Inflation Forecasts and the New Keynesian Phillips Curve*

Sophocles N. Brissimis[a,b] and Nicholas S. Magginas[c]
[a]Economic Research Department, Bank of Greece
[b]Department of Economics, University of Piraeus
[c]Strategy and Economic Research Division, National Bank of Greece

We examine the ability of the New Keynesian Phillips curve to explain U.S. inflation dynamics when inflation forecasts (from the Federal Reserve's Greenbook and the Survey of Professional Forecasters) are used as a proxy for inflation expectations. The New Keynesian Phillips curve is estimated against the alternative of the hybrid Phillips curve, which allows for a backward-looking component in the price-setting behavior in the economy. The results are compared with those obtained using actual data on future inflation as conventionally employed in empirical work under the assumption of rational expectations. The empirical evidence provides, in contrast to most of the relevant literature, considerable support for the standard forward-looking New Keynesian Phillips curve when inflation expectations are measured using inflation forecasts that are observable in real time. In this case, lagged-inflation terms become insignificant in the hybrid specification. The evidence in favor of the New Keynesian Phillips curve becomes even stronger when real-time data on lagged inflation are used instead of the final inflation data used in standard specifications. Our work is closely related to the work of Roberts (1997), who used survey measures of inflation expectations in an empirical inflation model and found evidence that it is less-than-perfectly rational expectations and not the underlying structure of the economy that account for the presence of lagged inflation in empirical estimates of the New Keynesian model.

JEL Codes: C13, C52, E31, E37, E50, E52.

*We are grateful to John Taylor (editor), an anonymous referee, and Heather Gibson for very helpful comments. The views expressed in this paper are of

1. Introduction

Inflation's short-run dynamics and cyclical interaction with real economic variables is a central issue in macroeconomics and especially in monetary policy analysis. In this respect, important advances have been made during the last two decades in the theoretical modeling of inflation dynamics. Much of the modern analysis of inflation is based on what Roberts (1995) termed the "New Keynesian Phillips curve," a model of price setting based on nominal rigidities (Taylor 1980; Calvo 1983), which implies that current inflation is determined by next period's expected inflation and by real marginal cost as the driving variable. This model is widely used in the analysis of monetary policy, leading Bennett McCallum (1997) to call it "the closest thing there is to a standard specification."

Despite the increasing attention that the New Keynesian Phillips curve has attracted in recent years, there have been conflicting results regarding its empirical validity (Roberts 2005). A large empirical literature has focused on estimating this model, both as a single equation and in the context of a general equilibrium model. Fuhrer and Moore (1995) have argued that the standard New Keynesian model with sticky prices and rational expectations does not fit U.S. postwar data, while Fuhrer (1997a) and Roberts (1997) have shown that modifying the model so as to include lags of inflation not implied by the standard model with rational expectations allows it to fit the data satisfactorily. The work of Chadha, Masson, and Meredith (1992) and Roberts (1998) also provided mixed evidence about the ability of the New Keynesian Phillips curve to fit the data adequately. Recent contributions by Galí and Gertler (1999), Galí, Gertler, and López-Salido (2001), and Sbordone (2001, 2002) have offered evidence in favor of the New Keynesian Phillips curve for the United States and the euro area, while Rudd and Whelan (2005a, 2005b) argue that traditional backward-looking price-setting rules appear to be preferable to the forward-looking alternatives in describing inflation behavior. The ambiguity over the ability of the

the authors and do not necessarily reflect those of their respective institutions. Corresponding author: Brissimis: Economic Research Department, Bank of Greece, 21 E. Venizelos Avenue, 10250 Athens, Greece; E-mail: sbrissimis@bankofgreece.gr; Tel: +30 210 3202388.

New Keynesian Phillips curve to square with the facts appears to arise inter alia from a central implication of the model. Although the price level is sticky in this model, the inflation rate, by contrast, is perfectly flexible—a situation that is at odds with the empirical evidence (Mankiw and Reis 2002). Thus, the model has trouble explaining why shocks to monetary policy have a delayed and gradual effect on inflation (Mankiw 2001). Other sources of difficulty concern the characteristics of the proper measure of the driving variable (i.e., real unit labor cost or output gap) as well as the assumption about the measure of expected inflation used.

A central point in the debate is whether a modification of the model can account for the persistence of inflation detected in the data. A common view is that this is possible insofar as a backward-looking component is allowed for: however, this poses problems from a modeling standpoint, as this component is introduced as an ad hoc feature of the model (Cogley and Sbordone 2005). Thus, the baseline theory underlying the New Keynesian Phillips curve is extended to allow for a subset of firms that set prices according to a backward-looking rule of thumb, creating the so-called hybrid Phillips curve (see Galí and Gertler 1999). There are also other ways to reconcile the empirical evidence with Phillips-curve theory appealing to expectations-related factors. Roberts (1997) shows that models derived under less-than-perfectly rational expectations and models based on alternative microfoundations implying inflation stickiness are in several cases observationally equivalent. The empirical results of Roberts (1997)—obtained by using survey measures of inflation expectations—suggest that it is imperfectly rational expectations and not the underlying structure of the economy that account for the presence of lagged inflation in empirical estimates of the New Keynesian model.

In this paper we reconsider estimates of the New Keynesian Phillips curve in light of recent advances in inflation modeling and use inflation forecasts, which are observable in real time, as a proxy for inflation expectations. Building on the work of Roberts (1997), we estimate the New Keynesian Phillips curve for the United States using inflation forecasts from the Federal Open Market Committee's (FOMC's) Greenbook and the Survey of Professional Forecasters (SPF) and compare the results with the estimates obtained on the basis of actual data conventionally used in empirical work

under the assumption of rational expectations. We also evaluate the baseline theory underlying the New Keynesian Phillips curve against the alternative of a hybrid Phillips curve that allows for a subset of firms to set prices according to a backward-looking rule of thumb. Doing so allows us to directly estimate the degree of departure from a pure forward-looking model needed for the Phillips-curve relationship to track the observed inflation persistence. Moreover, given the changes in the definition of the GDP deflator over the sample period, a real-time data set on this deflator (obtained from the Federal Reserve Bank of Philadelphia) is used to derive the lagged-inflation variable in the hybrid specification, with a view to ensuring consistency with the Greenbook and SPF inflation forecasts.

We estimate the alternative Phillips-curve specifications on quarterly U.S. data spanning the period from 1968:Q4 to 2000:Q4 (1968:Q4 to 2006:Q4 in a specification including inflation forecasts obtained from the Survey of Professional Forecasters). The beginning of the sample corresponds to the earlier quarter for which both SPF and Greenbook inflation-forecast data is available, whereas 2000:Q4 is the latest quarter for which Greenbook data is available. All the estimations are made by using the generalized method of moments (GMM). Several results stand out and appear to be quite robust in these estimations. Using the Greenbook and SPF inflation forecasts as proxies for private-sector inflation expectations, we find—in contrast to the findings of Fuhrer (1997a) and Rudd and Whelan (2005a, 2005b, 2006)—that expected inflation becomes the main determinant of current inflation. Overall, the empirical relevance of the hybrid specifications appears to depend largely on the assumption of rational expectations (i.e., the use of actual data on future inflation). Indeed, the lagged-inflation terms in the hybrid specification become insignificant when we approximate inflation expectations with inflation forecasts, which may deviate from full rationality, whereas significant and plausible estimates for the effect of expected inflation and the real unit labor cost are obtained.

The paper proceeds as follows. Section 2 reviews the basic theory underlying the New Keynesian Phillips curve as well as the hybrid Phillips curve and discusses the existing empirical literature. Section 3 presents estimates of different specifications of the Phillips

curve using, in turn, actual data and inflation forecasts in estimation, and shows that the forecast-based specifications do a reasonably good job of describing the data. Section 4 puts the results under the perspective of the relevant theoretical literature. Some concluding remarks and tentative implications are provided in section 5.

2. Modeling Inflation Dynamics

2.1 The New Keynesian Phillips Curve

A large part of the literature has used what today is called the New Keynesian Phillips curve, in which the inflation rate is a function of the expected future inflation rate and a measure of real marginal cost, typically the output gap or real unit labor cost (Lindé 2005). The New Keynesian Phillips curve can be derived from microeconomic foundations; see, e.g., Roberts (1995), Woodford (1996), and Rotemberg and Woodford (1997). In particular, as shown in Roberts (1995), the forward-looking dynamics that underlie the New Keynesian Phillips curve emerge from optimal firm responses to obstacles to adjusting prices of the type introduced by Rotemberg (1982) and Calvo (1983).

The New Keynesian Phillips curve, as advocated by Galí and Gertler (1999), is based on a model of price setting[1,2] by monopolistically competitive firms and is given by

$$\pi_t = \frac{(1-\theta)(1-\theta\beta)}{\theta - \theta\eta\mu} s_t + \beta E_t \pi_{t+1}, \tag{1}$$

where s is excess demand, θ is the probability that firms will keep their price unchanged (or proportional to trend inflation), μ is the firm's demand elasticity, and η is the elasticity of marginal cost with respect to output.

Several authors, such as Fuhrer and Moore (1995) and Estrella and Fuhrer (2002), argue that the pure forward-looking New Keynesian Phillips curve has implications that are inconsistent with

[1]This price-adjustment rule is in the spirit of Taylor's (1980) staggered-contracts model.

[2]Similar reduced-form Phillips-curve equations can be obtained using the quadratic adjustment-cost model of Rotemberg (1982).

the data, because of the "jump dynamics" in inflation adjustment that would imply a costless disinflation, which is counterfactual.

Thus, largely empirical reasons provided motivation for the introduction of the hybrid Phillips curve.[3] Fuhrer (1997b) and Roberts (1998) have shown that modifying the model so as to include lags of inflation not implied by the standard model with rational expectations allows it to fit the data satisfactorily. In this vein, Galí and Gertler (1999), with a view to capturing inflation inertia, extend the basic Calvo model to allow a proportion ω of firms to use a backward-looking rule of thumb. The net result is the following hybrid Phillips curve that nests equation (1):

$$\pi_t = \lambda \left(\frac{1}{(1-\eta\mu)} \right) s_t + \gamma_f E_t \pi_{t+1} + \gamma_b \pi_{t-1}, \tag{2}$$

where

$$\begin{aligned} \lambda &= \left(\frac{(1-\omega)(1-\theta)(1-\theta\beta)}{\theta} \right) \phi^{-1}, \\ \gamma_f &= \beta\theta\phi^{-1}, \\ \gamma_b &= \omega\phi^{-1}, \\ \phi &= \theta + \omega[1-\theta(1-\beta)]. \end{aligned}$$

While the story may be plausible, it is not derived from an explicit optimization problem, in contrast to the New Keynesian Phillips-curve formulation.

Oddly enough, however, even the hybrid Phillips curve has met with rather limited success in providing a stable and consistent description of inflation behavior. In particular, the relation has proved inadequate to describe inflation dynamics at the

[3]There is also some theoretical work supporting the hybrid-Phillips-curve specification. Brayton et al. (1997) extend the quadratic adjustment-cost model to allow for higher-order adjustment costs, leading to the appearance of lagged inflation in the reduced form of the price-adjustment equation. Smets and Wouters (2003, 2005) and Christiano, Eichenbaum, and Evans (2005) show that the hybrid model can be motivated by a form of dynamic price indexing. Another possibility is that lagged inflation might reflect some form of least-squares learning on the part of private agents, as suggested by Erceg and Levin (2003), Collard and Dellas (2005), and others.

quarterly frequency. Chadha, Masson, and Meredith (1992) and Roberts (1997, 1998) obtain reasonable parameter estimates only with annual and semiannual data. With quarterly data, there are also difficulties in obtaining significant estimates of the effect of the output gap on inflation. In this case, the empirical relevance of the standard specification was improved through the substitution of real unit labor cost for the output gap as the driving variable in the model (Galí and Gertler 1999).[4]

2.2 Near-Rational Expectations and the Phillips-Curve Specification

There are also other ways to reconcile the empirical evidence with Phillips-curve theory. It may be possible to invoke expectations-related factors, such as central bank imperfect credibility or bounded rationality (Roberts 1997, 1998, 2005), to explain sluggish inflation dynamics. In this respect, inflation lags may be thought of as capturing inflation expectations that deviate from full rationality.

Roberts (1997) shows that inflation models derived under imperfectly rational expectations and models based on alternative microfoundations (such as the sticky-inflation model of Fuhrer and Moore 1995) are in several cases observationally equivalent. He argues that real-time measures of expectations, such as those obtained from inflation surveys, "can be used to distinguish between the structural and expectational sources of lagged inflation." To this end, he derives an empirical model that nests the sticky-inflation model as well as the sticky-price model, under the assumption that the inflation surveys are good proxies for inflation expectations in the latter

[4]Recent studies by Galí and Gertler (1999), Galí, Gertler, and López-Salido (2001, 2005), and Sbordone (2001, 2005) have argued that the New Keynesian Phillips curve (as well as the hybrid Phillips curve) is empirically valid, provided that real unit labor cost rather than detrended output is used as the variable driving inflation. Galí, Gertler, and López-Salido (2001) conclude that real unit labor cost is not closely related to the output gap and that monetary policy models need therefore to take into account labor market rigidities. One interpretation provided by the authors is that the results imply that the relationship between real unit labor cost and the output gap is weak. If the labor market is not competitive, labor frictions must be taken into account. Incorporating labor market imperfections is then necessary to model the response of inflation to a monetary policy shock.

model. On the basis of this empirical model and by using survey measures of inflation (obtained from the Michigan and Livingston surveys), he formulates a direct test of the sticky-inflation hypothesis by examining a variety of specifications and finds that, in most cases, the results appear to favor the hypothesis of sticky prices under less-than-perfectly rational expectations over the hypothesis that inflation is inherently sticky. These results would appear to imply that it is imperfectly rational expectations and not the underlying structure of the economy that account for the presence of lagged inflation in empirical estimates of the New Keynesian model. The findings based on survey data would be reinforced if direct estimation of the New Keynesian Phillips curve on the basis of alternative measures of expectations—such as the Greenbook and SPF forecasts, which are generally considered unbiased and broadly efficient measures of expected inflation—yielded similar results.

Thus, the present paper investigates the ability of these two other measures of inflation expectations—i.e., the forecasts included in the FOMC's Greenbook and the SPF forecasts—to account for the actual inflation-expectation formation process in the economy and provides evidence supporting the pure New Keynesian Phillips curve.[5] To the extent that such forecasts provide good proxies for private-sector expectations, they allow us to disregard issues related to the detailed specification of the actual expectation formation process. Thus, we are able to focus exclusively on the question of whether the New Keynesian Phillips curve is correctly specified and describes properly inflation dynamics once expectations are approximated by forecasts observable in real time.

[5]To our knowledge there are a few papers that attempt to estimate the New Keynesian Phillips curve for the United States by using survey measures of expectations. None of them, however, consider the Greenbook as a source of real-time inflation expectations. Roberts (1995, 1997) estimated the Phillips curve using the Livingston and Michigan survey data, arguing that this specification can describe inflation dynamics at a semiannual or annual frequency, although in his model lagged inflation remains significant. Adam and Padula (2003) used the inflation forecasts obtained from the Survey of Professional Forecasters in a quarterly model, whereas Paloviita and Mayes (2005) estimated the Phillips curve for a panel of euro-area countries by using forecast data obtained from the OECD *Economic Outlook*. The lagged-inflation term also remains an important part of the description of inflation dynamics in both papers.

Both the Greenbook and the SPF forecasts appear to incorporate efficiently a large amount of information from all sectors of the economy as well as forecasters' judgmental adjustments, making them ideal as proxies of the private sector's inflation expectations. The SPF forecasts, especially, are considered to have an edge as a summary of the private sector's inflation expectations (Carroll 2003). Moreover, these forecasts are considered to be free of several problems that usually plague other survey forecast data (e.g., excessive gradualism, inefficiency in information processing, etc.).

3. Phillips-Curve Estimation on the Basis of Inflation Forecasts

In this section we present estimates of the New Keynesian Phillips curve as well as of "hybrid" variants of the model, including both forward-looking and backward-looking components, along the lines of Galí and Gertler (1999) and Galí, Gertler, and López-Salido (2001, 2005). We use quarterly U.S. data from 1968:Q4 through 2000:Q4 (2006:Q4 in a specification including the SPF inflation forecasts), where the beginning of the sample is determined by the earlier available inflation-forecast data, and the end of the sample period is determined by the availability of the Greenbook and/or SPF inflation forecasts. Inflation is measured as the annualized quarterly change of the GDP/GNP deflator, which—to ensure consistency with the Greenbook and SPF forecasts—corresponds to the GNP deflator from 1968 to end-1991, the GDP deflator from 1992 to end-1995, and the GDP price index since 1996. The Greenbook and SPF inflation forecasts correspond to the annualized quarterly change in the same deflator one quarter ahead. Given that both measures of inflation forecasts are constructed in real time and are not subject to any revisions—in contrast to the deflator variable, which reflects final/revised data—we also estimate the Phillips curve by using real-time data on the GDP/GNP deflator as provided by the Federal Reserve Bank of Philadelphia to obtain the lagged-inflation variable. Finally, real unit labor cost concerns the nonfarm business sector and is obtained from the National Bureau of Labor Statistics. This is the measure used by Galí and Gertler (1999) and Sbordone (2002).

3.1 Observable Measures of Expectations and Instrumental-Variables Estimation

Given that measurement errors may affect the left-hand-side and especially the right-hand-side variables of the Phillips curve, estimation requires the use of an instrumental-variables (IV) estimator. Measurement errors with respect to the explanatory variables could arise as a result of the use of inflation forecasts as proxies for (unobservable) inflation expectations and of the real unit labor cost as a proxy for real marginal cost. Estimates of the alternative specifications are obtained by using the two-step generalized method of moments.[6]

In implementing the instrumental-variables estimator, we replace the mathematical expectation of inflation with observable inflation forecasts under the assumption that the instruments used correspond to the agents' information set at the time expectations were formed. The use of instrumental variables also helps avoid the possibility that the error term in the equation is correlated either with the demand variable or with the difference between lagged and future inflation.

Given that the Greenbook and SPF forecasts proved to be unbiased and broadly efficient (see, among others, Romer and Romer 2000 and Swanson 2004), it is likely that the forecast errors will be orthogonal to the information available to agents at the time of the forecast. This is important for the consistency of the instrumental-variables estimator, which assumes orthogonality of forecast errors to lagged variables of the information set.

Thus, under the assumption that the forecast error of π_{t+1} is uncorrelated with information dated t and earlier, it follows from equation (2) that

$$E_t \left\{ \left(\pi_t - \lambda \left(\frac{1}{(1-\eta\mu)} \right) s_t - \gamma_f E_t \pi_{t+1} - \gamma_b \pi_{t-1} \right) z_t \right\} = 0, \quad (3)$$

[6]It is well known that full-information estimation methods, such as those used by Fuhrer (1997a, 1997b) and Lindé (2005), display greater econometric efficiency when the correct specification of the model is known, but that does not seem to be the case in most monetary policy models. On the other hand, limited-information methods, such as GMM, are robust to incorrect model specification and to uncertainty about modeling assumptions (Roberts 2005).

where z_t is a vector of variables dated t and earlier (and, thus, orthogonal to the inflation surprise in period $t + 1$). The orthogonality condition given by equation (3) then forms the basis for estimating the model with GMM.

The use of future inflation as a proxy for expectations suggests that under the assumption of less-than-perfectly rational expectations, the instruments must reflect information available in real time, i.e., dated at period t and earlier and, in the case of serially correlated errors in the model, at period $t - 1$ or earlier. If we also take into account publication lags, so that agents forming their expectations in period t have information only up to period $t - 1$, then the instruments must be dated at period $t - 1$ and earlier.

Thus, our instrument set includes two lags of the real unit labor cost, the output gap, and nominal-wage growth and three lags of inflation (real-time inflation in the specifications estimated with real-time inflation data). To allow for the possibility of serially correlated errors, all instrument lags are dated at period $t-1$ and earlier, while in the GMM estimation we use the Newey-West weighting matrix, allowing for up to sixth-order serial correlation.

3.2 Estimating the New Keynesian and Hybrid Phillips Curves

Tables 1 and 2 present estimates of different—reduced-form—specifications of the New Keynesian and the hybrid Phillips curves obtained by using, alternatively, actual data on future inflation or the respective Greenbook and SPF inflation forecasts. Probabilities of the J-test for instrument exogeneity are also presented in the last column of the tables.

With respect to estimates of the New Keynesian Phillips curve (presented in table 1), it appears that the inclusion of the real-time forecast of next period's inflation makes relatively little difference to the results, compared with the estimation based on actual inflation data. The coefficient on expected inflation (the discount rate) is in line with what theory would predict as well as with the respective estimate obtained from the specification including actual future inflation. The coefficient on the marginal cost is statistically significant and has the correct sign.

Table 1. New Keynesian Phillips Curve (1968:Q4–2000:Q4)

	π^e_{t+1}	ulc_t	$\bar{R}^2$	J-test
Specification with Greenbook Forecast	0.91 (17.09)	0.04 (7.11)	0.83	0.69
Specification with SPF Forecast	0.95 (23.12)	0.06 (7.65)	0.85	0.71
Specification with Final Data on Future Inflation	0.94 (17.59)	0.03 (2.11)	0.81	0.59

Note: π^e_{t+1} denotes inflation expected by the private sector for period $t+1$, expressed in terms of the annualized rate of change in the GDP deflator; π_{t-1} is the lagged value of the annualized rate of change of the GDP deflator; and ulc_t is real unit labor cost. Numbers in parentheses are t-statistics, and the last column shows the p-values associated with a test of the model's overidentifying restrictions (Hansen's J-test).

As a next step, we evaluate the New Keynesian Phillips curve against the alternative of the hybrid Phillips curve that includes a lagged-inflation term. From table 2, it is clear that the balance of expectation formation moves strongly toward the forward-looking side when we use inflation forecasts (Greenbook or SPF) instead of actual data on future inflation. Indeed, while in the estimate based on actual data that is presented in the last line of table 2 the lagged-inflation term remains significant, explaining about 40 percent of current inflation,[7] it becomes insignificant when the Greenbook or SPF forecasts are used as proxies for expected inflation.[8]

[7]These estimates of the hybrid model including final inflation data are broadly in line with the respective estimates of Galí and Gertler (1999) and Galí, Gertler, and López-Salido (2001, 2005), whereas the small difference in the estimated coefficient on the driving variable is largely attributed to the different sample period (1968:Q4–2000:Q4 in our paper compared with 1960:Q1–1997:Q4 in these papers) as well as to the more parsimonious instrument set used in the present paper.

[8]Adam and Padula (2003) find a statistically significant effect of lagged inflation when estimating a hybrid Phillips curve for the United States using SPF inflation-forecast data. Given the significant measurement errors affecting the explanatory variables, their results are likely to be contaminated by the use of an OLS estimator.

In these forecast-based specifications, the coefficient on expected inflation ranges from 0.84 to 0.86 and is significantly higher than the respective estimates of Galí and Gertler (1999), Galí, Gertler, and López-Salido (2001, 2005), and Sbordone (2002), whereas the coefficient on the real marginal cost is statistically significant and has the correct sign.[9] Moreover, in sharp contrast to these contributions, the estimated coefficient on the backward-looking inflation term is insignificant in all forecast-based specifications. Overall, the inclusion of the observable inflation forecasts appears to increase substantially the weight of the forward-looking variable in inflation

Table 2. Hybrid Phillips Curve (1968:Q4–2000:Q4)

	π^e_{t+1}	π_{t-1}	ulc_t	$\bar{R}^2$	J-test
Specification with Greenbook Forecast	0.84 (4.30)	0.18 (1.03)	0.04 (5.06)	0.85	0.68
Specification with SPF Forecast	0.86 (5.03)	0.21 (1.51)	0.05 (5.25)	0.86	0.59
Specification with Final Data on Future Inflation	0.61 (6.19)	0.38 (3.98)	0.01 (0.28)	0.83	0.65

Note: π^e_{t+1} denotes inflation expected by the private sector for period $t+1$, expressed in terms of the annualized rate of change in the GDP deflator; π_{t-1} is the lagged value of the annualized rate of change of the GDP deflator; and ulc_t is real unit labor cost. Numbers in parentheses are t-statistics, and the last column shows the p-values associated with a test of the model's overidentifying restrictions (Hansen's J-test).

[9] We also estimated the Phillips curve using three alternative measures of the output gap as proxies of the real marginal cost. One was obtained by detrending the GDP series through the application of the Hodrick-Prescott (HP) filter, a second was based on the Congressional Budget Office's measure of potential output, and a third was obtained by using—in view of the significant revisions in the output-gap series—a real-time measure of the output gap constructed on the basis of the Federal Reserve Bank of Philadelphia data set and a recursive estimation of potential output through the application of the HP filter on the GDP data available at each point of time. All the output-gap-based specifications are characterized by a large degree of instability across different subsamples as regards the coefficients of the forward- and backward-looking inflation components as well as a wrongly signed and/or statistically insignificant coefficient on this variable in the earlier part of the sample (i.e., from 1968:Q4 to 1979:Q2).

determination, suggesting that the significance of lagged inflation in conventional specifications reflects largely its role as a proxy for deviations of inflation expectations from full rationality. That being said, the hybrid Phillips curve including the inflation forecasts is rejected in favor of the New Keynesian Phillips curve.

It must be noted that data on the GDP deflator are often subject to substantial revisions. Given that the one-quarter-ahead inflation forecasts from both sources (the Greenbook and the SPF) are constructed before the first revision of the GDP deflator data (which is usually released with a delay of about a quarter), conditioning the pricing decisions of the private sector on final inflation data does not appear to provide a realistic description of the price-setting behavior in real time. Final/revised data on the GDP deflator do not reflect the private sector's information set in real time, nor are the data at the disposal of forecasters at the time they prepare their forecasts. Thus, the significance of inflation forecasts could reflect to a significant extent the inability of the standard hybrid-Phillips-curve specification to account for issues related to real-time availability of data. Therefore, we estimate the hybrid specification using real-time data for lagged inflation. The results presented in table 3 suggest that the use of a real-time lagged-inflation measure confirms the relevance of the New Keynesian specification, as the coefficient on expected inflation increases in both

Table 3. Hybrid Phillips Curve with Real-Time Lagged Inflation (1968:Q4–2000:Q4)

	π^e_{t+1}	π_{t-1}	ulc_t	$\bar{R}^2$	J-test
Specification with Greenbook Forecast	0.95 (4.97)	0.01 (0.57)	0.05 (6.64)	0.85	0.65
Specification with SPF Forecast	0.97 (4.77)	0.16 (0.93)	0.05 (5.85)	0.75	0.63

Note: π^e_{t+1} denotes inflation expected by the private sector for period $t+1$, expressed in terms of the annualized rate of change in the GDP deflator; π_{t-1} is the lagged value of the annualized rate of change of the GDP deflator; and ulc_t is real unit labor cost. Numbers in parentheses are t-statistics, and the last column shows the p-values associated with a test of the model's overidentifying restrictions (Hansen's J-test).

forecast-based specifications. On the other hand, the coefficient on lagged inflation is reduced further and becomes virtually zero, providing some indication that its significance, in specifications based on final data, is likely to reflect the additional—possibly forward-looking—information incorporated through subsequent data revisions rather than its role as a benchmark for rule-of-thumb price setters.

Similar results are obtained when we reestimate the SPF-based specifications on an extended sample ending in 2006:Q4 (table 4). The most notable differences relate to the declining weight on the forward-looking inflation component in the real-time specification, where the coefficient on expected inflation declines to 0.84 (compared with 0.97 in the smaller sample), and also to the declining coefficient on unit labor cost. This latter result could reflect the contamination of unit labor cost data by stock-option exercises, which obscure real marginal cost developments in the most recent part of the sample. Finally, in the last row of table 4, we reestimate

Table 4. Hybrid Phillips Curve: Specification with SPF Forecast—Extended Sample (1968:Q4–2006:Q4)

	π^{e}_{t+1}	π_{t-1}	ulc_t	$\bar{R}^2$	J-test
Specification with Final Data on Lagged Inflation	0.82 (3.27)	0.25 (1.62)	0.05 (5.06)	0.83	0.71
Specification with Real-Time Lagged Inflation	0.84 (4.15)	0.22 (1.39)	0.04 (5.48)	0.82	0.63
Specification with Real-Time Lagged and Contemporaneous Inflation	0.88 (4.45)	0.18 (0.83)	0.03 (3.52)	0.77	0.59

Note: π^{e}_{t+1} denotes inflation expected by the private sector for period $t+1$, expressed in terms of the annualized rate of change in the GDP deflator; π_{t-1} is the lagged value of the annualized rate of change of the GDP deflator; and ulc_t is real unit labor cost. Numbers in parentheses are t-statistics, and the last column shows the p-values associated with a test of the model's overidentifying restrictions (Hansen's J-test).

the hybrid model for the full sample, including real-time data on contemporaneous as well as lagged inflation, with no significant changes in the results.

3.3 Evaluating the Robustness of the Results

To evaluate the robustness of our preferred specifications based on inflation forecasts, we first include in the model additional lags of the explanatory variables and test for their significance. It turns out that both lagged measures of real unit labor cost and lagged inflation are not statistically significant, with the exception of the third lag of inflation that appears significant in the specifications based on SPF forecasts.

We further explore the stability of the Phillips curve by considering the estimates obtained from two subsamples—one corresponding to the Chairmanships of Arthur Burns and G. William Miller (1968:Q1–1979:Q2) and the other to the Chairmanships of Paul Volcker and Alan Greenspan (1979:Q3–2000:Q4). The inflation experience was quite different in the two subperiods: during the 1970s, inflation was rising and volatile; then it dropped sharply during the 1980s and was low and relatively stable during the 1990s.

Estimates for the different subperiods (presented in table 5) confirm that the forward-looking behavior remains dominant irrespective of the sample period examined.[10] Most notably, the coefficient on the inflation forecast during the Volcker-Greenspan period declines to 0.78 (from 0.86 during the pre-Volcker period) for the Greenbook-based specification, and from 1.09 to 0.75 for the SPF-based specification, suggesting that the forward-looking behavior in price setting was even more relevant during the earlier period. Overall, the evidence from subperiod estimates supports the ability of the New Keynesian Phillips curve, in which inflation expectations are approximated by the inflation forecasts, to adequately describe inflation dynamics in the United States during the 1968–2000 period.

[10]The instrument set used includes two lags of inflation, the real unit labor cost, the output gap, and nominal-wage growth.

Table 5. Subsample Estimates of the Forecast-Based Specifications of the New Keynesian Phillips Curve

	π^e_{t+1}	π_{t-1}	ulc_t	$\bar{R}^2$	J-test
1968:Q4–1979:Q2 (Pre-Volcker Period) Greenbook-Based Specification	0.86 (4.16)	0.17 (1.08)	0.05 (4.17)	0.59	0.54
1979:Q3–2000:Q4 (Volcker-Greenspan Period) Greenbook-Based Specification	0.78 (3.91)	0.29 (1.77)	0.02 (2.35)	0.67	0.69
1968:Q4–1979:Q2 (Pre-Volcker Period) SPF-Based Specification	1.09 (4.88)	−0.001 (−0.006)	0.03 (2.13)	0.57	0.55
1979:Q3–2000:Q4 (Volcker-Greenspan Period) SPF-Based Specification	0.75 (5.33)	0.27 (1.96)	0.02 (3.30)	0.89	0.67

Note: π^e_{t+1} denotes inflation expected by the private sector for period $t+1$, expressed in terms of the annualized rate of change in the GDP deflator; π_{t-1} is the lagged value of the annualized rate of change of the GDP deflator; and ulc_t is real unit labor cost. Numbers in parentheses are t-statistics, and the last column shows the p-values associated with a test of the model's overidentifying restrictions (Hansen's J-test).

4. Interpreting the Empirical Results

According to the results presented in the previous section, when allowing for deviations from rationality in inflation expectations (by using observed inflation forecasts), the New Keynesian Phillips curve appears to provide an adequate description of inflation dynamics in the United States during the 1968–2006 period. This result contrasts with a large part of the empirical literature, which generally favors Phillips-curve specifications including lags of inflation.

Under the assumption of rational expectations, inflation expectations by themselves cannot explain the persistence of the inflation

process. However, relatively small deviations from the assumption of rational expectations can change significantly this result (Angeloni et al. 2006). The significance of the forward-looking inflation term provides a strong case in favor of theories modeling expectations formation through limited/asymmetric information and information-processing constraints (Mankiw and Reis 2002; Woodford 2003; Adam 2004) or bounded rationality and learning (Evans and Honkapohja 2001; Sims 2003).

Consequently, the source of the observed inflation persistence may be due not to structural parameters stemming from the characteristics of the agents' price-setting behavior or institutional constraints (such as indexation) but rather to expectations-related factors such as expectations about future monetary policy movements or the private sector's gradual learning of monetary policy's inflation target (Erceg and Levin 2003), or uncertainty about the nature of inflationary shocks and their persistence (Ehrmann and Smets 2003).

Such sources of less-than-perfectly rational behavior of agents in their price-setting decisions and the persistence it implies can spuriously be reflected as significant lag dynamics in the hybrid New Keynesian Phillips curve. Thus, the insignificance of the lagged-inflation term when inflation forecasts are included in the specification suggests that inflation inertia is likely to stem from imperfectly rational behavior in a purely forward-looking price-setting process.

The significance of the less-than-perfectly rational forward-looking component in the New Keynesian Phillips curve bears an important policy implication: as inflation dynamics are likely to reflect the combined influence of several sources of less-than-perfectly rational behavior, the inflation-expectations management is a very difficult task, with potentially significant costs in terms of output volatility even in the absence of backward-looking price setters.

5. Conclusions

This paper examined the ability of the New Keynesian and hybrid Phillips curves to explain U.S. inflation dynamics if inflation forecasts obtained from the Federal Reserve's Greenbook or the Survey

of Professional Forecasters are used as proxies of inflation expectations. The empirical evidence provides considerable support for the standard forward-looking New Keynesian Phillips curve insofar as deviations from rationality as reflected in inflation forecasts are taken into account in estimation. In particular, theoretically plausible coefficient estimates of expected inflation and real unit labor cost have been obtained. Overall, the empirical relevance of the hybrid specifications used in the literature to explain the persistence of inflation detected in the data appears to depend on the standard assumption of rational expectations usually made (reflected in the use of actual data on future inflation). Thus, lagged-inflation terms in the hybrid Phillips curve, intended to capture inflation inertia, are not significant when we consider less-than-perfectly rational forecast proxies of inflation expectations.

Appendix. Data Sources

All data series are quarterly, beginning in 1968:Q4 and ending in 2006:Q4 (with the exception of Greenbook inflation forecasts, which are available from 1968:Q4 through 2000:Q4). Data on gross domestic product, the GDP deflator, and nominal-wage growth are all from the Federal Reserve System's Database (FRED). Data on the GDP deflator forecasts were taken from the FOMC's Greenbook and the Survey of Professional Forecasters data sets available at the Federal Reserve Bank of Philadelphia. Real-time data on the GDP/GNP deflator were compiled on the basis of the relevant data set available at the Federal Reserve Bank of Philadelphia. Finally, data on unit labor cost in the nonfarm business sector were taken from the U.S. Bureau of Labor Statistics.

References

Adam, K. 2004. "Optimal Monetary Policy with Imperfect Common Knowledge." CEPR Discussion Paper No. 4594.

Adam, K., and M. Padula. 2003. "Inflation Dynamics and Subjective Expectations in the United States." ECB Working Paper No. 222.

Angeloni, I., L. Aucremanne, M. Ehrmann, J. Galí, A. Levin, and F. Smets. 2006. "New Evidence on Inflation Persistence and Price

Stickiness in the Euro Area: Implications for Macro Modeling." *Journal of the European Economic Association* 4 (2–3): 562–74.

Brayton, F., A. Levin, R. Tryon, and J. C. Williams. 1997. "The Evolution of Macro Models at the Federal Reserve Board." *Carnegie-Rochester Conference Series on Public Policy* 47: 43–81.

Calvo, G. A. 1983. "Staggered Prices in a Utility-Maximizing Framework." *Journal of Monetary Economics* 12 (3): 383–98.

Carroll, C. D. 2003. "Macroeconomic Expectations of Households and Professional Forecasters." *Quarterly Journal of Economics* 118 (1): 269–98.

Chadha, B., P. R. Masson, and G. Meredith. 1992. "Models of Inflation and the Costs of Disinflation." *IMF Staff Papers* 39 (2): 395–431.

Christiano, L. J., M. Eichenbaum, and C. L. Evans. 2005. "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy." *Journal of Political Economy* 113 (1): 1–45.

Cogley, T., and A. M. Sbordone. 2005. "A Search for a Structural Phillips Curve." Federal Reserve Bank of New York Staff Report No. 203.

Collard, F., and H. Dellas. 2005. "The New Keynesian Model with Imperfect Information and Learning." Forthcoming in *Journal of Money, Credit, and Banking*.

Ehrmann, M., and F. Smets. 2003. "Uncertain Potential Output: Implications for Monetary Policy." *Journal of Economic Dynamics and Control* 27 (9): 1611–38.

Erceg, C. J., and A. T. Levin. 2003. "Imperfect Credibility and Inflation Persistence." *Journal of Monetary Economics* 50 (4): 915–44.

Estrella, A., and J. C. Fuhrer. 2002. "Dynamic Inconsistencies: Counterfactual Implications of a Class of Rational-Expectations Models." *American Economic Review* 92 (4): 1013–28.

Evans, G. W., and S. Honkapohja. 2001. *Learning and Expectations in Macroeconomics*. Princeton, NJ: Princeton University Press.

Fuhrer, J. C. 1997a. "Inflation/Output Variance Trade-Offs and Optimal Monetary Policy." *Journal of Money, Credit, and Banking* 29 (2): 214–34.

———. 1997b. "The (Un)Importance of Forward-Looking Behavior in Price Specifications." *Journal of Money, Credit, and Banking* 29 (3): 338–50.

Fuhrer, J., and G. Moore. 1995. "Inflation Persistence." *Quarterly Journal of Economics* 110 (1): 127–59.

Galí, J., and M. Gertler. 1999. "Inflation Dynamics: A Structural Econometric Analysis." *Journal of Monetary Economics* 44 (2): 195–222.

Galí, J., M. Gertler, and J. D. López-Salido. 2001. "European Inflation Dynamics." *European Economic Review* 45 (7): 1237–70.

———. 2005. "Robustness of the Estimates of the Hybrid New Keynesian Phillips Curve." *Journal of Monetary Economics* 52 (6): 1107–18.

Lindé, J. 2005. "Estimating New-Keynesian Phillips Curves: A Full Information Maximum Likelihood Approach." *Journal of Monetary Economics* 52 (6): 1135–49.

Mankiw, N. G. 2001. "The Inexorable and Mysterious Tradeoff between Inflation and Unemployment." *Economic Journal* 111 (471): C45–61.

Mankiw, N. G., and R. Reis. 2002. "Sticky Information Versus Sticky Prices: A Proposal to Replace the New Keynesian Phillips Curve." *Quarterly Journal of Economics* 117 (4): 1295–1328.

McCallum, B. 1997. "Comment on 'An Optimization-Based Econometric Framework for the Evaluation of Monetary Policy.' " In *NBER Macroeconomics Annual 1997*, 355–59.

Paloviita, M., and D. Mayes. 2005. "The Use of Real-Time Information in Phillips-Curve Relationships for the Euro Area." *North American Journal of Economics and Finance* 16 (3): 415–34.

Roberts, J. M. 1995. "New Keynesian Economics and the Phillips Curve." *Journal of Money, Credit, and Banking* 27 (4): 975–84.

———. 1997. "Is Inflation Sticky?" *Journal of Monetary Economics* 39 (2): 173–96.

———. 1998. "Inflation Expectations and the Transmission of Monetary Policy." Finance and Economics Discussion Series Paper No. 43, Board of Governors of the Federal Reserve System.

———. 2005. "How Well Does the New Keynesian Sticky-Price Model Fit the Data?" *Contributions to Macroeconomics* 5 (1): 1206–42.

Romer, C. D., and D. H. Romer. 2000. "Federal Reserve Information and the Behavior of Interest Rates." *American Economic Review* 90 (3): 429–57.

Rotemberg, J. J. 1982. "Sticky Prices in the United States." *Journal of Political Economy* 90 (6): 1187–1211.

Rotemberg, J. J., and M. Woodford. 1997. "An Optimization-Based Econometric Framework for the Evaluation of Monetary Policy." In *NBER Macroeconomics Annual*, ed. B. S. Bernanke and J. J. Rotemberg, 297–346. Cambridge, MA: MIT Press.

Rudd, J., and K. Whelan. 2005a. "Does Labor's Share Drive Inflation?" *Journal of Money, Credit, and Banking* 37 (2): 297–312.

———. 2005b. "New Tests of the New-Keynesian Phillips Curve." *Journal of Monetary Economics* 52 (6): 1167–81.

———. 2006. "Can Rational Expectations Sticky-Price Models Explain Inflation Dynamics?" *American Economic Review* 96 (1): 303–20.

Sbordone, A. M. 2001. "An Optimizing Model of U.S. Wage and Price Dynamics." Departmental Working Paper No. 10, Rutgers University.

———. 2002. "Prices and Unit Labor Costs: A New Test of Price Stickiness." *Journal of Monetary Economics* 49 (2): 265–92.

———. 2005. "Do Expected Future Marginal Costs Drive Inflation Dynamics?" *Journal of Monetary Economics* 52 (6): 1183–97.

Sims, C. A. 2003. "Implications of Rational Inattention." *Journal of Monetary Economics* 50 (3): 665–90.

Smets, F., and R. Wouters. 2003. "An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area." *Journal of the European Economic Association* 1 (5): 1123–75.

———. 2005. "Comparing Shocks and Frictions in US and Euro Area Business Cycles: A Bayesian DSGE Approach." *Journal of Applied Econometrics* 20 (2): 161–83.

Swanson, E. T. 2004. "Assessing the Rationality of Federal Reserve 'Greenbook' Forecasts." Unpublished Manuscript, Board of Governors of the Federal Reserve System.

Taylor, J. B. 1980. "Aggregate Dynamics and Staggered Contracts." *Journal of Political Economy* 88 (1): 1–23.

Woodford, M. 1996. "Control of the Public Debt: A Requirement for Price Stability?" NBER Working Paper No. 5684.

———. 2003. *Interest and Prices: Foundations of a Theory of Monetary Policy*. Princeton, NJ: Princeton University Press.