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Observed Inflation Forecasts and the New Keynesian Phillips Curve

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Abstract

Estimating the micro-founded New Keynesian Phillips Curve using rational inflation expectation proxies has often found that the output gap is not a valid measure of inflation pressure. This paper investigates the empirical success of the NKPC in explaining US inflation, using observed measures of inflation expectations and taking account of serial correlation in the stylized NKPC. Contrary to recent results indicating no role for the GDP gap, we find it to be a statistically significant driving variable for inflation while labor income share is generally insignificant. The paper also develops an extended model in which serial correlation is absent and the output gap remains a valid inflation driving force. 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: Inflation, New Keynesian Phillips Curve, GMM, inflation forecasts, monetary policy

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 recently 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), Levin *et al.* (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 *et al*. (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, as discussed in the next section, so that little consensus has been achieved.

In order to work in a single framework, some authors, including Gali and Gertler (1999), employ realized future inflation data to proxy (rational) inflation expectations, with instrumental variables (IV) methods accounting for the resulting endogeneity. However, in addition to the weak IV concern raised in Mavroeidis (2004), this practice also induces a measurement error whose volatility may distort inference for the NKPC, as indicated in Sun and Phillips (2004) and discussed in Zhang *et al*. (2006).

It may be preferable to use observed inflation survey data rather than realized future values to measure unobserved inflation expectations, because the former may mimic more realistically and more accurately peoples' responses to economic performance and hence

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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.

are better measures of expectations than realized future inflation; see Roberts (1995). In addition, recent studies present evidence in favor of using such forecasts as measures of inflation expectations in models of monetary policy analysis; see Croushore (1993). 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. Most importantly, however, inflation survey data are directly observable and hence reduce the potential role of measurement error in estimation of the NKPC.

Another important, yet often overlooked, issue is the possible serial correlation in the stylized NKPC. Much of the literature adopts the common approach of employing lags of inflation (and other variables) as instruments when estimating the NKPC. However, the presence of serial correlation in the dynamic NKPC model would invalidate lagged values of inflation as legitimate IV, rendering the resulting estimates not only biased but also inconsistent.

In this paper, therefore, we employ directly observed inflation forecasts as measures of inflation expectations and carefully characterize serial correlation. We find that commonly used output gap measures, rather than labor share, remain significant as indicators of inflation pressure in the NKPC. Further, empirical results also imply that the stylized specification with a single lag of inflation is insufficient to capture inflation dynamics and extra lags of inflation are statistically significant in accounting for current inflation. However, the addition of lags to account for this serial correlation leads to the conclusion that inflation dynamics appear more concerned with backward-looking behavior than forward-looking price-setting over 1968-2005. This baseline finding is robust to the use of a variety of inflation survey data measures and different detrending methods in computing the real output gap.

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 of Gali and Gertler (1999), including Gali *et al*. (2001), as well as those of 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

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

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, under this setup, all variables are assumed to be expressed as percentage deviations from their respective steady states.

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. This finding has subsequently 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. 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), but based on a special GDP gap measure constructed in line with dynamic general equilibrium models.

Linde (2005) is able to obtain 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. However, in addition to relying on the relatively strong normality assumption, FIML estimation is sensitive to the specification of the structural equations in the system. For instance, 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 *et al*.

(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 very 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) carefully 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 (2005c, 2006).

Despite this interest in the estimation of the NKPC, the use of observed inflation forecasts as a measure of the inflation expectation $E_t\pi_{t+1}$, at least for quarterly models, 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, even with rational expectations, π_{t+1} is more noisy than $E_t\pi_{t+1}$, which may render estimation of the NKPC problematic with finite samples.

Rather than employ a rational expectations assumption, 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. Table 1 reports OLS estimates of (1) using the SPF one-quarter-ahead GDP inflation forecasts over 1968Q4-2005Q4, using the approach of Adam and Padula (2003). These baseline coefficient estimates seem to confirm the Adam and Padula’s (2003) arguments. For example, the estimated coefficient on labor income share of the non-farm business sector is indeed positively and significantly driving GDP inflation (denoted GDPIPD in the table), albeit insignificant in a model for non-farm business sector price inflation (denoted NFBIPD).

However, the significant *p*-values for the diagnostic test of autocorrelation (the last column in Table 1) imply that the error term in the stylized NKPC is serially correlated and hence OLS estimates are inconsistent for this dynamic model, which casts doubt on the econometric validity of the results in Adam and Padula (2003).

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. 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. The focus of this paper, therefore, is 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. The paper also addresses the important issue of serial correlation in the stylized specification and concerns of possible weak instruments in the GMM estimation, which lead to an extended form of the NKPC with additional dynamics.

3 The Data

The data used in our baseline empirical work (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 will influence decision-makers.

The top 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 multicollinearity between lagged and expected inflation that might be anticipated in (1). 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.

To assess the robustness of baseline findings, 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 additional 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, the forecasts may be interpreted as the monetary policy designers' view of future inflation. Also, because the NKPC model is often used in the macroeconometric models of monetary policy analysis, it is useful to check whether the baseline estimates are robust to the Greenbook inflation forecasts[3]. On the other hand, the Michigan survey aims to capture the views of the general public. Thererfore, these series represent different groups of agents with (presumably) different 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

[3] For macroeconometric models of monetary policy analysis incorporating the NKPC, see Clarida *et al*. (1999).

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 remaining 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 concentrate on the GDP gap computed using real potential output estimates by the U.S. Congressional Budget Office (CBOGAP) and the conventional Hodrick-Prescott filtered GDP gap (HPGAP), with measures by alternative detrending methods (described in the appendix) being used to assess sensitivity of our baseline findings. We also evaluate the validity of the labor income share advocated by Gali and Gertler (1999) as a real driving variable for inflation. The alternative output gap measures and the labor income share are plotted in Figure 3.

4 The Stylized Model

Since the empirical success of the stylized NKPC model (1) using the output gap as the real driving force is contentious, we start by estimating this model. Prior to empirical estimation, sub section 4.1 discusses relevant econometric issues, focusing particularly on the necessity for and the design of IV estimation. Section 4.3 then summarizes empirical results using a variety of observed inflation forecasts as measures of inflation expectations and different output gap measures. An important finding from the empirical analysis is the strong evidence of serial correlation in the stylized NKPC, which entails an extension for the inflation dynamics, a task taken in section 5.

4.1 Econometric Issues

The empirical version of the stylized NKPC can be written as

$$\pi_t = c_0 + \alpha_f E_t \pi_{t+1} + \alpha_b \pi_{t-1} + \alpha_y y_t + \eta_t \qquad (2)$$

where η_t is a disturbance term allowed to be nonspherical. Compared to (1), and in addition to the inclusion of the disturbance, an intercept is included in the model as the variables here are used in levels rather than as deviations from their steady state values.

To account for possible endogeneity of the regressors, we employ IV, or more generally a Generalized Method of Moments (GMM) estimator to estimate the NKPC. Since GMM estimation underscores the validity of selected instrumental variables, we briefly discuss the IV set that we choose to estimate (2).

First, the current-period real variable y_t may be correlated with the contemporaneous noise η_t, since demand shocks may influence both variables. Although it is less obvious whether survey inflation expectations should be treated as endogenous, it may be noted that the SPF survey data are based on professionals' forecasts collected in the middle of the quarter, and hence may reflect some current period information. Therefore, it is desirable to employ appropriate instruments for both expected inflation and the current-period real variable in estimating the stylized NKPC model[4]. To this end, we assume lagged inflation expectations and lagged real variables are uncorrelated with current-period η_t shocks, while correlated with their current-period observations, so that these lagged variables are employed as valid instruments.

Another important issue is whether π_{t-1} should be instrumented. Although it is not conventional to do so, it should be noted that the lagged inflation variable on the right-hand side of (2) is correlated with the error term if η_t is serially correlated. Preliminary serial correlation tests treating π_{t-1} as exogenous typically indicate the presence of serial correlation, so that we also instrument lagged inflation.

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 throughout the estimations.

The choice of instruments and the 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

[4] 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).

test proposed by Davidson and MacKinnon (1993) and Godfrey (1994)[5]. In the presence of serial correlation, we correct the estimated standard errors using the Bartlett kernel with Newey-West HAC covariance estimate (fixed bandwidth), while employ the Heteroskedasticity Consistent Covariance Matrix Estimator (HCCME) otherwise. Further, to guard against the weak IV concern raised in Mavroeidis (2004), we use the Cragg-Donald statistic (generalized F-statistic) developed by Stock and Yogo (2003) to test for weak IV.

4.2 Estimation Results of the Stylized Model

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

First, consider the coefficient estimates on the GDP gap, which are uniformly positive and statistically significant. Therefore, contrary to the findings of Gali and Gertler (1999) based on rational expectations and actual future inflation, Table 2 shows that conventional measures of the output gap play a significant role in the NKPC when inflation expectations are measured using the SPF median forecasts. The magnitude of the estimates ranges from 0.13 to 0.27, 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[6]. Interestingly, for each inflation series, the coefficient estimate on HPGAP is slightly larger than 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 in all regressions with CBOGAP as the real driving variable. These findings are also robust to the convex restriction $\alpha_f + \alpha_b = 1$[7].

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[5] This test is implemented by adding appropriate lagged residuals from the initial estimation to the regressors from the initial model and checking their joint significance by the Lagrange Multiplier (LM) principle.

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

[7] The convex restriction implies that the subjective discount factor in the micro foundations of the NKPC is

Several additional issues associated with the baseline model also merit discussion. First, its goodness of fit improves when CBOGAP enters the regression. Second, *p*-values of the overidentifying restrictions tests are larger than 10 percent in all cases, supporting the validity of the moment conditions used in the IV estimations. Third, the IV serial correlation test indicates that the HAC-robust standard errors (as employed here) are 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. Of course, a stronger IV set would be obtained if lags of inflation variable were allowed to enter the IV set. In that case, however, serial correlation is present, and hence invalidates the moment conditions in the GMM estimation[8]. We return to the issue of the dynamics and the IV set in section 5.

It should be emphasized that the principal findings remain unchanged when the IV set is altered, for example, using the same instruments as in Gali and Gertler (1999) with sample size restricted to end in 1997Q4. Consequently, our results are unlikely to be induced by our specific instrument choice or the extended sample.

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

The results in Table 3 are consistent with those of Table 2: without exception, the estimates for the output gap are statistically significant and the magnitude ranges from 0.11 to 0.25. However, the effects of future expected inflation appears slightly more dominant in regressions of using CBOGAP as inflation pressure when the convex restriction on inflation coefficients is not imposed. Lastly, Hansen's *J*-test suggests that the instruments are valid. Nonetheless, the IV set is relevantly weak.

Table 4 investigates the use of a longer inflation forecast horizon and the results 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

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one, which is often imposed in the literature.

[8] Adam and Padula (2003) estimate the stylized NKPC by OLS, verifying its validity through an exogeneity test. However, it is unclear that their test takes account of serial correlation. As already noted, our finding of serial correlation invalidates the use of OLS due to the presence of the lagged dependent variable in (2).

price index than the non-farm business sector inflation. In most cases, however, the magnitude of the estimated output gap coefficients in Table 4 do not substantially differ from the corresponding estimates in Tables 2 and 3. In addition, in most regressions of Table 4, the estimated coefficients on lagged inflation are larger than those on inflation expectations, which is consistent with the baseline finding.

Finally, Table 5 reports results for the stylized NKPC using alternative measures of the GDP gap and the non-farm business sector labor income share, in conjunction with the SPF quarterly inflation forecasts as inflation expectations. It is evident that the alternative detrending methods for the output gap yield coefficients that are statistically significant in virtually all cases. However, the labor income share is statistically insignificant in all cases at conventional levels.

Taken as a whole, the baseline estimates of the stylized quarterly NKPC model are in accord with the underlying economic theory. However, in contrast to the results of Gali and Gertler (1999) and Gali *et al*. (2001; 2005), the output gap remains a statistically significant driving force with correct sign for inflation in the NKPC model when directly observed inflation forecasts are used to capture expected future inflation. This finding is robust to a variety of detrending methods. However, unlike Adam and Padula (2003), who use the SPF data but employ OLS, we find that labor income share appears not to be a driving force for price inflation. Nonetheless, as discussed above, the presence of serial correlation in the stylized model implies that the OLS estimator is not consistent.

In addition, backward-looking behavior is more important than forward-looking behavior in GDP inflation dynamics, but this does not always apply for non-farm business sector inflation dynamics. Nevertheless, intrinsic inflation inertia in either case should not be omitted from the NKPC, which is in line with Linde (2005), Roberts (2005), and Rudd and Whelan (2005b, 2006).

Virtually all regressions of the stylized NKPC model indicate the presence of serial correlation. Although we employ a baseline IV set which 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 real variable, which are used as instruments. This assumption might be relatively strong given the dynamic interaction among inflation, interest rates and the real variable. Therefore, the following section investigates an extended version of the NKPC in order to attenuate any concerns about the validity of lagged values of the relevant variables as instruments.

5 An Extended NKPC Model

5.1 Description

The presence of serial correlation indicates that the stylized specification (2) does not capture inflation dynamics observed in practice. Further, the theoretical model is more likely to be retrievable when it takes into account of realistic and practical issues; see Rudebusch (2002) and Orphanides (2004). Therefore, this section extends the stylized NKPC by which we hope to mitigate the evident serial correlation that is potentially induced by insufficient inflation dynamics. 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 with a proportion of $(1-\omega)$ and ω respectively. Gali and Gertler (1999) assume that the backward-looking firms adjust their price by one lag of inflation, viz.

$$p_t^B = p_{t-1}^* + \pi_{t-1} \qquad (3)$$

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

$$p_t^B = p_{t-1}^* + \rho(L)\pi_{t-1} \qquad (4)$$

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 $\rho(1) = 1$. Note that q is an optimal lag selection based on AIC and serial correlation tests in empirical estimations. Clearly, (4) is the same as (3) when lag order is one.

Combining this with the regular assumptions in Calvo's (1983) model, it can be shown that the empirical NKPC model follows

$$\pi_t = c_0 + \alpha_f E_t \pi_{t+1} + \alpha(L)\pi_{t-1} + \alpha_y y_t + \eta_t . \qquad (5)$$

Since the 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

$$\pi_t = c_0 + \alpha_f E_t \bar{\pi}_{t+4} + \alpha(L)\pi_{t-1} + \alpha_y y_t + \eta_t \,. \tag{6}$$

where $E_t \bar{\pi}_{t+4}$ refers to one-year-ahead inflation expectations. The form of the extended NKPC in (6) may be particular appealing as the optimal lag order 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 centres on the forward- and backward-looking coefficients. By construction, $\alpha(1)$ is the sum of the coefficients on lagged inflation in (6) or (7), 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 (6) or (7) as

$$\alpha(L)\pi_{t-1} = \alpha_b \pi_{t-1} + \sum_{j=1}^{p} \alpha_{\Delta bj} \Delta\pi_{t-j} \tag{7}$$

where $\alpha_b = \alpha(1)$ and $\Delta\pi_{t-j} \equiv \pi_{t-j+1} - \pi_{t-j}$. Clearly, this reparametrization does not alter the least squares 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 correlation between the lagged values. Another advantage of the reparametrization is that the convex restriction of $\alpha_f + \alpha_b = 1$ can be easily imposed.

It is of interest to consider the joint significance of the additional inflation lags, since much of the existing literature, including Gali and Gertler (1999), suggests that these are statistically insignificant.

To estimate the extended model, we employ as IV set two lags of each of the real variable in the regression, inflation forecasts, unemployment rate, short-term interest rate, and M2 growth, which appears to be reasonably conservative and sufficient to explain the dynamics of the extended model. Of course, a constant and lagged inflation are included as their own instruments.

The IV estimator is consistent even if the inflation expectation and the contemporaneous real variable are orthogonal to the (serially uncorrelated) disturbance. Nevertheless, we test this orthogonality through the Durbin-Wu-Hausman (denoted Hausman) specification test (HCCME-robust). In principle, the OLS estimator is more efficient than the IV estimator if the null hypothesis is true. 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 entails the use of GMM.[9]

5.2 Estimation Results of the Extended Model

Based on the foregoing description, Table 6 reports results for the extended NKPC model using the four inflation forecasts measures of inflation expectations. Several notable points are summarized below.

First, the serial correlation test and the Akaike Information Criterion (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 extension of the stylized model is generally free of serial correlation. Nonetheless, serial correlation appears to be significant in regressions using Michigan survey data in conjunction with the NFBIPD. One explanation is that the Michigan survey data may incorporate a broader information set than that of the non-farm business sector.

Second, in regressions using SPF data, both HPGDP and CBOGAP are statistically significant. 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. It is also important to note that the joint significance tests on the extra inflation dynamics are rejected in all regressions at the 1 percent level, as indicated by the *p*-values reported in the column headed *p*-($\tilde{\alpha}_{\Delta bj}$), supporting the extension of the NKPC to incorporate additional lagged inflation terms.

It is reassuring that the null hypothesis of no serial correlation in the error term of the extended NKPC up to order four cannot be rejected in all regressions using the SPF survey data. In addition, the *J*-test and the Weak IV test suggest that the IV choice is generally legitimate and statistically strong.

The above findings also are robust to the use of Greenbook and Michigan inflation

[9] It should be noted here that the Hausman test was 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.

forecasts when the GDP deflator inflation is considered. 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.

Another interesting and important finding embedded in Table 6 is associated with the Hausman specification test (HCCME-robust). By construction, small *p*-values of the Hausman test imply significant rejection of the null hypothesis that the OLS is consistent in estimating the NKPC. Therefore, the significant *p*-values reported in the last column in Table 6 suggest that the OLS is inconsistent in most cases and, in particular, (at the 5 percent level) when SPF inflation forecasts are used. As noted above, the survey of professional forecasters is generally undertaken in the middle month of each quarter and hence may contain significant information correlated with the contemporaneous disturbance η_t.

As a final robustness check, we assess subsample estimates of the extended NKPC with subsamples chosen to be close to those used in Gali and Gertler (1999). Empirical results reported in Table 7 suggest that the principle findings that the output gap measures are valid driving force and the extended NKPC is free of serial correlation are robust to the different sub samples[10].

6 Discussion and Conclusions

This paper empirically investigates the New Keynesian Phillips Curve model using directly observed inflation forecasts as measures of inflation expectations. We establish that the commonly used GDP gap measures remain valid driving forces for inflation in the NKPC while the labor income share appears not to be a valid inflation pressure variable. 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) and the selection of instruments may account for the differences between results. In particular, our instrument choice allows for serial correlation to be present in the stylized NKPC and we

[10] 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.

employ observed inflation expectations.

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 extreme 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 to estimate the NKPC models is not the issue of (ir)rationality, but the econometric issue of avoiding an 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 work, however, demonstrates that the NKPC is empirically coherent when the common output gap measures are used. Therefore, monetary policy models should not derive current inflation from expected inflation alone. In this sense, the NKPC may still be a useful part of the toolkit in monetary policy analysis, which nonetheless indicates that the argument in Mavroeidis (2004; 2005) questioning the validity of the NKPC as a model of inflation dynamics may be too strong.

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 leading economic 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 collected 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 are collected from the website of the Federal Reserve Bank of St. Louis, which are published by the relevant U.S. economic departments. The sources of each series are listed below.

In addition, most raw data were transformed prior to empirical work. Monthly available data were transformed into quarterly frequency using the last month observation of the quarter before any further transformation. Real GDP data are used to construct the following five 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 deterministic quadratically detrended log real GDP defined as $\text{QDGAP}=100\times[\ln(GDP_t)-a_0-a_1t-a_2t^2]$; (3) a two-sided Hodrick-Prescott filtered log real GDP with penalty parameter $\lambda=1{,}600$ (HPGAP2S); (4) an one-sided HP filtered log real GDP (HPGAP1S) as in Stock and Watson (1999b) with relative variances q=0.000625 (i.e. smoothness parameter of 1,600). (5) the Christiano-Fitzgerald full sample asymmetric band-pass (one-sided Band Pass) filtered log real GDP (CFGAP) based on Christiano and Fitzgerald (2003); (6) a segmented deterministic linearly detrended log real GDP (LDGAP); and (7) the Baxter and King (1999) band pass filtered log real GDP based on twelve quarters centered moving average (hence the twelve filtered values at beginning and end of the sample are missing).

Sources of the raw data:

BEA	U.S. Department of Commerce: Bureau of Economic Analysis
BLS	U.S. Department of Labour: Bureau of Labour Statistics
CBO	U.S. Congress: Congressional Budget Office
BGF	Board of Governors of the Federal Reserve System
CRB	U.S. Commodity Research Bureau

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)
SPOTP	4	CRB	Spot Markt Price Index: CRB, all commodities (index 1967=100, NSA, M)
FFR	1	BGF	Effective Federal Funds Rate (NSA, M)
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.

Observed Inflation Forecasts Data Series

SPF Data

The SPF inflation forecasts data used in the baseline estimation is the quarterly median forecasts of the 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 used in this chapter are published inflation forecasts for the chain-weighted GDP price index. These forecasts relate 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 the data spanning over 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) were used in our empirical work. The data 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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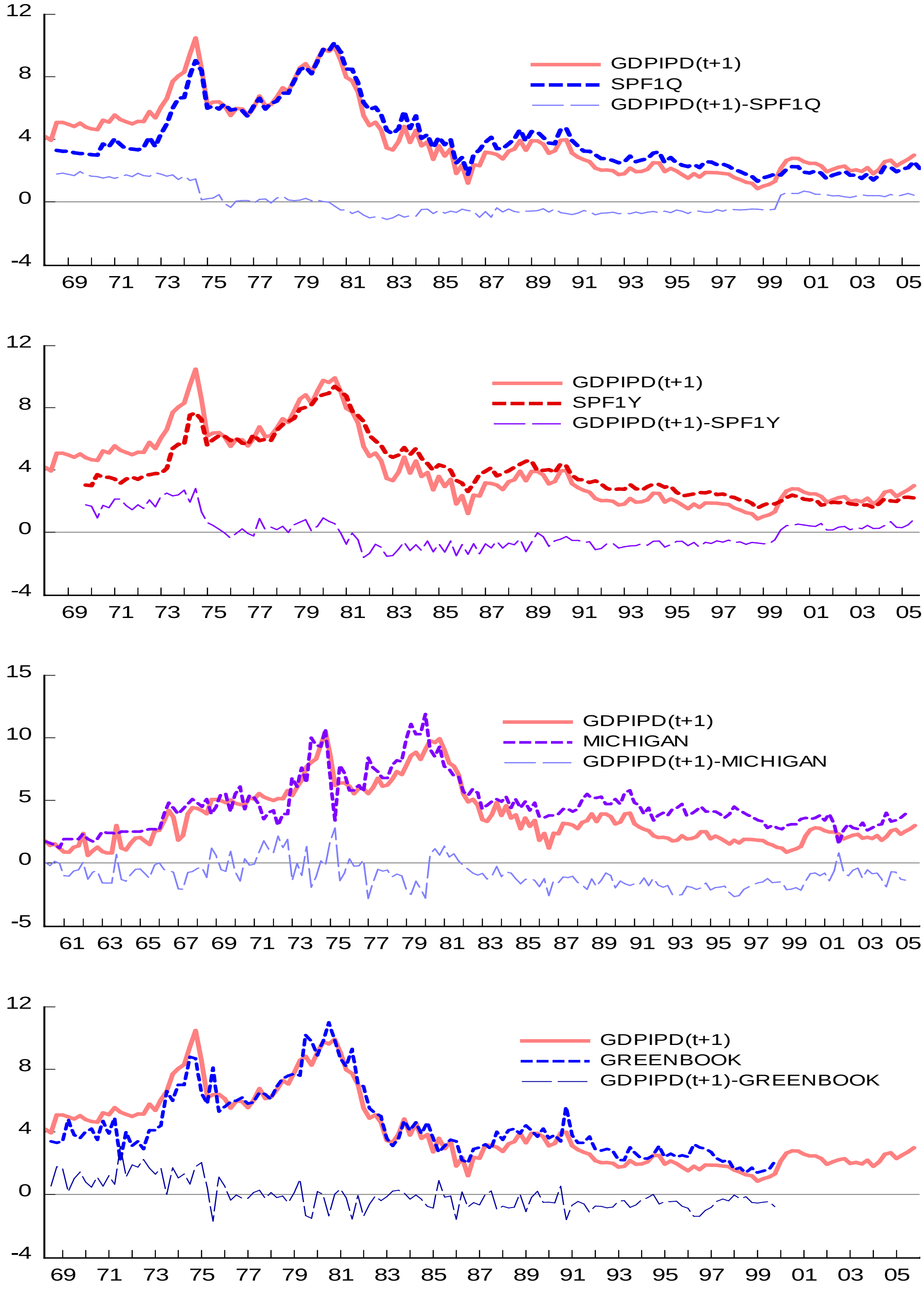
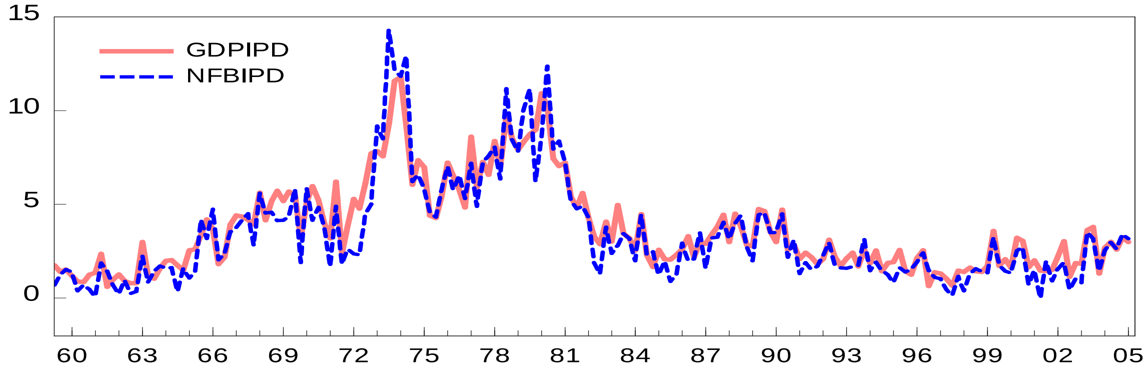
Figure 1 Actual Future GDP Inflation (GDPIPD(t+1)) and Observed Inflation Forecasts



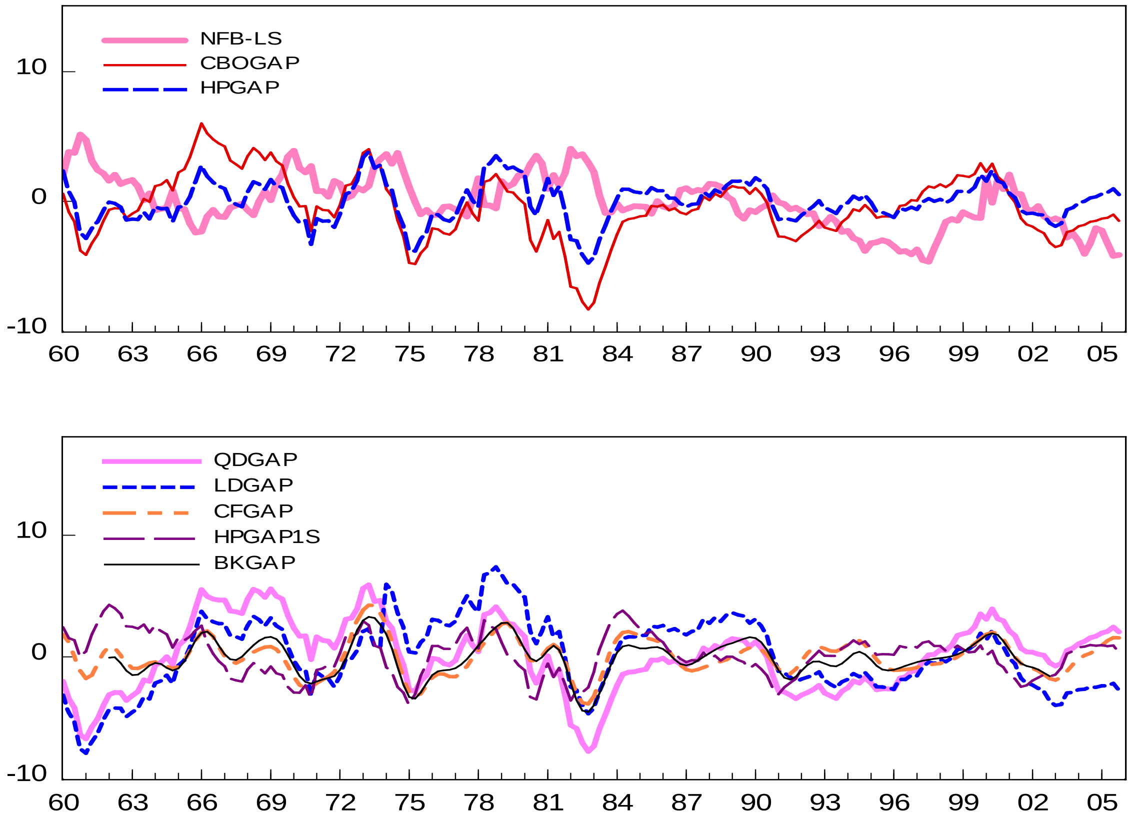
Notes: SPF1Q is the SPF one-quarter-ahead GDP inflation forecasts (1968Q4-2005Q4); SPF1Y is the SPF one-year-ahead GDP inflation forecasts (1970Q1-2005Q4); MICHIGAN is the Michigan one-year-ahead general price inflation forecasts (1960Q1-2005Q2); GREENBOOK is the Greenbook one-quarter-ahead GDP inflation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

Figure 3 The Output Gap Measures and the Labor Income Share: 1960Q1-2005Q4



Notes: In the upper graph, NFB-LS, CBOGAP and HPGAP refer to the labor income share for the non-farm business sector, the output gap computed by using the potential real GDP estimates from the Congressional Budget Office, and the two-side HP filtered GDP gap (with penalty parameter 1,600). In the lower graph, QDGAP, LDGAP, CFGAP and HPGAP1S denote the output gap measures based on a quadratically detrending method, a segmented deterministic linearly detrending method, the Christiano-Fitzgerald full sample asymmetric band-pass filter, the Baxter and King (1999) band pass filter and one-sided HP filter (Kalman filter) respectively; see the Appendix.

Table 1 OLS Estimates of the Stylized NKPC

$\pi_t =$	$y_t =$	$\hat{\alpha}_f$	$\hat{\alpha}_b$	$\hat{\alpha}_y$	$\bar{R}^2$	***p*-auto**
		$\pi_t = c_0 + \alpha_f E_t \pi_{t+1} + \alpha_b \pi_{t-1} + \alpha_y y_t + \eta_t$				
GDPIPD	CBOGAP	0.570 (0.091)	0.455 (0.088)	0.116 (0.035)	0.811	0.000
	HPGAP	0.500 (0.097)	0.491 (0.096)	0.096 (0.056)	0.804	0.000
	NFB-LS	0.494 (0.096)	0.412 (0.088)	0.172 (0.066)	0.813	0.000
NFBIPD	CBOGAP	0.785 (0.095)	0.350 (0.105)	0.155 (0.049)	0.776	0.001
	HPGAP	0.706 (0.105)	0.379 (0.113)	0.147 (0.083)	0.768	0.000
	NFB-LS	0.704 (0.118	0.342 (0.107)	0.095 (0.083)	0.764	0.000
Convex Restriction						
GDPIPD	CBOGAP	0.541 (0.091)	0.459 (0.091)	0.110 (0.032)	0.812	0.000
	HPGAP	0.510 (0.096)	0.490 (0.096)	0.095 (0.057)	0.805	0.000
	NFB-LS	0.570 (0.090	0.430 (0.090)	0.115 (0.066)	0.810	0.000
NFBIPD	CBOGAP	0.610 (0.127)	0.390 (0.127)	0.125 (0.045)	0.768	0.000
	HPGAP	0.594 (0.130)	0.406 (0.130)	0.155 (0.081)	0.765	0.000
	NFB-LS	0.652 (0.110)	0.348 (0.110)	0.120 (0.086)	0.765	0.000

Notes: Inflation expectations are measured by the SPF one-quarter-ahead GDP inflation forecasts over 1968Q4-2005Q4. 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), potential real GDP estimates from Congressional Budget Office (CBO); NFB-LS denotes the non-farm business sector labour income share. ***p***-auto refers to Breusch-Godfrey serial correlation test (up to 4 lags) for residuals computed using the LM test with finite sample adjustment (*F*-statistic).

Table 2 GMM Estimates of the Stylized NKPC Using the SPF1Q Data

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 the 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), and *WeakIV* refers to the statistics of 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 Data

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 (0.223)	0.410 (0.193)	**0.120** (0.040)	0.830	0.003	0.136	1.875
	HPGAP	0.264 (0.198)	0.731 (0.172)	**0.149** (0.056)	0.802	0.030	0.136	2.154
NFBIPD	CBOGAP	0.945 (0.280)	0.272 (0.276)	**0.159** (0.047)	0.749	0.006	0.182	3.117
	HPGAP	0.623 (0.255)	0.481 (0.240)	**0.195** (0.067)	0.748	0.001	0.168	2.560
Convex Restriction								
GDPIPD	CBOGAP	0.438 (0.180)	0.562 (0.180)	**0.106** (0.033)	0.826	0.008	0.130	1.875
	HPGAP	0.279 (0.151)	0.721 (0.151)	**0.146** (0.058)	0.805	0.019	0.217	2.154
NFBIPD	CBOGAP	0.415 (0.195)	0.585 (0.195)	**0.138** (0.044)	0.744	0.001	0.125	3.117
	HPGAP	0.339 (0.203)	0.661 (0.203)	**0.248** (0.079)	0.734	0.000	0.219	2.560

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 that in Table 2.

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								
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								
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. See footnotes to Table 2 relating to diagnostic tests.

Table 5 GMM Estimates of the Stylized NKPC Using Alternative GDP Gap Measures

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	QDGAP	0.316	0.690	**0.147**	0.807	0.006	0.308	4.669*
		(0.144)	(0.137)	(0.034)				
	LDGAP	-0.061	0.951	**0.117**	0.756	0.003	0.125	6.705**
		(0.124)	(0.134)	(0.042)				
	CFGAP	-0.021	0.994	**0.132**	0.751	0.002	0.190	6.171**
		(0.125)	(0.129)	(0.045)				
	HPGAP1S	-0.162	1.149	**0.139**	0.707	0.002	0.127	3.984
		(0.145)	(0.155)	(0.057)				
	BKGAP	0.041	0.937	**0.153**	0.770	0.002	0.317	6.120**
		(0.123)	(0.122)	(0.047)				
	NFB-LS	-0.012	0.977	**0.022**	0.749	0.007	0.100	6.768**
		(0.137)	(0.163)	(0.071)				
NFBIPD	QDGAP	0.677	0.425	**0.214**	0.786	0.012	0.230	7.624**
		(0.257)	(0.237)	(0.051)				
	LDGAP	0.253	0.662	**0.155**	0.740	0.000	0.118	9.016**
		(0.253)	(0.212)	(0.051)				
	CFGAP	0.254	0.760	**0.187**	0.726	0.000	0.072	9.413**
		(0.239)	(0.213)	(0.079)				
	HPGAP1S	0.308	0.725	**0.083**	0.725	0.000	0.129	5.599*
		(0.325)	(0.286)	(0.091)				
	BKGAP	0.320	0.716	**0.203**	0.735	0.001	0.154	9.203**
		(0.242)	(0.212)	(0.071)				
	NFB-LS	0.455	0.536	**0.126**	0.753	0.000	0.148	10.025**
		(0.234)	(0.210)	(0.088)				
Convex Restriction								
GDPIPD	QDGAP	0.303	0.697	**0.145**	0.807	0.006	0.399	4.669*
		(0.137)	(0.137)	(0.033)				
	LDGAP	0.101	0.899	**0.061**	0.766	0.004	0.112	6.705**
		(0.142)	(0.142)	(0.029)				
	CFGAP	0.020	0.980	**0.131**	0.755	0.003	0.273	6.171**
		(0.136)	(0.136)	(0.045)				
	HPGAP1S	-0.148	1.148	**0.142**	0.709	0.002	0.188	3.984
		(0.158)	(0.158)	(0.058)				
	BKGAP	0.082	0.918	**0.152**	0.775	0.002	0.430	6.120**
		(0.128)	(0.128)	(0.048)				
	NFB-LS	0.001	0.999	**-0.005**	0.744	0.005	0.158	6.768**
		(0.149)	(0.149)	(0.048)				
NFBIPD	QDGAP	0.469	0.531	**0.195**	0.773	0.003	0.516	7.624**
		(0.204)	(0.204)	(0.042)				
	LDGAP	0.391	0.609	**0.117**	0.751	0.000	0.090	9.016**
		(0.207)	(0.207)	(0.048)				
	CFGAP	0.227	0.773	**0.189**	0.726	0.000	0.130	9.413**
		(0.196)	(0.196)	(0.080)				
	HPGAP1S	0.241	0.759	**0.088**	0.719	0.000	0.219	5.599*
		(0.252)	(0.252)	(0.088)				
	BKGAP	0.249	0.751	**0.209**	0.729	0.000	0.298	9.203**
		(0.187)	(0.187)	(0.072)				
	NFB-LS	0.467	0.533	**0.121**	0.755	0.000	0.223	10.025***
		(0.204)	(0.204)	(0.091)				

Notes: Inflation expectations are measured by the SPF one-quarter-ahead inflation forecasts (1968Q4-2005Q4). IV set as in Table 2. QDGAP, LDGAP, CFGAP and HPGAP1S denote output gap measures based on quadratic detrending, segmented deterministic linearly detrending, the Christiano-Fitzgerald full sample asymmetric band-pass filter, the Baxter and King (1999) band pass filter and one-sided HP filter (Kalman filter) respectively; see the Appendix. See footnotes to Table 2 relating to diagnostic tests.

Table 6 GMM Estimates of the Extended NKPC

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

Table 6 (continued)

	Regression		Baseline Estimates					Diagnostic Tests			
	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. See footnotes to Table 2 relating to other diagnostic tests.

Table 7 Sub-Sample GMM Estimates of the Extended NKPC

Regression		Baseline Estimates					Diagnostic Tests			
Sub-sample	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
GDPIPD										
1968Q4-1997Q4	HPGAP	0.414 (0.167)	0.691 (0.144)	**0.273** (0.051)	0.001	0.81	0.564	0.182	20.57****	0.025
	CBOGAP	0.049 (0.197)	0.924 (0.166)	**0.335** (0.084)	0.003	0.77	0.167	0.063	13.47***	0.005
1968Q4-1989Q4	HPGAP	0.369 (0.176)	0.714 (0.149)	**0.267** (0.058)	0.010	0.74	0.689	0.148	15.55***	0.015
	CBOGAP	0.024 (0.201)	0.929 (0.170)	**0.313** (0.089)	0.020	0.69	0.273	0.090	9.88**	0.002
1980Q1-2005Q4	HPGAP	0.319 (0.206)	0.603 (0.191)	**0.111** (0.050)	0.088	0.76	0.035	0.005	15.13***	0.099
	CBOGAP	0.293 (0.199)	0.580 (0.178)	**0.242** (0.066)	0.022	0.77	0.156	0.018	15.00***	0.070
Convex Restriction										
1968Q4-1997Q4	HPGAP	0.262 (0.144)	0.738 (0.144)	**0.241** (0.052)	0.004	0.80	0.464	0.055	20.57****	0.018
	CBOGAP	0.096 (0.155)	0.904 (0.155)	**0.327** (0.081)	0.003	0.78	0.206	0.107	13.47***	0.008
1968Q4-1989Q4	HPGAP	0.281 (0.152)	0.719 (0.152)	**0.240** (0.055)	0.026	0.74	0.601	0.086	15.55***	0.012
	CBOGAP	0.081 (0.165)	0.919 (0.165)	**0.309** (0.087)	0.017	0.70	0.329	0.155	9.88**	0.005
1980Q1-2005Q4	HPGAP	0.362 (0.202)	0.638 (0.202)	**0.144** (0.045)	0.068	0.75	0.278	0.009	15.13***	0.084
	CBOGAP	0.421 (0.202)	0.579 (0.202)	**0.256** (0.072)	0.055	0.75	0.255	0.009	15.00***	0.120

Table 7 (continued)

		Baseline Estimates					Diagnostic Tests			
		$\tilde{\alpha}_f$	$\tilde{\alpha}_b$	$\tilde{\alpha}_y$	p-$(\tilde{\alpha}_{\Delta bj})$	$\bar{R}^2$	p-auto	p-over	Weak IV	Hausman
NFBIPD										
1968Q4-1997Q4	HPGAP	0.701 (0.200)	0.455 (0.142)	**0.246** (0.066)	0.006	0.79	0.168	0.115	23.03****	0.020
	CBOGAP	0.424 (0.245)	0.596 (0.170)	**0.305** (0.113)	0.003	0.77	0.103	0.052	10.60***	0.023
1968Q4-1989Q4	HPGAP	0.674 (0.228)	0.473 (0.146)	**0.250** (0.073)	0.008	0.74	0.188	0.074	15.90***	0.023
	CBOGAP	0.395 (0.274)	0.599 (0.178)	**0.287** (0.122)	0.005	0.72	0.155	0.040	7.23**	0.022
1980Q1-2005Q4	HPGAP	0.427 (0.178)	0.541 (0.132)	**0.147** (0.072)	0.031	0.71	0.004	0.197	23.87****	0.362
	CBOGAP	0.321 (0.160)	0.572 (0.119)	**0.379** (0.118)	0.004	0.73	0.004	0.354	22.92****	0.133
Convex Restriction										
1968Q4-1997Q4	HPGAP	0.463 (0.130)	0.537 (0.130)	**0.215** (0.068)	0.001	0.78	0.092	0.059	23.03****	0.011
	CBOGAP	0.382 (0.129)	0.618 (0.129)	**0.317** (0.104)	0.001	0.77	0.089	0.073	10.60***	0.002
1968Q4-1989Q4	HPGAP	0.482 (0.138)	0.518 (0.138)	**0.214** (0.073)	0.001	0.74	0.133	0.104	15.90***	0.011
	CBOGAP	0.406 (0.139)	0.594 (0.139)	**0.285** (0.116)	0.002	0.72	0.146	0.063	7.23**	0.003
1980Q1-2005Q4	HPGAP	0.465 (0.134)	0.535 (0.134)	**0.159** (0.056)	0.038	0.71	0.004	0.259	23.87****	0.356
	CBOGAP	0.479 (0.131)	0.521 (0.131)	**0.374** (0.111)	0.037	0.72	0.019	0.235	22.92****	0.212

Notes: Expected inflation is measured by the SPF1Q in all regressions. Other notes as for Table 6.