NBER WORKING PAPER SERIES

UNDERSTANDING INFLATION IN INDIA

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Working Paper 22948
http://www.nber.org/papers/w22948

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
December 2016

Prepared for the Brookings-NCAER India Policy Forum. We would like to thank Pami Dua, Subir Gokarn, Ken Kletzer, and participants at the India Policy Forum conference for comments, and Edmund Crawley, Manzoor Gill, Jianhui Li, Wasin Siwasarit, and Ray Wang for excellent research assistance. The views represent those of the authors and not of the Reserve Bank of India, any of the institutions to which the authors belong, or the National Bureau of Economic Research.

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NBER Working Paper No. 22948
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JEL No. E31,E58,F0

ABSTRACT

This paper examines the behavior of quarterly inflation in India since 1994, both headline inflation and core inflation as measured by the weighted median of price changes across industries. We explain core inflation with a Phillips curve in which the inflation rate depends on a slow-moving average of past inflation and on the deviation of output from trend. Headline inflation is more volatile than core: it fluctuates due to large changes in the relative prices of certain industries, which are largely but not exclusively industries that produce food and energy. There is some evidence that changes in headline inflation feed into expected inflation and future core inflation. Several aspects of India's inflation process are similar to inflation in advanced economies in the 1970s and 80s.

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I. INTRODUCTION

"Inflation poses a serious threat to the growth momentum. Whatever be the cause, the fact remains that inflation is something which needs to be tackled with great urgency …"

[Dr. Manmohan Singh, Prime Minister of India, February 4, 2011, New Delhi]

Over the last decade, inflation has emerged as a leading concern of India's economic policymakers and citizens. Worries grew as the inflation rate (measured as the twelve-month change in the consumer price index) rose from 3.7% to 12.1% over 2001-2010. The inflation rate has since fallen to 5.2% in early 2015, leading to a debate about whether this moderation is likely to endure or inflation will rise again.

What explains the movements in India's inflation rate? Economists, policymakers, and journalists have proposed a variety of answers to this question. Many emphasize the effects of rises and falls in food price inflation, especially for certain staples such as pulses, milk, fruits, and vegetables.[2] These price increases are in turn explained by factors including shifting dietary patterns, rising rural wages, and a myriad of government policies such as price supports and the rural unemployment guarantee scheme (Rajan, 2014). Some suggest that the monetary and fiscal stimulus following the crisis led to higher inflation, while others cite supply side constraints arising from policy bottlenecks (Economic Survey, 2013).

Many, including RBI Governor Rajan, fear that high levels of inflation may become embedded in the expectations of price setters, creating a self-sustaining "inflationary spiral" (Rajan, 2014). The role of monetary policy is controversial, with media reports and analysts debating the role of interest-rate increases in explaining the recent fall in inflation, and more generally the RBI's ability to control inflation and the effects on the real economy (Bhalla, 2014, and Lahiri, 2014).

[2] Gokarn (2011), for example, analyzes the micro-level price dynamics of the major dietary sources of protein in India.

The debates about inflation in India are reminiscent of debates that have been going on for decades in advanced economies--especially debates about the 1970s and 1980s, when inflation in the U.S. and Europe reached double-digit rates, like India more recently. These debates have spurred a large body of research on inflation, especially in the United States. We draw on this literature to explore inflation in India. One broad theme is that, despite the differences between the Indian and U.S. economies, the factors driving inflation fluctuations are similar in many respects.

Section II of this paper explores a central issue in discussions of inflation: the distinction between headline and core inflation. Core inflation captures the underlying trend in inflation, and headline inflation fluctuates around core because of large changes in the relative prices of certain goods—price changes that are often called "supply shocks." We follow an approach to measuring core inflation developed by the Federal Reserve Bank of Cleveland: core inflation is measured by the weighted median of price changes across industries. To implement this approach for India, we examine the inflation rate in the wholesale price index (WPI). WPI inflation is highly disaggregated by sector, allowing us to compute a historical series for median inflation.

We find that weighted median inflation is substantially less volatile at the quarterly frequency than headline inflation, a result that researchers have found for many other countries. We also have a finding that is not typical of other countries: the average level of median inflation (about 3.4 percent per year since 1994) is substantially lower than the average level of headline inflation (5.6 percent). This difference arises because the distribution of price changes across industries is often skewed to the right—there is a tail of large price increases that raise headline inflation, but are filtered out of the median—and the distribution is rarely skewed to the left. Many of the large price increases that raise headline WPI inflation--but far from all of them--occur for different types of food and fuel. The role of food prices is consistent with the common view that these prices strongly influence aggregate inflation.

Section III explores the determinants of core inflation. We estimate a version of a standard inflation equation in textbooks, and in a large body of empirical research: a Phillips curve. In this equation, core inflation at the quarterly frequency depends on expected inflation, which is determined by past levels of inflation; and by the level of economic activity, as captured by the deviation of output from its long run trend. Our estimates of the Phillips curve are somewhat imprecise compared to estimates for advanced economies, reflecting the facts that the necessary data are available only since 1996, and that they are noisy, with substantial quarter-to-quarter movements in weighted median inflation. Nonetheless, the data point to two conclusions about India's Phillips curve:

First, current core inflation depends on many lags of past inflation with weights that decline slowly. We interpret this finding as reflecting slow adjustment of expected inflation. In particular, we estimate that a one-percentage-point deviation of inflation from its expected level changes expected inflation in the next quarter by only 0.1 percentage points. This inertia in expectations is consistent with the view that, once a high level of inflation becomes embedded in expectations, it is not easy to reduce.

Second, for a given level of expected inflation, there is a positive relationship between inflation and the deviation of output from trend. This effect is central to the textbook Phillips curve, but some previous work has questioned it for India.[3] Along with our finding about the slow adjustment of expectations, the estimated effect of output implies that monetary policy can reduce inflation, but with a short-run cost in output. In particular, we estimate a sacrifice ratio—the loss in percentage points of annual output needed for a permanent one-point fall in inflation--of approximately 2.7. This estimate is the same order of magnitude as sacrifice ratios for other economies.

Section IV studies the dynamic interactions among core inflation, headline inflation, and supply shocks. One finding is that movements in headline inflation appear to influence expected inflation and hence future levels of core inflation. As a result, a one-time supply shock, such as a large spike in food prices, can have a persistent effect on inflation. Like other aspects of India's inflation, this finding is reminiscent of inflation in advanced economies in the 1970s and 80s.

Section V concludes. We have used data on weighted median inflation to find a Phillips curve for

[3] There is a significant body of literature going back at least to Rangarajan (1983) and Dholakia (1990) that estimates Phillips curve for India. Most of the early literature uses annual data, and does not find much evidence for the existence of a short-run trade-off between inflation and output. See also Chaterji (1989), Rangarajan and Arif (1990), Das (2003), Virmani (2004), Bhattacharya and Lodh (1990), Balakrishnan (1991), Callen and Chang (1999), Nachane and Laxmi (2002), Brahmananda and Nagaraju (2002), and Srinivasan et. al. (2006). However, more recently several studies have used quarterly data and demonstrated the existence of a positive relationship between output gap and inflation. Dua and Gaur (2009), Mazumder (2011), Patra and Kapur (2012), Kapur (2013), Kotia (2013), and Das (2014) are recent studies on the topic.

India and estimate its slope, which we cannot do with headline inflation because of its quarterly volatility. Understanding the Phillips curve is essential for effective policies to control inflation.

II. CORE INFLATION AND SUPPLY SHOCKS

Here we discuss the decomposition of headline inflation into core inflation and supply shocks, which is common in studies of inflation, and apply these concepts to quarterly data for India since 1994.

A. Background

By "core inflation," economists and central bankers mean an underlying trend in the inflation rate determined by inflation expectations and the level of economic activity, a trend that follows a relatively smooth path. The headline inflation rate is the sum of core inflation and "supply shocks," which reflect large changes in the prices of particular industries. Headline inflation is more volatile than core inflation.

The most common measure of supply shocks in empirical work is the change in the relative price of food and energy. Consistent with this practice, core inflation is often measured by the inflation rate excluding the prices of food and energy. This practice is motivated by the fact that food and energy prices are volatile, and excluding them produces a much smoother inflation series.

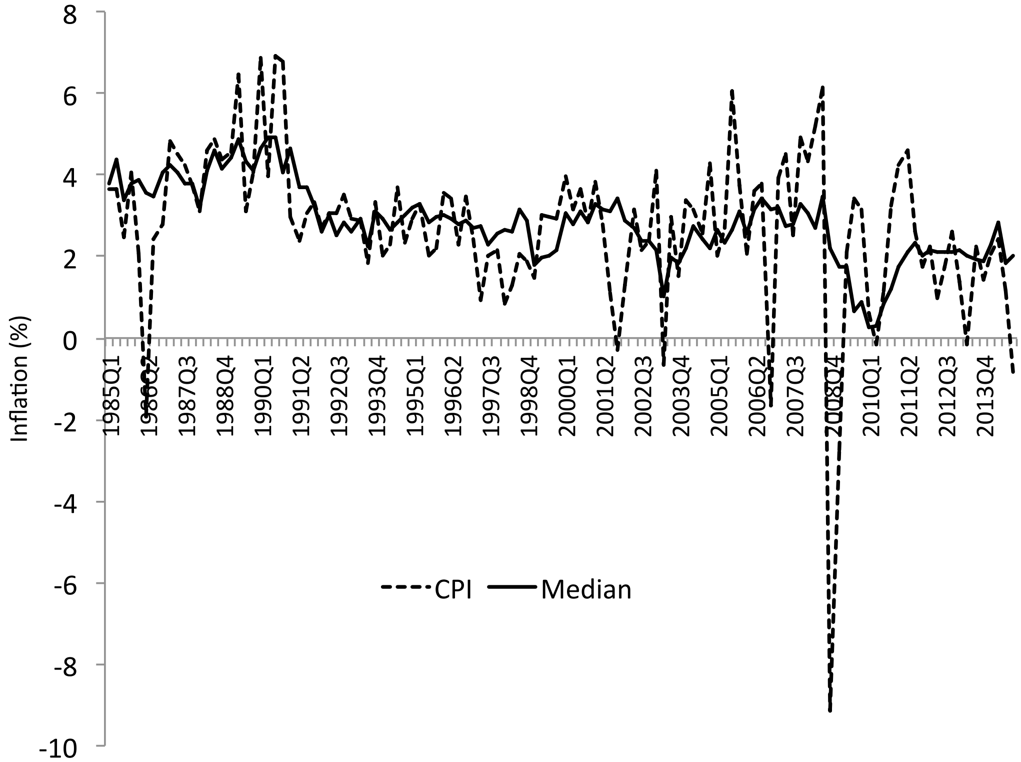
However, from a theoretical point of view, it is arbitrary to choose certain industries as the source of supply shocks, and to exclude from measures of core inflation. Ball and Mankiw (1995) define supply shocks as unusually large changes in the prices of *any* industries. They suggest that supply shocks be measured by the degree of asymmetry in the distribution of price changes across industries. If there is a tail of unusually large price increases, skewing the distribution to the right, that is a supply shock that raises inflation; a tail of unusually large price decreases has the opposite effect. Ball and Mankiw motivate this view of supply shocks with models of costly price adjustment, in which large changes in firms' desired relative prices have disproportionately large effects on inflation, because they trigger price adjustment while other prices are sticky.[4]

If supply shocks reflect asymmetries in the distribution of price changes, then a measure of core inflation should strip away the effects of these asymmetries—it should eliminate the effects of the tails of the price distribution. A simple measure that does that is the weighted median of price changes across industries. This measure of core inflation is proposed by Bryan and Cecchetti (1994), and the Federal Reserve Bank of Cleveland maintains a measure of weighted median inflation for the United States.

Figure 1 (based on Ball and Mazumder, 2014) illustrates these ideas for the United States by comparing headline CPI inflation to the weighted median of price changes across U.S. industries, for the period 1985-2014. We see that the weighted median filters out much of the quarter-to-quarter volatility in headline inflation, suggesting that it is a good measure of core inflation.

[4] Although unusually large changes in the prices are assumed to be caused by "supply shocks" in Ball and Mankiw (1995), a tail of unusually large price increases, in our framework, has the same effect on the price-change distribution, and hence on inflation, regardless of whether it is determined by demand or supply factors. Gokarn (1997), for example, also examines the behavior of the skewness of the distribution of relative price changes in India over the period from 1982-1996, and interprets the skewness to be caused by supply shocks. See more on this later.

Figure 1. Headline CPI and Weighted Median Inflation: United States



In U.S data, there is a strong correlation between median inflation and the common core measure of inflation excluding food and energy—but far from a perfect correlation. These findings reflect the fact that many of the large price increases filtered out by the median occur in the food and energy industries, but not all. Research on the U.S. finds that median inflation, with all large price changes removed, has less short-term volatility than inflation less food and energy.

In our analysis below, we find that in India, as in the United States, median inflation is substantially less volatile than headline inflation. Once again, the large price changes filtered out by the median occur largely but not entirely in food and energy industries.

We note that the traditional measure of core inflation, inflation less food and energy, is particularly unattractive for India. Given India's level of development, food is a large share of the aggregate economy, and its relative price has increased or decreased substantially for sustained periods. Thus stripping out food prices leaves an inflation series that wanders far away from the headline inflation rate that is the ultimate concern of policymakers; it does not just dampen quarterly fluctuations in inflation.

B. Application to India

Here we begin to describe our empirical analysis for India. For some aspects of our approach, we outline what we do and provide details in the Appendix to the paper. The measures of inflation that we study are the rate of change in the headline wholesale price index (WPI), and core inflation in the WPI as measured by the weighted median inflation rate. We study the WPI because, starting in 1994, it has a relatively high level of disaggregation into industry inflation rates, which is critical for measuring median inflation. We note that the Central Statistical Organization began releasing disaggregated CPI data in 2014. In the future, these data could be used to compare headline and median inflation based on the CPI.

Historically, the Wholesale Price Index (WPI) has been the most commonly used price index for measuring inflation in India.[5] Our raw data are monthly WPI prices disaggregated by industry from April 1994 through December 2014. We aggregate across three month periods to create quarterly series from 1994Q2 through 2014Q4.

For each quarter, the headline inflation rate for the WPI is approximately the mean of inflation rates across industries, weighted by the importance of the industries.[6] We compare this inflation rate, as reported in official statistics, to the weighted median of inflation rates across industries—the inflation rate such that industries with 50% of the total weights have higher inflation rates, and the others have lower rates. The set of industries and weights in the WPI are revised every decade, so our sample comprises a subsample from 1994Q3 through 2004Q1 with 61 industries and one from

[5] The term "wholesale" in the index is however misleading in that the index does not necessarily measure prices in the wholesale market. In practice, the WPI in India measures prices at different stages of the value chain. As discussed in Srinivasan (2008), according to the National Statistical Commission (NSC, 2001), "in many cases, these prices correspond to farm-gate, factory-gate or mine-head prices; and in many other cases, they refer to prices at the level of primary markets, secondary markets or other wholesale or retail markets".

[6] We computed the weighted mean of price changes across industries. As one would expect, this series closely follows the inflation rate calculated from the official series for the WPI.

2004Q2 through 2014Q4 with 81 industries. Given the discontinuity in the series, an approximation is needed to compute the inflation rate in 2004Q2, the first quarter with the revised set of industries (see Appendix for details). We use the second level of disaggregation that is available. Examples of industries include primary articles such as Food (Grains:Cereals) and Minerals (Metallic) as well as manufacturing such as textiles (Cotton: Yarn) and electrical apparatus and appliances.

Figure 2 shows the series for official WPI inflation and weighted median inflation, with all quarterly inflation rates annualized by multiplying by 4. Panel A shows the series we construct from our raw data, which is not seasonally adjusted, and Panel B shows series that are seasonally adjusted with the X-13 Arima-Seats procedure from the U.S. Census Bureau. The seasonally adjusted and unadjusted series are highly correlated (correlation = 0.9 for median inflation), but the seasonally adjusted series are somewhat less volatile.

As expected, weighted median inflation is substantially less volatile than headline WPI inflation. For our seasonally adjusted series, the standard deviation of WPI inflation is 3.93% while the standard deviation of the weighted median is 2.62% between 1994q2 and 2014q4.

We also find that the average level of median inflation over the sample, 3.43 percent, is substantially lower than the average level of WPI inflation, 5.56 percent. As we see in the Figure, this result reflects the fact that WPI inflation often spikes up above median inflation, whereas median inflation is almost never substantially above WPI inflation (with only a few exceptions e.g. 2008Q4 and 2009Q1). This result is surprising, because in other economies median inflation fluctuates fairly symmetrically around headline inflation and the average levels are similar, as shown for the U.S. in Figure 1.

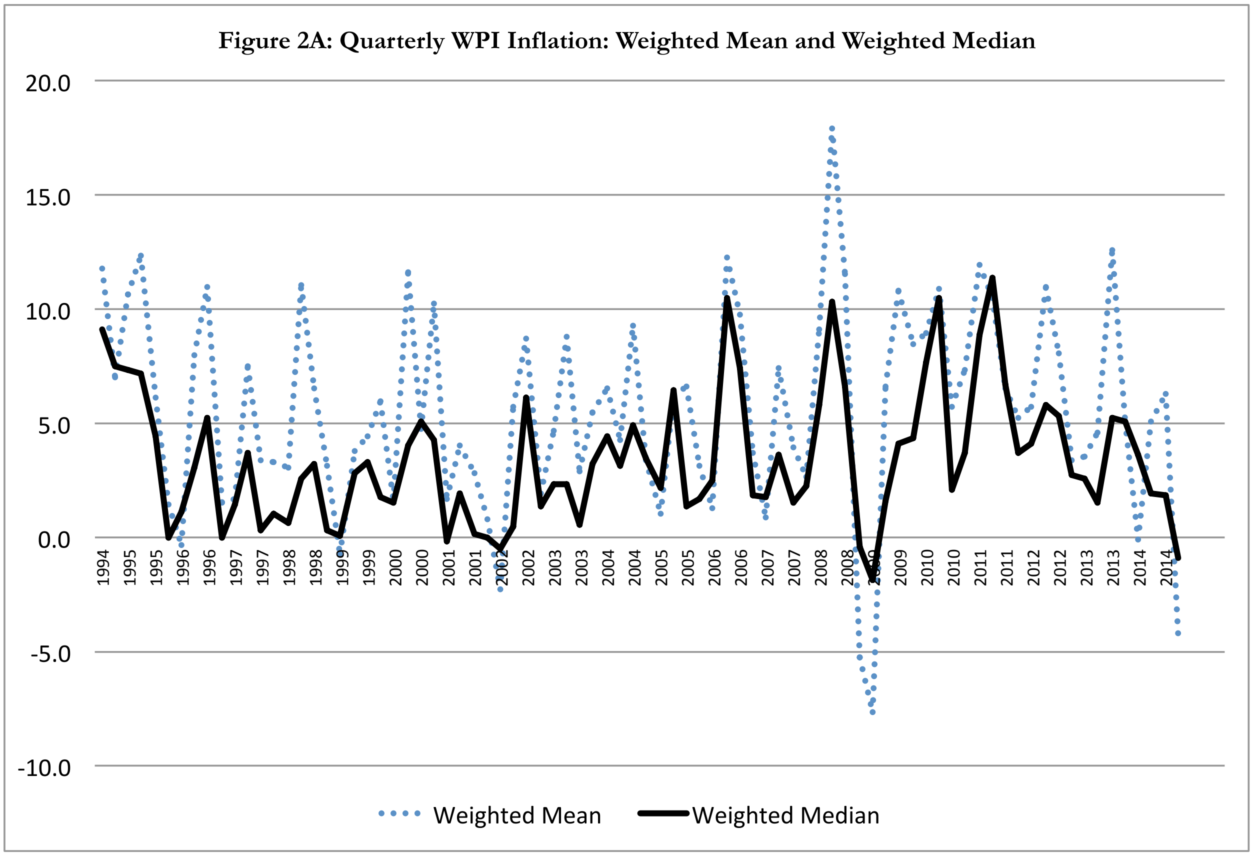
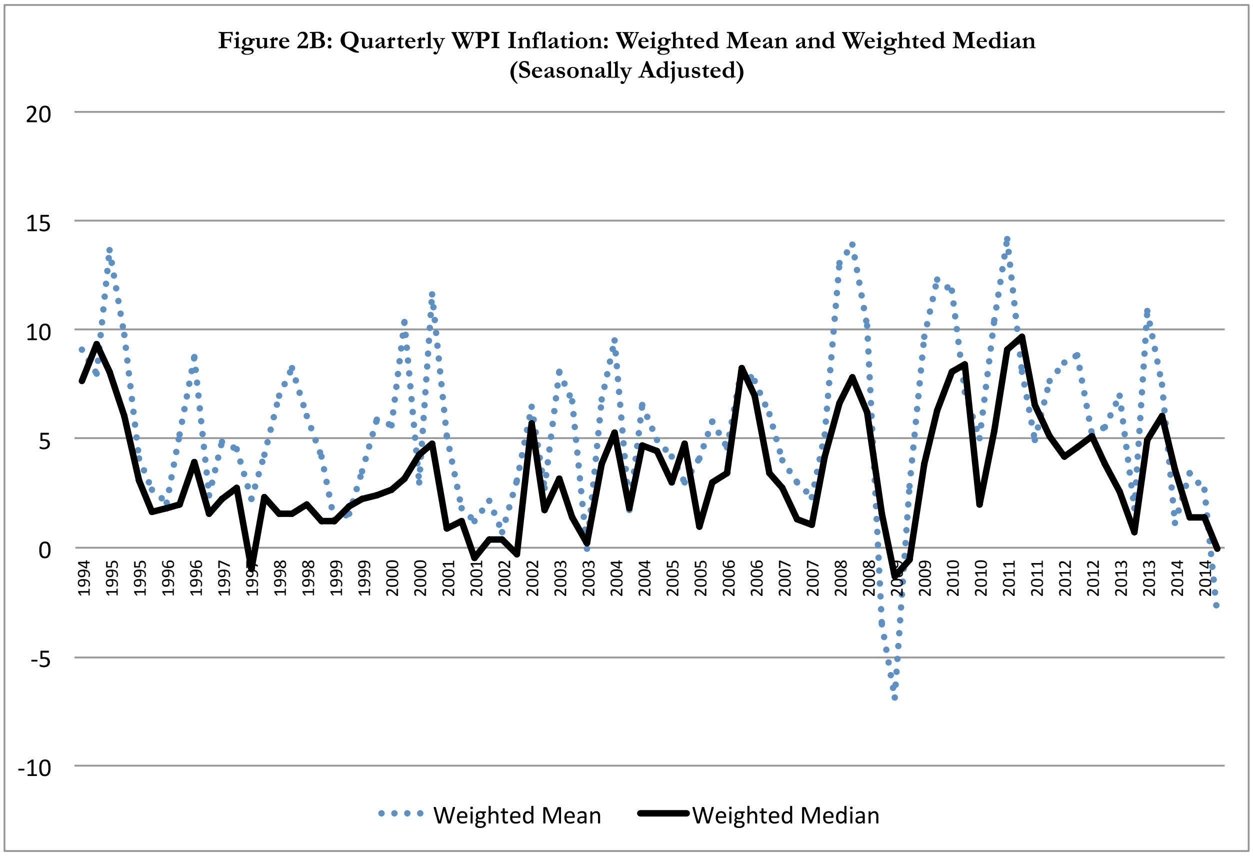
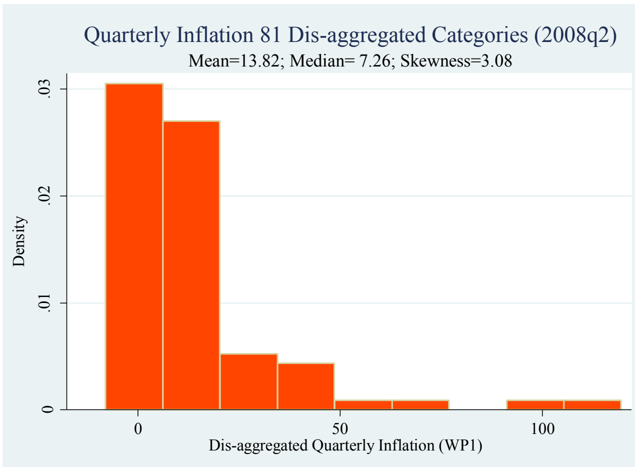


Figure 2A: Quarterly WPI Inflation: Weighted Mean and Weighted Median
20.0
15.0
10.0
5.0
0.0
-5.0
-10.0
Weighted Mean
Weighted Median

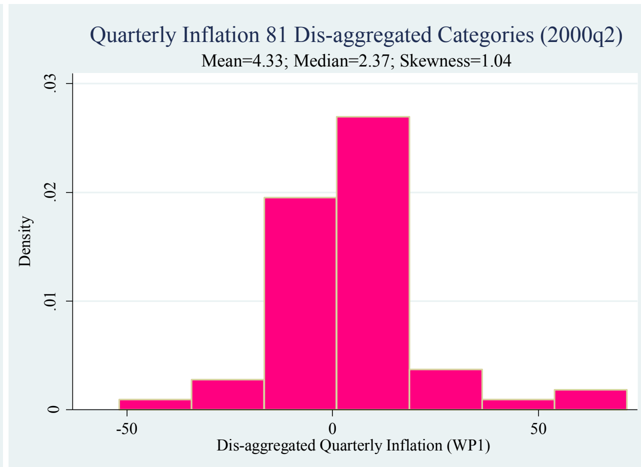


Mechanically, WPI inflation exceeds median inflation when the distribution of industry price changes is skewed to the right–- in other words, when there is a thick tail of large price increases. Figure 3 illustrates this fact with some examples of the cross-sectional distribution of industry price changes, based on the seasonally unadjusted series that we use initially to compute weighted medians. Panels A and B show the distribution of inflation rates for 2008q2 and 2000q2, two quarters in which WPI inflation is substantially greater than median inflation. In 2008Q2, industries including fruits and vegetables, fibres, other minerals, tea and coffee and ferrous metals have inflation rates greater than 35%, and crude petroleum, metallic minerals, coal, food (others) have rates greater than 50%, creating strong skewness in the distribution. In 2000q2, milk had a rate of 40% and rubber and mineral oils had rates greater than 60%. Panel C shows a sample quarter, 2011Q4, in which the distribution of price changes is close to symmetric, implying that WPI and median inflation are approximately the same. Panel D shows 2014q4, a quarter with negative skewness. In 2014q4, fruits and vegetables, other food, non-food fibres and oil seeds, crude petroleum, mineral oils, manufactured food: tea and coffee, bakery products and oil cakes were in the left tail (lowest 10 percent) of the distribution and experienced inflation rates of -7.8% or lower.

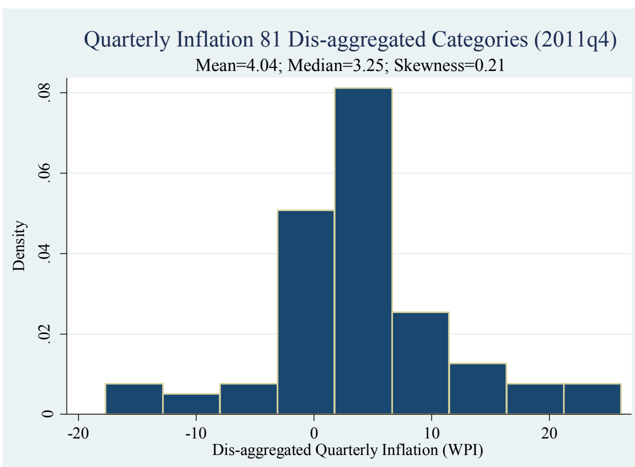
Figure 3. Cross Sectional Distribution of Industry Price Changes



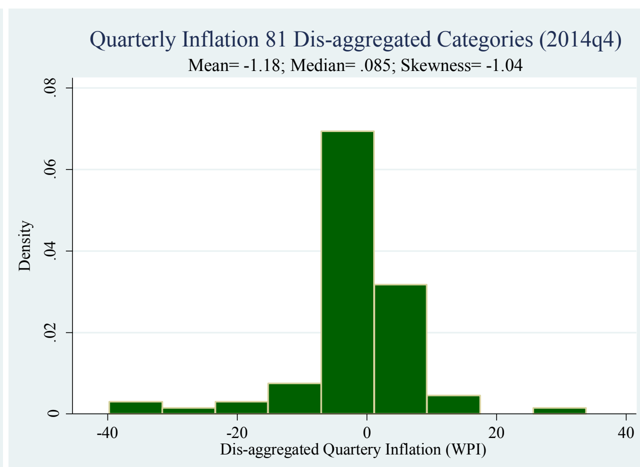
Panel A



Panel B



Panel C



Panell D

C. The Role of Food and Fuel Prices

Changes in food and fuel prices cause many of the episodes of skewed price change distributions in India, as suggested by the example of 2008q2. The same is true in advanced economies. To demonstrate this point systematically, we examine the industries that account for the top ten percent of the weighted distribution of inflation rates in each quarter—the right tail of the distribution, which creates skewness in many quarters and raises WPI inflation above median inflation. Many of these industries are producers of various kinds of food and fuel, such as fruits, vegetables, milk, crude petroleum, coal, and electricity. For each of our industries, we examine its contribution to the right tail of the distribution for each quarter. This contribution is zero if the industry is not in the 10% tail; the industry's WPI weight times ten if it is in the tail; and somewhere in between if the industry's price change puts it at the border of the top 10%, in which case part of the industry's weight is included in the tail. For each industry, we compute the average contribution to the 10% tail over our 82 quarterly observations on prices. These average contributions sum to 100%.

Recall there are 81 industries for the second part of our sample period; of these, 18 are different types of food (both primary articles and manufactured food) and 4 are different types of fuel or power. To see the influence of these industries more clearly, we aggregate them by one level into three broad industries: primary articles: food, manufacturing: food, and fuel and power. We also aggregate the other industries one level leaving us with 15 industries. For each of these industries, Table 1 shows the total of the average contributions of it components to the top ten percent of price changes.

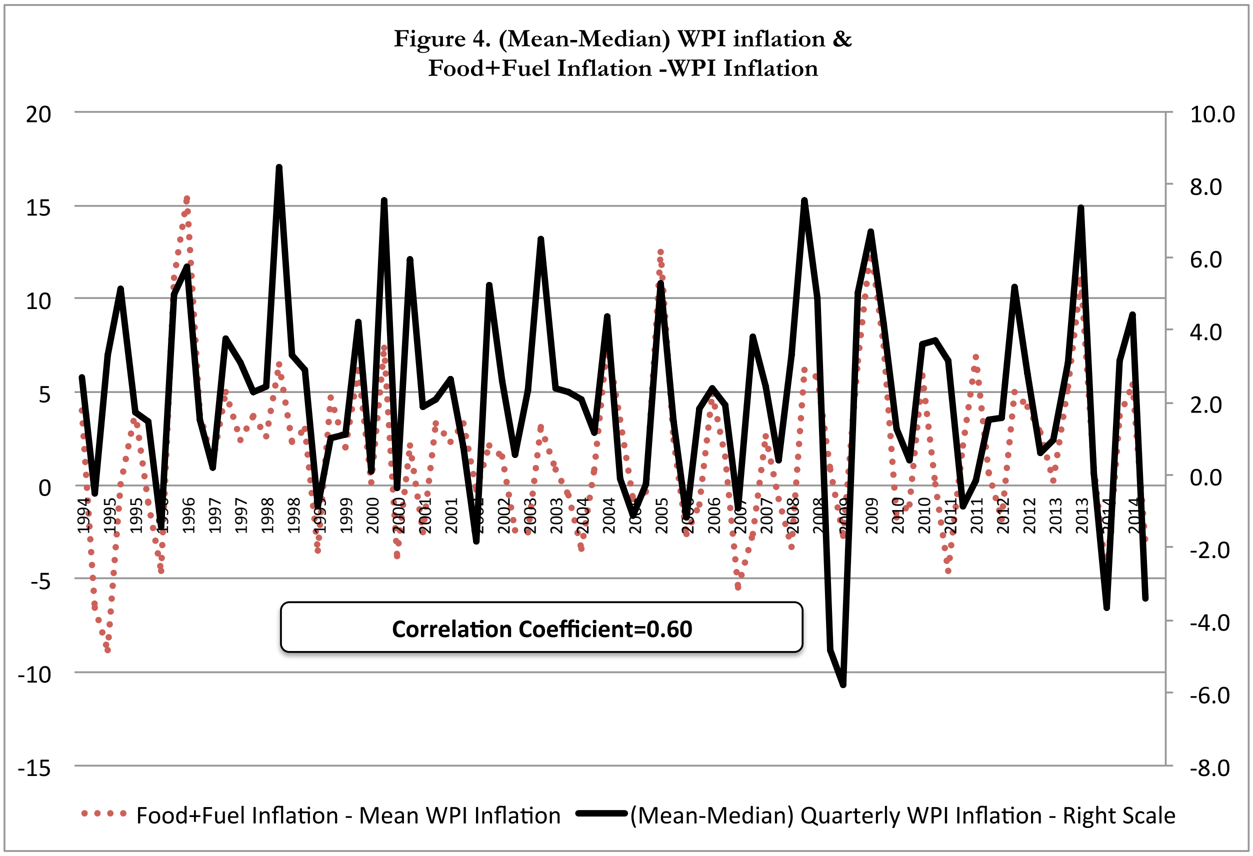
The results are striking. The three food and fuel industries are the three largest contributors to the ten percent tail, with a contribution that sums to 63.5 percent. Notice if we add in non-food commodities, the fourth largest contributor, the total rises to 72 percent. Thus if inflationary supply shocks are captured by right-skewness in the price-change distribution, Indian data confirm the common view that a large share of supply shocks originate in food and fuel industries—but not all. Notice that metals, chemicals, and textiles also are significant contributors to the ten percent tail.

Table 1. Contributors to Top 10% of Price Changes

Industry	Rescaled Weighted Frequency
Primary Articles: Food	27.83
Fuel & Power	23.50
Mfg: Food	12.22
Primary Articles: Non Food	8.50
Mfg: BM: Basic Metals, Alloys and Metal Products	7.55
Mfg: CC: Chemicals & Chemical Products	6.02
Mfg: Textiles	4.46
Primary Articles: Minerals	2.31
Mfg: NM: Non Metallic Mineral Products	1.95
Mfg: Paper & Paper Products	1.21
Mfg: MM:Machinery & Machine Tools	0.96
Mfg: BT: Beverages, Tobacco & Tobacco Products	0.95
Mfg: TE: Transport, Equipment & Parts	0.93
Mfg: Rubber & Plastic	0.85
Mfg: Leather & Leather Products (LL)	0.52
Mfg: Wood Wood Products	0.25

Notes. Weighted frequency is rescaled to sum to 100. Industries are sorted By weighted frequency. Total number of quarters=82 (1994q3:2014q4)

Figure 4 illustrates the importance of food and fuel in a different way. It shows two series: the difference between WPI inflation and median inflation, which captures the asymmetry in the distribution of price changes; and the change in the relative price of food and fuel, calculated as average inflation for food and fuel minus WPI inflation. We can see that the two series have a strong positive relationship. For the non-seasonally adjusted series shown here, the correlation is 0.60. The correlation is somewhat lower, 0.41, when we seasonally adjust both series. Once again, we see that increases in food and fuel prices explain a large share but not all of the right tails in the distribution of inflation rates.



III. A PHILLIPS CURVE FOR CORE INFLATION

The canonical Phillips curve explains inflation with expected inflation and the level of economic activity relative to the economy's potential. In many applications, researchers assume that expected inflation can be captured by lagged values of actual inflation. Here we examine the fit of a simple Phillips curve to core inflation in India, as measured by the weighted median.

<u>Milton Friedman's Phillips Curve</u>

A large body of research is based on the Phillips curve introduced in Milton Friedman's Presidential Address to the AEA (1968). This relation can be written as

(1) $\pi_t = \pi_t^e + \alpha(x_t - x_t *) \quad + \epsilon_t$

where π_t is inflation, π_t^e is expected inflation, and x_t is a measure of economic activity, typically either the log level of output or the unemployment rate. The variable x_t* is the long run level of x, which is called the natural rate when x is unemployment and potential output when x is output. The term $x_t - x_t*$ captures short-run fluctuations in output or unemployment. The error term $\in_t$ captures unobservable factors that influence inflation.

This Phillips curve is exposited in leading textbooks in macroeconomics. The expected inflation term captures the idea that expectations of inflation tend to be self-fulfilling: if price and wage setters expect a certain level of inflation, they raise their nominal prices to keep up, and in aggregate their price increases create the inflation they expect. The $x_t - x_t*$ term captures the idea that an increase in activity relative to the economy's normal level raises firms' marginal costs, which causes them to raise prices by more than they otherwise would.

Here we examine the fit of equation (1) to the behavior of core inflation. In Section IV of this paper, we examine how core inflation and supply shocks interact to determine the behavior of headline WPI inflation.

To estimate equation (1), we must choose measures of x_t, x_t*, and π_t^e.

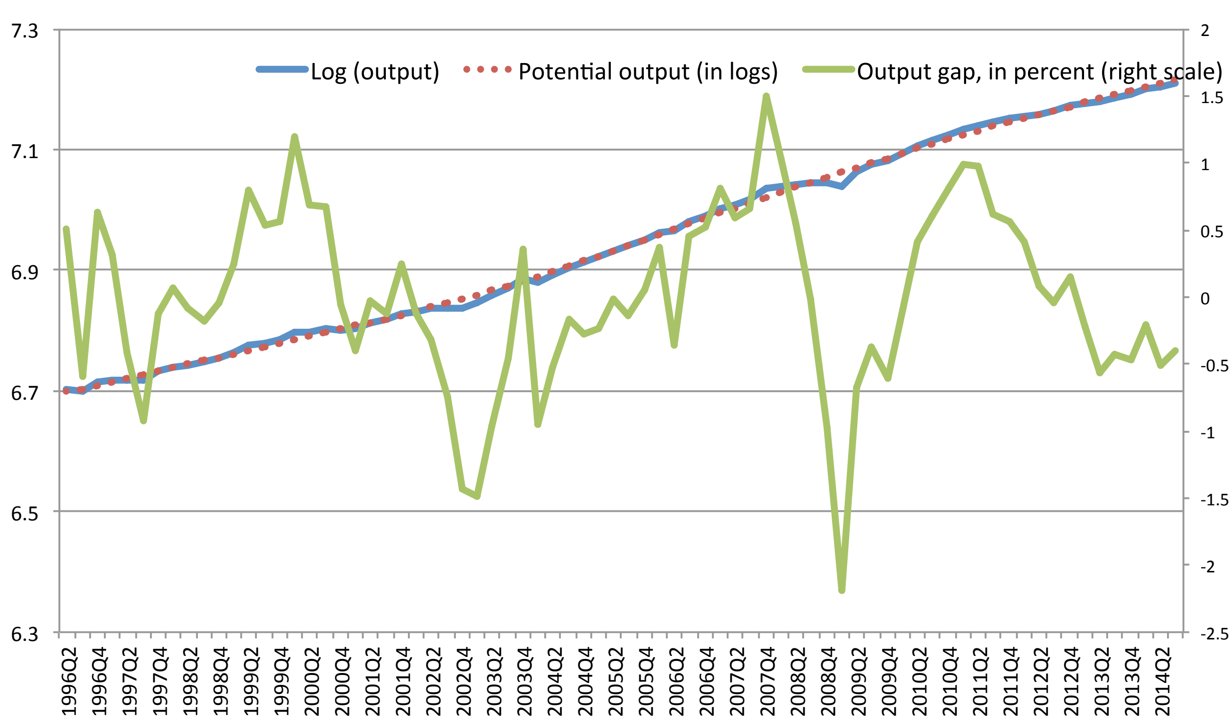
Measuring Economic Activity

We lack quarterly data on aggregate unemployment for India. Quarterly data on output, however, are available from the Central Statistical Organization (CSO). In our empirical analysis, we use quarterly GDP (at market prices) since 1996Q2. We combine the 2004-05 base-year GDP series and the 1999-2000 series to create a common series from 1996Q2 to 2014Q3, using a commonly used splicing methodology. The details of the splicing methodology are provided in Appendix 1. We measure activity x_t with the logarithm of output. Before taking the logarithm, we seasonally adjust the output series using the U.S. Census Bureau's X-13 procedure. This adjustment is important because there are large seasonal movements in India's output.

We measure potential output by smoothing the log output series with the Hodrick-Prescott filter, using a smoothing parameter of 1600. This common approach is atheoretical but yields a plausible series for $x*$, and no other approach is obviously better in the absence of accurate, direct measures of the economy's productive capacity.[7]

Figure 5 shows the levels of x and x* that we calculate, and the output gap x-x*. The fluctuations in our measured output gap are consistent with common views about India's business cycle. The output gap was positive, with its magnitude being the highest during the sample, right before the Global Financial Crisis (GFC). Output was recorded at 1.5% and 1% above its long-run potential in 2007Q4 and 2008Q1 respectively. Not surprisingly, the output gap was the most negative in our sample during the GFC. Output was 2.2% below its potential in 2009Q1. Our estimates also suggest a negative output gap of -0.4% for 2014Q3, or the last data point in our sample.

Figure 5. Output, Trend, and Output Gap



[7] See Kotia (2013) and Mishra (2013) for shortcomings of the HP filter.

One questionable feature of the output gap series is that the size of fluctuations is small. The estimated output gap is never more than one or two percent in absolute value; even in the wake of the global financial crisis (GFC), the gap reaches only -2%. By contrast, U.S. output gaps as measured by the HP filter reach levels around 5% in absolute value in deep recessions and strong expansions. We are not confident that cyclical fluctuations in India are as small as our estimated gaps suggest, and suspect that the quarterly data reported for real GDP could be smoother than true GDP. We will keep this issue in mind in interpreting our estimated effects of the output gap on inflation.[8]

Measuring Expected Inflation

In presenting his Phillips curve, Friedman said that "unanticipated inflation generally means a rising rate of inflation." This is the same as saying that expected inflation is determined by past inflation. Following Friedman, much of the U.S. Phillips curve literature (e.g. Gordon (1982), Stock and Watson (2007), Ball and Mazumder (2011)) has used lags of inflation to capture expected inflation. With quarterly data, researchers typically include a number of inflation lags in the Phillips curve, with the restriction that the coefficients on the lags sum to one.

In recent years, inflation expectations have appeared to be "anchored" in advanced economies including the U.S. and Europe. Since around 2000, the Fed and ECB have been targeting inflation rates near two percent, and expected inflation has stayed close to that level: expectations have *not* varied based on lagged values of actual inflation. We doubt, however, that inflation expectations were anchored in India over our sample period. The RBI formally announced an inflation target only in 2015.[9] Over our sample, the inflation rate was volatile without a clear tendency to return to some fixed level, much as inflation rates wandered in the U.S. and Europe between 1960 and 2000. In such a regime, it is natural to assume that expected inflation responds to lagged values of actual inflation.

[8] Some suggest using a lower HP smoothing parameter for emerging economies. This would produce even smaller estimated output gaps.
[9] See http://finmin.nic.in/reports/MPFAgreement28022015.pdf on agreement between Government of India and Reserve Bank of India on new monetary policy framework.

As we saw in Figure 2, quarterly core inflation is quite volatile in India–-more volatile than core inflation in advanced economies. We conjecture that expected inflation is less volatile: a few quarters of high or low inflation do not change expectations dramatically. To capture this idea, we want to allow expected inflation to depend on lagged inflation over many quarters. At the same time we do not want to include numerous lags with unrestricted coefficients; we want a parsimonious Phillips curve with a minimum of free parameters. These goals lead us to a simple partial-adjustment model of expectations.

Specifically, we assume that expected inflation is determined by:

(2) $\pi_t^e = \gamma\pi_{t-1}^e + (1-\gamma)\pi_{t-1}$

In this specification, expected inflation depends on its own lag and the lag of actual inflation with weights γ and $1-\gamma$. This implies that a one-percentage point deviation of lagged inflation from its expected level changes current expected inflation by $1-\gamma$ percentage points. Repeated substitution for lagged inflation leads to the following reduced form:

(3) $\pi_t^e = (1-\gamma)\pi_{t-1} + \gamma(1-\gamma)\pi_{t-2} + \gamma^2(1-\gamma)\pi_{t-3} + \gamma^3(1-\gamma)\pi_{t-4} + \cdots$..

Here, expected inflation depends on all lags of past inflation, with exponentially declining weights. The adjustment parameter γ determines the relative weights on recent and less recent inflation rates. We treat γ as a parameter to be estimated.

If we write our equation for expected inflation compactly and substitute it into Friedman's Phillips curve (1), we get

(4) $\pi_t = (1-\gamma)[\sum_{k=1}^{\infty}\gamma^{k-1}\pi_{t-k}] + \alpha(x_t - x_t*) \quad +\epsilon_t$

To estimate this equation with the available data, we must make two approximations, which we describe in Appendix 2. First, we truncate the infinite sum in the theoretical Phillips curve: we include only 40 lags of inflation with exponentially declining weights, while maintaining the restriction that the weights sum to one.[10]

Second, we must address the problem that, even with the lags truncated at forty, we do not have data on median inflation that extends far enough back to include forty lags in the early part of our sample. In our regressions, the sample starts in 1996Q2, the first quarter for which output data are available, and our median inflation series extends back only seven quarters before that, to 1994Q3. Since we cannot measure π_t^e for our entire sample, we treat π_t^e in 1996Q2 as an unobserved parameter, which we estimate along with the parameters γ and α in the Phillips curve. We estimate the initial π_t^e, γ and α by non-linear least squares: we find the values of these three parameters that minimize the sum of squared residuals in the equation. Notice that an estimate of the initial π_t^e and an estimate of γ allow us to calculate π_t^e for all observations in our regression using the partial adjustment equation (3).

Estimates

Table 2 presents our estimation results. The estimate of the initial level of expected inflation is about 1.9, and the estimate of γ is 0.90, with a standard error of 0.05. If we put this estimate into our reduced-form equation for expected inflation, it implies that the first four inflation lags have coefficients of approximately 0.1, 0.09, 0.08, and 0.07, which sum to 0.34 out of the total sum of coefficients of one. This confirms that relatively long lags of inflation—beyond one year—have substantial weight in determining the current levels of expected and actual inflation, as we conjectured based on the volatility of quarterly inflation.

[10] Some readers of this paper have questioned the structure of inflation lags that we assume, so we have experimented with alternatives. As we expect based on the volatility of inflation, a large number of lags is needed to capture the behavior of expectations. We verify this point by estimating a version of equation (4) in which we replace the exponentially weighted sum of inflation lags with 16 lags with unrestricted coefficients. In this specification, we reject the hypothesis that the coefficients on lags 13-16 are zero (p= 0.0383), which suggests that at least 16 lags are needed to fit the data. At the same time, when we include 16 unrestricted lags, the pattern of estimated coefficients on the lags is erratic, suggesting the model is over-parameterized. These findings confirm the usefulness of restricting the coefficients with our partial adjustment model.

Table 2. Phillips Curve Estimates

Dependent Variable. Weighted Median WPI Inflation	
Output gap, α	1.074**
	[0.540]
Adjustment parameter, γ	0.902***
	[0.053]
Number pf observations	74
R-squared	0.19
Adjusted R-squared	0.179

Notes: ***, **, and * denote statistical significance at 1,5, and 10 percent percent respectively. Standard errors are denoted in parentheses.

The estimate of the output gap coefficient α is 1.07 with a standard error of 0.54. The t-statistic of 1.99 puts the coefficient at the borderline of statistical significance at the five percent level. Thus we find evidence of a substantial effect of output on inflation, the central prediction of the Phillips curve, but with considerable uncertainty about the magnitude of the effect.

The top panel of Figure 6 shows our series for core inflation and the fitted values of this variable based on our estimated Phillips curve. This graph also shows the level of expected inflation implied by our estimate of the parameter γ; the deviation between this level and the fitted value of inflation is the estimated contribution of the output gap (the gap times the estimated value of α). The bottom panel of Figure 6 shows eight-quarter moving averages of the actual inflation, expected inflation, and fitted value series in the top panel. This graph smooths out much of the quarterly volatility in median inflation, allowing us to see how well our equation fits somewhat longer-term movements in inflation.

With eight-quarter averages, the inflation movements over our sample are dominated by upward trends in actual and expected inflation from the early 2000s to 2012. Output movements help to explain some of the movements in inflation, such as the period around 2011-2012 when the output gap was positive--as indicated by fitted values for inflation that exceed expected inflation--helping to push median inflation to its peak of around 7%. However, much of the long rise of inflation was generated by unexplained shocks to our Phillips curve, indicated by actual inflation above its fitted values. These shocks feed back into expected inflation in our partial adjustment equation, so a series of shocks pushed the level of inflation higher and higher. Negative shocks have partially reversed this process since 2012. We explore the nature of these shocks in Section IV of this paper.

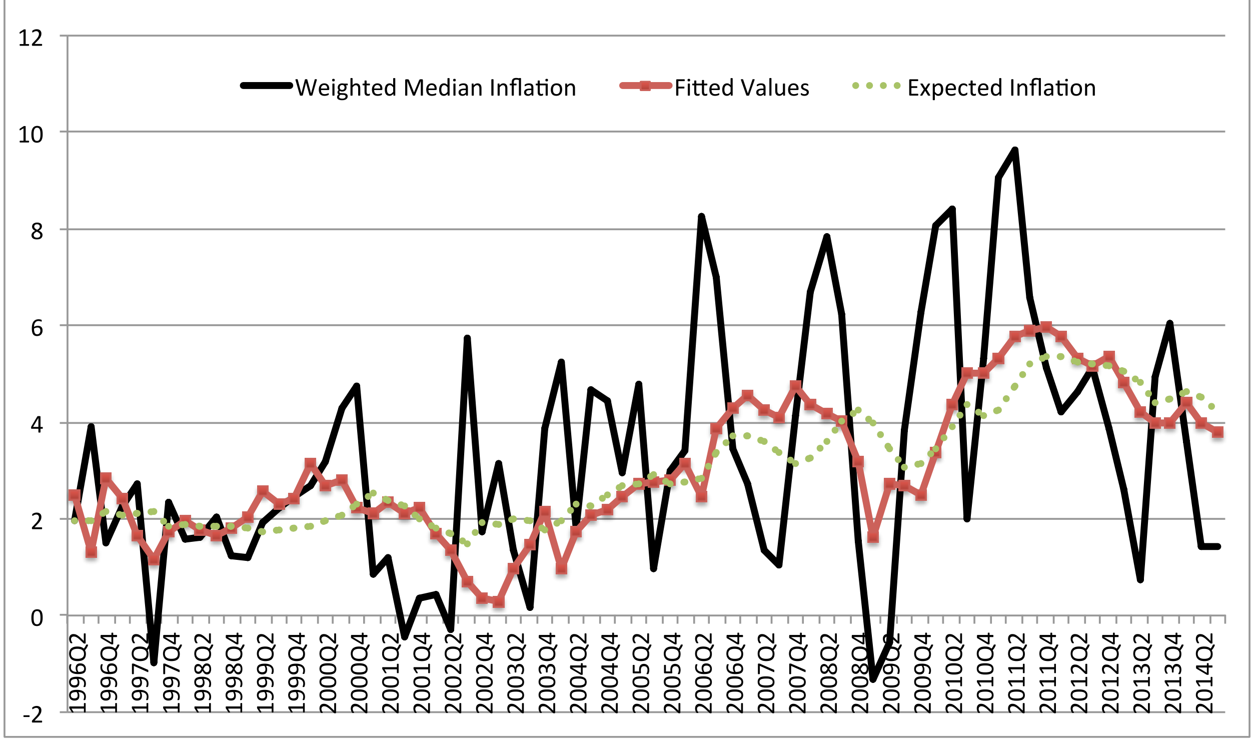
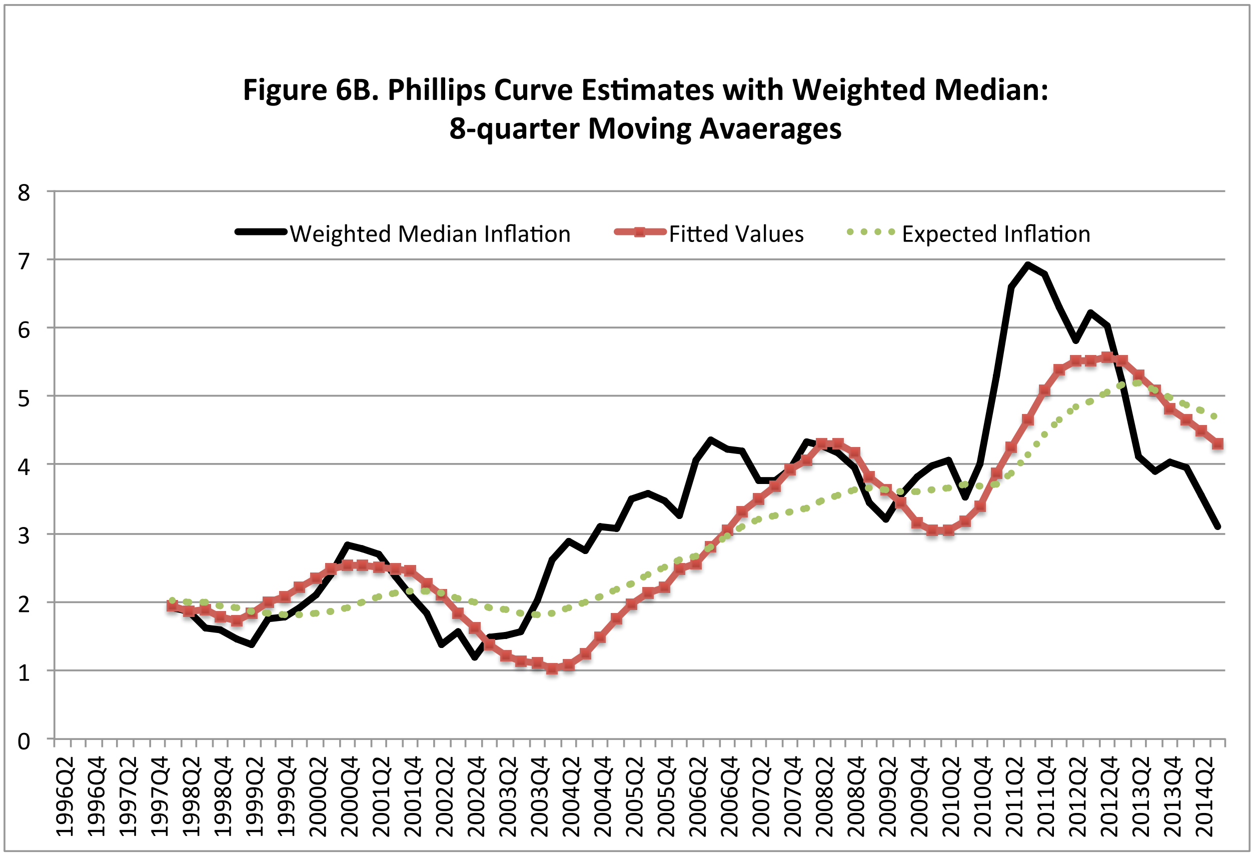


Figure 6A. Phillips Curve Estimates with Weighted Median



The Sacrifice Ratio

The RBI aims to reduce the inflation rate to 4% by 2018. The Phillips curve implies a cost to reducing inflation: absent a lucky disinflationary shock, policymakers need to reduce output temporarily below its trend to reduce inflation.

A common measure of the cost of disinflation is the "sacrifice ratio." This concept is the number of percentage points of reduction in annual output needed to reduce the inflation rate permanently by one percentage point. Estimates of sacrifice ratios in advanced economies in the 1980s and 1990s, before the recent period of anchored expectations, are often on the order of two or three. In other words, roughly a 2-3 percentage point loss of output relative to trend is needed to reduce the inflation rate in advanced economies by one percentage point (see Mitra et al (2015) for a literature review).

Using our Phillips curve, we can calculate the sacrifice ratio as follows. A loss of output of one percentage point for one quarter reduces current inflation by α percentage points. Given our specification of expectations, that fall in inflation reduces expected inflation by $(\alpha) * (1-\gamma)$ in the following period. If output returns to normal at that point and there are no shocks to the Phillips curve, then actual inflation is $(\alpha) * (1-\gamma)$ below its initial level, and stays there.

Thus a one-point fall in output below normal for one quarter reduces inflation by $(\alpha) * (1-\gamma)$ points. A one-point fall in output that lasts for four quarters–-a loss of one point of annual output–-reduces inflation by $4*(\alpha) * (1-\gamma)$. The sacrifice ratio is the inverse of this effect: in order to reduce the inflation rate by one percentage point, a loss of $1/[4*(\alpha) * (1-\gamma)]$ percentage points of annual output is required.

Substituting in our estimates of γ and α yields a sacrifice ratio of 2.7, which is the same order of magnitude as estimates for other countries. If the current level of inflation is 5.2% and the RBI wishes to reduce it to 4%, the cost will be 1.2*2.7=3.2 percentage points of annual output. Notice that our estimated sacrifice ratio for India is quite close to estimates by Mitra et al (2015) (around 2.3 or 2.8 depending on the state of the economy), despite large differences between their methodology and ours.

Two caveats: First, the RBI is targeting CPI inflation, whereas we calculate a sacrifice ratio for core WPI inflation. Future work should examine whether the relationships of output to CPI and WPI inflation are similar.

Second, as noted above, we suspect that quarterly output data may understate the size of short-run fluctuations. If so, the true output gaps associated with given changes in inflation may be larger than the estimated gaps, which would imply a larger sacrifice ratio.

IV. CORE INFLATION, SUPPLY SHOCKS, AND MEDIAN INFLATION

The previous section found that the behavior of India's core inflation, as measured by weighted median inflation, can be explained to a significant degree by a simple Phillips curve. We saw earlier, however, that many of the fluctuations in headline inflation are deviations from core inflation caused by supply shocks, as measured by asymmetries in the cross-sectional distribution of price changes.

Here we seek a broader understanding of India's inflation by examining the interactions among core inflation, headline inflation, and supply shocks. One finding is that movements in headline inflation appear to influence expected inflation and hence future levels of core inflation. As a result, a one-time supply shock, such as a large spike in food prices, can have a persistent effect on inflation. Like other aspects of India's inflation, this finding is reminiscent of inflation in advanced economies in the 1970s and 80s.

A Phillips Curve for Headline Inflation?

As a first exercise, we examine how well the simple Phillips curve fits inflation behavior if we ignore the concept of core inflation and examine the headline WPI. In Table 3, the first column repeats our Phillips curve for median inflation, for purpose of comparison, and the second column reports estimates of an equation for headline inflation. This specification is the same as the first except that the dependent variable is headline WPI inflation *and* the lagged inflation rates with which we capture expected inflation are also WPI inflation.

Table 3. Phillips Curve Estimates

Dependent Variable	Weighted Median WPI Inflation	Headline WPI Inflation	Weighted Median WPI Inflation	Weighted Median WPI Inflation
	[1]	[2]	[3]	[4]
Output gap, α	1.074**	1.792*	1.063**	1.267
	[0.540]	[1.05]	[0.500]	[0.500]
Adjustment parameter, γ - Weighted Median	0.902***			
	[0.053]			
Adjustment parameter, γ - Headline WPI		1.022***	0.877***	
		[0.053]	[0.043]	
Adjustment parameter, γ -(constrained to be the same for Weighted Median WPI and Headline WPI)				1.086***
				[0.101]
Weight on average of past median inflation, β				0.256
				[0.277]
Number pf observations	74	74	74	74
R-squared	0.19	0.076	0.169	0.265
Adjusted R-squared	0.179	0.063	0.158	0.244

Notes: ***, **, and * denote statistical significance at 1,5, and 10 percent percent respectively. Standard errors are denoted in parentheses. β is the weight on an exponential average of past median inflation in the equation for determining expectations. The average of past headline WPI inflation rates has a weight of 1-β. The exponential coefficient γ is constrained to be the same in the two averages.

It appears that this second Phillips curve is mis-specified. In particular, the estimate of the parameter γ is statistically indistinguishable from one (in fact, the point estimate is slightly above one). Our model of expected inflation, Equation (3), assumes γ is less than one; as it approaches one, adjustment of expectations diminishes to the point that expected inflation is constant. Thus, in this case, we fail to find any effect of past inflation on current inflation. Note also that the output coefficient α is less significant statistically (p=0.09) than in our equation for median inflation. In sum, we fail to find strong evidence that headline WPI is explained by the variables on the right side of our Phillips curve.

This result, we believe, reflects the very great volatility of headline WPI inflation at the quarterly frequency. This noise in the series obscures any underlying Phillips curve. This negative result points to the desirability of examining median inflation when estimating the Phillips curve.

Core Inflation, Headline Inflation, and Expectations

Here we return to an equation with median inflation as the dependent variable. However, we consider the possibility that the lagged inflation terms on the right of the equation are headline WPI inflation. We interpret such a specification as saying that price setters base their expectations of inflation on past levels of headline inflation, so that movements in headline inflation are passed into future core inflation.

It is not clear a priori whether expected inflation should depend on past levels of headline inflation or past levels of core inflation. Empirically, a number of studies for the United States find a sharp break in inflation behavior around the Volcker disinflation of the early 1980s. Inflation is explained by lags of headline inflation before that time, and by lags of core inflation afterwards. The usual interpretation is that price setters in the 1970s based their expectations on past headline inflation, so expected inflation responded to movements in headline inflation even if those movements were the result of transitory supply shocks. After the Volcker disinflation, however, it became clear that the Federal Reserve was determined to reverse transitory inflation movements due to supply shocks, so those shocks no longer influenced expectations and actual inflation going forward. In the terminology of central bankers, in the post-Volcker era, supply shocks have first round effects-they directly affect current headline inflation-but not second round effects on expectations and future inflation.

Before using lagged headline inflation rates to explain median inflation, we account for the fact that headline inflation is systematically higher than median inflation-the difference averages 2.42 percentage points over the sample period for our regressions. We subtract this constant from the headline WPI series, resulting in an adjusted series with the same average value as the median. We can interpret this specification as explaining median inflation with lagged levels of headline inflation, both measured relative to their sample averages.

The third column of Table 3 reports this specification. The results for this case are quite close to those with median inflation on both sides of the equation, in column (1): the estimates of α and γ are similar, and so are the R-squared. The estimate of γ is well below one in both economic and statistical terms, unlike the case with WPI inflation on the left. Comparing columns (1) and (3), it appears that we can explain median inflation about equally well when we measure expected inflation with lags of median inflation and with lags of headline inflation.

For the regression with median inflation on the left and lagged headline inflation on the right, Figure 7 shows actual median inflation, expected inflation, and fitted values from the regression, along with eight-quarter moving averages of these series.

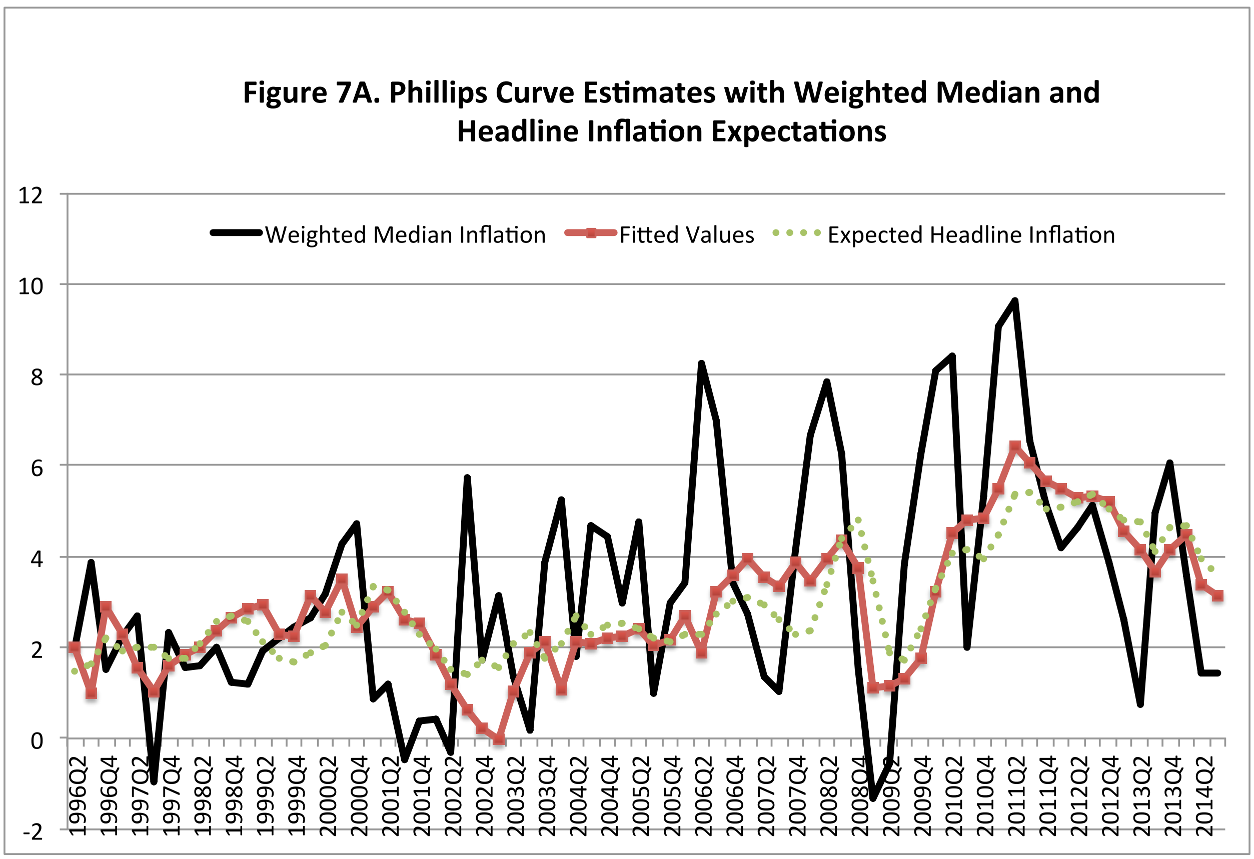
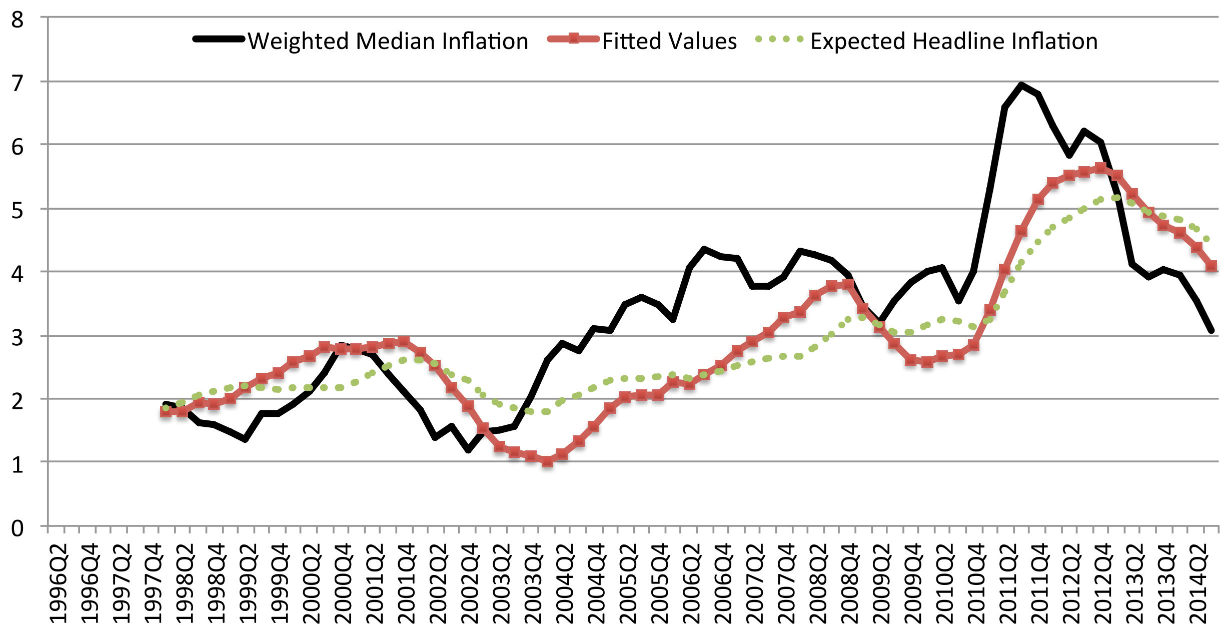


Figure 7B. Phillips Curve Estimates with Weighted Median and Headline Inflation Expectations: 8-quarter Moving Avaerages



In column (4), we investigate whether lagged headline or lagged core inflation belongs on the right side of the Phillips curve by including both in a horserace.

Here, we assume that an exponential average of past median inflation has a weight of β in determining expectations, and an average of past WPIs has a weight of $1-\beta$. Notice that we constrain the exponential coefficient γ to be the same in the two averages; the qualitative results are similar if we estimate two different γs.

Our estimates for this specification are imprecise. This reflects the fact that median inflation and WPI inflation have similar medium-term movements; thus, while these two inflation rates have only a modest correlation at the quarterly frequency, slow moving averages of the two are strongly correlated, so there is a problem of multicollinearity.

Nonetheless, we can see where the estimates point. The key result is that the estimate of the weight

β on past median inflation is 0.26 with a standard error of 0.28. A two-standard error confidence interval is [-0.30, 0.82]. While this range is wide, we can reject the hypothesis that β is one--that only past median inflation affects expectations--and cannot reject the hypothesis that β is zero--that only past headline inflation matters. The estimate of γ exceeds one, but this may simply reflect sampling error, as a two-standard-error band extends down to 0.88.

In sum, the data suggest that past headline inflation has a substantial effect on expected inflation, so, as in the pre-Volcker United States, a supply shock that raises inflation in one quarter can have a persistent effect on core inflation through its effect on expectations.

Food and Energy Again

Throughout our analysis, we have examined the effects of changes in the relative price of food and energy, measured by food and energy inflation minus aggregate WPI inflation. This relative price changes when are there events in the real economy affecting the supply and demand for food and energy. In our framework, large shocks of this nature influence aggregate inflation; again, the underlying theory is that of Ball and Mankiw (1995), in which large shocks have disproportionately large effects on inflation because they trigger adjustment of nominal prices that might otherwise be sticky.

In India, economists debate the reasons for rises and falls in food prices. In particular, some cite supply side factors such as low and stagnant production of food, and others emphasize demand factors such as shifting diets. We do not take a position in this debate, and our results do not shed light on it. In our framework, a large shock to food and fuel prices has the same effect on the price-change distribution, and hence on inflation, regardless of its underlying demand or supply causes.

Much of the literature on India's inflation investigates the interactions of food inflation-the change in the nominal price of food - with non-food inflation or aggregate inflation. In our view, such empirical analyses do not have a clear interpretation. A change in food prices is an event in the real economy only to the extent it differs from aggregate inflation; otherwise, it is simply part of the inflationary process affecting all prices.

In an accounting sense, one can explain aggregate inflation with an equation that includes different components of inflation. If all the components are included, one obtains an equation with an R squared of one, and coefficients on each component equal to its share in the aggregate price index. Even if only one or a few components are included in the equation, they can appear to have high explanatory power if movements in aggregate inflation cause correlated movements in the inflation rates for many industries.

A similar point applies to studies that regress aggregate inflation or non-food inflation on lags of food inflation or other sectoral inflation rates. In these equations, lagged food inflation may simply be a proxy for lagged aggregate inflation if there is a strong common component in the inflation rates of different sectors. Whether a measure of food inflation is contemporaneous or lagged, it can tell us something about the determinants of inflation only if is measured relative to aggregate inflation.

In Table 4, we include the change in the relative price of food and energy, measured by food and energy inflation minus headline inflation, in the estimation of the Phillips curve. The dependent variables are weighted median and headline inflation in columns [1] and [2] respectively. Not surprisingly, as shown in column [1], the relative price of food and energy does not have a significant effect on weighted median inflation, which is stripped of volatile components. Column [2] shows that the relative price of food and energy *does* have a statistically significant effect on headline inflation. The estimated coefficient is 0.43, and the standard error is 0.14. The results support the earlier evidence that changes in the relative price of food and energy, which predominantly constitute the right tail of the distribution of price changes, strongly influence aggregate inflation.

Table 4. Phillips Curve Estimates with Relative Price of Food and Energy

Dependent Variable	Weighted Median WPI Inflation	Headline WPI Inflation
	[1]	[2]
Output gap, α	1.062**	1.918*
	[0.523]	[1.148]
Adjustment parameter, γ - Headline WPI	0.866***	1.004***
	[0.044]	[0.062]
Food and Energy Inflation - Headline WPI Inflation	0.056	0.429***
	[0.108]	[0.139]
Number pf observations	74	74
R-squared	0.1725	0.1726
Adjusted R-squared	0.1492	0.1493

Notes: ***, **, and * denote statistical significance at 1,5, and 10 percent percent respectively.

V. CONCLUSION

Leading macroeconomics textbooks explain inflation with a Phillips curve in which the inflation rate depends on expected inflation, the level of output relative to trend, and supply shocks. Typically the models assume that expected inflation is determined by lags of the inflation rate, and that supply shocks are largely changes in the relative prices of food and energy. One-time supply shocks can have persistent effects because they feed into expectations. In this framework, a central bank can guide inflation to a desired level, but if inflation starts above this level it is costly to reduce it, and it can also be costly to offset supply shocks and prevent them from raising inflation.

While still common in textbooks, this model of inflation is considered to be somewhat less relevant now for advanced economies including the U.S. and Europe. In these economies in the 2000s, a commitment to an inflation target has led to an anchoring of inflation expectations, which makes it easier for central banks to maintain stable inflation with less cost to output stability. In contrast, we have seen that the textbook model explains much of the behavior of inflation in India in recent years. Time will tell whether inflation behavior will change under the RBI's new monetary framework.

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APPENDIX

Appendix 1. Data Details

Median Inflation in 2004Q2

There is a discontinuity in the monthly series on industry price levels that we use to calculate weighted median inflation. A new series begins for each industry in April 2004, and it is not comparable to the earlier data. In addition, 20 industries are added, bringing the total number from 61 to 81. For our quarterly analysis, this break in the data makes it difficult to measure median inflation for 2004Q2.

We approximate median inflation in 2004Q2 as follows. We use the 61 industries that exist both before and after the quarter. For each industry, we assume that the gross monthly inflation rate for April 2004 is the geometric average of the gross inflation rates for February, March, May, and June 2004. With this industry inflation rate in hand, we can compute a consistent series of monthly price levels that spans April 2004. We aggregate monthly price levels to get quarterly price levels for each industry; then calculate quarterly inflation rates; and then calculate weighted median inflation for the 61 industries.

Splicing Methodology for GDP Series

We compute a consistent series for real GDP (before seasonal adjustment) using two series with base years of 1999-2000 and 2004-2005. Essentially, we project the 2004-05 series (which starts in 2004Q2) backwards using the growth rates from the 1999-2000 series. Specifically:

For observations starting in 2004Q2, we use the output levels from the 2004-2005 base year series.

We work backward to get output in 2004Q1, 2003Q4, and so on, using the formula

$$y_t = \frac{y_{t+4}}{(1+g_{t+4})}$$

where y_t and y_{t+4} are output levels in quarters t and $t + 4$, and g_{t+4} is the growth rate of output from t to $t + 4$. For all the observations for 2004Q1 and earlier, g_{t+4} is computed from the output series for base year 1999-2000. For observations from 2004Q1 back to 2003Q2, y_{t+4} is from the output series with 2004-2005 base year. For observations for 2003Q1 and earlier, y_{t+4} comes from an earlier step in our backward iteration.

Appendix 2: Details of Estimation

To estimate the Phillips curve, equation (4), we make two approximations to our equation for expected inflation, (3).

First, we truncate the series of inflation lags after 40 quarters, adjusting the coefficients so they still sum to one. This yields

$$\pi_t^e = \frac{(1-\gamma)}{(1-\gamma^{40})}\left[\sum_{k=1}^{40} \gamma^{k-1}\,\pi_{t-k}\right] + \epsilon_t$$

Second, we must address the problem that data on 40 lags of median inflation are not available for the early part of our sample. We assume that the level of expected inflation in 1996Q3, the first observation in our regression, is some unobserved level π_0^e . This is observationally equivalent to assuming that actual inflation is constant at π_0^e in all quarters before 1996Q3. We estimate this parameter along with the parameters gamma and alpha in the Phillips curve by non-linear least squares.