Working Paper Series

The Output Gap, Expected Future Inflation and Inflation Dynamics: Another Look

WP 04-06

Yash P. Mehra
Federal Reserve Bank of Richmond

THE FEDERAL RESERVE BANK OF RICHMOND
RICHMOND ▪ BALTIMORE ▪ CHARLOTTE

The Output Gap, Expected Future Inflation and Inflation Dynamics: Another Look

Yash P. Mehra
Federal Reserve Bank of Richmond
701 E. Byrd Street
Richmond, VA 23219
August 12, 2004

Working Paper No: 04-06

Yash.Mehra@Rich.frb.org

Key Words: Output Gap, Supply Shocks, Expected Future Inflation
JEL: E10 E31

Abstract

The empirical test of the output gap-based New Keynesian Phillips curve often has been implemented by estimating a hybrid specification that includes both lagged and future inflation and then by examining whether the estimated coefficient on future inflation is significantly larger than the one on lagged inflation. This article presents the evidence that indicates supply shocks significantly enter the hybrid specification. The results reported in previous research – the output gap is irrelevant and expected future inflation is the major determinant of inflation – arise if the hybrid specification is estimated omitting supply shocks and/or lagged inflation. In the hybrid specification estimated with supply shocks, the output gap is significant. The estimated coefficient on future inflation is quantitatively small, but the estimated coefficient on lagged inflation is significantly larger than the one on future inflation. The null hypothesis that the estimated coefficient on lagged inflation is unity is not rejected if the hybrid specification nests an alternative version of the traditional Phillips curve in which inflation responds also to a change in the output gap. Together these results suggest that expected future inflation is not the major determinant of current inflation.

Senior Economist and Policy Advisor. The opinions expressed are those of the author and do not necessarily reflect views of the Federal Reserve Bank of Richmond or the Board of Governors of the Federal Reserve System.

1 Introduction

The new theoretical work on inflation dynamics emphasizes staggered nominal wage and price settings by forward-looking individuals and firms. As shown in Roberts (1995), the models of staggered contracts developed by Taylor (1979, 1980) and Calvo (1983) and the quadratic price adjustment model of Rotemberg (1982) have a common formulation that is similar to a New Keynesian Phillips curve of the form given in (1).

(1) $$\pi_t = E_t \pi_{t+1} + b\, y_t + \varepsilon_t\,,$$

where π is current inflation, y is output gap, $E_t \pi_{t+1}$ is expected future inflation, and ε_t is the disturbance term which may be serially correlated. In (1) current inflation is modeled as a function of the contemporaneous output gap and expectations of next period's inflation rate. The key feature of this particular New Keynesian Phillips curve (denoted hereafter as NKPC) is that lagged inflation does not directly enter the Phillips curve, so that expected future inflation is the major determinant of current inflation. This NKPC differs from the traditional expectations-augmented Phillips curve where instead lagged inflation plays the major role as shown in (2):

(2) $$\pi_t = a(L)\pi_{t-1} + \gamma\, y_t + \mu_t\,.$$

In (2) current inflation depends on the contemporaneous output gap and lagged inflation, the later modeled as a distributed lag on past inflation rates. Lagged inflation enters (2) because it is a proxy for agents' expectations of the current-period inflation rate.

In order to determine which inflation model best describes actual inflation dynamics, several analysts following Gali and Gertler (1999) have estimated a hybrid specification of the form given in (3):

(3) $$\pi_t = w^b a(L)\pi_{t-1} + w^f E_t \pi_{t+1} + b\, y_t + \varepsilon_t\,.$$

In (3) current inflation depends on the contemporaneous output gap and on lagged as well as future inflation. The estimated coefficients on lagged and future inflation rates are then compared to infer the relative importance of backward- and forward-looking inflation terms in explaining current inflation.

The empirical work that has investigated the validity of the NKPC (1) by estimating the hybrid specification has produced mixed results. In previous work the estimated coefficient on the output gap is mostly either insignificant, or it is incorrectly signed. While the estimated coefficient on lagged inflation w^b is correctly signed and usually significant, estimates that indicate the relative importance of lagged and future inflation differ amongst studies. Gali and Gertler (1999) and Gali et al. (2001) present estimates where the estimated w^f is significantly larger than w^b, leading them to conclude that expected future inflation is the major determinant of current inflation. Roberts (2001) on the other hand presents estimates where the estimated w^b is significantly larger than w^f, suggesting instead that lagged inflation is the major determinant of current inflation. In contrast, the hybrid specification estimated in Fuhrer (1997) yields the estimated w^b that is not statistically different from unity, supporting the traditional Phillips curve.

This article provides new evidence on the role of the output gap and expected future inflation in explaining inflation. In most previous research the hybrid Phillips curve has been estimated without controlling for the *direct* influence of supply shocks on inflation. This article provides evidence that indicates supply shocks have a significant effect on inflation and that inference regarding the empirical validity of the NKPC (1) is sensitive to whether or not we include supply shocks in the hybrid specification.[1]

The empirical evidence here indicates that if the hybrid specification (3) is estimated without lagged inflation and supply shocks, the estimated coefficient on future inflation w^f is close to unity and that on the output gap is incorrectly signed. However, if the hybrid specification is estimated with lagged inflation and supply shocks, then the estimated coefficient on future inflation w^f is quantitatively small and not statistically different from zero. Furthermore, the estimated coefficient on the output gap is correctly signed and mostly significant. These results are robust to the use of alternative estimates of the output gap and hold over two sample periods studied here, 1961Q1 to 1997Q4 and 1961Q1 to 2003Q2.

As a robustness check, I also estimate a hybrid Phillips curve in which inflation also responds to a change in the output gap. The evidence reported here indicates there is a *rate of change effect* and supply shock variables remain significant. The estimated coefficients on the output gap and its rate of change are correctly signed and statistically significant. The estimated coefficient on future inflation w^f is not statistically different from zero, as before. The hypothesis that the estimated coefficient on lagged inflation w^b is unity is not rejected, supporting the traditional Phillips curve. Together these results suggest that the evidence in previous research that indicates output gap does not matter and that expected future inflation is the major determinant of current inflation must be viewed with caution.

The empirical work here complements the work of Fuhrer (1997), Rudd and Whelan (2001, 2003), and Roberts (2001). Rudd and Whelan (2001,2003) argue that the test of the NKPC implemented by estimating a hybrid specification of the form (3) is likely to be sensitive to the specification of the alternative hypothesis, as is demonstrated by my empirical work.[2] Using a different methodology they do not find that current inflation depends on expected future inflation. Roberts (2001) estimates the hybrid specification, but without supply shocks. As indicated here, inference regarding the role of the output gap is sensitive to whether or not one allows for the direct influence of supply shocks on current inflation. Fuhrer (1997) also estimates a hybrid Phillips curve without supply shocks, but imposes symmetry restrictions across lags and leads of inflation implied by an extended Taylor staggered contracting framework developed in

---

[1] The variables measuring supply shocks do not directly enter the reduced-form Phillips curves estimated in Fuhrer (1997), Gali and Gertler (1999), Gali et al. (2001), and Roberts (2001).

[2] Rudd and Whelan (2001) do not explicitly estimate the hybrid model as in Gali and Gertler (1999). They, however, point out that the test of the role of expected future inflation implemented by estimating a hybrid Phillips curve may not be powerful, in the sense that test results can be sensitive to what other variables enter as part of the alternative hypothesis. For example, if the true model is the traditional Phillips curve but the researcher instead estimates the NKPC of the form given in equation (1) of the text, then the estimated coefficients that appear on future inflation and the output gap may be biased. The bias arises because the researcher has omitted

Fuhrer and Moore (1995). He reports evidence that indicates current inflation depends primarily on lagged inflation and the output gap. The empirical work here does not impose restrictions on the shape of lead-lag structure and generates the results that are qualitatively similar to those in Fuhrer.

The plan of this article is as follows. Section 2 reviews the conventional hybrid specification that is used in the empirical test of the NKPC (1) and suggests some alternative empirical specifications. Section 3 presents the empirical results, and section 4 contains concluding observations.

2 A New Keynesian Phillips Curve and Some Alternative Empirical Specifications

Consider the NKPC of the form given in (1) where current inflation depends on the contemporaneous output gap and expected future inflation. Assume that agents' expectations of future inflation are rational as in (4).

$$(4) \qquad \pi_{t+1} = E_t \pi_{t+1} + \eta_{t+1},$$

where η is the rational forecast error that is uncorrelated with any information known to agents in period t. If we substitute (4) into (1), we get the following reduced-form inflation equation:

$$(5) \qquad \pi_t = \pi_{t+1} + b\, y_t + \varepsilon_t - \eta_{t+1}.$$

The inflation equation (5) relates current inflation to the contemporaneous output gap and one-period future inflation rate. Since under the assumption of rational expectations the random disturbance term is uncorrelated with lagged information, the reduced-form inflation equation has been estimated using instrumental variables procedure. Estimates of the reduced-form inflation equation (5) appear in Gali and Gertler (1999) and Gali et al. (2001).

---

other direct determinants of inflation (such as supply shocks) implied by the alternative inflation model.

The key feature of the NKPC (5) is that lagged inflation does not directly enter the inflation equation,[3] a restriction that is usually rejected by the data. This has led many analysts either to modify the underlying staggered pricing behavior or assume some form of departure from the assumption of rationality. Gali and Gertler (1999) modify the Calvo model by introducing a fraction of firms that set prices using a simple rule of thumb that is based on the recent history of aggregate price behavior. Their modification yields a hybrid specification of the form given in (6):

$$\pi_t = w^b a(L)\pi_{t-1} + w^f \pi_{t+1} + b\, y_t + \varepsilon_t - \eta_{t+1}, \tag{6}$$

where the coefficient w^b is the weight on lagged inflation, and it measures the proportion of firms that set prices following the rule of thumb.

In most previous research the NKPC (5) or its hybrid specification (6) has been estimated without controlling for the direct influence of supply shocks on inflation. In New Keynesian models supply shocks such as an increase in the price of oil or imported material inputs affect inflation by changing the firm's real marginal cost. It is generally assumed that the response of prices to an increase in factor costs does not differ from its response to an increase in marginal cost generated by expanding demand and production. Under this assumption, supply shocks do not directly enter the NKPC, as long as marginal costs are properly measured. I, however, investigate the possibility that supply shocks play an independent role in the New Keynesian Phillips curve, which may happen if prices respond differently to increases in output and factor input costs. The empirical evidence in Bils and Yongsung (2000) indicates that product prices respond considerably more to cost increases due to higher material or energy prices than to those due to higher wages precipitated by expanding production.

The traditional Phillips curve often has been estimated with measures of supply shocks included. Even if we continue to assume that supply shocks do not directly enter the NKPC (1), the empirical test of the NKPC implemented by estimating a hybrid specification that nests the traditional Phillips curve must control for the potential direct effect of supply shocks on inflation. If those supply shocks do enter the traditional

[3] Lagged inflation may however help predict the next-period inflation rate and thus indirectly affect current inflation.

Phillips curve, their omission from the estimated hybrid specification may bias inferences regarding the role of expected future inflation and output gap, as argued eloquently by Rudd and Whelan (2001).

In view of the above-discussed considerations, the empirical work here considers the hybrid specification of the form given in (7):

$$\pi_t = w^f \pi_{t+1} + w^b a(L)\pi_{t-1} + b_1 y_t + cSS_t + \varepsilon_t - \eta_{t+1}, \tag{7}$$

where SS is supply shock, $a(L)\pi_{t-s}$ is a distributed lag on past inflation rates, and where all other variables have been defined as before. It should be noted that the hybrid specification (7) nests two alternative versions of the NKPC estimated in previous research. If $w^b = c = 0$ in (7), we get the NKPC (1) estimated in Gali and Gertler (1999); if $c = 0$ in (7), we get the NKPC (6) estimated in Fuhrer (1997) and Roberts (2001); and if $w^f = 0$ in (7), we then have the traditional Phillips curve.

In the NKPC (1), the output gap enters because it captures excess demand in the labor or product market, depending upon the model that underlies the NKPC as shown in Roberts (1995). In the NKPC derived using the sticky price models of Calvo (1983) and Rotemberg (1982), the output gap enters because the firm is assumed to have an upward-sloping supply curve, so that it wants to raise prices if excess demand or income is high. In the NKPC derived using the model of staggered contracts developed by Taylor (1979), the output gap enters as proxy for the unemployment rate (measured relative to its natural rate) that measures the degree of slack in the labor market.

In some recent research, analysts have suggested that current inflation may also respond to a change in the output gap. Mankiw and Reis (2003) have derived an aggregate inflation equation under the hypothesis that information, not prices, are sticky in the short run, current inflation there depends on a change in the output gap, in addition to the contemporaneous output gap and past expectations of the current-period inflation rate. A traditional Phillips curve in which inflation also responds to a change in the output gap appears in Gordon (1983). As a robustness check, I also consider a hybrid specification that nests this class of Phillips curves as in (8):

(8) $$\pi_t = w^f \pi_{t+1} + w^b a(L)\pi_{t-1} + b_1 y_{t-1} + b_2 \Delta y_t + cSS_t ,$$

where Δy is change in the output gap and where all other variables are defined as before. As can be seen, if $w^f = 0$ in (8), we get the traditional Phillips curve in which inflation also responds to a change in the output gap.

Another feature of the hybrid specification (7) is that lagged inflation is approximated by a distributed lag on past inflation rates, whereas the expected future inflation term contains just one future value of the inflation rate. Gali and Gertler (1999) estimate the hybrid Phillips curve including one future and up to four lagged values of the inflation rate. This particular lead-lag structure comes about because Gali and Gertler (1999) modify the Calvo model to include a fraction of firms that set prices based on the recent history of aggregate inflation. Given such a model, the estimated coefficient on lagged inflation is often interpreted as capturing the proportion of firms that set prices following the rule of thumb, which implies firms are not forward-looking. But this interpretation of the estimated weight on lagged inflation found in the reduced-form hybrid Phillips curve has been called into question by Dotsey (2002), who shows how a generalized Taylor price-setting can generate a significant weight on lagged inflation even when all firms are rational and forward-looking.

Under a generalized Taylor price-setting, current inflation may depend on leads and lags of the inflation rate, the exact lead and lag lengths and any symmetry restrictions being determined by the nature of the underlying staggered contracts. I, however, continue to work with the reduced-form hybrid Phillips curve of the form postulated by Gali and Gertler (1999). As a robustness check, I do examine the sensitivity of results to allowing more leads of the inflation rate. I also test whether or not we need more than one lag to capture the effect of lagged inflation. In particular, I estimate the following hybrid specifications that include four leads and lags of the inflation rate as in (9) and (10):

(9) $$\pi_t = \sum_{s=1}^{4} w_s^f \pi_{t+s} + \sum_{s=1}^{4} w_s^b \pi_{t-s} + b_1 y_t + c\, SS_t + v_t , \textit{ and}$$

(10) $$\pi_t = \sum_{s=1}^{4} w_s^f \pi_{t+s} + \sum_{s=1}^{4} w_s^b \pi_{t-s} + b_1 y_{t-1} + b_2 \Delta y_t + cSS_t + v_t ,$$

where all variables are defined as before. The hybrid specifications summarized in (9) and (10) nest the hybrid specifications given in (7) and (8), respectively. I then examine whether inferences regarding the role of the output gap and future inflation change when Phillips curves are estimated including more leads of the inflation rate.

I estimate the hybrid specifications using quarterly data over two sample periods, 1961Q1 to 1997Q4 and 1961Q1 to 2003Q2, and inflation measured by the behavior of the chain-weighted GDP deflator. The shorter sample period corresponds to the period covered in previous work. In previous tests of the NKPC (1) the potential output is estimated fitting a quadratic trend to real output as in Gali and Gertler (1999) or using the Hodrick-Prescott (1997) filter as in Roberts (2001).[4] I also consider estimates of the potential output prepared by the Congressional Budget Office. In addition, I consider estimates of the potential output generated using the one-sided version of the Hodrick-Prescott filter.[5] 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 dummy variables: PC1, defined to be unity over 1971Q3 to 1972Q4 and zero otherwise, and PC2, defined to be unity over 1973Q1 to 1974Q4 and zero otherwise. The relative import price series is the GDP deflator for imports divided by the implicit GDP deflator.

As in previous research I estimate the hybrid specifications under the assumption that agents' expectations of future inflation are rational as in (4) and use an instrumental variables procedure. The instruments used are a constant; change in current nominal defense expenditures; and four lagged values of the inflation rate, change in the nominal federal funds rate, change in relative import prices, and the output gap variables. The hybrid specifications are initially estimated including four lags and one lead of the inflation rate, the sum of estimated coefficient on past inflation rates being an estimate of

[4] Following Roberts (2001) I also use a smoothness parameter of 16,000 rather than the recommended value of 1600, because the use of the lower value generates a trend that is pro-cyclical.

[5] As one of the referees pointed out, the standard HP filter is a two-sided filter. The estimates of the output gap generated using the standard HP filter could generate biased results in a hybrid specification that includes future values of the inflation rate. As a robustness check, I estimate the hybrid specifications using the estimates generated by one-sided HP filter. The one-sided HP filter is implemented by running a loop over time and retaining the final value from the HP-filtered output at each point in time. The one-sided HP filter used the smoothness parameter of 16,000 as in the standard HP filter.

the weight on lagged inflation as in Gali and Gertler (1999). I do examine the robustness to changes in the lead and lag structure. The Phillips curves are estimated including two lagged values of the relative import price inflation, besides President Nixon's price control dummies.

3 Empirical Results

I first focus on estimates of the hybrid Phillips curve (7), which relates current inflation to the contemporaneous output gap, one lead of inflation, a distributed lag on past inflation rates, and supply shocks. Since the hybrid specification (7) nests the NKPC (1), I also report estimates under the null hypothesis that the estimated coefficients on lagged inflation and supply shocks are zero.

Table 1 presents instrumental variable estimates of various versions of the hybrid Phillips curve (7) over two sample periods. Rows 1.1 and 1.2 present estimates under the null that lagged inflation and supply shocks do not enter the Phillips curve. The estimates use the measure of the output gap generated fitting a quadratic trend. As can be seen, the estimated coefficient on the output gap is statistically significant, but it is incorrectly signed. The estimated coefficient on future inflation w^f is significant and close to unity. These results hold over both the sample periods. These empirical results have been interpreted to suggest that the output gap-based NKPC curve is not empirically valid, as argued in Gali and Gertler (1999) and Gali et al. (2001).

Rows 2.1 and 2.2 in Table 1 present estimates of the hybrid Phillips curve without supply shocks.[6] As can be seen, the estimated coefficient on future inflation w^f is now below unity, but it is larger in magnitude than the one on lagged inflation w^b, suggesting future inflation is the major determinant of current inflation. The estimated coefficient on the output gap, though positive, is still statistically insignificant. The null hypothesis that the estimated coefficient on lagged inflation is zero is easily rejected.

Rows 3.1 and 3.2 in Table 1 present estimates of the hybrid Phillips curve with supply shocks. As can be seen, the estimated coefficients on all the variables are statistically significant and correctly signed. The output gap appears with a positively signed estimated coefficient, suggesting that current inflation responds positively to the level of economic activity. The estimated coefficient on lagged inflation w^b is positive, significant and less than unity, with point estimates falling in a .6 to .7 range. The estimated coefficient on future inflation w^f is positive, but it is now quantitatively small and not significantly different from zero. Since the estimated coefficient on lagged inflation is larger than the one on future inflation, this result may be interpreted to suggest that lagged inflation is the major determinant of current inflation. The estimated coefficient on the relative import price inflation is positive, suggesting current inflation is sensitive to supply shocks. The significance levels of the Chi-squared statistic x_1^2 reported in Table 1 suggest that the instruments used are not correlated with the residuals.[7]

If we compare the estimated coefficients on the output gap and future inflation presented across rows 1, 2 and 3 of Table 1, we see that estimates are highly sensitive to the exclusion restrictions pertaining to supply shocks and lagged inflation. Since both supply shocks and lagged inflation are significant in the hybrid Phillips curve (7),[8] their omission produces biased inferences regarding the role of expected future inflation and output gap in explaining inflation, as argued in Rudd and Whelan (2001).

Rows 4, 5 and 6 in Table 1 present the robustness of results from using alternative estimates of the output gap: Hodrick-Prescott, Hodcrick-Prescott (one-sided) and Congressional Budget Office. I present estimates of the hybrid model (7) without any exclusion restrictions.[9] As can be seen, the output gap remains significant and appears with a correctly signed estimated coefficient. The estimated coefficient on the relative imports price inflation is positive and significant. The estimated coefficient on lagged inflation w^b is significant and now falls in a .6 to .8 range. The estimated coefficient on

---

[6] The instruments used to estimate the Phillips curve include supply shock variables.
[7] The test is implemented regressing the residuals from the instrumental variable regression on the instruments. The reported values are the significance levels of the 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 the instruments.
[8] The significance level of the Chi-squared statistic that tests the null hypothesis --- lagged inflation and supply shocks do not enter the Phillips curve --- is .01, leading to the rejection of the null hypothesis.
[9] The inference regarding the role of the output gap and expected future inflation does not change if the Phillips curves given in Rows 1 and 2 are estimated using alternative estimates of the output gap.

future inflation w^f remains quantitatively small, with point estimates falling in a .0 to .3 range. Table 1 reports the significance level of a Chi-squared statistic x_2^2 that tests the null hypothesis the estimated weight on lagged inflation w^b is unity. The null hypothesis is rejected in some empirical specifications, suggesting that the estimated weight on lagged inflation may be less than one. Together these estimates suggest that in the estimated hybrid Phillips curve of the form (7), the output gap is significant and the estimated coefficient on future inflation is quantitatively small.

I now examine the robustness of results along another dimension that allows inflation to depend also on a change in the output gap. The estimates of the hybrid Phillips curve that includes a change in the output gap are presented in Table 2. The hybrid model is estimated, using three alternative potential output series and over two sample periods as in Table 1. As can be seen, output gap variables are significant and appear with correctly signed estimated coefficients, suggesting there is a *rate of change* effect. The estimated coefficient on lagged inflation w^b remains significant, with point estimates now falling in a .7 to .9 range. One can not reject the null hypothesis that the estimated coefficient on lagged inflation is unity; this finding is robust to the use of alternative estimates of the output gap and holds over both the sample periods (see the significance levels of the Chi-squared statistic x_2^2 reported in Table 2). The estimated coefficient on future inflation w^f is small and not significantly different from zero. Together these results support the traditional Phillips curve.

The empirical work in Tables 1 and 2 uses the hybrid Phillips curve in which lagged inflation enters as a result of appending the Calvo (1983) model to include a fraction of firms who set prices using the rule of thumb. The Phillips curve is estimated including four lags and one lead of inflation. As a robustness check, I now test the implicit restrictions on lags and leads. In particular, I estimate the hybrid models (9) and (10) that include four lags and four leads of the inflation rate. I then test two types of restrictions. The first is that estimated coefficients on second-through-fourth lagged values of the inflation rate are zero. The other is that estimated coefficients on second-through-fourth future values of the inflation rate are zero. If both sets of restrictions are correct, we get the hybrid model with one lag and one lead. If restrictions hold only for the leads, then we get the hybrid model reported in Tables 1 and 2.

Table 3 reports estimates of the hybrid Phillips curve (9). The reported coefficient on future inflation is now the sum of the estimated coefficients on four future values of the inflation rate. Table 3 reports the significance levels of two Chi-squared statistics. The first, denoted as x_3^2, tests the null that the estimated coefficients on second-through-fourth lagged values of the inflation rate are zero, and the second statistic, denoted as x_4^2, tests the null that the estimated coefficients on second-through-fourth future values of the inflation rate are zero. The significance levels associated with these two statistics clearly suggest that the estimated coefficients on lagged values of the inflation rate are significant whereas that is not the case for its future values. These results support the lead-lag structure assumed in the hybrid model (7). These results also imply that a hybrid model estimated assuming one lag and one lead of inflation is misspecified.[10]

Table 4 presents estimates of the hybrid Phillips curve (10) that allows inflation to depend also on a change in the output gap. As can be seen, this hybrid model yields inferences that are qualitatively similar to those provided by the hybrid model estimated with the level of output gap.

4 Concluding Observations

The empirical test of the New Keynesian Phillips curve often has been implemented by estimating a hybrid specification which includes both future and lagged inflation and then by examining whether the estimated coefficient on future inflation is significantly larger than the one on lagged inflation. In most previous work, the hybrid specification has been estimated without controlling for the direct influence of supply shocks on current inflation. This article presents empirical evidence that indicates supply shocks significantly enter the Phillips curve and that inference regarding the empirical validity of the NKPC is not robust to the omission of supply shocks.

---

[10] If the hybrid model is estimated with one lead and one lag of inflation, then the estimated coefficient on future inflation becomes significant.

The empirical findings reported in some previous work – the output gap is irrelevant and expected future inflation is the major determinant of current inflation – arise if the hybrid specification is estimated omitting supply shocks and/or lagged inflation. This article reports two versions of the hybrid specification estimated with supply shocks and lagged inflation included. In those estimated models, the output gap is significant and appears with a correctly signed estimated coefficient. The estimated coefficient on expected future inflation is quantitatively small and not significantly different from zero. The estimated coefficient on lagged inflation is substantially larger than the one on future inflation, suggesting lagged inflation is the major determinant of current inflation. The null hypothesis that the estimated weight on lagged inflation is unity is not rejected if the hybrid specification nests an alternative version of the traditional Phillips curve in which inflation depends also on a change in the output gap. This result supports the traditional Phillips curve. Together the empirical work here suggests that expected future inflation is not the major determinant of current inflation.

Table 1

Estimated Hybrid Phillips Curves
GDP Inflation and Output Gap
4 Lags and 1 Lead of Inflation

Row No.	End Period	Output Gap (b_1)	Future Inflation (w^f)	Lagged Inflation (w^b)	Import Prices (c)	R^2	x_1^2	x_2^2
		Estimated Coefficient on						
Quadratic Trend								
1.1	1997Q4	-.02 (2.4)	.99 (26.7)			.78	.11	
1.1	2003Q2	-.01 (1.9)	.99 (27.8)			.78	.14	
2.1	1997Q4	.004 (.7)	.63 (10.0)	.38 (4.0)		.85	.55	
2.2	2003Q2	.001 (.3)	.67 (10.5)	.34 (5.4)		.85	.74	
3.1	1997Q4	.02 (1.9)	.22 (1.0)	.69 (4.0)	.05 (2.6)	.87	.88	.08
3.2	2003Q2	.01 (1.8)	.30 (1.5)	.62 (3.9)	.05 (2.6)	.88	.94	.02
Hodrick-Prescott								
4.1	1997Q4	.04 (2.1)	.04 (0.1)	.83 (4.2)	.06 (2.8)	.87	.96	.38
4.2	2003Q2	.03 (1.9)	.13 (0.5)	.76 (3.3)	.07 (2.8)	.88	.97	.22
Hodrick-Prescott (One-Sided)								
5.1	1997Q4	.04 (2.2)	.04 (0.2)	.85 (4.4)	.07 (2.7)	.87	.96	.07
5.2	2003Q2	.03 (1.7)	.17 (0.7)	.74 (3.8)	.06 (2.5)	.88	.97	.11
Congressional Budget Office								
6.1	1997Q4	.02 (1.9)	.18 (.8)	.74 (4.1)	.05 (2.8)	.87	.92	.14
6.2	2003Q2	.02 (1.7)	.30(1.5)	.64 (3.8)	.05 (2.6)	.88	.95	.03

Notes: The estimated coefficients (with t-values in parentheses) are from reduced-form Phillips curves of the form $\pi_t = w^f \pi_{t+1} + w^b a(L)\pi_{t-1} + b_1 y_t + c\ SS_t$, where π is the inflation rate; y is output gap; and SS is relative import prices. The reported coefficient on lagged inflation is the sum of estimated coefficient on four lagged values of the inflation rate. All t-values are corrected allowing for the presence of fourth-order, moving-average serial correlation and hetersocedasticity. The estimation period begins in 1961Q1 but ends as shown above. The instruments used are a constant; change in the current nominal defense expenditures; and four lagged values of the inflation rate, output gap variables, changes in the federal funds rate, and relative import prices. The estimated Phillips curves also included the Nixon price control dummies. x_1^2 is the significance level of the Chi-squared statistic that tests the hypothesis that the instruments are uncorrelated with the residuals. x_2^2 is the significance level of the test that the estimated coefficient on lagged inflation is unity.

Table 2

Estimated Hybrid Phillips Curves
GDP Inflation
Change in Output Gap
4 Lags and 1 Lead of Inflation

Row No.	End Period	Estimated Coefficient on Output Gap (b_1)	Change in Gap (b_2)	Future Inflation (w^f)	Lagged Inflation (w^b)	Import Prices (c)	R^2	x_1^2	x_2^2
Quadratic Trend									
3.1	1997Q4	.03 (2.6)	.10 (2.2)	.13 (0.6)	.80 (4.6)	.06 (3.8)	.86	.97	.25
3.2	2003Q2	.02 (2.3)	.10 (1.8)	.19 (1.0)	.66 (5.4)	.06 (3.8)	.89	.96	.11
Hodrick-Prescott									
4.1	1997Q4	.04 (2.4)	.10 (2.7)	.01 (0.1)	.87 (4.5)	.06 (3.6)	.89	.90	.48
4.2	2003Q2	.04 (2.4)	.10 (2.6)	.04 (0.2)	.84 (4.4)	.07 (3.5)	.87	.96	.41
Hodrick-Prescott (One-Sided)									
5.1	1997Q4	.04 (2.4)	.08 (2.2)	.04 (0.2)	.86 (4.5)	.07 (3.4)	.87	.93	.28
5.2	2003Q2	.03 (1.9)	.08 (1.9)	.14 (0.5)	.79 (4.1)	.07 (3.1)	.87	.98	.47
Congressional Budget Office									
6.1	1997Q4	.03 (2.5)	.10 (2.3)	.12 (0.6)	.83 (3.7)	.06 (3.7)	.88	.94	.33
6.2	2003Q2	.02 (2.4)	.10 (2.1)	.18 (1.0)	.78 (4.4)	.06 (3.5)	.89	.98	.20

Notes: The estimated coefficients (with t-values in parentheses) are from reduced-form Phillips curves of the form
$\pi_t = w^f \pi_{t+1} + w^b a(L)\pi_{t-1} + b_1 y_{t-1} + b_2 \Delta y_t + cSS_t$, where Δy is change in the output gap and where all other variables are defined as before. See notes in Table 1.

Table 3

Estimated Hybrid Phillips Curves
GDP Inflation and Output Gap
4 Lags and Leads of Inflation

Row No.	End Period	Output Gap (b_1)	Future Inflation (w^f)	Lagged Inflation (w^b)	Import Prices (c)	R^2	x_3^2	x_4^2
		Estimated Coefficient on						
Quadratic Trend								
3.1	1997Q4	.02 (1.5)	.26 (1.0)	.66 (3.1)	.05 (2.3)	.78	.05	.61
3.2	2003Q2	.02 (1.7)	.30 (1.3)	.62 (3.5)	.05 (2.4)	.80	.02	.48
Hodrick-Prescott								
4.1	1997Q4	.06 (1.9)	.16 (0.4)	.97 (3.0)	.07 (2.5)	.74	.03	.42
4.2	2003Q2	.04 (2.0)	.04 (0.1)	.82 (3.4)	.06 (2.6)	.88	.01	.50
Hodrick-Prescott (One-Sided)								
5.1	1997Q4	.06 (1.8)	- .12 (0.3)	.97 (2.8)	.07 (2.5)	.73	.04	.55
5.2	2003Q2	.04 (1.9)	.06 (0.2)	.83 (3.1)	.06 (2.6)	.76	.02	.48
Congressional Budget Office								
6.1	1997Q4	.02 (1.6)	.20 (.7)	.73 (3.2)	.05 (2.5)	.78	.04	.48
6.2	2003Q2	.02 (1.6)	.30(1.3)	.65 (3.4)	.05 (2.4)	.79	.03	.50

Notes: The estimated coefficients (with t-values in parentheses) are from reduced-form Phillips curves of the form

$\pi_t = \sum_{s=1}^{4} w_s^f \underset{t}{E}\pi_{t+s} + \sum_{s=1}^{4} w_s^b \pi_{t-s} + b_1 y_t + c\,SS_t$, where all variables are defined as before. The reported coefficient on lagged inflation is the sum of estimated coefficient on four lagged values of the inflation rate, and the reported coefficient on future inflation is the sum of estimated coefficients on four future values of the inflation rate. x_3^2 is the significance level of the Chi-squared statistic that tests the hypothesis that the estimated coefficients on second-through-fourth lagged values of inflation are zero. Similarly, x_4^2 is the significance level of the Chi-squared statistic that tests the hypothesis that the estimated coefficients on second-through-fourth future values of the inflation rate are zero.

Table 4

Estimated Hybrid Phillips Curve
GDP Inflation
Level and Change in Output Gap
4 Lags and Leads of Inflation

Row No.	End Period	Output Gap (b_1)	Change in Gap (b_2)	Future Inflation (w^f)	Lagged Inflation (w^b)	Import Prices (c)	R^2	x_3^2	x_4^2
		Estimated Coefficient on							
Quadratic Trend									
3.1	1997Q4	.04 (2.0)	.16 (2.2)	.07 (0.2)	.84 (2.8)	.07 (2.2)	.62	.09	.48
3.2	2003Q2	.03 (2.1)	.13 (2.1)	.13 (.4)	.78 (3.1)	.07 (2.4)	.68	.05	.40
Hodrick-Prescott									
4.1	1997Q4	.08 (2.2)	.18 (2.4)	- .32 (0.7)	.99 (2.9)	.08 (2.5)	.60	.04	.36
4.2	2003Q2	.07 (2.5)	.17 (2.3)	- .21 (0.5)	.99 (3.3)	.07 (2.6)	.63	.02	.34
Hodrick-Prescott (One-Sided)									
5.1	1997Q4	.06 (2.0)	.14 (2.2)	- .14 (0.3)	.99 (2.8)	.08 (2.5)	.64	.06	.49
5.2	2003Q2	.06 (2.2)	.14 (2.0)	- .08 (0.2)	.96 (2.9)	.07 (2.6)	.63	.05	.45
Congressional Budget Office									
6.1	1997Q4	.04 (2.0)	.16 (2.4)	.06 (0.2)	.88 (2.9)	.07 (2.3)	.62	.09	.49
6.2	2003Q2	.04 (2.1)	.16 (2.2)	.08 (.2)	.87 (3.0)	.06 (2.3)	.63	.08	.43

Notes: The estimated coefficients (with t-values in parentheses) are from reduced-form Phillips curves of the form

$\pi_t = \sum_{s=1}^{4} w_s^f \underset{t}{E} \pi_{t+s} + \sum_{s=1}^{4} w_s^b \pi_{t-s} + b_1 y_{t-1} + b_2 \Delta y_t + c\, SS_t$, where all variables are defined as before.

See notes in Table 3.

References

Bils, Mark and Yongsung Chang (2000). “Understanding how price responds to costs and production.” *Carnegie-Rochester Conference Series on Public Policy*, 52, pp. 33-77.

Calvo, Guillermo A. (1983). “Staggered Prices in a Utility-Maximizing Framework.” *Journal of Monetary Economics*, 12, pp. 383-98.

Dotsey, Michael (2002). “Pitfalls in Interpreting Tests of Backward-Looking Pricing in New Keynesian Models.” Federal Reserve Bank of Richmond *Economic Quarterly*, 88, pp. 37-50.

Fuhrer, Jeffrey and George R. Moore (1995). “Inflation Persistence.” *Quarterly Journal of Economics*, 110, pp. 127-59.

Fuhrer, Jeffrey (1997). “The (Un)Importance of Forward-Looking Behavior in Price Specifications.” *Journal of Money Credit and Banking*, 29, pp. 338-350.

Gali, Jordi and Mark Gertler (1999). “ Inflation dynamics: A Structural econometric analysis.” *Journal of Monetary Economics*, 44, pp. 195-222.

_________, and J. David Lopez-Salido (2001). “ European inflation dynamics.” *European Economic Review*, 45, pp. 1237-1270.

Gordon, Robert (1983). “A Century of Evidence on Wage Price Stickiness in the United States, the United Kingdom, and Japan.” in *Macroeconomics, Prices and Quantities* ed. by James Tobin.

Hodrick, Robert J. and Edward C. Prescott (1997). “Postwar Business Cycles: An Empirical Investigation.” *Journal of Money, Credit and Banking*, 29, pp.1-16.

Mankiw, N. Gregory and Ricardo Reis (2002). “Sticky Information versus Sticky Prices: A Proposal to replace the New Keynesian Phillips Curve.” *Quarterly Journal of Economics*, 117, pp. 1295-328.

Roberts, John M (1995). “New Keynesian Economics and the Phillips Curve.” *Journal of Money, Credit and Banking*, 27, pp. 976-984.

___________ (2001). “How Well Does the New Keynesian Sticky-Price Model Fit the Data.” Board of Governors, Mimeo.

Rotemberg, John M. (1982). “Sticky Prices in the United States.” *Journal of Political Economy*, 60, pp. 1187-1211.

Rudd, Jeremy and Karl Whelan (2001). "New Tests of the New Keynesian Phillips Curve," Federal Reserve Board, Mimeo.

___________(2003). "Can Rational Expectations Sticky Price-Models Explain Inflation Dynamics?" Federal Reserve Board, Mimeo.

Taylor, John B. (1979). "Staggered Contracts in a Macro Model." *American Economic Review*, 69, pp. 108-113.

___________(1980). "Output and Price Stability: An International Comparison." *Journal of Economic Dynamics and Control*, 2, pp. 109-32.