks than the traditional variables. And traditional variables performed well in earlier studies because they were acting as proxy for asymmetries. Model also confirms that the relationship between asymmetries and inflation holds across all time periods. In contrast energy prices affect inflation only when they have major effect on asymmetries.

Such distribution based measures of supply shocks perform better than traditional measures, such as prices of energy and food, in regressions explaining inflation. They moderate the price puzzle, whereby a rise in policy rates increases inflation, and are significant in estimations of New Keynesian aggregate supply. Our results show that an average Indian firm changes prices about once in a year, the estimated Calvo parameter implies half of Indian firms reset their prices in any period, and 66 percent of firms are forward looking in their price setting.

These estimated real and nominal price rigidities imply that a sharp policy response to a rise in expected future excess demand can prevent 66 percent of firms from raising prices. Since the higher prices 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 percent of firms are backward looking, so there would be some persistence of inflation and lagged effects of policy rate changes. Since supply shocks affect inflation independently of demand, there is an output cost in reducing demand in response to a supply shock. Therefore policy may allow the price level effect of a temporary price shock without tightening, or consider alternatives such as a temporary appreciation that can neutralize the supply shock.

References:

Álvarez, Luis J. and Ignacio Hernando (2006), Price Setting Behavior in Spain. Evidence from Consumer Price Micro-data, *Economic Modeling* 23, 699-716.

Ball, L. and Mankiw Gregory, (1994) Asymmetric Price adjustment and Economic Fluctuations, *The Economic Journal*,104 (423), 247-62.

Ball, L. and Mankiw Gregory, (1995) Relative-Price Changes as Aggregate Supply Shocks, *Quarterly Journal of Economics*, 110 (1), 161-93

Barros, Rebecca, Marco Bonomo, Carlos Carvalho, and Silvia Matos (2009), Price Setting in a Variable Macroeconomic Environment: Evidence from Brazilian CPI, unpublished paper, Getulio Vargas Foundation and Federal Reserve Bank of New York.

Bernanke, Ben S. (1983), Irreversibility, Uncertainty, and Cyclical Investment, *Quarterly Journal of Economics* 98 (February), 85-106.

Bernanke, Ben S., and Alan S. Blinder (1992), The Federal Funds Rate and the Channels of Monetary Transmission, *American Economic Review* 82 (September), 901–21.

Blinder, Alan S., Elie Canetti, David Lebow, and Jeremy Rudd (1998), Asking About Prices: A New Approach to Understanding Price Stickiness. New York: Russell Sage Foundation.

Bunn, Philip and Colin Ellis (2009), Price-Setting Behaviour in the United Kingdom: A Microdata Approach, *Bank of England Quarterly Bulletin*, 2009 Q1.

Calvo, Guillermo A. (1983). Staggered Prices in a Utility-Maximizing Framework, *Journal of Monetary Economics* 12 (3), 383–398.

Dias, Mónica, Daniel Dias and Pedro D. Neves (2004), "Stylised Features of Price Setting Behaviour in Portugal: 1992-2001," ECB Working Paper 332.

Fabiani, Silvia, Martine Druant, Ignacio Hernando, Claudia Kwapil, Bettina Landau, Claire Loupias, Fernando Martins, Thomas Y. Mathä, Roberto Sabbatini, Harald Stahl, and Ad C.

J. Stokman (2005). The Pricing Behavior of Firms in the Euro Area: New Survey Evidence, ECB Working Paper 535.

Ferderer, J. Peter. (1996) Oil Price Volatility and the Macroeconomy, *Journal of Macroeconomics* 18, 1-16.

Gabriel, Peter and Adam Reiff (2008), Price setting in Hungary – a Store-level Analysis, unpublished paper, Magyar Nemzeti Bank.

Galí, Jordi, and Mark Gertler (2000). Inflation Dynamics: A Structural Econometric Analysis, *Journal of Monetary Economics* 44 (2), 195–222.

Galí, Jordi, Mark Gertler, J. David López-Salido (2001). European Inflation Dynamics, *European Economic Review* 45 (7), 1237–1270.

Gautier, Erwan (2008). The Behaviour of Producer Prices: Some Evidence from the French PPI Micro Data, *Empirical Economics*, 35 (September): 301-332.

Goldberg, Pinelopi K. and Rebecca Hellerstein (2009). How Rigid are Producer Prices, FRBNY Staff Report 407.

Hamilton, James D. (1996), This is What Happened to the Oil Price-Macroeconomy Relationship, *Journal of Monetary Economics* 38 (2), 215-20.

Horvath, Roman. (2011). The Frequency and Size of Price Changes: Evidence from non-parametric estimation. *Macroeconomics and Finance in Emerging Market Economies*, 4 (2): 263-268.

Lilien, David (1982), Sectoral Shifts and Cyclical Unemployment, *Journal of Political Economy* 90 (4), 777-93.

Loungani, Prakash. (1986), Oil Price Shocks and the Dispersion Hypothesis, *Review of Economics and Statistics 6*8 (3), 536-39.

Lucas, Robert Jr., 1972. Expectations and the neutrality of money, *Journal of Economic Theory*, Elsevier, 4(2), pages 103-124,

Mankiw, G. (1985). Small Menu Costs and Large Business Cycles: A Macroeconomic Model, *The Quarterly Journal of Economics*, 100(2), 529-538

Medina, Juan Pablo, David Rappoport, and Claudio Soto (2007), "Dynamics of Price Adjustment: Evidence from Micro Level Data for Chile," Central Bank of Chile Working Paper 432

Klenow, P. and Malin, B. (2010). Microeconomic Evidence on Price Setting, NBER WP, No. 15826.

Mork, Knut Anton. (1989) Oil Shocks and the Macroeconomy When Prices Go Up and Down: An Extension of Hamilton's Results, *Journal of Political Economy* 97 (3), 740-44.

Pindyck, Robert,(1991) Irreversibility, Uncertainty, and Investment, *Journal of Economic Literature* 29 (3), 1110-48.

Rotemberg, J. (1982). Sticky Prices in the United States, *Journal of Political Economy*, 90 (3), 1187-1211

Sargent, Thomas J. 1971. Interest rates and prices in the long run: a study of the Gibson paradox, Working Papers 75, Federal Reserve Bank of Minneapolis

Shapiro, Adam Hale. (2008) Estimating the New Keynesian Phillips Curve: A Vertical Production Chain Approach, *Journal of Money, Credit and Banking*, Blackwell Publishing, vol. 40(4), pages 627-666.

Sims, Christopher A. (1992), Interpreting the Macroeconomic Time Series Facts: The Effects of Monetary Policy, *European Economic Review* 36 (June): 975 –1000.

Appendix

Kernel density

```
[f,yi] = ksdensity(y)
f = ksdensity(y,yi)
plot(yi,f);
```

Spline function:

```
y=TR;          %TR is my signal
x=1:30000;     % time axis
b=1:10:30000;  % knots
a=spline(b,y(:)'/spline(b,eye(length(b)),x(:)'));
v=ppval(x,a);
plot(x,y,'*',x,v,'.')
```

Table A1. Statistics used in the Regression

Years	Inflation	SD	Skew	Laginf	SD*Skew	NOPI	Monpol	AsymX
1973	0.08	0.13	2.07	0.04	0.26	8.78	1.95	10.61
1974	0.10	0.17	2.55	0.08	0.43	167.85	6.88	20.30
1975	0.00	0.10	0.05	0.10	0.00	7.59	-3.12	-4.13
1976	0.01	0.06	0.41	0.00	0.03	13.31	0.88	-1.68
1977	0.02	0.07	0.86	0.01	0.06	13.05	-1.10	-1.05
1978	0.00	0.08	-0.73	0.02	-0.06	3.88	-2.13	-4.45
1979	0.07	0.12	3.32	0.00	0.40	50.87	0.42	6.77
1980	0.07	0.13	3.61	0.07	0.47	66.82	-1.23	8.03
1981	0.04	0.09	1.67	0.07	0.15	0.00	1.37	0.41
1982	0.01	0.08	-0.75	0.04	-0.06	0.00	-1.34	-2.04

1983	0.03	0.06	1.56	0.01	0.09	0.00	1.03	-0.23
1984	0.03	0.05	1.39	0.03	0.07	0.00	1.65	-0.57
1985	0.02	0.08	2.28	0.03	0.18	0.00	0.05	-2.66
1986	0.02	0.06	2.45	0.02	0.15	0.00	-0.05	0.46
1987	0.03	0.07	2.06	0.02	0.14	33.84	-0.12	1.34
1988	0.03	0.08	1.67	0.03	0.14	0.00	-0.10	-2.99
1989	0.03	0.07	2.23	0.03	0.16	23.29	1.66	0.12
1990	0.04	0.06	2.00	0.03	0.13	24.51	4.18	2.35
1991	0.06	0.09	1.96	0.04	0.18	0.00	3.78	3.75
1992	0.04	0.12	1.30	0.06	0.16	0.00	-4.11	1.76
1993	0.03	0.05	1.59	0.04	0.08	0.00	-6.60	-0.84
1994	0.05	0.17	6.75	0.03	1.16	0.00	-1.50	12.30
1995	0.03	0.17	-7.21	0.05	-1.20	7.26	8.44	-2.28
1996	0.02	0.06	-1.12	0.03	-0.07	20.07	-4.53	-1.00
1997	0.02	0.06	1.72	0.02	0.10	0.00	-5.75	-2.17
1998	0.03	0.07	2.41	0.02	0.16	0.00	2.72	0.91
1999	0.01	0.05	-0.33	0.03	-0.02	32.95	0.84	-2.63
2000	0.03	0.07	2.36	0.01	0.17	58.17	0.41	0.73
2001	0.02	0.04	3.13	0.03	0.14	0.00	-1.61	-1.22
2002	0.01	0.05	2.06	0.02	0.11	0.95	-1.50	-1.09
2003	0.02	0.07	5.09	0.01	0.34	19.07	-1.19	0.09
2004	0.03	0.08	5.69	0.02	0.44	33.29	-0.40	2.42
2005	0.02	0.05	0.20	0.03	0.01	36.19	0.52	-2.41
2006	0.02	0.04	1.87	0.02	0.07	17.02	1.38	0.35
2007	0.02	0.06	0.81	0.02	0.05	9.44	0.29	-1.44
2008	0.04	0.07	4.30	0.02	0.29	37.77	1.02	1.23
2009	0.02	0.09	3.20	0.04	0.30	0.00	-4.22	-1.22
2010	0.03	0.01	2.52	0.02	0.02	28.71	0.59	-0.81

Inflation: refers to year on year change in log WPI index over all commodities.

Laginf: WPI Inflation with one period lag.

SD: standard deviation of the log wholesale price changes for each year in our sample.

$$SD = \sqrt{\frac{\sum (X - M)^2}{n - 1}}$$

Skew: skewness of the log industry price changes for each year in our sample.

$$Skewness = \frac{\sum \left(\frac{X - M}{sd}\right)^3}{n}$$

NOPI: net oil price increase as defined by Hamilton

MonPol: Change in call money rate.

AsymX: variable measuring asymmetric behavior of prices as defined in the text.