INFLATION DYNAMICS AND SUBJECTIVE EXPECTATIONS IN THE UNITED STATES

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We estimate a forward-looking New Keynesian Phillips Curve (NKPC) for the United States using data from the Survey of Professional Forecasters as proxy for expected inflation. We obtain significant and plausible estimates for the structural parameters independently of whether we use the output gap or unit labor costs as a measure of marginal costs. Moreover, when estimating a Phillips curve where lagged inflation enters due to price indexation by nonreoptimizing firms, we obtain significant parameter estimates of the sign predicted by theory independently of the marginal cost measure used. (*JEL* E31)

I. INTRODUCTION

This paper analyzes the ability of sticky-price models to explain the dynamics of U.S. inflation when using survey data as proxies for inflation expectations.

Testing sticky-price models with survey expectations is attractive since, to the extent that survey data correctly capture agents' expectations, they allow to disregard issues related to the specification of agents' expectations functions. One neither has to impose untested orthogonality restrictions, as required when estimating under the assumption of rational expectations, nor has to make restrictive assumptions about the precise form of nonrationality present in agents' forecast functions. This allows to focus on the question whether the economic models under consideration are correctly specified.

Previous tests of sticky-price models, performed under the assumption that agents hold rational expectations, have generated mixed results. Prominently, Fuhrer and Moore (1995) have reported that sticky-price models do not generate sufficient stickiness for inflation when the output gap is used as a measure of real marginal costs. Recent evidence, however, has shown that the empirical performance depends crucially on how one measures real marginal costs, the main determinant of inflation according to sticky-price models. For instance, Galí and Gertler (1999) and Sbordone (2002) show that sticky-price models perform well once marginal costs are approximated by average unit labor costs.[1]

It makes an important difference whether sticky-price models successfully explain inflation dynamics as a function of output behavior or they relate inflation dynamics to the behavior of unit labor costs. Given that the ultimate objective is a model explaining the joint behavior of output and inflation, the latter case would require an additional empirically plausible theory linking

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1. A different view about the ability of unit labor costs to explain U.S. inflation dynamics has recently been expressed by Rudd and Whelan (2002, 2005).

ABBREVIATIONS

AR: Autoregressive
CPI: Consumer Price Index
GDP: Gross Domestic Product
GNP: Gross National Product
IFO: Information and Forschung
IV: Instrumental Variable
NIPA: National Income and Product Account
NKPC: New Keynesian Phillips Curve
OLS: Ordinary Least Squares

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the dynamics of unit labor costs to the behavior of output.

This paper studies whether the currently popular New Keynesian Phillips Curve (NKPC), which can be derived from Calvo (1983) style sticky-price models, is able to explain a relationship between inflation on the one hand and output or unit labor costs on the other hand. Thus, we let the data speak whether a theory linking output to costs is warranted, once expectations are approximated by data reported in the Survey of Professional Forecasters.

Our main finding is that the NKPC performs equally well with both measures of marginal costs, output and unit labor costs. Whatever measure is used, the estimate of the quarterly discount factor is close to one and the point estimate of the degree of price stickiness implies that firms reset their prices roughly every five quarters on average.

These results suggest that potential nonrationalities in expectations, as they show up in surveys, have biased previous estimates using output as a measure for marginal costs. Quite surprisingly, the same nonrationalities do not seem to play a role when using unit labor costs. Here our estimates confirm the results obtained by Galí and Gertler (1999) and Sbordone (2002), who assumed rational expectations.

We show that the reason for this finding is that approximating the agents' information set using the unit labor cost variable rests on more solid grounds than approximating it using the output variable. In particular, the survey data suggest that the hypothesis of rational expectations implies a too high correlation between lagged output and future inflation expectations. We show that this causes the coefficient estimate for output to become negative, contrary to what is implied by theory.

These results suggest that once one takes account of potentially nonrational expectations via survey expectations, sticky-price models are able to establish a close link between output dynamics and the behavior of inflation.

To assess the robustness of this finding, we include into the price equation lags of various variables and test for their significance. While lagged measures of marginal costs (unit labor costs and output) and lagged expectations remain insignificant, lagged inflation enters significantly. Moreover, lagged inflation remains significant even when we account for the fact that agents might use this variable to inform their inflation forecasts.

The significance of lagged inflation suggests that this variable plays a role in explaining inflation dynamics that goes beyond explaining how actual inflation expectations might deviate from rationality, contrary to what seems to be the predominant interpretation in the recent literature.

To account for the role of lagged inflation, we estimate the inflation-indexation model of Christiano, Eichenbaum, and Evans (2005), where lagged inflation enters because firms are assumed to index their prices using lagged inflation rates in periods, where they do not adjust prices optimally. We obtain significant estimates of the correct sign for all parameters independently of the measure of marginal cost used. This suggests that the indexation model may account for the role of lagged inflation if it is combined with subjective inflation expectations.

Obviously, we are not the first to estimate sticky-price models using survey expectations. Roberts (1995, 1997) estimated sticky price models using the Livingston and Michigan surveys and showed that sticky-price models can account for inflation dynamics at a semi-annual or annual frequency. Since data in the Survey of Professional Forecasters is collected on a quarterly basis, we can construct a quarterly model. Our estimates thereby remain more easily comparable to recent estimates based on quarterly data.

Moreover, the use of the Survey of Professional Forecasters allows us to focus on the GDP deflator, a less questionable measure of inflation than the Consumer Price Index.[2]

We extend Roberts' (1995, 1997) studies in two further dimensions. First, we consider an additional proxy for the marginal cost, a measure of average economy-wide real unit labor costs. This choice follows Gali and Gertler's (1999) observation that the sticky-price models used to derive NKPC imply that the correct driving variable for inflation is real marginal costs, which are well approximated by real average unit labor costs. Second, we use our estimates to back-out explicit parameters values for two specific structural sticky-price models, the Calvo model and the dynamic indexation model of Christiano, Eichenbaum, and Evans (2005).

On the more theoretical side, we contribute the existing literature by deriving the conditions under which subjective expectations act

2. Gordon (2006) shows that CPI inflation is biased and that the bias for the years 1995–1996 is 1.2–1.3% per year, and that the bias for more recent years is about 0.8.

as a sufficient statistic for the forecasts of all agents. This allows circumventing the problem of higher-order expectations (or equivalently, forecasting the forecasts of others).

The paper is structured as follows. In Section II, we present conditions under which the first-order conditions characterizing firms' optimal pricing decision give rise to a New Keynesian Phillips Curve when expectations are potentially nonrational. Section III presents the data and assesses the rationality of survey expectations. The estimation results for the benchmark NKPC are presented in Section IV.[3] Section V then presents the results for the inflation indexation model, and a conclusion briefly summarizes.

II. MONOPOLISTIC PRICE SETTING WITH SUBJECTIVE EXPECTATIONS

This section derives the New Keynesian Phillips Curve for the case where expectations are subjective and potentially nonrational. The resulting Phillips curve will be similar to widely used specifications of Galí and Gertler (1999) and Roberts (1995). For illustrative purposes, we use Calvo's (1983) time-dependent pricing model to derive our results, but similar reduced-form Phillips curve equations can be obtained using the quadratic adjustment cost model of Rotemberg (1982).

Firms in monopolistic competition must precommit to prices that can be reset with probability $1-\theta \in (0, 1)$ each period. Firms' forecasts are produced by professional forecasters. Each forecaster $i \in \{1, \ldots, I\}$ thereby advises a fixed share $1/I$ of firms. The (subjective) forecast delivered by forecaster i will be denoted by $F_t^i[\cdot]$.

Let P_t denote the aggregate price level at period t and P_t^{*i} the price chosen by a firm that can reset prices in period t and is advised by forecaster i. Then the new price level can be expressed as

$$(1) \quad P_t = (1-\theta)(1/I)\sum_{i=1}^{I} P_t^{*,i} + \theta P_{t-1}.$$

The new price level is a convex combination between the old price level and the average price selected by firms that adjust their price. Firms that reset prices maximize expected discounted profits, which are given by

$$(2) \quad \max_{P_t^{*,i}} F_t^i\left[\sum_{j=0}^{\infty}(\beta\theta)^j (P_t^{*,i}/P_{t+j})^{-\varepsilon}(P_t^{*,i} - MC_{t+j})\right]$$

where $\beta \leq 1$ is the discount factor, $\varepsilon > 1$ is the elasticity of the demand function, and MC are the nominal marginal costs of production. Linearizing the first-order conditions of this problem around a zero inflation steady state delivers

$$(3) \quad p_t^{*,i} = (1-\beta\theta)F_t^i\left[\sum_{j=0}^{\infty}(\beta\theta)^j mc_{t+j}\right]$$

where lower case variables denote percentage deviations from steady state. Under the assumption of rational expectations Equations (1) and (3) can be used to derive the familiar New Keynesian Phillips Curve

$$(4) \quad \Pi_t = \beta E_t\left[\Pi_{t+1}\right] + \left[(1-\theta)(1-\beta\theta)/\theta\right] rmc_t$$

where current inflation, $\Pi_t \equiv P_t - P_{t-1}$, is a function of (rational) inflation expectations and real marginal costs rmc_t.

Deriving an equation similar to Equation (4) when expectations are subjective is not entirely obvious. Profit-maximizing prices depend on nominal costs and therefore on forecasted inflation. Inflation is determined by other agents' pricing decisions and their marginal cost forecasts. As a result, optimal price setting behavior would require forecasting the marginal cost forecasts of others, see Woodford (2001) for a recent treatment. Obviously, expectations survey data do not report agents' subjective forecasts of other agents' forecasts. Therefore, we want to delineate conditions under which subjective inflation forecasts summarize all beliefs about other agents' marginal cost expectations.

Suppose the following condition holds:

Condition 1

$$(5) \quad F_t^i[F_{t+1}^h[mc_{t+s}] - F_t^h[mc_{t+s}]] = 0 \quad \forall i, h, s > 0$$

Condition 1 requires that agents do not expect that current forecasts of future variables will be revised in a particular direction in the next period, that is, they do not expect predictable movements of their own or other agents'

3. In the interest of space, we refer the reader to the working paper for several robustness checks (see the CSEF Working Paper no. 78).

expectations. This is the case whenever expectations fulfill the "law of iterated expectations."

Importantly, Condition 1 does not rule out nonrationalities in expectations. Suppose, for example, that marginal costs are expected to follow an AR(1) process, where multi-step forecasts are obtained by simply iterating the AR(1) equation. Condition 1 is then satisfied, but expectations will be nonrational if actual inflation follows some other stochastic process.

Appendix shows that whenever Condition 1 holds, the subjective inflation forecast of the aggregate inflation rate is a sufficient statistic summarizing all forecasts of other agents' forecasts. One then obtains a Phillips curve of the form:

(6)
$$\Pi_t = \beta \overline{F}_t \left[\Pi_{t+1}\right] + [(1-\theta)(1-\beta\theta)/\theta] rmc_t .$$

The only difference between the Phillips curve and Equation (4) is that rational expectations are now substituted by the average of the forecasters' subjective expectations, which is defined as

(7)
$$\overline{F}_t\,[\cdot] = 1/I \sum_{i}^{I} F_t^i\,[\cdot]\,.$$

III. DATA ISSUES

This section describes the data used to estimate Equation (6). A more detailed description of data sources and variable definitions is given in the Appendix.

We use quarterly U.S. data from 1968:4 to 2003:1, where the starting date is determined by the availability of inflation survey data. Inflation is calculated using the implicit GDP deflator.[4] We use aggregate GDP and GDP inflation instead of data for the nonfarm private business sector, which is the usual sector considered in the literature, because inflation forecasts are available only for aggregate deflators. Since nonfarm private business accounts for approximately 75% of aggregate GDP our results can be expected to be comparable to the remaining literature.[5] In any case, the broader activity measure should only strengthen the importance of our findings.

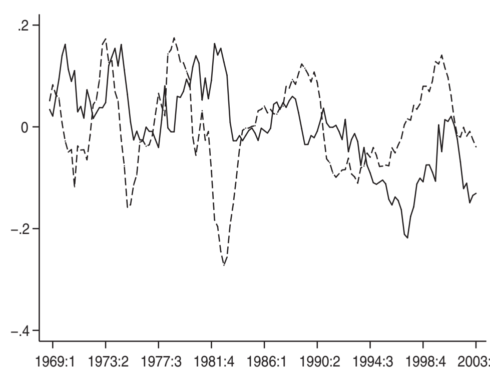
We use two measures for the real marginal costs in Equation (6). Firstly, we use the unit labor costs. This is the measure used by Galí and Gertler (1999) or Sbordone (2002).[6] Secondly, we consider the output gap, obtained by linearly detrending the log of real GDP.[7] The output gap has been used by Fuhrer and Moore (1995), for example.

Figure 1 graphs the unit labor costs and the output gap. This figure shows that there is a negative contemporaneous correlation between the two series, as was the case for the data used by Galí and Gertler (1999).

Inflation expectations are approximated with data from the Survey of Professional Forecasters. The survey collects data from around 80 professional forecasters on a quarterly basis from 1968 onwards. A description of the survey can be found in Croushore (1993). Given that we estimate a quarterly model, we use the mean of the one-quarter ahead inflation forecast for the implicit GDP deflator as the measure for expected inflation in Equation (6).

Figure 2 plots actual and expected quarterly inflation rates and shows that actual and expected inflation rates move closely together over the sample period. At each date the figure shows actual quarterly inflation and the forecast made for the date in the previous quarter. Comparing actual with subjective expectation

FIGURE 1
Unit Labor Costs and Output



Note: Solid line: unit labor costs; Dashed line: detrended output gap.

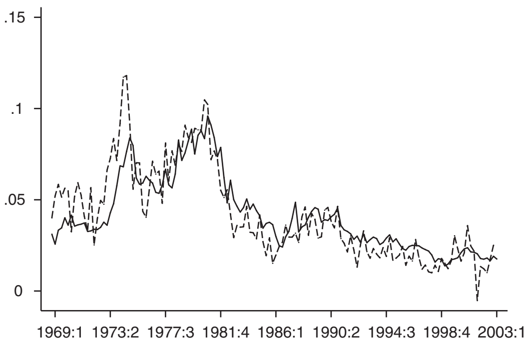
4. GNP deflator prior to 1992 since subjective forecasts related to GNP data before this date.

5. Proxing real activity with the output in the nonfarm business sector or in the nonfarm business sector less housing leads to similar results as reported in this paper.

6. We follow these authors and use data for the nonfarm private business sector only. We also tried the ratio of the compensation to employees to the national income minus the proprietor's income, which leads to similar results.

7. At the 5% level we reject that the series of real GDP exhibit a quadratic trend.

FIGURE 2
Expected and Actual Inflation



Note: Solid line: expected inflation; Dashed line: actual inflation.

data provides the basis to evaluate the inflation forecasts, an exercise to which we turn in the next section.

A. *Are Inflation Forecasts Biased or Inefficient?*

To assess whether inflation forecasts are biased or inefficient, we perform a standard test. This test requires to regress actual inflation rates on a constant and on expected inflation rates and to check if the constant is equal to zero and the coefficient pertaining to the expectations term equal to one. For our survey data this delivers:[8]

$$\Pi_t = \underset{(0.001)}{-0.001} + \underset{(0.077)}{1.081}\,\overline{F}_{t-1}[\Pi_t] \tag{8}$$

and shows that based on this test one cannot reject rationality of survey expectations. This result is similar to that found by Croushore (2006) using real time data.

A closer look at Figure 2, however, suggests that expected inflation is lagging actual inflation slightly. Indeed, it is not difficult to find evidence that the survey expectations are inefficient. In particular, the constant appearing in Equation (8) is not equal to zero in various sub-periods. This is shown in Table 1, which presents results from regressing forecast errors on a constant and dummy variables for the 1970s and 1980s, where the latter intend to capture different policy regimes.

The estimates in Table 1 show that inflation expectations have been significantly below actual inflation rates during the 1970s and considerably above the actual rates during the 1980s and 1990s. This seems hardly surprising given that inflation rates were generally rising during the 1970s, but falling thereafter and indicates that forecasts are far from being efficient.[9]

Table 2 presents further evidence on the time series structure of forecast errors. Column two of the table shows that forecast errors display significant positive autocorrelation. Correlation moderately decreases when accounting for different policy regimes via time dummies in the third column.

To the extent that survey expectations correctly capture inflation expectations the previous evidence shows that these expectations are inefficient and, thus, can be biased during sub-periods. However, as made clear by Croushore (2006), any conclusion on the quality

TABLE 1
Biasedness of Expectations

Constant	0.004
	(0.001)**
Dummy (1968:4–1979:4)	−0.014
	(0.003)**
Dummy (1980:1–1989:4)	0.001
	(0.002)
Observations	138
R-squared	0.32

Note: The dependent variable is the inflation forecast error. Asymptotic Newey-West 12 lags standard errors are reported in parentheses.
**Significant at the 1% level.

TABLE 2
The Structure of Forecast Errors

Constant	−0.001	0.004
	(0.002)	(0.001)**
ρ_1	0.462	0.207
	(0.087)**	(0.104)*
Dummy (1968:4–1979:4)		−0.014
		(0.003)**
Dummy (1980:1–1989:4)		0.001
		(0.002)
Observations	138	138

Note: The dependent variable is the inflation forecast error. The second column fits an AR(1) and reports the AR-coefficient; the third column adds two time dummies. Asymptotic standard errors are reported in parentheses.
*Significant at the 5% level; **Significant at the 1% level.

8. The values in parentheses are asymptotic Newey-West 12 lags standard errors. The lag structure follows Galí and Gertler (1999).

9. See also Croushore (1996).

TABLE 3
Orthogonality Tests

	F-statistics				
	Unit Labor Costs	**Output Gap**	**Inflation**	**CPI Inflation**	**All**
Lags 1–4	6.98	5.26	5.73	5.25 (0.0006)	3.33
	(0.0001)	(0.0006)	(0.0003)	(0.0006)	(0.0001)
Observations	134	134	134	134	134
R-squared	0.1523	0.1135	0.1246	0.1134	0.2190
Lags 2–4	3.99	6.50	4.68	5.01	3.54
	(0.0093)	(0.0004)	(0.0039)	(0.0025)	(0.0002)
Observations	134	134	134	134	134
R-squared	0.0632	0.1305	0.0975	0.1037	0.1863

Note: The inflation forecast error is regressed on lags 1–4 (top panel) and 2–4 (bottom panel) of output, inflation, unit labor costs, CPI inflation, and on all of these variables in the row named "All." The table reports F-statistics for the hypothesis that the coefficients on all included regressors are jointly equal to zero with p-values in parentheses.

of expectation data should take into account that forecasts are likely to be based on real time data, while inflation is measured on GDP revised data. Therefore, we also measure inflation using real time data. In particular, each quarter inflation is measured using the closest vintage GDP deflator. This implies, for instance, that the nominal and real GDP for 1977 first quarter are measured using the 1976 fourth quarter vintage data. We therefore compare the inflation expectations with real time data. While the results, reported in the Appendix, are quantitatively different, they disclose the same general picture: the mean of expectation errors is different from zero and forecast errors are auto-correlated. The possibility that inflation expectations are biased suggests investigating whether forecast errors are orthogonal to information available to agents at the time of the forecast. This is what we turn to next. This is important because instrumental variable techniques, which are commonly employed to estimate the NKPC under rational expectations, assume orthogonality of forecast errors with respect to lagged information.

To check whether commonly used instruments are correlated with the forecast errors implied by the survey data, we thus regressed these errors on a constant and lags of output, inflation, unit labor costs, commodity price inflation, and all variables together. The upper panel of Table 3 reports F-statistics testing the null hypothesis that the coefficients on lags 1–4 of these regressors are jointly equal to zero. The hypothesis is strongly rejected in all cases. The results are similar in the lower panel of Table 3 where we regress forecast errors on lags 2–4 only: the assumption that agents do not know the first lag of the considered variables does not seem to be responsible for the rejection of the orthogonality conditions.[10]

If survey data correctly capture agents' inflation expectations, these preliminary findings cast doubts on the validity of Phillips curve estimates that have been derived under the assumption of rational expectations.

IV. ESTIMATION RESULTS

This section presents the results from estimating Equation (6) with the data described above.

If theory was correct and all variables were measured without error, then Equation (6) would perfectly fit the data. Obviously, this is highly implausible for a number of reasons. The time-dependent pricing setting rules underlying Equation (6) are at best an approximation to firms' actual price setting behavior. Moreover, the variables entering Equation (6) are not precisely measured by our data; this might hold for the GDP deflator as well as for the two measures of real marginal cost.

We proceed by assuming that deviations from Equation (6) are due to measurement error. Consequently, we estimate

$$\Pi_t = \beta \overline{F}_t \left[\Pi_{t+1}\right] + \lambda rmc_t + \varepsilon_t \quad (9)$$

where ε_t captures measurement errors and where

$$\lambda = (1-\theta)(1-\beta\theta)/\theta.$$

10. We also check if the commonly used instruments are correlated with the forecast errors computed using real time data. The results are reported in the Appendix and show a lower, but nonnegligible, correlation of forecast error with the instruments.

TABLE 4
The New Keynesian Phillips Curve

	Unit Labor Costs	Output Gap
β	1.002	1.031
	(0.039)**	(0.048)**
λ	0.059	0.026
	(0.019)**	(0.013)*
θ	0.783	0.839
	(0.039)**	(0.042)**
Observations	138	138

Note: The dependent variable is actual inflation. In the second column it is regressed on expected inflation and unit labor costs, in the third column on expected inflation and output gap. The coefficients β and λ denote the discount factor and the coefficient attached to marginal costs. The value of the stickiness parameter θ is calculated using the point estimates of β and λ. Asymptotic Newey-West 12 lags standard errors are reported in parentheses.

*Significant at the 5% level; **Significant at the 1% level.

Measurement errors might affect the left-hand and right-hand side of Equation (9). Errors affecting the left-hand side are of little concern since OLS estimators can deal with them. Measurement errors on the right-hand side, however, would require the use of instrumental variable (IV) estimators. Right-hand side errors could arise because we replaced the mean expected inflation by the sample average across forecasters or because of our approximate real marginal cost measures. We then used the Hausman test to compare IV and OLS estimates. The test does not reject the consistency of OLS and therefore we will report the OLS estimates of Equation (9).[11]

Table 4 shows the estimates of Equation (9) when using the unit labor costs (column 2) and the output gap (column 3), respectively, as a measure for marginal costs.[12] Independently from the specification of marginal costs, all coefficients have the correct sign and are significant at least at the 5% level. The discount rate is close to one, as theory would predict, and the estimate of λ is positive.

The value for the degree of price stickiness θ implied by the point estimates for β and λ is also reported in the table. The estimates suggest that firms adjust prices roughly once every five quarters on average. This seems largely consistent with survey data on price stickiness, see Blinder et al. (1998).

The results for the unit labor costs are in line with estimates obtained by Galí and Gertler (1999), who assumed inflation expectations to be rational. The only difference is that the point estimate of the discount factor is much closer to one in our case. The relative robustness of the findings of Galí and Gertler (1999) is rather surprising since, as shown in Table 3, the forecast errors implied by survey expectations are not orthogonal to lagged unit labor costs, which is an identification assumption made by these authors. This seems to suggest that the distortion caused by such an identification assumption is not strong enough to seriously affect the parameter estimates. We will come back to this point below.[13]

Even more surprising are the results reported for the output gap in Table 4. It has been rather difficult to obtain parameter estimates with the correct sign and of a plausible magnitude when using output as a measure for marginal costs. Fuhrer and Moore (1995) and Galí and Gertler (1999), for example, find a negative and insignificant estimate of λ when real marginal costs are approximated by detrended output. Table 4, however, shows that with the help of survey expectations one can establish a plausible link between output and inflation dynamics via the NKPC. This suggests that the assumption of rational expectations is not innocuous in this case.

The previous findings show that taking account of nonrationalities in expectations seems to be important when using the output gap as a measure of marginal costs but less so when using unit labor costs. Below, we discuss why the use of subjective expectations does make a difference when the output gap is used as a measure for real marginal costs.

The standard practice to estimate the NKPC is to replace the expected inflation rate with the next period's actual inflation rate. Therefore, to contrast our results with the available evidence, one should investigate how our marginal cost measures correlate with the next period's actual inflation rate and the subjective expectation

11. The CSEF Working Paper no. 78 provides more details on how the test is carried out.

12. Since Bartlett tests reject the null hypothesis that the residuals follow a white noise we use the Newey-West correction with 12 lags to compute the standard errors for the regression.

13. The issue with Galí and Gertler (1999) is that expected inflation is not observed and therefore is proxied with actual inflation. This implies that the forecast error falls in the error term of their regression. The same issue does not apply here because expected inflation is made observable by the forecasts from the Survey of Professional Forecasters. For the same argument in a different context see Pistaferri (2001) and Padula (2004).

of inflation rate. If the correlation between the marginal cost and the next period's actual inflation rate is similar to that between the marginal cost and the subjective expectation of inflation rate, we cannot expect our results to depart from the available evidence.

To understand how the coefficient on the marginal cost measure in Equation (9) depends on the proxy for expected inflation, notice that λ can be written as:

$$\lambda = 1/A(corr(\Pi_t, rmc_t) - corr(\overline{F}_t[\Pi_{t+1}], rmc_t) \cdot B) \quad (10)$$

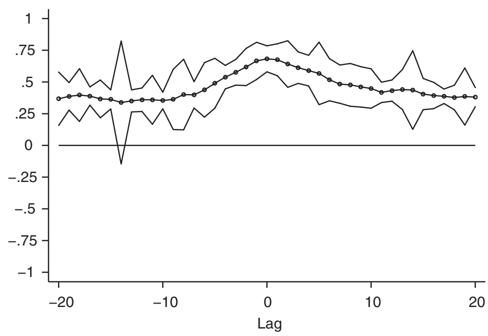
where A is the determinant of a positive definite matrix and therefore always positive, $corr(\cdot, \cdot)$ denotes the correlation coefficient between two variables, and $B = corr(\overline{F}_t\left[\Pi_{t+1}\right], \Pi_t)$ is approximately equal to .88 and independent from whether subjective expectations or actual future inflation rates are used as a proxy for expected inflation. This means that the sign of λ depends mainly on the difference between $corr(\Pi_t, rmc_t)$ and $corr(\overline{F}_t\left[\Pi_{t+1}\right], rmc_t)$. The correlation between inflation and marginal costs is not affected by the chosen proxy for expected inflation and is equal to .68 for the unit labor costs and to .09 for the output gap, as shown in Figures 3 and 4 for unit labor costs and output gap respectively, which report the correlations at various leads and lags together with the 95% confidence intervals.[14] Therefore, whether our results differ from the available evidence depends on how the correlation between expected inflation and marginal costs changes with the proxy used for expected inflation.

For the case of unit labor costs, the correlation between next period's actual inflation and marginal costs is of about the same size as the correlation between the subjective expectation of inflation rate and marginal costs (.67 against .61). This suggests that inflation forecasts incorporate a large part of the information contained in current unit labor costs and therefore our results do not differ from the available evidence.[15] The λ-coefficient turns out to be positive, whatever proxy for expected inflation is used, because $corr(\overline{F}_t\left[\Pi_{t+1}\right], rmc_t)$ is smaller than $corr(\Pi_t, rmc_t)$.

The situation is quite different for the case of the output gap. There, the correlation between next period's actual inflation and current output is .17, a much higher number than the correlation between the subjective expectation of the inflation rate and output, which is equal to .003. Thus, identifying restrictions that impose orthogonality of forecast errors with respect to current output impute too much information to expectations.

FIGURE 3

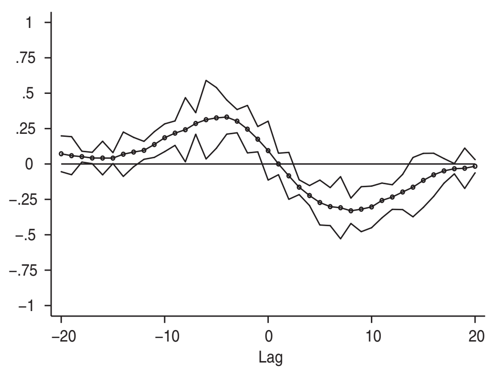
Correlation between Actual Inflation(t) and Unit Labor Costs($t + k$)



Note: The figure shows the correlation between actual inflation at time t and unit labor costs at time $t + k$ with k varying between −20 and 20 and bootstrapped 95% confidence bands.

FIGURE 4

Correlation between Actual Inflation(t) and Output Gap($t + k$)



Note: The figure shows the correlation between actual inflation at time t and output gap at time $t + k$ with k varying between −20 and 20 and bootstrapped 95% confidence bands.

14. Confidence intervals have been computed using bootstrapped standard errors.

15. The fact that $corr(\Pi_{t+1}, rmc_t) \approx corr(\overline{F}_t[\Pi_{t+1}], rmc_t)$ implies that in a regression of the forecast error $(\Pi_{t+1} - \overline{F}_t[\Pi_{t+1}])$ on a constant and marginal costs rmc_t the coefficient in front of rmc_t is (approximately) equal to zero. Thus, rmc_t cannot explain the forecast errors. Obviously, this does not imply that forecasts contain the information in lagged values of rmc_t. Table 3 shows that this is not the case.

Therefore, if one proxies expected inflation with next period's actual inflation, $corr(\overline{F}_t[\Pi_{t+1}], rmc_t)$ is larger than $corr(\Pi_t, rmc_t)$ (.17 against .09), and the λ-coefficient is negative. If instead subjective expectations are used to proxy expected inflation, $corr(\overline{F}_t[\Pi_{t+1}], rmc_t)$ is smaller than $corr(\Pi_t, rmc_t)n$ (.003 against .09), which explains why the estimated λ is positive.

Obviously, one might ask whether these results emerge simply because survey expectations proxy for lagged inflation. To assess whether this is the case, we estimate Equation (9) replacing expected with lagged inflation. Results are reported in columns 2 and 3 of Table 5. While the estimated β for both measures of marginal cost are similar to those shown in Table 4, the estimated λ differ, depending on the marginal cost measure used. The reason for the difference can be understood by inspecting how marginal cost correlates with lagged inflation and with the subjective expectation of inflation. Namely, the correlation between output and lagged inflation is not statistically different from that between output and the subjective expectation of inflation. In contrast, the correlation between unit labor costs and lagged inflation is statistically different from that between unit labor costs and the subjective expectation of inflation.[16]

Our evidence shows that the NKPC can link inflation dynamics to both output gap and unit labor cost dynamics once survey data are used to proxy for inflation expectations. At the same time, survey data suggest that the identification of expectations assuming orthogonality with respect to output is responsible for the unsatisfactory performance of the NKPC when using output as a measure for marginal costs.[17]

16. This is easily checked by regressing the difference between lagged inflation and the subjective expectation of inflation on the measure of marginal cost and testing the null that the coefficient associated to the measure of marginal cost is equal to zero. For detrended output, we cannot reject the null (the t-statistics is 0.11), for unit labor costs we reject the null at the standard significance level (the t-statistics is -5.50).

17. In the CSEF Working Paper no. 78, we provide several robustness checks. In particular, we test and do not reject that OLS estimates are consistent, which provides the basis for using the OLS estimator throughout the paper. Second, we test for sub-sample stability and show that despite some important difference across the different time periods, all estimates still have the correct sign. Third, we add lagged values of expected inflation, and marginal costs to Equation (9) and find that the results are unchanged.

TABLE 5
Lagged Inflation

	Unit Labor Costs	**Output Gap**
β	0.961	0.967
	(0.016)**	(0.011)**
λ	0.010	0.026
	(0.011)	(0.008)**
Observations	137	137

Note: The dependent variable is actual inflation. In the second column it is regressed on lagged inflation and unit labor costs, in the third column on lagged inflation and output gap. The coefficients β and λ denote the discount factor and the coefficient attached to marginal costs. Asymptotic Newey-West 12 lags standard errors are reported in parentheses.

**Significant at the 1% level.

V. EXTENSION: THE INDEXATION MODEL

In this section, we consider the model of Christiano, Eichenbaum, and Evans (2005), which attributes a role to lagged inflation because firms that do not re-optimize their prices are assumed to index their prices using lagged inflation rates.

The analog to Equation (9) for this model is given by

(11)
$$\Pi_t = \gamma_1 \Pi_{t-1} + \gamma_2 \overline{F}_t [\Pi_{t+1}] + \gamma_3 rmc_t + \varepsilon_t$$

where $\gamma_1 = 1/1 + \beta$, $\gamma_2 = \beta/1 + \beta$, $\gamma_3 = (1 - \beta\theta)(1 - \theta)/(1 + \beta)\theta$, and Π_{t-1} is the lagged inflation rate. For $\beta = 1$ the model is very similar to the relative contracting model of Fuhrer and Moore (1995), the only difference being that it does not contain a moving average of real marginal costs.

The results from estimating Equation (11) by OLS are reported in Table 6.[18] The second and fifth columns show the unrestricted estimates using unit labor costs and output, respectively, as measures for marginal costs. All coefficients have the predicted sign and are significant.

The structural parameters β and θ can be retrieved using $\beta = \gamma_2/\gamma_1$ together with the definition of γ_3 and are reported in the lower panel of Table 6. The standard errors indicate that both parameters are estimated rather imprecisely.

18. We also used IV estimation with two lags of expected inflation, and four lags of marginal costs as instruments. The results are very similar to the ones reported in Table 6.

TABLE 6
The Indexation Model

	Unit Labor Costs Unrestricted	$\gamma_1 = \gamma_2$	$\gamma_1 = \gamma_2 = 0.5$	Output Unrestricted	$\gamma_1 = \gamma_2$	$\gamma_1 = \gamma_2 = 0.5$
γ_1	0.365	0.470		0.463	0.521	
	(0.078)**	(0.018)**		(0.072)**	(0.020)**	
γ_2	0.595			0.595		
	(0.085)**			(0.076)**		
γ_3	0.044	0.041	0.030	0.025	0.025	0.025
	(0.019)*	(0.018)*	(0.010)**	(0.008)**	(0.008)**	(0.010)*
Constant	0.000	0.001	0.000	−0.001	0.000	0.000
	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)
Observations	137	137	137	137	137	137
		$\gamma_1 = \gamma_2$	$\gamma_1 = 0.5$		$\gamma_1 = \gamma_2$	$\gamma_1 = 0.5$
		2.10	2.85		0.87	1.12
F-tests		(0.15)	(0.093)		(0.352)	(0.293)
β	1.628			1.285		
	(0.564)**			(0.347)**		
θ	0.531	0.752	0.782	0.686	0.799	0.799
	(0.160)**	(0.0162)**	(0.009)**	(0.141)**	(0.007)**	(0.009)**

Note: The dependent variable is actual inflation, which is regressed on lagged inflation (γ_1), expected inflation (γ_2), and real marginal costs (γ_3), where the latter are given by unit labor costs (detrended output) in columns 2–4 (5–7). Columns 2 and 5 report unrestricted estimates; columns 3 and 6 constrain γ_1 and γ_2 to be equal; columns 4 and 7 restrict γ_1 and γ_2 to be equal to 0.5. Successive F-tests for these restrictions with p-values in parentheses are reported in the respective columns. The values of β and θ reported are the ones implied by the point estimates of γ_1, γ_2, and γ_3. Asymptotic Newey-West 12 lags standard errors are reported in parentheses.

*Significant at the 5% level; **Significant at the 1% level.

For a discount factor close to one, Model (11) implies $\gamma_1 = \gamma_2$. Columns 3 and 6 of Table 6 report the results of estimating Equation (11) when imposing this restriction. For both specifications F-tests do not reject the equality of γ_1 and γ_2. This contrasts to the results reported by Galí and Gertler (1999), who estimated Equation (11) under the assumption of rational expectations.[19] For all specifications reported in Table 2 of their paper, equality of the two coefficients would be rejected. This suggests that the indexation model performs better when survey expectations are used as a proxy for agents' inflation expectations.

The more stringent restriction $\gamma_1 = \gamma_2 = 1/2$ is also not rejected, as shown in columns 4 and 7 of Table 6.

Overall, the estimated coefficients of Equation (11) have the correct sign and are statistically significant independently from the measure of marginal costs used. Moreover, the restrictions implied by theory cannot be rejected.

VI. CONCLUSIONS

In this paper, we studied the ability of the New Keynesian Phillips Curve to explain the U.S. inflation experience once the assumption of rational inflation expectations is relaxed.

The approach of the paper can be extended in various directions. Paloviita (2005) and Gorter (2005) investigate the empirical performance of the NKPC in several European countries under nonrational expectations; structural breaks in the inflation are studied by Chengsi et al. (2008) (see also the Working Paper version of this paper), while Milani (2009) explores the role of adaptive learning as a potential source of inflation persistence.[20]

The data gave considerable support for the parameter restrictions implied by the standard forward-looking New Keynesian Phillips Curve. In particular, the discount factor was found to be close to one, inflation was positively

19. These authors gave a different economic interpretation to Equation (11): lagged inflation was supposed to enter because of the presence of backward-looking agents.

20. Using the IFO World Economic Survey, Henzel and Wollmershäuser (2006) provide evidence on selected euro zone countries, the United States and the United Kingdom. They find that in comparison with the rational expectations approach, backward-looking behavior turns out to be more relevant.

affected by real marginal costs, and the degree of price stickiness implied by the estimates suggested that about one-fifth of firms reset price every quarter. These results were found to be independent from whether unit labor cost or detrended output were used as a measure for real marginal costs.

Despite the generally supportive evidence, we showed that lagged inflation seems to be a significant determinant of inflation dynamics, even when taking care of potential nonrationalities in inflation expectations through the use of survey expectations. The standard New Keynesian Phillips Curve cannot account for this finding.

When estimating the indexation model suggested by Christiano, Eichenbaum, and Evans (2005), which introduces an explicit role for lagged inflation, we find that our data supports the implied parameter restrictions.

Although uncertainty remains about the role of lagged inflation, the results presented in this paper seem to suggest that the New Keynesian Phillips Curve offers an empirically plausible explanation of inflation dynamics as a function of output dynamics or unit labor costs once inflation expectations are approximated with survey data.

APPENDIX

Subjective Expectations and the NKPC

Here we show how one can derive the NKPC, Equation (6), with subjective expectations. Subtracting Equation (1) from the same equation shifted one period forward delivers

$$\text{(A1)} \qquad \Pi_{t+1} = (1-\theta)\Pi^*_{t+1} + \theta\Pi_t$$

where

$$\Pi^*_{t+1} = 1/I \sum_i \Pi^{*,i}_{t+1} = 1/I \sum_i (p^{*,i}_{t+1} - p^{*,i}_t).$$

Applying the operator $\overline{F}_t$ (as defined in Equation [7]) to Equation (A1) gives

$$\text{(A2)} \qquad \overline{F}_t\left[\Pi_{t+1}\right] = (1-\theta)\overline{F}_t\left[\Pi^*_{t+1}\right] + \theta\Pi_t.$$

Next, we express the average expectation $\overline{F}_t\left[\Pi^*_{t+1}\right]$ in terms of expectations of observable variables. Consider the expectation of a single firm

$$\begin{aligned} F^i_t\left[\Pi^*_{t+1}\right] &= [1/I]F^i_t\left[\sum_{h=1}^{I} p^{*,h}_{t+1} - p^{*,h}_t\right] \\ &= [(1-\beta\theta)/I]F^i_t\left[\sum_{h=1}^{I}\left(F^h_{t+1}\left[\sum_{s=0}^{\infty}(\beta\theta)^s mc_{t+1+s}\right]\right.\right. \\ &\quad \left.\left. - F^h_t\left[\sum_{s=0}^{\infty}(\beta\theta)^s mc_{t+s}\right]\right)\right] \end{aligned}$$

where we used the first-order condition (3) to obtain the second line. From this result,

$$\begin{aligned} F^i_t\left[\Pi^*_{t+1}\right] &= [(1-\beta\theta)/I]F^i_t \\ &\left[\sum_{h=1}^{I} F^h_{t+1}\left[(1-\beta\theta)\left(\sum_{s=0}^{\infty}(\beta\theta)^s mc_{t+1+s}\right)\right] - mc_t\right] \\ &= (1-\beta\theta)\left(F^i_t\left[1/I\sum_{h=1}^{I} p^{*,h}_{t+1}\right] - mc_t\right) \\ &= (1-\beta\theta)\left(F^i_t\left[(p_{t+1}-\theta p_t)/(1-\theta)\right] - mc_t\right) \\ &= (1-\beta\theta)\left([1/(1-\theta)]\, F^i_t\left[\Pi_{t+1}\right] - rmc_t\right) \end{aligned}$$

where we use condition (1) to obtain the first, the first-order condition to obtain the second, $p_{t+1} = (1-\theta)[1I]\sum_{h=1}^{I} p^{*,h}_{t+1} + \theta p_t$ to obtain the third, and $mc_t = rmc_t + p_t$ to obtain the last line. Using this result one obtains an expression for the average expectations

$$\text{(A3)} \qquad \overline{F}_t\left[\Pi^*_{t+1}\right] = (1-\beta\theta) \times \left([1/1-\theta][1/I]\sum_{i=1}^{I} F^i_t\left[\Pi_{t+1}\right] - rmc_t\right).$$

Substituting Equation (A3) into Equation (A2) delivers Equation (6).

Real Time Data

Here we provide the results for testing the unbiasedness and efficiency of survey expectations using real time data. As pointed out by Croushore (2006), the evaluation on the quality of survey expectations data depends on whether one uses real time or revised data. The argument is that professional forecasters plausibly base their forecast on real time data, and cannot fully anticipate the GDP revisions. Therefore, to put expected and actual inflation on the same grounds, we compute forecast errors using real time data. Each quarter inflation is measured using the closest vintage GDP deflator. This implies, for instance, that the nominal and real GDP for 1977 first quarter are measured using the 1976 fourth quarter vintage data.

Using the real time forecast errors, we check for whether expectations are unbiased and efficient. In Table A1, we regress forecast error on a constant and dummies for the 1970s and 1980s. The results are different from those presented in Table 1 in the main text, but tell a similar story: the forecast error are on average different from zero. As for the structure of forecast errors, Table A2 confirms that the forecast error can be described by a AR(1) process.

We also check whether the instruments commonly used in the estimation of the NKPC pass the orthogonality test. The results are reported in Table A3. Interestingly, even if the orthogonality conditions are rejected, the extent of the correlation between forecast errors and instruments is lower than when using revised inflation data.

The Data Sources

Below we describe the data sources and the data definitions used in the paper.

Expected inflation is constructed using the quarterly mean forecast of the implicit GDP price deflator (GNP price deflator prior to 1992) from the Survey of Professional Forecasters and the actual value of the current implicit GDP deflator (GNP deflator prior to 1992), 1968:4–2003:1. The

TABLE A1

Biasedness of Expectations, Real Time Data

Constant	−0.029
	(0.006)**
Dummy (1968:4–1979:4)	−0.010
	(0.008)
Dummy (1980:1–1989:4)	0.005
	(0.008)
Observations	138
R-squared	0.022

Note: The dependent variable is the inflation forecast error. Asymptotic Newey-West 12 lags standard errors are reported in parentheses.

**Significant at the 1% level.

TABLE A2

The Structure of Forecast Errors, Real Time Data

Constant	−0.031	−0.029
	(0.004)**	(0.006)**
ρ_1	0.286	0.271
	(0.080)**	(0.084)**
Dummy (1968:4–1979:4)		−0.009
		(0.01)
Dummy (1980:1–1989:4)		0.005
		(0.01)
Observations	138	138

Note: The dependent variable is the inflation forecast error. The second column fits an AR(1) and reports the AR-coefficient; the third column adds two time dummies. Asymptotic standard errors are reported in parentheses.

**Significant at the 1% level.

inflation rate is obtained form the price level data. Borrowing the notation from the Survey of Professional Forecasters documentation manual, the next quarter expected inflation rate is computed as:

$$\frac{\hat{X}_{t+1|t-1}}{\hat{X}_{t|t-1}} - 1$$

where $\hat{X}_{t+1|t-1}$ and $\hat{X}_{t|t-1}$ are, respectively, the expected price deflator for quarter $t+1$ and for quarter t.[21] The data and the documentation manual can be downloaded from the Federal Reserve Bank of Philadelphia web site at http://www.phil.frb.org/.

Actual inflation is constructed using the quarterly nominal and real GDP from the April 2003 release of the NIPA Tables 1.7 and 1.8, 1968:4–2003:1, which can be downloaded at http://www.bea.gov/bea/dn/nipaweb/SelectTable.asp?Selected=N.

Unit labor costs used in the main text are constructed using the Bureau of Labor Statistics Unit Labor Costs series PRS85006113, 1968:4–2003:1, deflated by the Bureau Labor Statistics Implicit Price Deflator series PRS85006143. Both series refers to the nonfarm business sector and can be downloaded at http://data.bls.gov/, under the heading Major Sector Productivity and Costs Index. To construct the measure of unit labor costs used in the regression we take the log deviations from the mean. We also experimented with the ratio of compensation of employees to national income minus proprietor's income. The compensation of employees, the national income, and the proprietor's income series, 1968:4–2003:1, are taken from the April 2003 release of the NIPA Table 1.15. The table is accessible at http://www.bea.gov/bea/dn/nipaweb/SelectTable.asp?Selected=N.

Output gap in the main text is constructed using real GDP from the April 2003 release of NIPA Table 1.8, 1968:4–2003:1, which can be downloaded at http://www.bea.gov/bea/dn/nipaweb/SelectTable.asp?Selected=N. To construct the measure of output gap used in the regression, we take the log and linearly detrend. We also experimented using the quarterly series of the real GDP in nonfarm business sector and in nonfarm business sector less housing as proxy for real activity, which are available from the same NIPA table.

Consumer Price Index is the CPI for All Urban Consumer, as issued by the Bureau of Labor Statistics, series CUSR0000SA0. This monthly series is available at the Bureau of Labor Statistics (ftp://ftp.bls.gov/pub/time.series/

21. The notation reflects the fact that the survey is conducted in quarter t, but the forecasters base their projections on $t-1$ data, see pages 12–13 of the Survey of Professional Forecasters documentation manual.

TABLE A3

Orthogonality Tests, Real Time Data

	***F*-statistics**				
	Unit Labor Costs	**Output Gap**	**Inflation**	**CPI Inflation**	**All**
Lags 1–4	2.07	6.4	2.31	3.01	3.52
	0.088	0.001	0.065	0.020	0.000
Observations	134	134	134	134	134
R-squared	0.061	0.167	0.068	0.0865	0.3286
Lags 2–4	2.79	4.48	1.30	3.46	2.41
	0.043	0.005	0.276	0.018	0.008
Observations	134	134	134	134	134
R-squared	0.06	0.095	0.029	0.075	0.196

Note: The inflation forecast error is regressed on lags 1–4 (top panel) and 2–4 (bottom panel) of output, inflation, unit labor costs, CPI inflation, and on all of these variables in the column named "All." The table reports F-statistics for the hypothesis that the coefficients on all included regressors are jointly equal to zero with p-values in parentheses.

cu/). Quarterly data are obtained by averaging the monthly inflation rates of the considered quarter.

Real time data set was also used for Macroeconomist (http://www.philadelphiafed.org/research-and-data/real-time-center/real-time-data/) to measure the GDP deflator (GNP deflator prior to 1992) on unrevised series for nominal and real GDP (GNP prior to 1992).

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