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ABSTRACT

The ability of the New Keynesian Phillips curve to explain US inflation dynamics when official central bank forecasts (Greenbook forecasts) are used as a proxy for inflation expectations is examined. The New Keynesian Phillips curve is estimated on quarterly data spanning the period 1970Q1−1998Q2 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 to 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 official inflation forecasts. In this case, lagged inflation terms become insignificant in the hybrid specification. The usefulness of real unit labor cost as the preferred proxy for real marginal cost in recent empirical work on the Phillips curve is confirmed by our results.

Keywords: Inflation; Phillips curve; Real marginal cost; Real-time data; GMM estimation
JEL classification: C13; C52; E31; E37; E50; E52

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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, which implies that current inflation is determined by the next period's expected inflation and 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".

The literature on the New Keynesian Phillips curve builds on earlier work by Taylor (1980), Calvo (1983) and others that emphasized staggered nominal wage and price setting by forward-looking individuals and firms. It extends this work by expressing a firm's price-setting decision as the result of an explicit optimization problem. Aggregating over all price-setting firms then leads to a relation that links inflation in the short run to some measure of real marginal cost (Gali and Gertler, 1999). The use of microfoundations on which the New Keynesian Phillips curve is based makes the relation an explicit function of structural coefficients (see among others, King and Watson, 1994).

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, 2001). A large empirical literature has focused on estimating this model, both as a single equation as well as 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 US post-war 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 *et al*. (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 Gali and Gertler (1999), Gali, Gertler and Lopez-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 (2005) 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 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 Reiss, 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, mainly related to the empirical identification of the Phillips curve, concern the characteristics of the proper measure of the driving variable (i.e. real unit labor cost or the output gap) as well as the assumption about the measure of expected inflation used.

A central point in the debate is whether 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. It appears difficult for the model to capture this persistence without appealing either to some form of price stickiness that is hard to motivate explicitly or to adaptive expectations, which also poses problems from a modeling standpoint as these expectations are introduced as an *ad hoc* feature of the model (Cogley and Sbordone, 2004). Thus, the baseline theory underlying the new 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, Gali and Gertler, 1999).

In this paper we reconsider estimates of the New Keynesian Phillips curve in the light of recent advances in inflation modeling and use official central bank forecasts as a proxy for inflation expectations. In this respect, we estimate the New Keynesian Phillips curve for the US using inflation forecasts from the FOMC's Greenbook 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 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. 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 official inflation forecasts, which may deviate from full rationality.

We estimate the alternative Phillips curve specifications on quarterly US data spanning the period 1970Q1−1998Q2 by using the Generalized Method of Moments (GMM). All specifications are tested for parameter stability across the different regimes of US monetary policy. Several results stand out and appear to be quite robust in these estimations. In the specifications including the Greenbook inflation forecasts we obtain significant and plausible estimates for the effect of expected inflation and real unit labor cost, whereas we find, as in Gali and Gertler (1999), Roberts (2001) and Rudd and Whelan (2002), that the coefficient of the driving variable has the wrong sign if the output gap is used as a measure of real marginal cost. The coefficient of the output gap is statistically significant with the correct sign only in the backward-looking specification, while the results based on real unit labor cost appear to be theoretically consistent across all subsamples.

Using the Greenbook inflation forecasts as a proxy for private sector inflation expectations, we find, in contrast to the findings of Fuhrer (1997a) and Rudd and Whelan (2002, 2005), that expected inflation becomes the main determinant of current inflation, and its coefficient ranges from 0.54 to 1.12, being higher compared with the Gali and Gertler (1999) and Gali, Gertler and Lopez-Salido (2001) estimates. Moreover, the success of the empirical specifications including less- than-perfectly rational proxies of inflation expectations (such as the Greenbook forecasts) appear to justify theoretical approaches to inflation modeling based on information processing constraints and learning mechanisms (Ball, 2000).

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 alternatively official forecasts and actual data in estimation as well as two alternative measures of the driving variable (output gap or real unit labor cost), and shows that the forecast-based specification does a reasonably good job of describing the data. Some concluding remarks and tentative implications are provided in Section 4.

2. Modeling inflation dynamics

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 (Linde, 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).

Yun (1996) constructs a rational expectations-monetary business cycle model consistent with the new Phillips curve. Under the assumption of monopolistically competitive firms that maximize their expected discounted profit stream subject to a sticky price adjustment constraint, the solution to the firms' problem can be cast as the New Keynesian Phillips curve in which price expectations are forward-looking and real marginal cost is the variable driving inflation. These features are a consequence of the fact that in this framework firms set prices in anticipation of future demand and factor costs. Compared to traditional reduced-form Phillips curves, which are subject to the Lucas critique, the New Keynesian Phillips curve is a structural model with parameters that are unlikely to vary as the policy regime changes (Guay and Pelgrin, 2004). This aspect is particularly important and has been outlined in a number of papers which argue that parameter instability in reduced-form models is a likely possibility. Furthermore, the New Keynesian Phillips curve specification has important implications for the conduct of

monetary policy in that a fully credible central bank can bring about disinflation at no recessionary cost if inflation is a purely forward-looking phenomenon.

2.1 The New Keynesian Phillips curve

The New Keynesian Phillips curve, as advocated by Gali and Gertler (1999), is based on a model of price setting[1,2] by monopolistically competitive firms. Following Calvo (1983), each firm, in any given period, may reset its price with a fixed probability 1-θ and, with probability θ, its price will be kept unchanged or proportional to trend inflation. These adjustment probabilities are independent of the firm's price history so that the proportion of firms that may adjust their price in each period is randomly selected. The average time over which a price is fixed is then given by 1/(1-θ) and the firms face a common subjective discount factor, β. Let s be excess demand, μ the firm's demand elasticity and η the elasticity of marginal cost with respect to output. The New Keynesian Phillips curve (Woodford, 2003) is then given by:

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

The derivation in Yun (1996) and Goodfriend and King (1997) corresponds to the particular case where the elasticity of marginal cost with respect to output (η) is equal to zero.

Several authors, such as Fuhrer and Moore (1995) and Estrella and Fuhrer (2000), argue that the pure forward-looking New Keynesian Phillips curve has implications that are inconsistent with the data, because of the "jump dynamics" in inflation adjustment that would imply a costless disinflation, which is counterfactual. Thus, the New Keynesian Phillips curve implies that a disinflation of any size could be achieved costlessly and immediately by a central bank that could commit to setting the future path of excess demand equal to zero.

[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).

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, Gali and Gertler (1999) with a view to capturing inflation inertia extend the basic Calvo model to allow a subset of firms to use a backward-looking rule of thumb. The net result is a hybrid Phillips curve that nests Eq.(1). From the three structural parameters ω, θ and β, the three reduced-form parameters γ_f , γ_b and λ can be defined, and the hybrid version of the Phillips curve developed by Woodford (2003) is given as follows:

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

where $$\lambda = \left(\frac{(1-\omega)(1-\theta)(1-\theta\beta)}{\theta}\right)\phi^{-1},$$

$$\gamma_f = \beta\theta\phi^{-1},$$

$$\gamma_b = \omega\phi^{-1},$$

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

where ω is the proportion of firms that use a backward-looking rule of thumb. 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 quarterly frequency. Chadha *et al*. (1992) and Roberts (1997, 1998) obtain reasonable parameter estimates only with annual and semi-annual data. With quarterly data, there are

[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. Christiano, Eichenbaum and Evans (2005) and Smets and Wouters (2003, 2004) show that the hybrid model can be motivated by a form of dynamic price indexing (Clarida, Gali and Lopez-Salido, 2005). Guerrieri (2001) has emphasized that under conventional time dependent staggered price setting (as in Taylor), lagged inflation may enter the Phillips curve specification even if firms set prices in a forward-looking manner. Another possibility is that lagged inflation might reflect some form of least squares learning on the part of private agents, as suggested by Collard and Dellas (2005) and others.

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 (Gali and Gertler, 1999) [4].

2.2 Other approaches to explaining sluggish inflation dynamics

There are also other ways to reconcile the empirical evidence with Phillips curve theory. It may be possible to appeal to imperfect credibility or to bounded rationality (Roberts 1997,1998,2001) to explain sluggish inflation dynamics. The imperfect credibility assumption implies that if, for example, the central bank cannot commit to stabilizing future output, then the reduction of inflation may involve current output losses (e.g. Ball, 1995). The latter theory, although warranting further investigation, clearly lacks empirical support since, even countries with highly credible central banks (e.g. Germany) have experienced very costly disinflations (Clarida and Gertler, 1999). On a more positive note, Roberts' approach, involving some form of adaptive rule for a subset of price setters instead of using lagged inflation, appears to be empirically more relevant. Inflation lags may be thought as capturing inflation expectations that deviate from full rationality. In particular, Roberts (1998) assumes that inflation expectations are a weighted average of rational expectations and a simple forecast of inflation, perhaps due to the fact that some fraction of the population uses a univariate rule for forecasting inflation.

[4] Recent studies by Gali and Gertler (1999), Gali, Gertler, and Lopez-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. Gali, Gertler, and Lopez-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. According to New Keynesian models, a simple structural relationship between inflation and the output gap does not hold in general—it holds only if the labor market is perfectly competitive. 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.

2.3 Near-rational expectations and the Phillips curve specification

Roberts (2001) shows that models derived under less-than-rational expectations and models based on alternative microfoundations can be shown to be in several cases observationally equivalent. Nevertheless, he argues that while structural models and the models based on imperfectly rational expectations can be shown to have the same reduced form, the use of real-time measures of expectations, such as surveys of inflation expectations, "can be helpful to distinguish between the structural and expectational sources of lagged inflation". In this respect, he finds that if surveys are assumed to capture inflation expectations accurately, then there is no need for additional lags of inflation. This result 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. This argument would hold *a fortiori* if survey measures of inflation expectations could be represented as a weighted average of forward-looking and backward-looking expectations. Roberts (1998) estimated the New Keynesian Phillips curve directly using the Michigan and Livingston survey measures of expected inflation. He found that 40 percent of the agents use a simple univariate rule for forecasting inflation while the remaining 60 percent have rational expectations.

While these findings are of interest, they rely on survey estimates of inflation expectations which, with some justification, can be viewed with suspicion, as survey respondents "have little incentive to take them seriously" (Roberts 2001), and which, even though unbiased (as in the case of inflation forecasts obtained from the Survey of Professional Forecasters[5]), appear to be inefficient, i.e. they fail to incorporate all available information related to future inflation developments. The findings based on the survey data would be reinforced if direct estimation of the New Keynesian Phillips curve on the basis of alternative, more reliable measures of expectations yielded similar results.

[5] Private inflation forecasts obtained from other sources such as the Michigan Household Survey and the Livingstone Survey do not even pass the unbiasedness test (see Romer and Romer, 2000), whereas Swanson (2004) finds that the Greenbook forecasts pass most standard tests of rationality with the notable exception of some interest rate variables that appear to have significant predictive power for Greenbook forecast errors.

Unfortunately, Fuhrer (1997b) estimated a similar equation obtaining, in contrast to Roberts, an estimate for the proportion of the rule-of-thumb price setters of 80 per cent.

In the present paper, we investigate the ability of another measure of inflation expectations, i.e. the forecasts included in the FOMC's Greenbook, to account for the actual inflation expectation formation process in the economy, and we provide evidence supporting the pure New Keynesian Phillips curve[6]. To the extent that official forecasts provide a good proxy for private sector expectations, they allow us to disregard issues related to the detailed specification of the actual expectation formation process. In this way, we need not impose untested orthogonality restrictions in estimation, as required when estimating under the assumption of rational expectations, and make restrictive assumptions about the precise form of non-rationality present in agents' forecasts (Adam and Padula, 2003). 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.

The Greenbook forecasts appear to incorporate efficiently a large amount of information from all sectors of the economy as well as forecasters' judgmental adjustments. As argued by Faust *et al.* (2004), the Fed's forecasts should compare more favorably to a measure of private sector inflation expectations that could be obtained by aggregating the forecasts from individual private-sector agents than to any of those individual forecasts by themselves. Moreover, the Greenbook forecasts are free of several problems usually plaguing professional and household survey forecast data (e.g. strategic considerations, excessive gradualism, inefficiency in information processing). Thus, Greenbook inflation forecasts emerge as a promising alternative for approximating private sector expectations when modeling inflation behavior.

[6] To our knowledge there is a small number of papers that attempt to estimate the New Keynesian Phillips curve for the US by using survey measures of expectations. None of them, however, considers 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 (2004) 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.

3. Phillips curve estimation on the basis of official 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 Gali and Gertler (1999) and Gali, Gertler and Lopez-Salido (2001). The estimation is carried out using the Generalized Method of Moments (GMM). We find that the pure New Keynesian Phillips curve where inflation is a function of expected future inflation, approximated by the official inflation forecasts included in the Greenbook, and of a measure of real marginal cost, does a very good job of describing inflation dynamics in the US during the past thirty years. We use quarterly US data from 1970 Q1 through 1998 Q2 where both the starting and the ending dates are determined by the availability of Greenbook inflation forecasts. Inflation is measured as the annualized quarterly change of the GDP deflator. The Greenbook inflation forecasts correspond to the annualized quarterly change in the same deflator one-quarter ahead[7].

We use the two measures of real marginal cost adopted in the literature, i.e. real unit labor cost and the output gap. Real unit labor cost concerns the non-farm business sector[8] and is obtained from the National Bureau of Labor Statistics. This is the measure used by Gali and Gertler (1999) and Sbordone (2002). Secondly, the output gap was obtained by detrending the log of real GDP through the application of the Hodrick-Prescott filter.

Given that measurement errors may affect the left-hand 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 official inflation forecasts as proxy for (unobservable) inflation expectations and of the output gap or real unit labor cost as proxies for real marginal cost. Estimates of the alternative specifications are obtained by using the two-step Generalized Method of Moments (GMM), and statistical significance is assessed on the basis of the Newey-West estimates of the covariance matrix.

[7] Both actual inflation and Greenbook inflation forecasts are measured in terms of the GNP deflator prior to 1992.

[8] We also tried the ratio of the compensation of employees to national income net of proprietors' income, which gave us similar results.

3.1 Observable measures of expectations and instrumental variables estimation

It is well-known that full-information estimation methods, such as those used by Fuhrer (1997a, b) and Linde (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, 2001). In implementing the instrumental variables estimator, we replace the mathematical expectation of inflation with official inflation forecasts under the assumption that the instruments used correspond to the agents' information set at the time expectations were formed. This substitution will yield consistent estimates under the rational expectations hypothesis. 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. Moreover, as noted above, instrumental variables can be useful in protecting against biases stemming from measurement errors in the data.

Given that the Greenbook 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 Eq.(2) that:

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

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 Eq.(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 be 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 or t-2 and earlier, respectively. Although the use of a larger number of instruments could increase the ability of the model to capture movements in the variable of interest, we choose to keep the number of instruments relatively small so as to avoid the increased probability of "overfitting" in a finite sample (Linde, 2005).

Thus our instrument set includes four lags of inflation, real unit labor cost (in the specifications including this variable as the measure of marginal cost), the output gap, the change in the federal funds rate and two lags of wage inflation[9]. To allow for the possibility of serially correlated errors, all instrument lags are dated at period t 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 to 2 present estimates of different specifications of the New Keynesian and the Hybrid Phillips curves obtained by using, alternatively, actual data on future inflation or, the respective Greenbook inflation forecasts. Each specification is also evaluated under the two alternative measures of real marginal cost, i.e. real unit labor cost and the output gap. 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 addition 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 not statistically different from unity, being in line with what theory would predict and with the respective estimate obtained from the specification including actual future inflation. The coefficient on the driving variable is statistically significant having the correct sign

[9] The lag length chosen for the instruments is also motivated by the literature on monetary VAR models where four lags appear to be sufficient for these models (estimated on quarterly data) to capture the economy's dynamics well (Roberts, 2001).

only when real unit labor cost is used. In the specification with the output gap as a measure of real marginal cost, we obtain the well-known result of a wrongly signed and/or statistically insignificant coefficient on this variable (e.g. Gali and Gertler, 1999)[10]. The coefficient estimates when real unit labor cost is used are also presented in the third column of Table 1. They have the correct sign and are broadly of the same order of magnitude with similar estimates in the literature.

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.[11,12] The coefficients on the hybrid models corresponding to the reduced-form specification of Clarida and Gali (1999) are all, except for the output gap, statistically significant at least at the five per cent level. It is immediately obvious from Table 2, which presents the estimates of the hybrid models, that the balance of expectations formation moves significantly toward the forward-looking direction when we use inflation forecasts instead of actual data on future inflation. Indeed, while in the estimates based on actual data that are presented in the last two lines of Table 2 the lagged inflation term remains significant, explaining about 60 per cent of current inflation, it becomes insignificant when Greenbook inflation forecasts are used in the specification including the unit labor cost. In the forecast-based specifications, the coefficient on expected inflation ranges from 0.54 to 1.12 and is almost 50 per cent higher than the respective estimates of Gali and Gertler (1999) and Sbordone (2002). The estimated coefficient of the backward-looking inflation term is insignificant in the forecast-based specification including the unit labor cost, whereas it remains significant in the hybrid specification that includes the output gap as the driving variable. In the latter case, lagged inflation is far less important compared to the inflation forecast in explaining inflation dynamics. Overall, the inclusion of the Greenbook forecasts appears to increase the weight of the forward-looking variable in inflation determination,

[10] Similar results were obtained by using an output gap series based on a log-linear trend of real GDP or the measure of potential output constructed by the Congressional Budget Office.

[11] We present only the specification with one lag in inflation, since more lags have not been found statistically significant.

[12] We also estimated versions of the model that use four-quarter averages of expected and lagged inflation with no qualitative difference in the results.

suggesting that the significance of lagged inflation in conventional specifications reflects its role in capturing deviations from full rationality.

One could plausibly argue that in view of the potential deviations of Greenbook forecasts from full rationality, it is likely that these forecasts include a significant backward-looking component which makes lagged inflation insignificant in the hybrid model (Adam and Padula, 2003). To assess whether this is true, we re-estimate the Hybrid Phillips curve by replacing the inflation forecast with the actual future inflation and the error term obtained from a regression of the Greenbook inflation forecast on four lags of actual inflation. In this way, we attempt to evaluate whether there is a part of the information set underlying the time t Greenbook forecast which, although orthogonal to lagged inflation, remains significant in explaining inflation behavior. As can be seen from Table 3, the lagged inflation term is insignificant confirming that the Greenbook proxy for inflation expectations contains valuable information for inflation modeling that goes above and beyond accounting for the proportion of backward-looking price setters in the economy. Moreover, the fact that the coefficient on the orthogonalised Greenbook forecast is significant in a specification containing the next period's inflation provides some indication that potential deviations from full rationality are a key element in the description of inflation dynamics.

With respect to the driving variable in the hybrid specification, it appears that, as in the case of the new Phillips curve, the coefficient on real unit labor cost has a theory-consistent sign and is statistically significant in all specifications except for the one involving the actual future inflation data. On the other hand, it has again proved impossible to obtain reasonable parameter estimates using the output gap as a measure of real marginal cost.

3.3 Evaluating the robustness of the results

To check for the time-invariance 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 marginal cost (real unit labor cost and output gap) and lagged inflation are not statistically significant.

We further analyze the stability of the Phillips curve by considering the estimates obtained by two sub-samples, one corresponding to the Chairmanships of Arthur Burns and George Miller (1970 Q1 through 1979 Q2), and one the Chairmanships of Paul Volcker and Alan Greenspan (1979 Q3 through 1998 Q2). The inflation experience was quite different in the two sub-periods: during the 1970s, inflation was rising and volatile, then it dropped sharply during the 1980s and has been low and relatively stable during the 1990s. To the extent that these changes have been caused by differences in the conduct of monetary policy, a test for parameter stability in the two sub-samples can be considered as a test for invariance of the price-setting behavior underlying the New Keynesian Phillips curve (Bardsen and Jansen, 2003).

Estimates from the different sub-periods (presented in Table 4 for the specification including the real unit labor cost), confirm that all coefficients are statistically significant and have the correct sign irrespective of the sample period examined. Finally, the Chow tests cannot reject the hypothesis of stability across the different periods no matter what measure of real marginal cost was used. Overall, the evidence from the stability tests supports the ability of the New Keynesian Phillips curve, in which inflation expectations are approximated by the Greenbook forecasts, to adequately describe inflation dynamics in the US during the 1970-1998 period.

4. Conclusions

This paper examined the ability of the New Keynesian and Hybrid Phillips curves to explain US inflation dynamics if Greenbook inflation forecasts 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 official 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 forecast proxies of inflation expectations. Moreover, the insignificance of the output gap in all estimated equations indicates that the use of real unit labor cost seems to rest on more solid theoretical grounds as a proxy for real marginal cost.

Inflation lags are also insignificant even when we correct for the backward-looking information contained in the inflation forecasts. Indeed, inflation forecasts appear to contain valuable information for inflation modeling that goes beyond accounting for the proportion of backward-looking price setters in the economy.

Appendix. Data sources

All data series are quarterly, beginning in 1970:1 and ending in 1998:2. Data on Gross Domestic Product, the GDP deflator, the federal funds rate and the wage rate are all from the Federal Reserve System's Database (FRED). Data on the GDP deflator forecasts was taken from the FOMC's Greenbook and the Survey of Professional Forecasters datasets available at the Federal Reserve Bank of Philadelphia. Finally, data on unit labor cost in the non-farm business sector was taken from the US Bureau of Labor Statistics.

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Table 1
New Keynesian Phillips curve (1970 Q1-1998 Q2) [a]

	π^{e}_{t+1}	x_t	ulc_t	$\bar{R}^2$	J-test
Forecast-based specifications	0.90 (28.4)	-0.31 (-1.72)	…	0.76	0.57
	0.95 (40.69)	…	0.09 (1.63)	0.80	0.79
Specifications with actual data on future inflation	1.01 (47.73)	-0.29 (-1.93)	…	0.71	0.56
	1.03 (28.84)	…	0.06 (2.98)	0.80	0.69

Table 2
Hybrid Phillips curve (1970 Q1-1998 Q2) [a]

	π^{e}_{t+1}	π_{t-1}	x_t	ulc_t	$\bar{R}^2$	J-test
Forecast-based specifications	0.54 (3.26)	0.38 (2.13)	0.01 (0.11)	…	0.89	0.67
	1.12 (2.49)	-0.17 (-0.39)	…	0.10 (2.08)	0.81	0.76
Specifications with actual data on future inflation	0.38 (3.06)	0.61 (4.81)	-0.037 (-0.48)	…	0.79	0.88
	0.40 (3.95)	0.58 (5.73)	…	-0.001 (-0.16)	0.83	0.54

Table 3
Forecast-based Phillips curve including the component of the inflation forecast that is orthogonal to lagged inflation [a]

	π^{e}_{t+1}	π_{t-1}	e_t	ulc_t	$\bar{R}^2$	J-test
Forecast-based specifications (1970 Q1-1998 Q2)	…	0.60 (3.69)	1.11 (5.99)	0.06 (2.16)	0.85	0.67
	0.65 (4.01)	0.12 (0.18)	1.07 (3.01)	0.13 (2.30)	0.81	0.46

Table 4
Stability test of the forecast-based specification of the New Keynesian Phillips curve[a]

	π^{e}_{t+1}	π_{t-1}	ulc_t	$\bar{R}^2$	J-test
1970 Q1-1979 Q2 (pre-Volcker period)	1.17 (3.23)	-0.29 (-1.23)	0.16 (2.66)	0.76	0.29
1979 Q3 –1998 Q2 (Volcker-Greenspan period)	0.88 (3.68)	0.05 (1.28)	0.07 (3.12)	0.86	0.55

[a] Note for Tables 1-4: π^{e}_{t+1} denotes expected private sector inflation in period t+1 expressed in terms of the annualized rate of change in the GDP deflator, x_t stands for the output gap estimate in the current quarter, ulc_t is real unit labor cost and e_t is the component of the inflation forecast that is orthogonal to the information included in four lags of inflation. Numbers in parentheses are t statistics and the last column includes the p-values associated with a test of the model's overidentifying restrictions (Hansen's J-test).

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