Predicting the Recent Behavior of Inflation Using Output Gap-Based Phillips Curves

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Many analysts believe that strong productivity growth has played an important role in the favorable inflation performance of the U.S. economy since the mid-1990s. Inflation, as measured by the behavior of the GDP deflator, hovered mostly near a low of 2 percent in the second half of the 1990s and has decelerated further during the past three years. Some policymakers think that, as a result of the continuing strong productivity and weak labor market, inflation may remain low throughout 2004, despite the continued strong pickup in economic activity.[1]

The traditional output gap-based Phillips curve relates current inflation to lagged inflation, supply shocks, and a measure of excess demand such as the level of the output gap. This Phillips curve is likely to overestimate inflation in the second half of the 1990s unless one revises upward estimates of real potential output made possible by the ongoing acceleration of productivity growth. However, in recent speeches, a few policymakers have highlighted two other potential anti-inflationary consequences of the recent surge in productivity. One is that the recent surge in productivity accompanied by weak labor markets has reduced unit labor costs, leading to possible downward pressures on inflation.[2] The other potential consequence stems from the ensuing

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[1] See, for example, recent speeches by Bernanke (2003, 2004).

[2] Fed Governor Ben Bernanke (2004), among others, has emphasized this factor in the recent evolution of inflation, as he observes:

> Recently . . . labor productivity has grown even more quickly than the cost of employing workers, with the result that unit labor costs have declined in each of the past three

behavior of aggregate demand. The strong productivity growth and the resulting surge of real potential output imply aggregate demand must grow fast enough to absorb higher potential output. Otherwise, disinflationary pressures may develop.[3]

In order to investigate the above-noted potential anti-inflationary consequences of acceleration of productivity, this article augments the traditional output gap-based Phillips curve to include two additional variables: the cyclical component of a markup variable defined as the markup of prices over unit labor costs and the change in the output gap. The markup allows for the short-term influence of a productivity-induced decline in unit labor costs on inflation, whereas the "rate of change" specification implies inflation depends also on how fast aggregate demand is growing relative to potential (called here the "demand growth gap"). I estimate the modified Phillips curve and examine whether it predicts the recent deceleration of inflation.[4] I also examine the robustness of the results of using wage share, rather than the markup, to capture the short-term influence of productivity-induced decline in unit labor costs on inflation.[5]

Some analysts have argued that Phillips curves are not useful for predicting inflation. In particular, Atkeson and Ohanian (2001) present evidence indicating that one-year-ahead inflation forecasts from several NAIRU (nonaccelerating-inflation rate of unemployment) Phillips curves are no more accurate than those from a naïve model that predicts inflation next year will be the same as it had been over the past year. Sims (2002) points out that the results in Atkeson and Ohanian arise entirely from having the forecast evaluation period restricted to 1984–1999, a period when inflation was very stable. I examine the robustness of the results in Atkeson and Ohanian along another dimension. Their forecasting exercise predicts the one-year-ahead inflation rate conditional on just past values of a real activity variable and the inflation rate, thereby ignoring the potential contribution of the future values

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> years. ... A decline in production costs must result in lower prices for final consumers, an increase in price-cost markup for producers, or both ("Monetary Policy," 3).

Ball and Moffitt (2001) have also emphasized the role of weak labor markets in explaining the recent behavior of inflation.

[3] See, for example, Kohn (2003), who argues that, as a result of the "jobless recovery," rapid productivity growth has been associated with weak growth in aggregate demand, resulting in a falling inflation rate.

[4] It should be noted that the hypothesis that inflation may depend on a change in the output gap is not new. Gordon (1983), in fact, uses such a Phillips curve to explain U.S. inflation dynamics over almost a century from 1892 to 1980. The role of such a Phillips curve in explaining the most recent inflation dynamics is, however, left unexplored. Similarly, the hypothesis that inflation may be influenced by unit labor costs is not new either, having been previously examined by Gordon (1988) and Mehra (1991, 1993, 2000), among others. The empirical evidence in previous research on the importance of unit labor costs in explaining inflation has, however, been mixed, as I find even here.

[5] Many analysts argue that labor share can better capture the influence of the productivity-led decline in unit labor costs on inflation. See, for example, Galí and Gertler (2003).

of real activity over the forecast horizon.[6] Their exercise may be a reasonable way to construct the forecast because, in real time, forecasters usually do not have information about the future values of the indicator variable. However, it is plausible that a forecast including this extra information may be more accurate than the one ignoring it. As a robustness check, I take the other extreme and generate one-year-ahead predictions of the inflation rate under the counter-factual assumption that the forecaster knows actual values of the indicator variable over the forecast horizon. I then investigate whether the Phillips curve still generates less accurate predictions of the inflation rate than does the naïve model.

The empirical work presented here estimates the modified Phillips curve over two sample periods, 1961Q1 to 1995Q4 and 1961Q1 to 2003Q4, using the chain-weighted GDP deflator as the measure of inflation.[7] It suggests the following conclusions. First, the estimated coefficients that appear on the output gap and its rate of change are significant and correctly signed, suggesting there is a "rate of change effect." Inflation is predicted to rise when the output gap is positive and when aggregate demand increases faster than real potential output. Second, the markup, which is usually defined as the excess of the price level over unit labor costs, has a slow-moving trend and is not statistically significant when included in the estimated Phillips curve. However, the cyclical component of the markup when included in the Phillips curve is significant and appears with a negatively signed estimated coefficient, meaning inflation is predicted to fall if the cyclical markup is high. If the Phillips curve includes the wage share instead of the markup, the estimated coefficient on the wage share is positive, suggesting inflation is predicted to fall if the wage share declines.

Third, the predictions of the one-year-ahead inflation rate conditional on actual values of the explanatory variables suggested by traditional and modified Phillips curves track actual inflation well, outperforming those based on the naïve model that predicts inflation using only its past values.[8] This result holds over 1980–2003 as well as over 1984–1999, a period when inflation was stable. The results also indicate demand growth and output gap variables help most in generating accurate predictions of the inflation rate. The markup (or the wage share) does not improve the predictive accuracy if it is included in

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[6] Their forecasting exercise also assumes that the NAIRU is constant over the sample period 1959–1999, because one of the indicator variables used is the unemployment rate, not the unemployment gap.

[7] In order to check whether results regarding the influences of additional factors on inflation are not simply due to the ongoing episode of productivity surge, the shorter sample period exludes the most recent period of productivity surge.

[8] The predictions, however, are dynamic in the sense that lagged values of the inflation rate used are those predicted by the model.

the modified Phillips curve. Together these results suggest that Phillips curves are useful for predicting inflation.

Regarding sources of the recent deceleration of inflation, the correlations summarized in the estimated modified Phillips curve suggest one plausible explanation of the recent behavior of inflation. As noted at the outset, inflation, after hovering near a low of 2 percent in the second half of the 1990s, decelerated further during the past three years. In the second half of the 1990s, the demand growth gap stayed close to the 2 percent range, as aggregate demand grew just fast enough to absorb the productivity-induced increase in potential. However, during the period 2000–2002, aggregate demand did not grow fast enough to absorb higher potential output, creating a declining demand growth gap and negative output gap. The recent deceleration is well predicted by the behavior of a Phillips curve that includes these two gap variables. However, the contribution of the markup (or wage share) in improving the prediction of the inflation rate since the mid-1990s remains negligible, suggesting the markup is not providing information beyond that contained in the gap variables. These results suggest that the weak demand growth gap together with the resulting negative output gap trump the cyclical markup (or wage share) as the major source of the recent deceleration of inflation.

The plan of this article is as follows. Section 1 discusses two modifications to the conventional expectations-augmented Phillips curve. It also provides an overview of the data including graphs of key variables that enter the Phillips curve, the estimation procedure, and the empirical specifications estimated here. Section 2 presents the new empirical work, and Section 3 contains concluding observations.

1. MODEL AND THE METHOD

Traditional and Modified Phillips Curves

The traditional reduced-form Phillips curve relates current inflation to lagged inflation, supply shocks, and a measure of excess demand such as the level of output or unemployment gap. Following Gordon (1985, 1988) and Stockton and Glassman (1987), the traditional output gap-based Philips curve can be derived from the following reduced-form price and wage equations.

$$\Delta p_t = h_0 + h_1 \Delta (w - q)_t + h_2 x_t + h_3 sp_t, \tag{1.1}$$

$$\Delta\,(w - q)_t = k_0 + k_1 \Delta p^e_t + k_2 x_t + k_3 sw_t, \text{ and} \tag{1.2}$$

$$\Delta p^e_t = g(L) \Delta p_t, \tag{1.3}$$

where all variables are in natural logarithms and where p is the price level; w is the nominal wage; q is labor productivity; x is a demand pressure variable;

p^e is the expected price level; sp represents supply shocks affecting the price equation; sw represents supply shocks affecting the wage equation; $g(L)$ is a lag operator; and Δ is the first difference operator. Equation (1.1) describes the price markup behavior: prices are marked over productivity-adjusted wage costs and are influenced by cyclical demand and the exogenous supply shocks. This equation implies that productivity-adjusted wages determine the price level, given demand pressures. Equation (1.2) is the wage equation: wages are assumed to be determined by cyclical demand and expected price level, the latter modeled as a distributed lag on past prices as in (1.3). The wage equation, together with the price expectation equation (1.3), implies that productivity-adjusted wages depend upon past prices, cyclical demand, and supply shocks.

If we substitute the price expectation equation (1.3) into the wage equation (1.2) and the resulting wage equation into the price equation (1.1), we get the traditional reduced-form Phillips curve of the form given in (2).

$$\Delta p_t = a_0 + a_1(L)\Delta p_t + a_2 x_t + a_3 SS_t, \tag{2}$$

where SS represents supply shocks, a_1 (L) is a lag operator, and other variables are defined as before. The parameters a_i, $i = 0$, 1, 2, in (2) are functions of the parameters in the underlying price and wage equations. Equation (2) says current inflation depends on lagged inflation, cyclical demand, and supply shocks.

The key feature of the Phillips curve (2) is that current inflation does not directly depend on the productivity-adjusted wage once we control for the influences of lagged inflation and the cyclical demand on inflation. This feature rests on the assumption that wages adjust one-for-one with productivity each period, so that the productivity-adjusted wages depend only on lagged inflation and the cyclical demand (as hypothesized in (1.2) and (1.3)). Under this specification, productivity-adjusted wages have no independent influence on inflation once we allow for the influences of lagged inflation and the cyclical demand.

The assumption above—wages adjust one-for-one with productivity each period—may not hold in practice, especially during a period when productivity is undergoing a structural shift. In that case, the productivity-adjusted wage may change due to reasons other than those captured in the wage equation (1.2) and hence may play an independent role in determining inflation in the short run. Thus, an acceleration of productivity growth that is accompanied by anemic wage growth may lead to lower inflation if firms pass through the productivity-induced declines in unit labor costs in lower product prices.

In order to motivate the empirical specification of the influence of productivity on inflation, note first that "the price markup hypothesis" that underlies (1.1) can be summarized in the following price equation:

$$p_t = b_0 + b_w w_t - b_q q_t, \tag{3.1}$$

where all variables are defined as before and the parameters b_w and b_q measure the responses of the price level to nominal wages and productivity, respectively. The price equation (3.1) says the price level declines if nominal wages decline or productivity rises; the magnitude of the price response depends in part on the size of the pertinent wage or productivity response coefficient. The assumption implicit in the inflation specification (1.1) is that the underlying wage and productivity response coefficients are equal in magnitude but opposite in signs, an assumption that may not hold in practice.

If we subtract w_t and add q_t to both sides of the price equation (3.1), we can rewrite the price equation (3.1) as (3.2).

$$p_t - w_t + q_t = b_0 + (b_w - 1)w_t - (b_q - 1)q_t, \tag{3.2}$$

where all variables are defined as before. The left-hand side of the reformulated price equation (3.2) is the markup, defined as the excess of the price level over unit labor costs. Equation (3.2) links the markup $(mrk_t \equiv p_t - (w_t - q_t))$ to the behavior of wages and productivity, given the price level. If we assume prices are sticky in the short run, then the markup will move in response to changes in wages and/or productivity. Since in the long run the price level adjusts to reflect economic fundamentals as envisioned in "the price markup hypothesis," a rise in the markup has implications for the near-term behavior of inflation. Thus, if unit labor costs decline in response to the acceleration of productivity and the markup rises, then the price level should eventually decline to reflect lower unit labor costs, leading to lower inflation down the road. Hence I modify the traditional Phillips curve to include the one-period lagged value of the markup as in (4).

$$\Delta p_t = a_0 + a_1(L)\Delta p_t + a_2 x_t + a_3 SS_t + a_4 mrk_{t-1}. \tag{4}$$

Under the assumption that the "price markup hypothesis" is valid, the expected sign of the coefficient that appears on the markup should be negative, suggesting that the high level of the markup is associated with a decline in the inflation rate. As can be seen, the modified Phillips curve reduces to the traditional Phillips curve if a_4= 0 in (4).

In some previous work analysts have captured the influence of unit labor costs on inflation by including wage share in the Phillips curve (Galí and Gertler 2003). The wage share, however, moves inversely with the markup, and one should obtain similar results using the wage share. Note that the (log of) wage share is just the (log of) real wage per hour minus the (log of) output per hour. Using the notation introduced above, the wage share can be expressed as (5).

$$WS_t = (w_t - p_t) - q_t \equiv -\{p_t - (w_t - q_t)\}, \quad (5)$$

where WS is the log of wage share and other variables are defined as before. Equation (5) shows wage share is just the inverse of the markup. If productivity rises faster than the real wage, wage share declines, and the markup may move up if prices are sticky in the short run. The expected sign of the coefficient on wage share when included in the Phillips curve is positive, implying inflation is predicted to fall if wage share declines. As a robustness check, I shall examine results using the wage share also.

In most previous empirical work, the Phillips curve (2) has been estimated with excess demand measured by the output gap or unemployment gap. I now consider another modification to the Phillips curve, arguing excess demand be measured by the level and change in output gap. The main reason for considering the rate of change specification is that in a reformulated version of this Phillips curve inflation depends explicitly on the excess of the growth rate of aggregate demand over that of potential. This reformulation better captures the potential demand channel consequence of the ongoing acceleration of productivity, emphasized by Kohn (2003). Consider the Phillips curve (4) augmented to include the change in output gap as in (6).[9]

$$\Delta p_t = a_0 a_1(L)\Delta p_t + a_2 y_t + a_3 SS_t - a_4 mrk_{t-1} + a_5 \Delta y_t, \quad (6)$$

where y is now the output gap and where all other variables are defined as before. Following Gordon (1983), I reformulate the inflation equation (6) as follows. Note first that the level of the output gap is linked to the growth rate of nominal GDP via the following identity.

$$y_t \equiv y_{t-1} + (\Delta Y_t - \Delta pot_t) - \Delta p_t, \quad (7)$$

where Y is nominal GDP and pot is real potential output. If we substitute (7) into (6) and rearrange terms, we get the modified Phillips curve (8).

$$\begin{aligned}\Delta p_t \quad = \quad & (1/(a_2 + a_5))[a_1(L)\Delta p_t + (a_2 + a_5)(\Delta Y_t - \Delta pot_t) \\ & + a_2 y_{t-1} + a_3 SS_t + a_4 mrk_{t-1}, \end{aligned} \quad (8)$$

where all variables are defined as before. According to equation (8), among other things, inflation depends on the contemporaneous “demand growth gap”

[9] A theoretical model consistent with a structural Phillips curve—in which current inflation depends also on a change in the output gap—appears in Mankiw and Reis (2001). Under the assumption that information is sticky, they derive a Phillips curve in which inflation depends on the level and change in the output gap, besides depending on past expectations of the current inflation rate.

defined as the excess of the growth rate of nominal aggregate demand over that of real potential output,[10] besides depending on the "level" of the output gap. In this framework, the estimated coefficient on the lagged output gap indicates the presence of an output "level effect," while the difference between the coefficient on the "demand growth gap" and the output gap indicates the relative size of the "rate of change effect." An interesting implication of this Phillips curve is that during the period when there is an outgoing shift in productivity indicating higher real potential output near term, aggregate demand has to grow fast enough to absorb higher potential output. If aggregate demand fails to keep up with higher potential output, disinflationary pressures may develop, even when there may be no slack as measured by the level of the output gap. To illustrate this point further, the most recent estimates of potential output prepared by the Congressional Budget Office indicate real potential output rising at a 3.5 percent annual rate since the mid-1990s. This trend growth rate of 3.5 percent is one percentage point higher than the trend rate for the preceding period of 1990 to 1994. This upward shift in the trend growth rate of real potential implies aggregate demand now has to grow at a higher rate than before, otherwise deflationary pressures will develop.

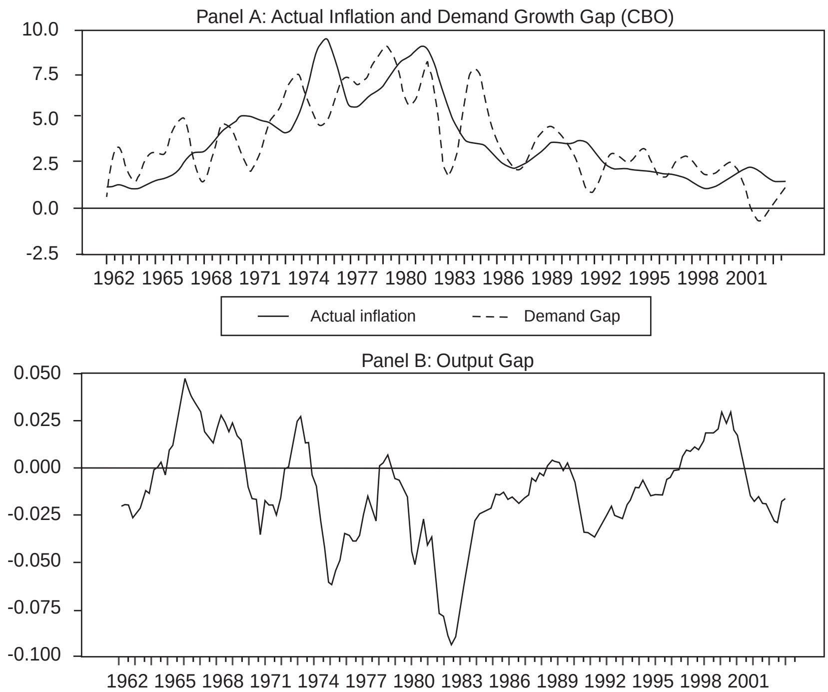
A Visual Look at Some Data: Demand Growth Gap, Output Gap, Markup, and Wage Share

I estimate the modified Phillips curve (8) using quarterly data from 1959Q1 to 2003Q4. Inflation is measured by the behavior of the chain-weighted GDP deflator. In most previous work, potential output has been estimated fitting a deterministic time trend to real output. I, however, use estimates of potential output prepared by the Congressional Budget Office. I consider two supply shock variables: one associated with change in the relative price of imports and the other arising as a result of the imposition and removal of President Nixon's price controls. The effects of price controls are captured by means of two dummies: PC1 defined to be unity from 1971Q3 to 1972Q4 and zero otherwise, and PC2 defined to be unity from 1973Q1 to 1974Q4 and zero otherwise. The relative import price series is the GDP deflator for imports divided by the implicit GDP deflator. The nominal wage series is compensation per man hour, and the productivity series is output per man hour, both of the nonfarm business sector.[11] The inflation equations are estimated with an instrumental variables procedure. The instruments used are: a constant;

[10] Gordon (1983) calls it "adjusted nominal growth." I think the term "demand growth gap" better captures the way inflation depends on how fast aggregate demand is growing relative to potential supply.

[11] The empirical work here is done using revised, not real-time, data. Hence the conclusions regarding the predictive accuracy of the Phillips curve must be viewed with caution.

Figure 1

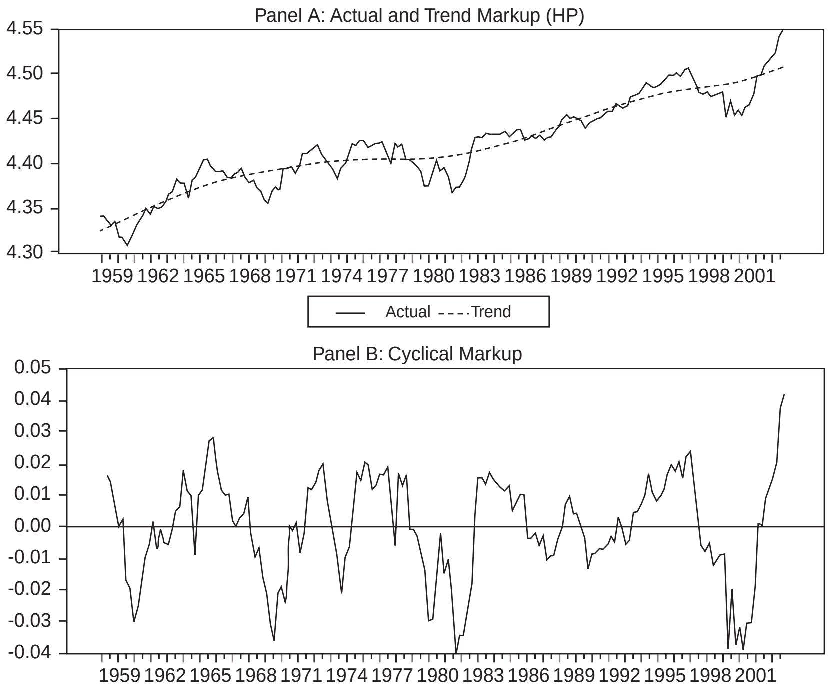


contemporaneous change in military expenditures; and four lagged values of the inflation rate, change in the federal funds rate, gap variables, and change in the relative price of imports.[12]

Figures 1 through 5 provide a visual look at the behavior of some key variables that enter the modified Phillips curve. Panel A of Figure 1 charts the demand growth gap and actual inflation. Both variables measure changes defined over four-quarter periods and are smoothed further by taking the four-quarter moving average of the variables. Figure 1 illustrates that actual inflation and the demand growth gap have moved together over time. Inflation steadily increased in the late 1960s and the 1970s, accompanied by steadily expanding demand growth gap. Similarly, a declining demand growth gap

[12] I do present results of the test that the instruments used are not correlated with the residuals of the estimated Phillips curves. That test is implemented regressing the residuals from the instrumental variables regression on the instruments. See Table 1 (p. 15) which reports the significance levels of the pertinent Chi-square statistic, x^2, defined as T times the R^2 from this regression and distributed Chi-square with (K-1) degrees of freedom, where T is the sample size and K is the number of instruments.

Figure 2

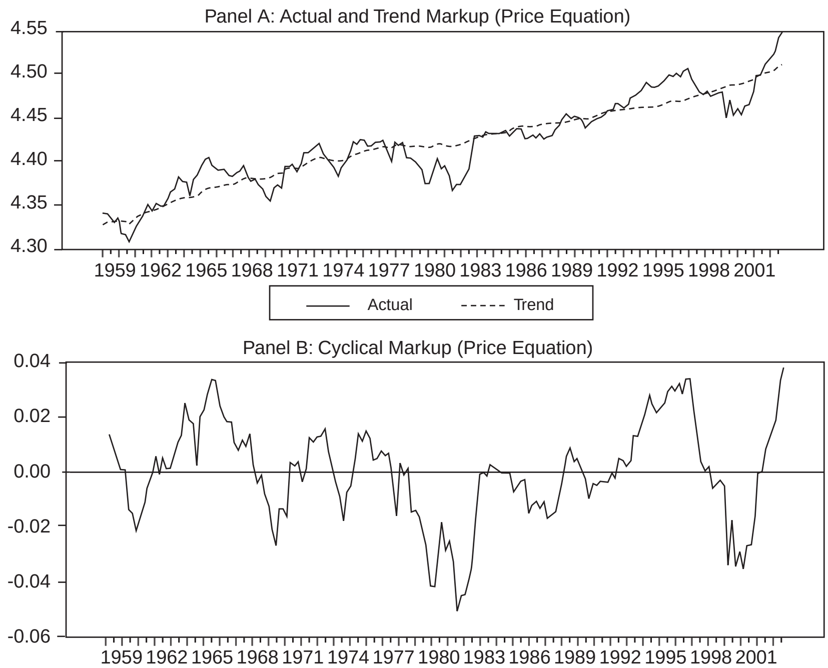


accompanied the steady decline in inflation observed during the 1980s and the 1990s. In particular, during the second half of the 1990s, inflation was stable and so was the demand growth gap. However, for most of the past three years aggregate demand has not kept up with real potential output and hence the resulting decline in the demand growth gap has accompanied the most recent decline in the inflation rate.

Panel B of Figure 1 charts the level of the output gap. The output gap is not smoothed. During the past three years the output gap has been negative and remains so currently, despite last year's upturn in the demand growth gap.

Panel A of Figure 2 charts the markup defined as the excess of the price level over productivity-adjusted wage (markup $= p_t - (w_t - q_t)$). As can be seen, the markup displays a slow-moving trend. I de-trend the markup, using the Hodrick-Prescott (1997) filter. Panel B of Figure 2 charts the cyclical component of the markup. As can be seen, for much of the 1990s the cyclical markup has been positive. Furthermore, in recent quarters the cyclical component has reached levels not seen in the recent past. As of the fourth quarter of 2003, the cyclical component is above 4 percent.

Figure 3

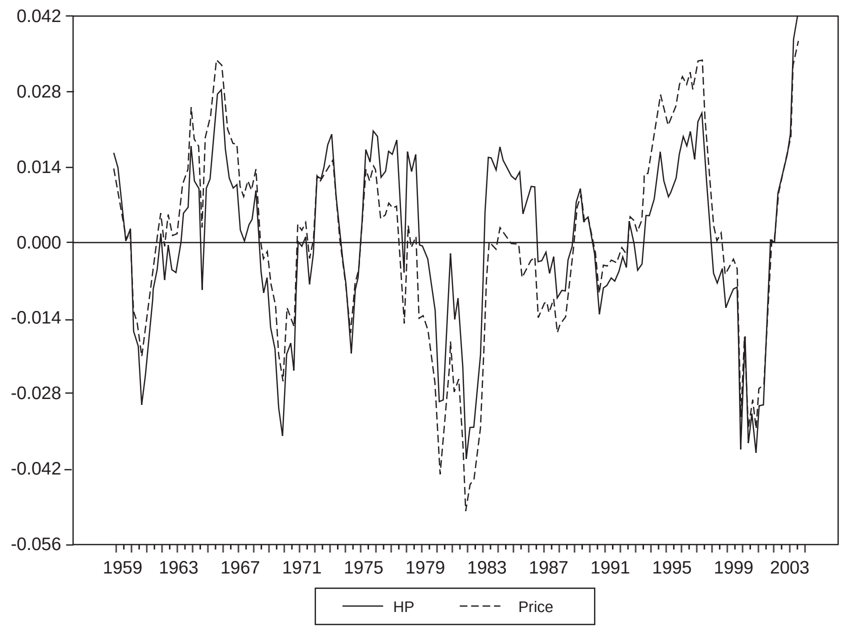


As indicated in Figure 2, the markup series has a slow-moving trend. One simple explanation of the trend in the markup series is suggested by the price equation (3.2), which is that the firms do not pass through part of the productivity-led decline in unit labor costs in lower product prices. In order to explain this point further, note that the markup, as formulated in the price equation (3.2), is constant if the coefficients that appear on wage and productivity variables are unity, as will be the case if there is perfect competition. However, if in practice these coefficients are different from unity, then the markup may have trend if wage and/or productivity series have trend.

In order to explore this source of trend in the markup series, I present below the price equation (3.2), estimated using aggregate data on the price level, nominal wages, and average productivity over the whole sample period 1959Q1 to 2003Q4.

$$p_t - w_t + q_t = 3.1 - \underset{(2.9)}{.04}\, w_t + \underset{(6.7)}{.34}\, q_t + \mu_t. \qquad (9)$$

Figure 4 Cyclical Markup: HP versus Price Equation



As can be seen, the estimated coefficient that appears on the wage variable is not economically different from zero, but the one that appears on the productivity variable is different from zero. Since the productivity variable has a trend, the estimated price equation implies the observed trend in the markup arises because not all of the productivity gain passes through in lower prices.[13]

Panel B in Figure 3 charts the residuals from the estimated price equation (9), which is the measure of the cyclical markup.[14] This measure of the cyclical markup appears similar to the one estimated using the HP filter, as shown in Figure 4. The simple correlation between these two cyclical measures of the markup is 0.84. I consider results with both these measures.

[13] The empirical evidence here that the estimated coefficient on productivity in the price equation is not unity is in line with the evidence in Bils and Chang (2000). Using the U.S. manufacturing data, they estimate industry price equations and find product prices respond weakly to declines in marginal costs driven by increases in labor productivity, suggesting not all of the gain in productivity shows up in the form of lower product prices. They attribute this result to the presence of imperfect competition. It is plausible that similar forces might be at work at the aggregate level.

[14] For generating the cyclical markup I have set the wage response coefficient in the estimated markup equation to zero, thereby implicitly assuming the wage response coefficient in the price equation is unity.

Figure 5 Wage Share

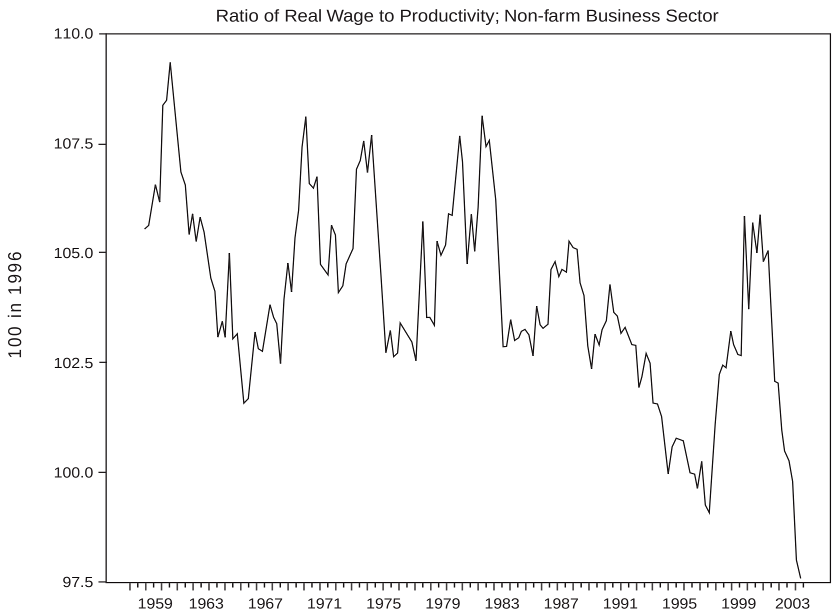


Figure 5 charts the wage share calculated using the nonfarm business sector data on the nominal average hourly compensation, price level, and average productivity. As shown in equation (5), the wage share can be expressed as the ratio of the real wage to the average product of labor.[15] A look at Figure 5 indicates that the wage share series calculated using the nonfarm business sector data does not have as noticeable a trend as the markup series shown in Figure 2. However, the wage share does show a distinct decline in recent years, indicating productivity has grown faster than the real wage. Since in previous research many analysts have used the wage share to explain inflation dynamics, as a robustness check, I also examine results using the wage share.[16]

[15] Wage share is usually calculated as total labor compensation $(W * n)$ divided by total factor income $(p * y)$. One can then express the wage share as the ratio of real wage to the average product of labor, as shown: Wage share $= (W * n) / (P * y) \equiv (W/P)/(y/n) \equiv (W/P)/(q)$, where W is the nominal wage; n is the number of hours; y is real output; P is the price level; and q is the average product of labor. The wage share declines if productivity rises faster than the real wage.

[16] See, for example, Galí and Gertler (2003).

2. EMPIRICAL RESULTS

This section reports and discusses empirical estimates of the modified Phillips curve (8). It also examines whether the estimated Phillips curve predicts the behavior of inflation during the 1980s and the 1990s.

Estimated Phillips Curves

Table 1 reports estimates of the traditional and modified Phillips curves over two sample periods, 1961Q2 to 1995Q4 and 1961Q2 to 2003Q4. The shorter sample period excludes observations pertaining to the most recent subperiod of productivity surge. The estimated coefficients (with t-values in parentheses) reported are those that appear on the demand growth gap, output gap, cyclical markup, lagged inflation, and the relative import price inflation. The coefficient on lagged inflation reported is the sum of coefficients that appear on four lagged values of the inflation rate.

Rows 1 and 2 present estimates of the traditional Phillips curve that relates current inflation to the contemporaneous output gap, lagged inflation, and the relative import price inflation. As can be seen, the estimated coefficients appearing on the output gap, lagged inflation, and import price inflation have positive signs and are statistically significant, suggesting current inflation is positively correlated with the contemporaneous output gap, lagged inflation, and import price inflation. These results hold over both the sample periods.

Rows 3 and 4 present estimates of the modified Phillips curve that allow inflation to depend on the change in the output gap, but not on the markup. As can be seen, the estimated coefficient that appears on the demand growth gap has a positive sign and is statistically significant, meaning inflation is predicted to rise if aggregate demand grows faster than real potential output. The other estimated coefficients that appear on the output gap, lagged inflation, and the relative import price inflation remain correctly signed and significant. The point estimates of the coefficient on the contemporaneous demand growth gap are in a 0.10 to 0.14 range, implying the current quarter predicted increase in inflation following a one percentage point rise in the demand growth gap is 0.10 to 0.14 of a percentage point. These estimates suggest that the cumulative predicted increase in inflation over one year, resulting from a one percentage point sustained increase in the demand growth gap, is about 0.4 to 0.6 of a percentage point.[17]

Rows 5 through 8 present the modified Phillips curve estimated with the demand growth gap and cyclical markup.[18] Rows 5 and 6 present estimates

[17] In Gordon (1983) the estimate of the cumulative increase in inflation over the year resulting from a sustained rise in the demand growth gap is 0.4 of a percentage point, which is near the low end of the range estimated here.

[18] The actual markup, when included in the estimated Phillips curve, is never significant. As can be seen from Figures 1 and 2, the markup series has a slow-moving trend whereas the inflation rate series appears stationary over the whole sample period.

Table 1 Conventional and Modified Reduced-form Phillips Curves GDP Inflation

Row No.	End Period	Output Gap (d_1)	Demand Growth Gap (d_2)	Cyclical Markup (d_3)	Lagged Inflation (d_4)	Import Prices (d_5)	R^2	x^2
1	1995Q4	0.03 (2.90)			00.90 (21.30)	0.07 (4.60)	0.84	0.80
2	2003Q4	0.03 (3.10)			00.91 (24.20)	0.06 (5.20)	0.86	0.67
3	1995Q4	0.03 (3.50)	0.10 (2.10)		00.85 (20.30)	0.07 (5.30)	0.86	0.84
4	2003Q4	0.03 (3.70)	0.10 (2.10)		00.86 (22.20)	0.07 (5.30)	0.87	0.72
5	1995Q4	0.04 (3.90)	0.14 (2.80)	−0.03 (1.90)	00.82 (18.90)	0.06 (4.50)	0.86	0.42
6	2003Q4	0.03 (3.90)	0.11 (2.30)	−0.02 (1.20)	00.85 (20.70)	0.06 (5.30)	0.87	0.47
7	1995Q4	0.05 (3.10)	0.13 (2.80)	−0.05 (1.90)	00.78 (18.90)	0.06 (4.60)	0.87	0.53
8	2003Q4	0.04 (2.10)	0.11 (2.40)	−0.03 (2.10)	00.83 (19.40)	0.06 (5.30)	0.88	0.48
9	1995Q4	0.04 (4.20)	0.14 (3.40)	0.02 (1.70)	00.81 (19.40)	0.06 (4.60)	0.86	0.63
10	2003Q4	0.04 (4.40)	0.12 (3.20)	0.02 (1.70)	00.83 (20.80)	0.06 (5.20)	0.87	0.78

Notes: With the exception of the coefficients in rows 9 and 10, the estimated coefficients (with t-values in parentheses) are from reduced-form Phillips curves of the form $\Delta p_t = d_0 + d_1 y_{t-1} + d_2(\Delta Y_t - \Delta pot_t) + d_3 mrk_{t-1} + d_4 \Delta p_{t-1} + d_5 SS_t$, where all variables are in their natural logs and where p is the price level; Y is nominal GDP; pot is real potential output; y is the output gap; $(\Delta Y_t - \Delta pot_t)$ is demand growth gap; and SS is relative import prices. The coefficients reported in rows 9 and 10 are from Phillips curves, estimated using wage share instead of the markup. The reported coefficient on lagged inflation is the sum of the estimated coefficient on its four lagged values. The inflation equations are estimated over the sample periods that all begin in 1961Q2 but end as shown above, using an instrumental variables procedure. The instruments are: a constant; four lagged values of the inflation rate, output gap variables, changes in the federal funds rate, and relative import prices; and change in the current nominal defense expenditure. The estimated inflation equations also included the Nixon price control dummies. The significance level of the test that the instruments are not correlated with the residuals of the Phillips curve is x^2.

generated using the cyclical markup based on the HP filter, and rows 7 and 8 present estimates with the cyclical markup generated using the estimated price equation. The estimated coefficient that appears on the markup has a negative sign and is significant, especially over the shorter sample period, meaning inflation is predicted to decline if the markup is high. In the longer sample period, the markup—though it continues to appear with a correctly signed estimated coefficient—is not significant if the Phillips curve is estimated using the cyclical markup based on the HP filter.[19]

The point estimates of the coefficient that appears on the cyclical markup fall in a –0.02 to –0.05 range, suggesting that in response to a one percentage point increase in the markup, the cumulative predicted decline in the inflation rate over the year is about 0.10 to 0.20 of a percentage point, which is not large in magnitude. Moreover, augmenting the Phillips curve to include the cyclical markup does not much improve the explanatory power of the inflation regression, as measured by the R-squared statistic. (Compare estimates in rows 3 and 4 with those in rows 5 through 8, Table 1).[20] Despite these caveats, the estimated Phillips curve with the markup is capable of generating the prediction of a significant fall in the inflation rate during periods of high cyclical markups, which may be periods when productivity is accelerating but wage growth remains anemic.[21]

Rows 9 and 10 present estimates of the coefficients from the modified Phillips curve that includes the wage share rather than the markup. The estimated coefficient on the wage share is positive, suggesting that inflation is predicted to decline if the wage share declines. The size of the estimated coefficient on the wage share appears to be of the magnitude found using the cyclical markup. All the remaining variables appear with correctly signed estimated coefficients and are significant in the estimated Phillips curve.

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[19] The serial correlation coefficients estimated using the residuals series from the estimated modified Phillips curve are small, indicating serial correlation is not a problem. The significance level of the Chi-squared test of the null hypothesis that instruments are uncorrelated with the residuals (reported in Table 1) indicates that the null is not rejected.

[20] In fact, the explanatory power of the regressions as measured by the R-squared statistic does not improve much if demand growth gap and markup variables are added into the traditional Phillips curve. However, these two variables significantly enter the modified Phillips curve. The significance level of the F statistic, testing the null hypothesis that the estimated coefficients on these two variables are zero, falls in a 0.00 to 0.03 range and leads to the rejection of the null. Together these results, however, do imply that the quantitative contribution of these two variables in predicting inflation may not be large, as we see later.

[21] In some previous research the potential influence of unit labor costs on inflation has been investigated, using cointegration and error correction methodology (Mehra 1991, 1993, 2000). In particular, the influence of unit labor costs on inflation is investigated in two steps. In step one, the cointegrating (long-run) relationship between the price level and unit labor costs is investigated, resulting in an estimated price equation like (3.1) in which wage and productivity response coefficients are assumed to be opposite in sign but equal in magnitude. The residual series from the estimated price equation is the error-correction variable, which measures the gap between the actual price level and the price based on unit labor costs—a variable similar in spirit to the cyclical markup used here. In the second step, the inflation equation is estimated including, among other variables, the lagged value of the error-correction variable. In previous research the error-correction variable is generally found to be insignificant, suggesting unit labor costs have no direct influence on inflation (Gordon 1988; Mehra 1993, 2000). The new empirical evidence here indicates that the error-correction variable estimated without imposing unitary coefficient restrictions on the price equation is somewhat more favorable to the view that productivity-led declines in unit labor costs may matter for the short-term behavior of inflation.

Predicting the Behavior of Inflation During the 1980s and the 1990s: Are Phillips Curves Useful?

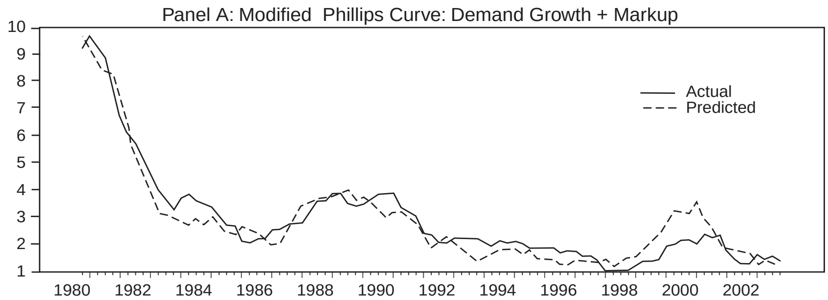
Panel A in Figure 6 charts the dynamic, one-year-ahead predictions of the inflation rate generated using the rolling regression estimates of the modified Phillips curve with the markup over the period 1980–2003.[22] As indicated before, these predictions are conditional on actual values of the explanatory variables suggested by the Phillips curve. Panel B charts the dynamic predictions of the inflation rate generated using a naïve model that predicts inflation using only four lagged values of the inflation rate. Actual inflation rates are also charted there. As can be seen, the estimated modified Phillips curve tracks actual inflation fairly well. The naïve model, however, tends to overpredict inflation, first during the early 1980s and then in the second half of the 1990s.

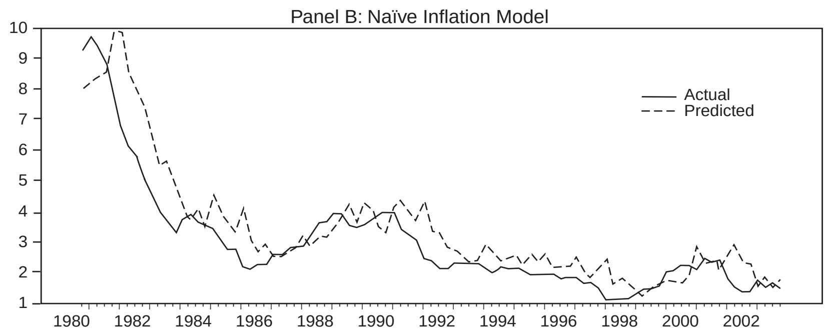
Table 2 presents the statistical evidence on the relative accuracy of inflation predictions. It presents the mean error (ME) and the root mean squared error (RMSE) of the prediction from several different Phillips curves including the one in which the unemployment rate, not the output gap, is the main activity variable as in Atkeson and Ohanian (2001). The predictive accuracy is evaluated over 1980–2003 as well as over the period 1984–1999 covered in Atkeson and Ohanian. The relative accuracy is evaluated by computing the ratio of the RMSE of the prediction from a given Phillips curve with the RMSE of the naïve model's prediction. The naïve inflation model is said to generate more accurate predictions of inflation than a given Phillips curve if the ratio is above unity. The Phillips curves considered here are: the traditional Phillips curve that relates current inflation to the contemporaneous output gap, lagged inflation, and supply shocks; the traditional Phillips curve augmented to include demand growth gap; the traditional Phillips curve augmented to include both demand growth gap and markup or wage share; the traditional Phillips curve augmented to include just the wage share; and the NAIRU Phillips curve that relates current inflation to four lagged values of the unemployment rate and the inflation rate.

If we focus on estimates of the ratio reported for the sample period 1980–2003, we see that the ratio is less than unity for all the Phillips curves considered here. The point estimates of the ratio fall in a 0.5 to 0.9 range, suggesting the Phillips curves considered here provide more accurate predictions of the inflation rate than does the naïve model. The ratio estimated using predictions from the traditional output gap-based Phillips curve or the modified Phillips curve with demand growth gap is close to 0.5, far below unity. The results also

[22] The estimation periods that underlie the rolling regressions all begin in 1961Q1 but end in the year before the forecast period. Thus the Phillips curve is first estimated over 1961Q1 to 1979Q4 and then dynamically simulated over 1980Q1 to 1980Q4 to generate the one-year-ahead prediction of the inflation rate for 1980. The end of the estimation period is then advanced one quarter, the Phillips curve re-estimated and dynamically simulated to generate the one-year-ahead prediction of the inflation rate, and so on.

Figure 6 Actual and Predicted Inflation: 1980–2003





indicate the markup or wage share does not aid much in improving the RMSE of the prediction as do the output gap and supply shock variables (compare RMSEs across models in Table 2).

If we focus on estimates of the ratio for the period 1984–1999, they suggest qualitatively similar inferences about the relative predictive accuracy of the Phillips curve and the naïve model. The prediction of inflation from the modified Phillips curve with demand growth gap has the lowest RMSE, outperforming the naïve model's prediction by a substantial margin. The ratio of the RMSEs for these two models is 0.56 (see Table 2). In contrast, the ratio of the NAIRU Phillips curve and naïve models' RMSEs is 0.88, not too far below unity, suggesting the NAIRU Phillips curve does not aid much in improving accuracy relative to the naïve model.[23] Together these results suggest Phillips curves are useful for predicting inflation.

[23] The relative poor accuracy of the NAIRU Phillips curve may be due to the use of the unemployment rate rather than the unemployment gap, implicitly assuming a constant NAIRU over the sample period.

Table 2 Test of Relative Predictive Accuracy

Panel A: Sample Period 1980–2003

Model	ME	RMSE	RATIO
Naïve	−0.48	0.91	
Traditional Phillips Curve	−0.10	0.53	0.56
Traditional Phillips Curve			
+ Demand Growth Gap	−0.00	0.48	0.53
+ Demand Growth Gap + Markup	0.05	0.51	0.56
+ Demand Growth Gap + Wage Share	0.20	0.52	0.57
+ Wage Share	0.03	0.55	0.62
NAIRU Phillips Curve	−0.20	0.80	0.88

Panel B: Sample Period 1984–1999

Model	ME	RMSE	RATIO
Naïve	−0.41	0.66	
Traditional Phillips Curve	−0.21	0.43	0.65
Traditional Phillips Curve			
+ Demand Growth Gap	−0.13	0.37	0.56
+ Demand Growth Gap + Markup	−0.10	0.42	0.64
+ Demand Growth Gap + Wage Share	0.13	0.40	0.60
+ Wage Share	0.04	0.38	0.65
NAIRU Phillips Curve	−0.25	0.58	0.88

Notes: ME is mean prediction error; RMSE is the root mean squared error; and RATIO is the ratio of Phillips Model/Naïve Model RMSEs. The traditional Phillips curve relates current inflation to contemporaneous output gap, lagged inflation, and supply shocks. The NAIRU Phillips curve relates current inflation to four lags of inflation and unemployment rate. The prediction of inflation used is the dynamic, one-year-ahead predicted inflation rate generated using the Phillips curve model and conditional on actual values of other explanatory variables. If the RATIO is below unity for a Phillips curve model, it implies the Phillips curve model generates more accurate predictions of the inflation rate than does the Naïve model.

Predicting the Behavior of Inflation since the Mid-1990s

Table 3 focuses on the behavior of inflation since the mid-1990s. The column labeled (2) presents the inflation predictions generated using the traditional output gap-based Phillips curve and estimates of potential output prepared by the Congressional Budget Office. As can be seen, the traditional Phillips curve still tends to overestimate inflation somewhat. The bias measured by the mean

Table 3 Actual Predicted Inflation 1995–2003

Year	Act. (1)	Pred. (2)	Pred. (3)	Pred. (4)	Pred. (5)	DGG (6)	OG (7)	mrk (8)
1995	1.90	2.50	2.30	1.50	1.70	1.10	−1.30	3.10
1996	1.80	1.90	1.90	1.30	1.50	3.10	−0.10	3.60
1997	1.50	1.90	1.90	1.40	1.50	2.40	0.90	2.30
1998	1.10	1.50	1.40	1.60	1.30	2.10	1.90	0.00
1999	1.50	2.00	1.90	2.50	2.00	2.60	3.00	−0.70
2000	2.20	2.70	2.50	3.30	2.70	**0.90**	1.70	−3.10
2001	2.40	2.10	1.70	2.20	1.80	**−1.00**	−1.70	−1.70
2002	1.40	2.00	1.80	1.80	1.60	**0.70**	−2.40	1.60
2003	1.50	1.70	1.60	1.30	1.20	2.30	−1.50	4.00
ME		−0.33	−0.21	−0.22	−0.04			
RMSE		0.42	0.35	0.56	0.35			

Notes: The predicted values are the dynamic, one-year ahead forecasts of the GDP inflation rate (4Q to 4Q) generated using rolling regression estimates of the modified Phillips curve reported in Table 1. The forecasts are conditional on actual values of nominal GDP growth, potential output, wage growth, productivity growth, and import prices. **Act.** is actual inflation; **Pred.** is the predicted inflation rate, **DGG** is demand growth gap; **OG** is the output gap; **mrk** is the cyclical markup (price equation); **ME** is the mean prediction error; and **RMSE** is the root mean squared error.

The predicted values given in column (2) are from the traditional Phillips curve; those given in column (3) are from the Phillips curve augmented to include demand growth gap; those given in column (4) are from the Phillips curve augmented to include demand growth gap plus the markup; and those in column (5) are from the Phillips curve augmented to include demand growth gap plus the wage share.

prediction error is -0.33, one-third of a percentage point, and the root mean squared error is 0.44.[24]

The inflation predictions generated using the modified Phillips curve are presented in the columns labeled (3), (4), and (5). The predictions in column (3) are from the Phillips curve with the demand growth gap, those in column (4) are from the Phillips curve with the demand growth gap and markup, and those in column (5) are from the Phillips curve with the demand growth gap and wage share. Augmenting the Phillips curve to include the demand growth gap does improve the predictive accuracy. The Phillips curve with the demand

[24] Note that the prediction bias is larger in magnitude if one does not allow for productivity-led increases in potential real output since the mid-1990s. Under the counterfactual assumption that real potential output continues to increase at its earlier trend growth rate of 2.5 percent since the mid-1990s, the inflation rates predicted using the traditional Phillips curve for the years 2000, 2001, 2002, and 2003 are 3.0, 2.5, 2.6, and 2.4 percent, respectively. The mean prediction error is -0.67 of a percentage point, and the RMSE is 0.74.

growth gap has a lower mean error and lower root mean squared error than the Phillips curve without the demand growth gap. But further augmenting the Phillips curve to include the cyclical markup or wage share does not aid much in improving the predictive accuracy of the long-range inflation forecasts.

Table 3 also presents the underlying data on the demand growth gap, output gap, and cyclical markup over the period since the mid-1990s. Regarding sources of the recent deceleration of inflation, the correlations summarized in the estimated modified Phillips curve suggest one plausible explanation of the recent behavior of inflation.[25] As can be seen in Table 3, inflation, after hovering mostly near a low of 2 percent in the second half of the 1990s, decelerated further during the past three years. In the second half of the 1990s, the demand growth gap stayed close to the 2 percent range as aggregate demand grew just fast enough to absorb the productivity-induced increase in potential. However, during the most recent period, 2000–2002, aggregate demand did not grow fast enough to absorb higher potential, creating a declining demand growth gap and a negative output gap. The recent deceleration is well predicted by the behavior of the Phillips curve that includes these two gap variables. However, the contribution of the markup (or wage share) in improving the prediction of the inflation rate since the mid-1990s remains negligible, suggesting the markup is not providing information beyond that contained in the gap variables. Together these results suggest a weak demand growth gap together with the resulting negative output gap, trumping the cyclical markup (or wage share) as the major source of the recent deceleration of inflation.

Generating a Conditional Prediction of the Inflation Rate for 2004

What do the Phillips curves estimated here imply about the behavior of inflation during 2004? In order to answer this question, I generate the conditional prediction of the inflation rate for 2004. During the past two years productivity has increased at an average annual rate of 4.5 percent, whereas nominal wages have increased at an average annual rate of 2.4 percent, implying an average annual decline of 2.5 percent in unit labor costs. Aggregate demand, as measured by nominal GDP, has grown at an average annual rate of 5 percent. Potential output, as estimated by the Congressional Budget Office, has grown at a 3.5 percent annual rate. If productivity, wages, aggregate demand, and potential output continue to grow in 2004 at rates observed during the past two years, the point estimate of the conditional prediction of inflation for 2004, generated using the Phillips curve with demand growth gap and markup, is

[25] There may be other structural models that are consistent with the correlations summarized in the modified Phillips curve. Hence one may come up with other explanations of the recent behavior of inflation.

1.0 percent. The conditional prediction of the inflation rate is 1.5 percent if the modified Phillips curve excludes the markup. Last year the GDP deflator grew 1.5 percent. The ensuing behavior of inflation this year would provide further evidence on the predictive accuracy of the Phillips curve that includes the markup.

3. CONCLUDING OBSERVATIONS

This article makes two modifications to the traditional output gap-based Phillips curve. It includes the cyclical component of a markup variable defined as the markup of prices over unit labor costs, and it allows inflation to depend also on a change in the output gap. The markup allows for the short-term influence of productivity-induced decline in unit labor costs on inflation, and the "rate of change" specification implies inflation depends also on how fast aggregate demand is growing relative to real potential output. The results indicate demand growth gap and the level of the cyclical markup enter the traditional Phillips curve with significant and correctly signed estimated coefficients. Inflation is predicted to increase if aggregate demand grows faster than real potential output, and it is predicted to fall if the markup is high.

The predictions of the one-year-ahead inflation rate conditional on actual values of the explanatory variables suggested by the traditional and modified output gap-based Phillips curves track actual inflation well over 1980–2003, outperforming those based on a naïve model that predicts inflation using only lagged inflation. These results imply output gap-based Phillips curves are useful in predicting inflation.

As a result of the recent acceleration of productivity, the trend growth rate of real potential output has increased since the mid-1990s. This upward shift in the trend growth rate of potential output implies aggregate demand needs to grow at higher rates than before in order to stabilize inflation. Inflation remained low in the second half of the 1990s and decelerated further during the past three years. This deceleration of inflation is well predicted by the modified Phillips curve that assigns a key role to demand growth and the output gap. The demand growth gap remained stable in the 2 percent range in the second half of the 1990s, but it declined considerably over the period 2000–2002, creating a negative output gap over the recent period. The negative predicted effect of these two gap variables on the inflation rate trumps the cyclical markup as the major source of the recent deceleration of inflation.

The cyclical component of the markup or the wage share, when added into the traditional and modified Phillips curves, appears with a correctly signed negative estimated coefficient and is generally significant. However, in the past the markup or wage share has not helped in improving the accuracy of the long-range inflation prediction if the estimated Phillips curve includes demand growth and output gap variables. This may be due to the fact that the markup or wage share is also influenced by cyclical demand, besides productivity, and hence is highly correlated with the cyclical measures of excess demand. So, the marginal predictive content of the markup or wage share is small once we control for the influence of cyclical demand on inflation.

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