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Abstract

Empirical estimations of the micro-founded New Keynesian Phillips Curve (NKPC) using rational inflation expectation proxies have often found that the output gap is an invalid measure of inflation pressure. This paper investigates the empirical success of the NKPC in explaining US inflation when observed measures of inflation expectations are used in conjunction with the output gap. The paper also contributes to the literature by addressing the important problem of serial correlation in the stylized NKPC and developing an extended model to account for this serial correlation. Contrary to recent results indicating no role for the output gap, we find it to be a statistically significant driving variable for inflation, with this finding robust to whether the inflation expectations series used relates to individual consumers, professional forecasters or the US Fed. In most of our estimations, however, lagged inflation dominates the role of inflation expectations, casting doubt on the extent to which price setting is forward-looking over the period 1968 to 2005. From an econometric perspective, the paper uses GMM estimation to account for endogeneity while also addressing concerns raised in recent studies about weak instrumental variables used in estimating NKPC models.

Key words: New Keynesian Phillips Curve, serial correlation, GMM, inflation forecasts

JEL Classification: E31, E58

1 Introduction

Based on the seminal work of Taylor (1980), Rotemberg (1982) and Calvo (1983), theoretical implications of short-run inflation dynamics for monetary policy analysis are now frequently studied through the so-called (hybrid) New Keynesian Phillips Curve (NKPC), which expresses current inflation as a function of expected future inflation, lagged inflation, and a measure of marginal cost. To date, the literature has achieved a broad consensus that implications of the NKPC for the conduct of monetary policy differ substantially from the traditional Phillips curve relationship; see Goodfriend and King (1997), Rotemberg and Woodford (1997), Nelson (1998), Ball (1999), Gali and Gertler (1999), McCallum (1999), Svensson (1999), Rudebusch (2002), and a comprehensive survey by Woodford (2003).

Nevertheless, the empirical validity of the NKPC has been mixed when the model is confronted with realized data.[1] In particular, Gali and Gertler (1999) argue that the empirical success of the NKPC is contingent on the labor income share, rather than the more common output gap, being utilized in the regression. Despite similar arguments in Gali, Gertler and Lopez-Salido (2001, 2005), GDP gap measures remain prevalent in both theoretical and empirical monetary policy analysis frameworks.[2] Further, the finding in Gali and Gertler (1999) is challenged by some recent research (discussed in the next section), so that little consensus has been achieved.

Any empirical estimation of the NKPC requires a view to be taken about the nature of expected future inflation. Many authors, including Gali and Gertler (1999), employ realized future inflation data to proxy inflation expectations, using generalized methods of moments (GMM) methods to account for the resulting endogeneity. While attractive in allowing a single framework to be used for the analysis, this practice is contentious because it assumes rationality (Adams and Padula, 2003), may be subject to problems of weak instruments (Mavroeidis, 2004), can conflate the roles of future and lagged values when the latter act as instruments (Rudd and Whelan, 2007) and induces a measurement error whose volatility may distort inference (Sun and Phillips, 2004; Zhang, Osborn and Kim, 2007).

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[1] See the 2004 special issue of the *Oxford Bulletin of Economics and Statistics*, Vol. 66, no. 1, and the 2005 special issue of *Journal of Monetary Economics*, Vol. 52, no. 6.

[2] See, for example, Fuhrer and Moore (1995a, 1995b), Judd and Rudebusch (1998), Clarida *et al*. (1999, 2000), Boivin and Giannoni (2002), Rudebusch (2002), Estrella and Fuhrer (2003), and Ireland (2004), to name a few.

An alternative approach is to use observed inflation expectations data derived from surveys to measure inflation expectations, because these may more accurately mimic the responses of agents to economic information than do realized future inflation values (see Roberts, 1995). This view is supported by the recent studies of Orphanides (2001, 2003) that emphasize the importance of using real time forecasts as measures of inflation expectations when analyzing historical monetary policy. Further, Roberts (1998) shows that expectations based on observed survey data match more closely the empirical costs of reducing inflation in the transmission of monetary policy, while Ang, Bekaert and Wei (2007) find that surveys forecast US inflation more accurately than a range of macroeconomic and statistical models. These studies point to the conclusion that inflation expectations are complex phenomena that are not well captured using simple assumptions. Therefore, it is important to examine the robustness of NKPC estimates to the use of observed inflation expectations series. Nevertheless, different groups of agents have differing information sets, and hence there is no single inflation expectations series that is necessarily appropriate for use in the NKPC.

Another important, yet often overlooked, issue is possible serial correlation in the stylized NKPC (with a single backward lag and a one-period forward-looking term) that is often employed. The possible presence of serial correlation is crucial for the choice of valid instruments for GMM estimation, since all lags of the dependent variable are invalid instruments in the presence of autoregressive serial correlation. Since lags of inflation are typically employed as instruments for estimation of the NKPC, the consistency of these estimates depends on the lack of such serial correlation.

The contribution of this paper is to investigate the NKPC using a range of directly observed inflation forecast series as measures of inflation expectations, while also addressing serial correlation and its consequences. In common with most of the empirical literature on the NKPC, and also based on the persuasive arguments of Rudd and Whelan (2007), we measure marginal cost through the output gap rather than the labor income share as proposed by Gali and Gertler (1999). Our study considerably extends Adam and Padula (2003), who employ a single inflation forecast series (the one-quarter ahead forecasts from the Survey of Professional Forecasters) in the NKPC and use ordinary least squares (OLS) estimation, whereas we use a range of inflation forecasts in order to capture the views of different agents and use GMM estimation as we find OLS to be typically invalid. Our principal results, which are robust to the inflation expectation series used, are that output gap measures are significant indicators of inflation pressure in the NKPC when due account is taken of serial correlation. Further, inflation dynamics are more concerned with backward-looking behavior than forward-looking price-setting over 1968-2005.

The paper is organized as follows. Relevant literature is discussed in Section 2, with Section 3 describing the data used in the empirical analysis. Section 4 presents estimates for the stylized NKPC model, with the extension to richer inflation dynamics explored in Section 5. Section 6 discusses the implications of the empirical findings and concludes the paper.

2 Literature Review

Recent studies, including Gali and Gertler (1999) and Gali *et al*. (2001), as well as Woodford (2001), Sbordone (2002), Linde (2005), Rudd and Whelan (2005b), and many others, have provoked a fierce debate as to the empirical success of the NKPC in relation to its theoretical underpinnings. Based on the standard pricing contracts models of Taylor (1980), Rotemberg (1982), and Calvo (1983), the NKPC can be expressed as

$$\pi_t = c_0 + \alpha_f E_t \pi_{t+1} + \alpha_b \pi_{t-1} + \alpha_y y_t + \eta_t \,, \tag{1}$$

where π_t is the rate of inflation, $E_t \pi_{t+1}$ is expected inflation for period t+1 given information available up to period t, π_{t-1} denotes lagged inflation which captures empirically observed inflation persistence, and y_t is an appropriate measure of the marginal cost of firms in the economy. Note that, as levels rather than deviations from their respective steady states are employed in (1), a constant c_0 is included in this specification of the NKPC. Finally, η_t is a disturbance term that may be nonspherical.

Gali and Gertler (1999) argue that the labor income share, rather than the output gap, is the appropriate measure of marginal cost in (1). Further, their results suggest that forward-looking behavior is far more important than the backward-looking element. Nevertheless, their findings have been challenged from different perspectives. For instance, Rudd and Whelan (2005a) estimate a reduced form VAR model incorporating the NKPC and find that the labor share is not a valid inflation driving force. Using an output gap measure constructed in line with general equilibrium models, Neiss and Nelson (2005) also suggest that the output gap-based NKPC explains inflation dynamics better than the one advocated by Gali and Gertler (1999).

Although Linde (2005) obtains a positive and significant estimate of the coefficient of the GDP gap (computed as quadratically detrended log real GDP) using a Full Information Maximum Likelihood (FIML) approach, FIML estimation relies on a normality assumption and is sensitive to the specification of the structural equations in the system. Using a similar framework to Linde (i.e. the NKPC in conjunction with an IS equation and a monetary policy reaction function), Roberts (2005) has difficulty in finding a significant estimate on the GDP gap. This discrepancy is, perhaps, unsurprising given the uncertainty surrounding specification and estimation of the Euler equation and the monetary policy reaction function: see Rudebusch (2002), Fuhrer and Rudebusch (2004), Orphanides (2001, 2003, 2004), and Jondeau, Gallès and Bihan (2004).

Focusing on the statistical significance of the forward-looking and backward-looking components in the NKPC, Rudd and Whelan (2005b) find that, irrespective of the specific measure of marginal costs, forward-looking behavior plays a small role in U.S. inflation dynamics. They ascribe the small role for lagged inflation obtained by Gali and Gertler (1999) to omission of variables that may influence inflation which, in conjunction with the use of instrumental variables correlated with future inflation, leads to inconsistent parameter estimates with an upward bias on the expected inflation coefficient. It is worth noting that in estimating their alternative NKPC formulation, Rudd and Whelan (2005b) also employ a large number of instrumental variables (IV), which may induce the over-instrumenting problem elaborated in Mavroeidis (2004). Indeed, Rudd and Whelan (2005b) note that their estimations yield an unintuitive (negative) coefficient on the output gap. Nonetheless, the main point in Rudd and Whelan (2005b) is that forward-looking behavior is not supported by the U.S. data.

The role of different econometric estimation methodologies for the success of the NKPC has also been a focus of recent literature, including Mavroeidis (2005), Sbordone (2005), and Rudd and Whelan (2006, 2007).

Despite this interest in the estimation of the NKPC, the use of observed inflation forecasts as a measure of the inflation expectation $E_t\pi_{t+1}$ has been under-investigated. A common approach in the literature is to use realized inflation at $t+1$, together with the rational expectation assumption that implies $\pi_{t+1} = E_t\pi_{t+1} + \varepsilon_{t+1}$ with ε_{t+1} white noise, to represent $E_t\pi_{t+1}$. The rationality assumption facilitates the estimation in that an explicit measure of inflation expectations is not needed. However, π_{t+1} is more noisy than $E_t\pi_{t+1}$, which may render estimation of the NKPC problematic with finite samples even when the rationality assumption is correct.

Rather than adopt rational expectations, Adam and Padula (2003) employ quarterly GDP inflation forecasts from the Survey of Professional Forecasters (SPF) to estimate the NKPC by OLS, finding that both the output gap and labor income share are significant when used as measures for the inflation pressure variable. In a relatively early empirical version of the purely forward-looking NKPC, Roberts (1995) uses IV in conjunction with survey measures of inflation expectations and obtains plausible estimates on the GDP gap, while more recently Rudebusch (2002) obtains a significant output gap coefficient in a hybrid Phillips curve estimated with quarterly data and employing observed survey expectations. However, Gali and Gertler (1999) attribute the empirical success of the former to the annual and semi-annual data frequency employed and of the latter to the use of the "old" Phillips Curve, with the significant positive coefficient on the lagged (not contemporaneous) output gap.

To date, therefore, there is little consensus on whether the output gap (as commonly measured) plays a significant role in the NKPC. Table 1 revisits features of this controversy, by reporting estimates of the stylized NKPC model of (1) over 1968Q4-2005Q4, with inflation measured by both GDP inflation (denoted GDPIPD in the table) and non-farm business sector price inflation (denoted NFBIPD), and employing the common output gap measures, obtained using the Congressional Budget Office (CBO) potential output and the Hodrick-Prescott (HP) filter. The estimates of Panel A are based on the approach of Adam and Padula (2003), using OLS estimates and one-quarter ahead SPF inflation forecasts, while Panel B adopts the Gali and Gertler (1999) GMM approach, which employs actual future inflation to represent inflation expectations.

The coefficient results in Table 1 are generally supportive of the arguments of the respective authors in relation to the role of the output gap.[3] More specifically, in line with

[3] For all cases in Table 1, we also estimated models imposing the convexity restriction (see below), but this did not substantially affect the results and hence these are not reported. The instruments used for the lower panel are the same instruments as Gali and Gertler (1999).

Adam and Padula (2003), the output gap appears to be a significant driver of GDP inflation,[4] with both lagged and forecast inflation also significant. The Panel B results on the other hand, apparently confirm the arguments of Gali and Gertler (1999) that the output gap is not the appropriate real driving variable for inflation, being insignificant with a perverse (negative) sign. To shed further light on the validity of these estimates, Table 1 includes results (expressed as *p*-values) for tests of serial correlation, and these provide clear evidence for the presence of such effects. As lagged inflation values are included as instruments, serial correlation has potentially serious consequences for the GMM estimates in the lower panel. Serial correlation also raises issues about the results of Adam and Padula (2003), since although they report results with extended dynamics, their tests for the validity of OLS are undertaken in (1) under the assumption of no serial correlation.

This paper tackles the issues raised by Table 1 by studying the empirical validity of the NKPC for quarterly U.S. data when observed inflation forecasts are employed in conjunction with common measures of the output gap. In particular, we examine whether the output gap is a significant driver of inflation (as argued by Adams and Padula, 2003) or not (as in Gali and Gertler, 1999). In doing so, we use a range of inflation expectation series to verify the results in relation to agents with different information sets. Further, we explicitly address the issue of serial correlation in the stylized specification and related concerns of possible weak instruments, which lead to an extended specification of the NKPC with additional dynamics.

3 The Data

The data used in our baseline empirical analysis (including Table 1) spans 1968Q4-2005Q4, dictated by the availability of the median quarterly GDP inflation forecasts from the Survey of Professional Forecasters (SPF1Q). As discussed by Croushore (1993), these forecasts have proven to be valuable for monetary policy analysis and for measuring the response of expectations to changes in monetary policy. Further, since the forecasters surveyed are professionals, it can be anticipated that they will be well informed and their forecasts may influence decision-makers. However, they may not represent the

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[4] Using a one-tailed test at a 5 percent level of significance.

expectations of individual consumers.

The upper left panel of Figure 1 plots realized future inflation using the growth rate of GDP implicit price deflator (denoted GDPIPD(t+1)) and the corresponding SPF1Q forecasts, both expressed at an annual rate. As anticipated, the forecast is less noisy than actual inflation at t+1. Further, the figure indicates that inflation forecasts tend to lag actual inflation, pointing to possible collinearity between lagged and expected inflation that might be anticipated in (1) and consequent potential difficulty in distinguishing between forward- and backward-looking behavior. Nevertheless, the comparison also indicates that actual future inflation and its one-step-ahead forecast have distinctive patterns, with the forecast error (actual less forecast) being negative for a substantial period during the 1980s and 1990s.

Alongside models based on SPF1Q, we also evaluate the empirical performance of the NKPC using other inflation expectations data, namely the one-year-ahead GDP inflation forecasts from the SPF (SPF1Y), the Greenbook quarterly forecasts for GDP inflation (Greenbook), and one-year-ahead general price inflation forecasts from the Michigan survey (Michigan), available over 1970Q1-2005Q4, 1968Q3-1999Q4 and 1960Q1-2005Q2, respectively. Figure 1 also depicts these three inflation forecast series, together with actual (one-quarter ahead) future GDP inflation.

The Greenbook forecasts are projections of the Federal Reserve staff prepared within the Fed for the Federal Open Market Committee (FOMC) and, at the time of writing, are available only to 1999Q4. Because of the role of the Greenbook data in FOMC meetings, it is possible that information in the Greenbook may be reflected in the final FOMC member forecasts of future inflation and their decisions on monetary policy (Gavin and Mandal, 2003).[5] Also, because the NKPC is often used in macroeconometric models of monetary policy analysis (see Clarida *et al.*, 1999), it is useful to check whether the baseline estimates are robust to the use of Greenbook inflation forecasts. On the other hand, the Michigan survey aims to capture the views of the general public. Therefore, the observed inflation forecast series we employ represent different groups of agents with (presumably) different

[5] The Greenbook forecasts reflect the views of research staff at the Board of Governors of the Federal Reserve System, not necessarily those of the FOMC. However, FOMC members have an opportunity to revise their forecasts after FOMC monetary policy decisions are taken and consequently information in the Greenbook forecasts may be reflected in the FOMC member forecasts; see Gavin and Mandal (2003).

information sets.

To facilitate comparisons with the relevant literature, we consider inflation as measured by the growth rate of the GDP implicit price deflator (GDPIPD) and the implicit price deflator of non-farm business sector (NFBIPD), both of which are annualized and seasonally adjusted. Figure 2 plots these two measures of price inflation. It is evident that the general pattern of the two inflation series is similar: inflation is very high from the middle of the 1970s to the early 1980s, while being relatively low and steady during other periods. Nonetheless, NFBIPD appears more erratic and volatile.

To investigate the role of the output gap in the NKPC, we adopt the conventional measures of the GDP gap computed using real potential output estimates by the U.S. Congressional Budget Office (CBOGAP) and the conventional HP filtered GDP gap (HPGAP).

4 The Stylized Model

Since the empirical success of the NKPC using the output gap as the real driving force is contentious, we focus on this case. Prior to empirical estimation, subsection 4.1 discusses relevant econometric issues, particularly in relation to IV estimation. Subsection 4.2 then presents empirical results using a variety of observed inflation forecasts. An important finding from this empirical analysis is strong evidence of serial correlation in the stylized NKPC of (1), which leads us to examine more extensive inflation dynamics in Section 5.

4.1 Econometric Issues

Following much of the literature, we estimate the stylized NKPC of (1) by GMM. Since GMM estimation relies on the validity of the selected instrumental variables, we briefly discuss the endogeneity issues that arise in (1).

First, the current-period real variable y_t (captured by the output gap) may be correlated with the contemporaneous noise η_t, since demand shocks may influence both variables. Further, survey inflation expectations may be endogenous as they are collected during the quarter (for example, SPF survey data are collected in the middle of the quarter), and hence may reflect some current-period information. Therefore, both expected inflation and the current-period real variable may require IV estimation in the stylized NKPC model.[6]

If current-period shocks η_t are serially uncorrelated, then lagged values of the observed variables provide valid instruments. However, the presence of serial correlation in (1) complicates the issue of endogeneity and hence the choice of instruments. In particular, the lagged inflation term on the right-hand side of (1) is correlated with the disturbance if η_t is serially correlated. Since (in common with the estimates in Table 1) preliminary serial correlation tests indicated the presence of serial correlation, we treat π_{t-1} as endogenous when estimating the stylized NKPC. Indeed, if η_t has an autoregressive form, all inflation lags are correlated with this disturbance and hence are invalid instruments.

We use two lags of inflation expectations and the output gap as instruments. In addition, the baseline IV set includes two lags of the unemployment rate, which is supported by the well-known Okun's law. Furthermore, based on the seminal work of Bernanke and Blinder (1992) showing the importance of interest rates for monetary policy, we also include two lags of the short-term interest rate (3-month Treasury Bill rate) in the instruments. Of course, a constant term is included as an IV for all estimations.

Rudd and Whelan (2005b, 2007) show the sensitivity of NKPC estimates in (1) to misspecification when variables that directly affect inflation are used as instruments, rather than these variables being given an explicit role in the model. This is related to the discussion of the next section, which investigates richer dynamics in the NKPC. For the present discussion, however, we are interested in the NKPC estimates that result when observed inflation expectations series are used in conjunction with the output gap, and hence we do not question the basic framework of (1). Nevertheless, we recognize that the validity of lagged inflation expectations as instruments may be doubtful in the presence of serial correlation in (1). For example, if observed π_{t-2} is used in forming $E_{t-1}\pi_t$, and the former is correlated with η_t due to serial correlation, then lagged inflation expectations are also invalid instruments. On the other hand, if inflation expectations are driven by other factors, or respond only sluggishly to past observed inflation, then lagged inflation values can provide valid instruments. Indeed, these complications in selecting appropriate instruments in the presence of serial correlation are the principal reason why we extend the

[6] The treatment of survey data as endogenous or exogenous in the literature seems mixed. Rudebusch (2002) describes the possible endogeneity of inflation forecasts, whereas Roberts (1998) and Orphanides (2001, 2003, 2004) assume observed inflation forecasts to be exogenous. In addition, there appears no clear evidence on whether the contemporaneous output gap is correlated with the error term; see Roberts (1998).

NKPC in Section 5 in order to explicitly account for the dynamics of inflation.

The choice of instruments and model specification are verified through several diagnostic tests. First, we use Hansen's (1982) *J*-test to verify overidentifying restrictions. The possibility of disturbance serial correlation is checked using the IV serial correlation test proposed by Godfrey (1994).[7] When serial correlation is present, we correct the estimated standard errors using the Bartlett kernel with Newey-West HAC covariance estimate (fixed bandwidth), and employ the Heteroskedasticity Consistent Covariance Matrix Estimator (HCCME) otherwise. Further, to guard against the weak instruments concern raised in Mavroeidis (2004), we use the Cragg-Donald statistic (generalized F-statistic) developed by Stock and Yogo (2003) to test for weak instrumental variables.

4.2 Estimation Results of the Stylized Model

Based on the design just described, Table 2 summarizes the GMM estimates and associated standard errors for the stylized NKPC model of (1) for different combinations of inflation and output gap measures in conjunction with SPF1Q inflation expectations. The results of the diagnostic tests associated with each regression are also reported in the right-hand block of the table.

First, note that the coefficient estimates on the GDP gap in Table 2 are uniformly positive and statistically significant, indicating that conventional measures of the output gap play a significant role in the NKPC when inflation expectations are measured using median one-quarter ahead SPF forecasts. The magnitude of these coefficient estimates range from 0.13 to 0.28, which has appropriate economic implications and interpretations in terms of the microeconomic structures described in Gali and Gertler (1999) and other relevant literature reviewed in Section 2.[8] Interestingly, for each inflation series, the coefficient estimate on HPGAP is slightly larger than the that on CBOGAP.

Second, comparing the forward-looking and backward-looking inflation coefficients, backward-looking behavior dominates forward-looking one over the sample period 1968Q4 to 2005Q4. This finding is in broad agreement with Linde (2005) and Rudd and Whelan (2005b). Nevertheless, future inflation is statistically significant at the conventional levels

[7] This test is implemented by adding appropriate lagged residuals from the initial estimation to the regressors of the initial model and checking their joint significance by the Lagrange Multiplier (LM) principle. In this test, the lagged residuals are also added as instruments.

[8] See Roberts (1995, section 4) for an intuitive illustration about this issue.

in all regressions with CBOGAP as the real driving variable. These findings are also robust to the imposition of the convex restriction $\alpha_f + \alpha_b = 1$.[9]

Several additional issues associated with these results also merit discussion. First, goodness of fit is marginally higher when CBOGAP is used in the regression. Second, *p*-values of the overidentifying restrictions tests are larger than 10 percent in all cases, supporting the validity of the over-identifying moment conditions used in the IV estimation.[10] Third, the IV serial correlation test indicates that the use of HAC-robust standard errors is warranted. In addition, the weak IV test results suggest that the IV set can be regarded as strong (at the 5 percent level) in all regressions if the desired maximal bias of the IV estimator relative to OLS is specified to be 20 percent.

The empirical performance of the stylized NKPC model using the Greenbook and longer horizon SPF1Y/Michigan inflation forecasts are shown in Tables 3 and 4, respectively.

The results in Table 3 are consistent with those of Table 2: without exception, the coefficient estimates for the output gap are statistically significant and range from 0.11 to 0.25. However, the effect of future expected inflation appears slightly more dominant in regressions using CBOGAP as the inflation pressure variable when the convex restriction is not imposed on the inflation coefficients. Also, Hansen's *J*-test suggests that the over-identifying restrictions implied by our instruments are valid. Nonetheless, the IV set is relatively weak in this case, perhaps due to the wider information set used by the Fed compared with private individuals when forecasting inflation (Romer and Romer, 2000).

The results of Table 4 using a longer inflation forecast horizon again generally indicate that the baseline findings are robust, except that the output gap variable is not significant when non-farm business sector price inflation is used in conjunction with the Michigan data when the convex restriction is not imposed. This might reflect the fact that the Michigan survey data are more conformable with a broader price index than the non-farm business sector inflation. In most cases, however, the magnitude of the estimated output gap

[9] The convex restriction implies that the subjective discount factor in the micro foundations of the NKPC is one, which is often imposed in the literature. In our estimations, the null hypothesis of the convex restriction can not be rejected at conventional levels.
[10] Adam and Padula (2003) verify their OLS estimation of the stylized NKPC through an exogeneity test. However, it is unclear that their test takes account of serial correlation.

coefficients in Table 4 do not substantially differ from the corresponding estimates in Tables 2 and 3. In addition, and in line with these tables, most regressions of Table 4 have larger estimated coefficients on lagged inflation than on inflation expectations.

Taken as a whole, the results of Tables 2 to 4 find the output gap to be a statistically significant driving force for inflation in the NKPC model when directly observed inflation forecasts are used to capture expected future inflation. Nonetheless, virtually all regressions of the stylized NKPC model indicate the presence of serial correlation. Although these results use an IV set that excludes lagged inflation, the implicit assumption in our construction is that the serially correlated error term is orthogonal to lagged values of interest rates and the output gap, as well as lagged inflation expectations, all of which are used as instruments. As discussed by Rudd and Whelan (2005b), the test of over-identifying restrictions we apply can lack power and, in our case, the dynamic interactions among inflation, inflation expectations, interest rates and the output gap cast doubt on the validity of these instruments in the presence of serial correlation. Therefore, the following section investigates an extended version of the NKPC in order to attenuate these concerns.

5 An Extended NKPC Model

5.1 Description

The presence of serial correlation indicates that the stylized specification (1) does not capture the inflation dynamics observed in practice. Therefore, this section extends the stylized NKPC in order to mitigate these effects. To be specific, we assume an economic environment similar to that of Calvo (1983), in which firms are assumed to be able to revise their prices in any given period with a fixed probability $1-\theta$. Following Gali and Gertler (1999), we assume both "forward-" and "backward-looking" firms co-exist in proportions $(1-\omega)$ and ω respectively. Gali and Gertler (1999) assume that the backward-looking firms adjust their price by one lag of inflation, viz.

$$p_t^B = p_{t-1}^* + \pi_{t-1}, \tag{2}$$

where p_t^B denotes the (log) price set by backward-looking firms, and p_t^* is the new price set in period *t*. Nonetheless, if we interpret one period as being reasonably short as in quarterly models, it may be more plausible that the backward-looking agents consider a weighted process of past inflation, instead of stylized one lag of inflation inertia, that is

$$p_t^B = p_{t-1}^* + \rho(L)\pi_{t-1}, \quad (3)$$

where $\rho(L) = \rho_1 + \rho_2 L + \rho_3 L^2 + \cdots + \rho_q L^{q-1}$ is a polynomial in the lag operator with $\rho(1) = 1$. In empirical estimations, we specify q based on the Akaike Information Criterion (AIC) and serial correlation test results. Clearly, (3) is equivalent to (2) when q = 1.

Combining this with the regular assumptions in Calvo's (1983) model, the NKPC model to be estimated becomes

$$\pi_t = c_0 + \alpha_f E_t \pi_{t+1} + \alpha(L)\pi_{t-1} + \alpha_y y_t + \eta_t. \quad (4)$$

Since one-year-ahead inflation forecasts (SPF1Y and Michigan) are available, in addition to the quarterly forecasts, we can also evaluate an alternative formulation of the extended NKPC as

$$\pi_t = c_0 + \alpha_f E_t \overline{\pi}_{t+4} + \alpha(L)\pi_{t-1} + \alpha_y y_t + \eta_t, \quad (5)$$

where $E_t \overline{\pi}_{t+4}$ refers to one-year-ahead inflation expectations. The form of the extended NKPC in (5) may be particular appealing as the optimal lag order in $\alpha(L)$ is also often around one-year in length.

In addition to assessing the validity of the output gap measures in the extended NKPC, our interest also centers on the forward- and backward-looking coefficients. By construction, $\alpha(1)$ is the sum of the coefficients on lagged inflation in (4) or (5), and it is convenient to use this single parameter as a measure of the extent of backward-looking behavior. This is estimated by reparametrizing the inflation dynamics in (4) or (5) as

$$\alpha(L)\pi_{t-1} = \alpha_b \pi_{t-1} + \sum_{j=1}^{q-1} \alpha_{\Delta bj} \Delta\pi_{t-j}, \quad (6)$$

where $\alpha_b = \alpha(1)$ and $\Delta\pi_{t-j} = \pi_{t-j} - \pi_{t-j-1}$. Clearly, this reparametrization does not alter the estimates of the coefficients of interest, while α_b can be estimated with sufficient precision even if the individual coefficients on lagged inflation are imprecisely estimated due to multicollinearity between the lagged values. Another advantage of the reparametrization is that the convex restriction of $\alpha_f + \alpha_b = 1$ can be easily imposed.

To estimate the extended model, we employ as IV set two lags of each of the output gap, inflation forecasts, unemployment rate, short-term interest rate, and M2 growth[11], which appears to be reasonably conservative and sufficient to explain the dynamics of the extended model. In addition, lagged inflation values are included as their own instruments, as (in contrast to the stylized model) these are now valid since autocorrelation is accounted for through the additional dynamics.

In principle, the OLS estimator is more efficient than IV if the explanatory variables in the extended model are orthogonal to the (serially uncorrelated) disturbance. Therefore, we test this orthogonality in the context of (4)/(5) through the Durbin-Wu-Hausman (denoted Hausman) specification test (HCCME-robust). However, as will be evident in the empirical results, the orthogonality of $E_t\pi_{t+1}$ and y_t with η_t is rejected in most cases at conventional levels of significance, which verifies the importance of our use of IV estimation.[12]

5.2 Estimation Results of the Extended Model

Based on the foregoing description, Table 5 reports results for the extended NKPC model using the four forecast measures of inflation expectations and two measures of the output gap. Several notable points arise from these results.

First, the serial correlation test and the AIC suggest the use of four lags in regressions associated with the GDPIPD and five lags for regressions pertaining to the NFBIPD (allowing a maximum of eight lags). Looking across the column headed *p*-auto, it is evident that *p*-values of the IV serial correlation test are larger than 10 percent in most cases, indicating that the extended model is generally free of serial correlation. Nonetheless, serial correlation remains significant in regressions using Michigan survey data, especially when used in conjunction with the NFBIPD. This may be because the Michigan survey data relate to a broader measure of inflation than that of the non-farm business sector. It is also important to note that the joint tests on the extra inflation dynamics are significant in all regressions at the 10 percent level (and typically much lower), as indicated by the *p*-values reported in the column headed p-($\tilde{\alpha}_{\Delta bj}$), supporting the extension of the NKPC to

[11] Lags of M2 growth are included as instruments as the diagnostic test results are improved when these are included. Many previous empirical studies, including Clarida *et al*. (2000), include M2 among the instrument set.

[12] It may be noted that the Hausman test is not employed for the stylized model because the presence of serial correlation in the stylized NKPC (including the lagged the dependent variable as a regressor) requires GMM estimation.

incorporate additional lagged inflation terms.

Second, in regressions using SPF data, both HPGDP and CBOGAP are statistically significant. Nonetheless, the coefficient estimates on the output gap in regressions involving non-farm business sector price inflation are not always significant, which again might reflect the different coverage of these series. The estimates of α_f are smaller than α_b in all regressions involving GDP inflation, while occasionally they are larger when NFBIPD is used.

Third, the significant p-values reported for the Hausman test in the final column of Table 5 suggest that the OLS is inconsistent in most cases and, in particular, (at the 5 percent level) when SPF inflation forecasts are used. As the survey of professional forecasters is generally undertaken in the middle month of each quarter, these forecasts may reflect information correlated with the contemporaneous disturbance η_t. However, this casts doubt on the use of OLS by Adam and Padula (2003), who employ the one-quarter ahead SPF forecasts.

Four, the overidentifying restrictions and Weak IV tests generally support the IV choice as valid and statistically strong. The main exception relates to the J-test of overidentifying restrictions when the Michigan survey data is used in conjunction with NBIPD inflation, but this may be associated with the serial correlation problem noted above.

As a final robustness check, we also assessed subsample estimates of the extended NKPC, choosing comparable subsamples to those used by Gali and Gertler (1999). Empirical results (not reported here) suggest that the principal findings that the output gap is a valid driving force and the extended NKPC is free of serial correlation are robust to the subsamples used.[13] This analysis is extended in Zhang, Osborn and Kim (2007), where formal tests are undertaken for structural breaks in the parameters of the NKPC.

6 Discussion and Conclusions

This paper empirically investigates the New Keynesian Phillips Curve model using directly observed inflation forecasts as measures of inflation expectations and, in this

[13] In practice, we also investigated the validity of the alternative output gap measures discussed in Section 4, without any substantial change to the baseline findings.

context, establishes that the commonly used GDP gap measures are driving forces for inflation. The empirical evidence here is in contrast to Gali and Gertler (1999) and Gali *et al*. (2001, 2005) who argue that the NKPC fails when the GDP gap enters the regression. The imposition of the rational inflation expectations proxy by Gali and Gertler (1999) through use of actual future inflation, together with the selection of instruments in the presence of serial correlation, may account for these differing results.

The studies of Roberts (1998) and Adam and Padula (2003) consider the possible non-rationality of inflation forecasts in the NKPC context. Departures from rational expectations should, however, be adopted with caution in that rational expectations has been one of the milestone assumptions of macroeconomics for decades (Roberts, 1998) and the NKPC has been developed from microeconomic foundations under rational expectations. In our view, the most appealing reason for using observed inflation forecasts when estimating the NKPC models is not the issue of (ir)rationality, but the econometric issue of minimizing induced measurement error and hence deriving arguably more accurate estimates for the coefficients and standard errors of the parameters of interest.

Although our finding as to the relatively small role played by forward-looking behavior in the NKPC is broadly in agreement with Rudd and Whelan (2005b), their results sometimes imply an unintuitive sign on the coefficient for either inflation expectations or the GDP gap. The current paper, however, demonstrates that the NKPC is empirically coherent when the common output gap measures are used. Nevertheless, we agree with Rudd and Whelan (2005b) that the choice of appropriate instruments is an important issue for valid estimation of the NKPC, although our focus for this is the role played by serial correlation. An implication of our results is that monetary policy models should not derive current inflation from expected inflation alone. In particular, since it is well established that monetary policy responds to the output gap, our empirical evidence that the output gap plays a significant role in the NKPC provides an important mechanism through which monetary policy drives inflation.

The current empirical study also suggests that extra lags in inflation dynamics are statistically significant. More importantly, extending lagged inflation dynamics in the stylized NKPC to about one-year-period takes account of serial correlation, without essentially changing the baseline results and entailing a substantive departure from the theory developed in the important contribution by Gali and Gertler (1999).

Appendix

This appendix describes the data series used in the empirical work, including price indices, interest rates, money aggregate, real variables, and inflation forecasts. The data of inflation forecasts are from the website of the Federal Reserve Bank of Philadelphia and the website of Survey of Consumers of the University of Michigan. Most of the other data, obtained from the website of the Federal Reserve Bank of St. Louis, are published by the relevant U.S. economic departments. The sources of each series are listed below.

In addition, most raw data are transformed prior to empirical analysis. Monthly data are transformed to the quarterly frequency using the last month observation of the quarter prior to any further transformation. Real GDP data are used to construct the following output gap measures: (1) $CBOGAP = 100 \times [\ln(GDP) - \ln(GDPPOT)]$ where $GDPPOT$ denote estimates of real potential GDP published by Congressional Budget Office; (2) a two-sided Hodrick-Prescott filtered log real GDP with penalty parameter $\lambda = 1600$ (HPGAP).

Appendix Table: Price Indices, Interest Rates, Money Aggregate, and Real Variables

Name	Trans - code	Source Code	Description
GDPIPD	3	BEA	Gross Domestic Product: Implicit Price Deflator (Index 2000=100, SA, Q)
NFBIPD	4	BLS	Non-farm Business Sector: Implicit Price Deflator (index 1992=100, SA, Q)
TB3M	6	BGF	3-Month Treasury Bill: secondary market rate (NSA, M)
TB10Y	6	BGF	10-Year Treasury Constant Maturity Rate (NSA, M)
UNEMPL	1	BLS	Civilian Unemployment Rate (SA, M)
GDP	2/5	BEA	Gross Domestic Product (Billions of Chained 2000 Dollars;SA, Q)
GDPPOT	2	CBO	Real Potential Gross Domestic Product (SA, Q)

Notes: The following abbreviations are used: M=monthly available; Q=quarterly available; SA=seasonally adjusted; NSA=non-seasonally adjusted. Data transformation codes are: 1. level of the original series; 2. logarithm of the series; 3. annualized first difference of the logarithm of the series; 4. transformed into quarterly data using end-of-quarter observations, then annualized first difference of the logarithm of the transformed data; 5. Hodrick-Prescott filtered; 6. first difference of levels. Sources: BEA is the US Department of Commerce: Bureau of Economic Analysis, BLS is U.S. Department of Labor: Bureau of Labor Statistics, CBO is U.S. Congress: Congressional Budget Office, BGF is Board of Governors of the Federal Reserve System, CRB is U.S. Commodity Research Bureau.

Observed Inflation Forecasts Data Series

SPF Data

The SPF one-quarter ahead inflation forecast is the quarterly median forecast of annualized GDP implicit price deflator inflation (before 1992, GNP price index) over the quarter following the survey data. The SPF one-year-ahead inflation forecasts are published inflation forecasts for the chain-weighted GDP price index relating to average inflation over the four quarters beginning with the quarter following the survey date. Note that before 1992Q1, one-year-ahead GDP price inflation was GNP deflator inflation. Between 1992Q1 and 1995Q4, it was the GDP deflator and after 1995Q4 it is the chain-weighted GDP price index inflation. The SPF inflation forecasts data is collected from the website of the Federal Reserve Bank of Philadelphia at http://www.philadelphiafed.org/econ/spf/index.html.

Greenbook Data

The Greenbook quarterly forecasts of the GNP/GDP inflation (quarterly growth rate, annualized) are available from 1965Q4 to 1999Q4. These data are the projections of the research staff of the Board of Governors. Because the one-quarter-ahead forecasts before 1968Q3 contain missing values, we use data spanning 1968Q3-1999Q4. These survey data are closely related to the U.S. monetary policy committee, i.e. the Federal Open Market Committee (FOMC) and in turn monetary policy. The central bank releases the data with a five-year lag and hence the data only run through 1999 at the time of the writing. Currently the Greenbook data is maintained by the Federal Reserve Bank of Philadelphia and is collected from the website of the Philadelphia Fed at http://www.phil.frb.org/econ/forecast/greenbookdatasets.html.

Michigan Survey Data

The mean values of the general price inflation forecasts (one-year-ahead) are available from 1960Q1-2005Q2 at the time of the writing. The data is available on the website of Survey of Consumers of the University of Michigan at http://www.sca.isr.umich.edu/.

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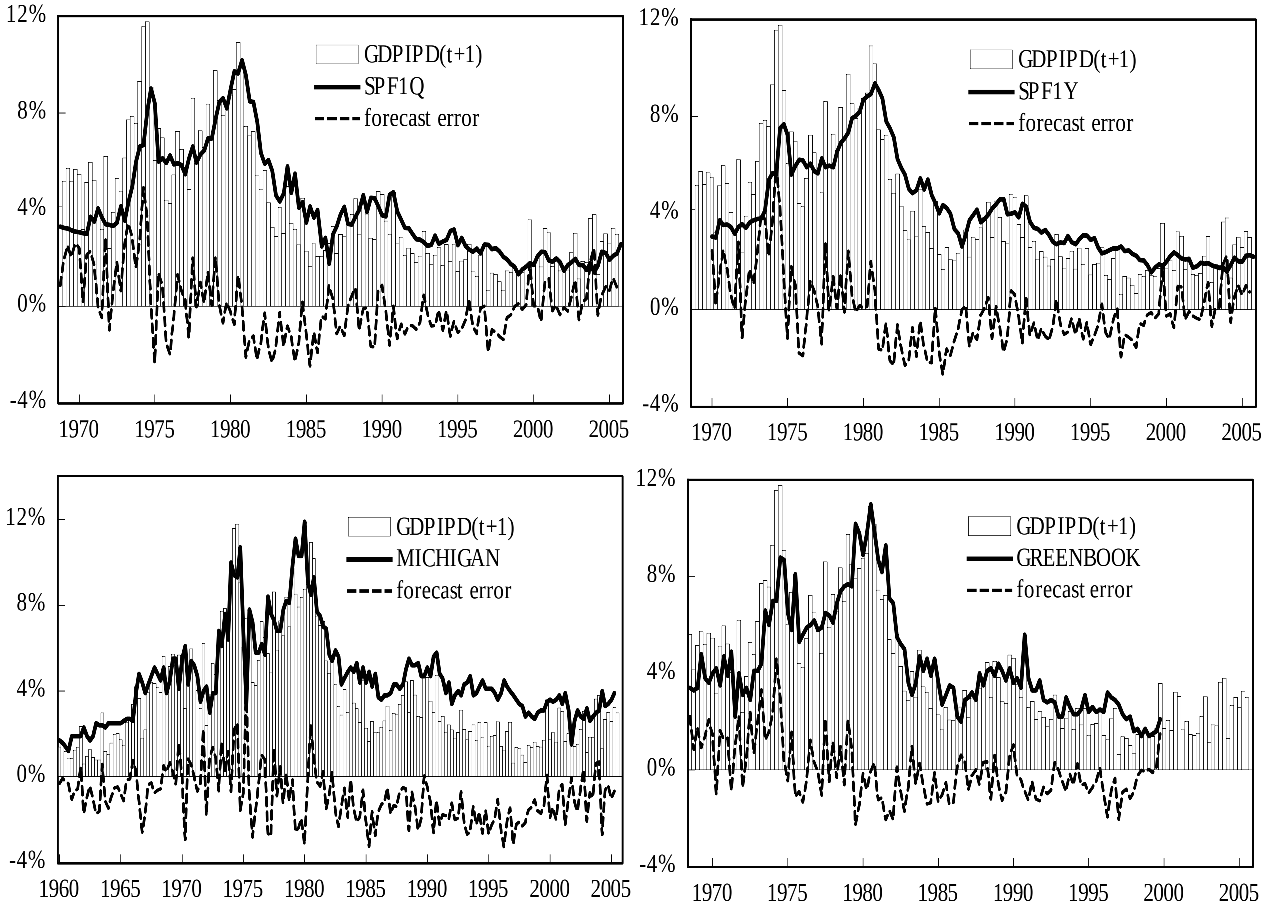

Figure 1 Actual Future GDP Inflation (GDPIPD(t+1)) and Observed Inflation Forecasts

Notes: SPF1Q is the SPF one-quarter-ahead GDP inflation forecasts (1968Q4-2005Q4); SPF1Y is the SPF one-year-ahead GDP inflation forecasts (1970Q1-2005Q4); MICHIGAN is the Michigan one-year-ahead general price inflation forecasts (1960Q1-2005Q2); GREENBOOK is the Greenbook one-quarter-ahead GDP inflation forecasts (1968Q3-1999Q4).

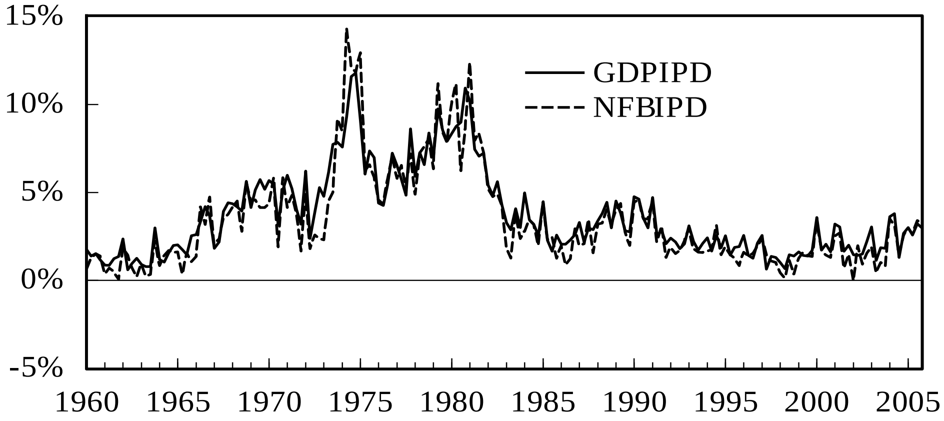

Figure 2 U.S. Inflation Series (%, annualized): 1960Q1-2005Q4

Notes: GDPIPD denotes GDP deflator inflation and NFBIPD is implicit price deflator inflation for the non-farm business sector.

Table 1 Estimation Results of the Stylized NKPC Using Adam-Padula and Gali-Gertler Approaches

π_t	y_t	$\hat{\alpha}_f$	$\hat{\alpha}_b$	$\hat{\alpha}_y$	$\bar{R}^2$	p-auto
A. Adam-Padula approach						
GDPIPD	CBOGAP	0.570	0.455	0.116	0.811	0.000
		(0.091)	(0.088)	(0.035)		
	HPGAP	0.500	0.491	0.096	0.804	0.000
		(0.097)	(0.096)	(0.056)		
NFBIPD	CBOGAP	0.785	0.350	0.155	0.776	0.001
		(0.095)	(0.105)	(0.049)		
	HPGAP	0.706	0.379	0.147	0.768	0.000
		(0.105)	(0.113)	(0.083)		
B. Gali-Gertler approach						
GDPIPD	CBOGAP	0.648	0.334	-0.024	0.822	0.000
		(0.078)	(0.090)	(0.026)		
	HPGAP	0.661	0.327	-0.028	0.820	0.000
		(0.080)	(0.088)	(0.041)		
NFBIPD	CBOGAP	0.812	0.168	-0.058	0.714	0.000
		(0.106)	(0.102)	(0.057)		
	HPGAP	0.816	0.173	-0.064	0.712	0.000
		(0.119)	(0.109)	(0.108)		

Notes: The equation estimated is given by (1). The sample spans 1968Q4-2005Q4 prior to lag adjustment; the Bartlett kernel with Newey-West (fixed bandwidth) HAC-robust standard errors are reported in parentheses; HPGAP and CBOGAP refer to GDP gap measures based on the conventional HP filter (with penalty parameter 1600) and potential real GDP estimates from Congressional Budget Office respectively. In panel A, OLS estimates are reported; inflation expectations are measured by the SPF one-quarter-ahead GDP inflation forecasts; and p-auto refers to Breusch-Godfrey serial correlation test for residuals (up to 4 lags) computed using the LM test with finite sample adjustment (F-statistic). In panel B, GMM estimates using Gali and Gertler's (1999) IV are reported; inflation expectations are proxied by one-quarter ahead rational expectations; p-auto in this case corresponds to Godfrey (1994) IV serial correlation test (up to 4 lags).

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Table 2 GMM Estimates of the Stylized NKPC Using SPF1Q Forecasts

Regression		Baseline Estimates				Diagnostic Tests		
π_t	y_t	$\tilde{\alpha}_f$	$\tilde{\alpha}_b$	$\tilde{\alpha}_y$	$\bar{R}^2$	*p*-auto	*p*-over	*Weak IV*
GDPIPD	CBOGAP	0.189 (0.133)	0.827 (0.127)	0.131 (0.036)	0.782	0.005	0.306	6.168**
	HPGAP	0.015 (0.117)	0.955 (0.116)	0.181 (0.053)	0.757	0.003	0.371	7.251**
NFBIPD	CBOGAP	0.512 (0.231)	0.585 (0.203)	0.193 (0.049)	0.760	0.001	0.242	9.052**
	HPGAP	0.309 (0.218)	0.706 (0.201)	0.273 (0.063)	0.738	0.000	0.459	9.237**
Convex Restriction								
GDPIPD	CBOGAP	0.162 (0.130)	0.838 (0.130)	0.126 (0.034)	0.782	0.005	0.393	6.168**
	HPGAP	0.059 (0.118)	0.941 (0.118)	0.178 (0.054)	0.761	0.003	0.509	7.251**
NFBIPD	CBOGAP	0.332 (0.174)	0.668 (0.174)	0.170 (0.041)	0.746	0.000	0.552	9.052**
	HPGAP	0.281 (0.192)	0.719 (0.192)	0.276 (0.067)	0.737	0.000	0.623	9.237**

Notes: Inflation expectations are measured by SPF one-quarter-ahead inflation forecasts. Sample spans 1968Q4-2005Q4 prior to lag adjustment. IV set includes two lags of each of inflation expectation, real variable in the regression, unemployment rate, and short-term interest rate; plus a constant (included throughout all IV estimations). The Bartlett kernel with Newey-West (fixed bandwidth) HAC-robust standard errors are reported in parentheses. *p*-over refers to *p*-value for the overidentifying restrictions test (Hansen's *J* test), *p*-auto corresponds to Godfrey (1994) IV serial correlation test (up to 4 lags), and *WeakIV* refers to the Stock and Yogo (2003) weak IV test. Critical values for the weak IV test are provided in Stock and Yogo (2003), table I, with ****, ***,**, and * denoting statistically significantly strong IV (5% significance level) when the desired maximal bias of the IV estimator relative to OLS is specified to be 5, 10, 20 and 30 percent respectively.

Table 3 GMM Estimates of the Stylized NKPC Using Greenbook Forecasts

Regression		Baseline Estimates				Diagnostic Tests		
π_t	y_t	$\tilde{\alpha}_f$	$\tilde{\alpha}_b$	$\tilde{\alpha}_y$	$\bar{R}^2$	*p*-auto	*p*-over	*Weak IV*
GDPIPD	CBOGAP	0.669	0.410	0.120	0.830	0.003	0.136	1.875
		(0.223)	(0.193)	(0.040)				
	HPGAP	0.264	0.731	0.149	0.802	0.030	0.136	2.154
		(0.198)	(0.172)	(0.056)				
NFBIPD	CBOGAP	0.945	0.272	0.159	0.749	0.006	0.182	3.117
		(0.280)	(0.276)	(0.047)				
	HPGAP	0.623	0.481	0.195	0.748	0.001	0.168	2.560
		(0.255)	(0.240)	(0.067)				
Convex Restriction								
GDPIPD	CBOGAP	0.438	0.562	0.106	0.826	0.008	0.130	1.875
		(0.180)	(0.180)	(0.033)				
	HPGAP	0.279	0.721	0.146	0.805	0.019	0.217	2.154
		(0.151)	(0.151)	(0.058)				
NFBIPD	CBOGAP	0.415	0.585	0.138	0.744	0.001	0.125	3.117
		(0.195)	(0.195)	(0.044)				
	HPGAP	0.339	0.661	0.248	0.734	0.000	0.219	2.560
		(0.203)	(0.203)	(0.079)				

Notes: Inflation expectations are measured by the Greenbook quarterly GDP inflation projections over 1968Q3-1999Q4 prior to lag adjustment. IV choice is the same as in Table 2. *p*-auto corresponds to Godfrey (1994) IV serial correlation test (up to 4 lags) and see footnotes to Table 2 relating to the other diagnostic tests.

Table 4 GMM Estimates of the Stylized NKPC Using Longer Forecasting Horizon

Regression		Baseline Estimates				Diagnostic Tests		
π_t	y_t	$\tilde{\alpha}_f$	$\tilde{\alpha}_b$	$\tilde{\alpha}_y$	$\bar{R}^2$	p-auto	p-over	*Weak IV*
SPF1Y Forecasts								
GDPIPD	CBOGAP	0.119 (0.155)	0.892 (0.139)	0.124 (0.040)	0.769	0.005	0.524	7.089**
	HPGAP	0.009 (0.141)	0.953 (0.129)	0.180 (0.054)	0.756	0.002	0.704	7.740**
NFBIPD	CBOGAP	0.457 (0.208)	0.656 (0.171)	0.205 (0.054)	0.743	0.000	0.402	9.806**
	HPGAP	0.283 (0.197)	0.739 (0.174)	0.301 (0.069)	0.729	0.001	0.606	10.009***
Convex Restriction								
GDPIPD	CBOGAP	0.097 (0.135)	0.903 (0.135)	0.121 (0.037)	0.769	0.003	0.620	7.089**
	HPGAP	0.079 (0.123)	0.921 (0.123)	0.177 (0.055)	0.764	0.004	0.797	7.740**
NFBIPD	CBOGAP	0.256 (0.139)	0.744 (0.139)	0.178 (0.048)	0.728	0.000	0.468	9.806**
	HPGAP	0.243 (0.160)	0.757 (0.160)	0.303 (0.071)	0.727	0.000	0.732	10.009***
Michigan Forecasts								
GDPIPD	CBOGAP	0.407 (0.122)	0.633 (0.112)	0.049 (0.024)	0.831	0.000	0.612	1.907
	HPGAP	0.187 (0.164)	0.798 (0.140)	0.117 (0.057)	0.804	0.002	0.680	1.504
NFBIPD	CBOGAP	0.987 (0.308)	0.243 (0.254)	0.030 (0.046)	0.778	0.000	0.097	4.809*
	HPGAP	0.986 (0.357)	0.241 (0.268)	-0.020 (0.129)	0.780	0.000	0.076	3.293
Convex Restriction								
GDPIPD	CBOGAP	0.281 (0.136)	0.719 (0.136)	0.057 (0.026)	0.820	0.001	0.746	1.907
	HPGAP	0.239 (0.131)	0.761 (0.131)	0.101 (0.059)	0.813	0.001	0.745	1.504
NFBIPD	CBOGAP	0.480 (0.147)	0.520 (0.147)	0.060 (0.033)	0.781	0.000	0.108	4.809*
	HPGAP	0.420 (0.144)	0.580 (0.144)	0.172 (0.062)	0.775	0.000	0.223	3.293

Notes: The SPF one-year-ahead GDP inflation forecasts (denoted by SPF1Y in the table) spans 1970Q1-2005Q4 while the Michigan Survey one-year-ahead general price inflation forecasts (denoted by Michigan) runs from 1960Q1 to 2005Q2 prior to lag adjustment. IV set is the same as that in Table 2. p-auto corresponds to Godfrey (1994) IV serial correlation test (up to 4 lags) and see footnotes to Table 2 relating to the other diagnostic tests.

Table 5 GMM Estimates of the Extended NKPC

Regression			Baseline Estimates					Diagnostic Tests			
$E_t\boldsymbol{\pi}_{t+1}$	$\boldsymbol{\pi}_t$	y_t	$\tilde{\alpha}_f$	$\tilde{\alpha}_b$	$\tilde{\alpha}_y$	p-($\tilde{\alpha}_{\Delta bj}$)	$\bar{R}^2$	p-auto	p-over	*Weak IV*	Hausman
SPF1Q	GDPIPD	CBOGAP	0.302 (0.142)	0.744 (0.131)	0.215 (0.045)	0.001	0.82	0.469	0.037	32.49****	0.020
		HPGAP	0.078 (0.155)	0.893 (0.143)	0.311 (0.074)	0.001	0.81	0.468	0.048	22.18****	0.006
	NFBIPD	CBOGAP	0.595 (0.169)	0.491 (0.130)	0.197 (0.055)	0.003	0.80	0.109	0.149	36.49****	0.015
		HPGAP	0.390 (0.177)	0.614 (0.135)	0.309 (0.096)	0.001	0.79	0.152	0.132	19.88****	0.006
	Convex Restriction										
	GDPIPD	CBOGAP	0.246 (0.133)	0.754 (0.133)	0.201 (0.044)	0.002	0.82	0.400	0.049	32.49****	0.020
		HPGAP	0.121 (0.141)	0.879 (0.141)	0.307 (0.073)	0.001	0.81	0.509	0.063	22.18****	0.010
	NFBIPD	CBOGAP	0.468 (0.124)	0.532 (0.124)	0.176 (0.056)	0.001	0.80	0.075	0.118	36.49****	0.011
		HPGAP	0.383 (0.121)	0.617 (0.121)	0.310 (0.094)	0.001	0.79	0.146	0.186	19.88****	0.001
SPF1Y	GDPIPD	CBOGAP	0.157 (0.156)	0.882 (0.138)	0.219 (0.048)	0.001	0.82	0.479	0.379	62.43****	0.000
		HPGAP	-0.036 (0.164)	0.988 (0.144)	0.339 (0.077)	0.000	0.81	0.495	0.516	38.06****	0.000
	NFBIPD	CBOGAP	0.535 (0.162)	0.572 (0.120)	0.198 (0.058)	0.001	0.80	0.250	0.248	70.25****	0.011
		HPGAP	0.329 (0.160)	0.685 (0.119)	0.348 (0.102)	0.001	0.80	0.312	0.363	35.24****	0.002
	Convex Restriction										
	GDPIPD	CBOGAP	0.100 (0.139)	0.900 (0.139)	0.209 (0.048)	0.001	0.82	0.473	0.483	62.43****	0.000
		HPGAP	0.047 (0.139)	0.953 (0.139)	0.329 (0.075)	0.001	0.81	0.589	0.437	38.06****	0.000
	NFBIPD	CBOGAP	0.372 (0.114)	0.628 (0.114)	0.178 (0.058)	0.000	0.80	0.181	0.119	70.25****	0.010
		HPGAP	0.304 (0.112)	0.696 (0.112)	0.354 (0.102)	0.000	0.80	0.303	0.438	35.24****	0.001

Table 5 (continued)

Regression			Baseline Estimates					Diagnostic Tests			
$E_t\pi_{t+1}$	π_t	y_t	$\tilde{\alpha}_f$	$\tilde{\alpha}_b$	$\tilde{\alpha}_y$	p-($\tilde{\alpha}_{\Delta bj}$)	$\bar{R}^2$	p-auto	p-over	*Weak IV*	Hausman
Greenbook	GDPIPD	CBOGAP	0.529	0.575	0.202	0.069	0.83	0.122	0.096	7.83^{**}	0.060
			(0.184)	(0.165)	(0.049)						
		HPGAP	0.275	0.738	0.262	0.075	0.82	0.197	0.075	4.98^{*}	0.072
			(0.214)	(0.189)	(0.088)						
	NFBIPD	CBOGAP	0.914	0.255	0.132	0.028	0.78	0.108	0.185	9.39^{**}	0.004
			(0.246)	(0.190)	(0.068)						
		HPGAP	0.779	0.318	0.141	0.015	0.78	0.081	0.092	4.13^{*}	0.017
			(0.346)	(0.254)	(0.159)						
	Convex Restriction										
	GDPIPD	CBOGAP	0.374	0.626	0.175	0.088	0.83	0.051	0.041	7.83^{**}	0.093
			(0.166)	(0.166)	(0.049)						
		HPGAP	0.244	0.756	0.269	0.058	0.82	0.249	0.108	4.98^{*}	0.072
			(0.180)	(0.180)	(0.087)						
	NFBIPD	CBOGAP	0.629	0.371	0.105	0.007	0.79	0.076	0.094	9.39^{**}	0.030
			(0.163)	(0.163)	(0.065)						
		HPGAP	0.513	0.487	0.233	0.006	0.78	0.117	0.142	4.13^{*}	0.031
			(0.163)	(0.163)	(0.115)						
Michigan	GDPIPD	CBOGAP	0.459	0.636	0.117	0.000	0.85	0.089	0.124	10.77^{***}	0.152
			(0.106)	(0.082)	(0.032)						
		HPGAP	0.373	0.667	0.167	0.000	0.85	0.030	0.038	6.77^{**}	0.135
			(0.135)	(0.099)	(0.074)						
	NFBIPD	CBOGAP	0.872	0.349	0.062	0.007	0.81	0.000	0.008	13.87^{***}	0.000
			(0.147)	(0.097)	(0.044)						
		HPGAP	0.867	0.332	0.029	0.007	0.81	0.000	0.002	7.12^{**}	0.001
			(0.190)	(0.119)	(0.125)						
	Convex Restriction										
	GDPIPD	CBOGAP	0.308	0.692	0.113	0.000	0.85	0.047	0.106	10.77^{***}	0.054
			(0.081)	(0.081)	(0.032)						
		HPGAP	0.287	0.713	0.199	0.000	0.84	0.065	0.082	6.77^{**}	0.049
			(0.092)	(0.092)	(0.064)						
	NFBIPD	CBOGAP	0.530	0.470	0.056	0.001	0.81	0.000	0.001	13.87^{***}	0.115
			(0.084)	(0.084)	(0.043)						
		HPGAP	0.452	0.548	0.207	0.000	0.81	0.000	0.003	7.12^{**}	0.021
			(0.089)	(0.089)	(0.095)						

Notes: Autoregressive lag order is four in GDPIPD regressions and five in NFBIPD regressions. IV set is lags of inflation, plus two lags of real variable in the regression, unemployment rate, short-term interest rate, survey inflation forecasts, and M2 growth rate. HCCME standard errors are reported in parentheses. p-($\tilde{\alpha}_{\Delta bj}$) is the p-value of joint significance test on lagged inflation beyond order one; Hausman refers to p-value of the Durbin-Wu-Hausman specification test; p-auto corresponds to Godfrey (1994) IV serial correlation test (up to 4 lags); see footnotes to Table 2 relating to other diagnostic tests.