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Abstract

The New Keynesian Phillips Curve (NKPC) model of inflation dynamics based on forward-looking expectations is of great theoretical significance in monetary policy analysis. Empirical studies, however, often find that inflation inertia, rather than inflation expectations, dominate the dynamics of the short-run aggregate supply curve. This paper examines this inconsistency by investigating multiple structural changes in the NKPC for the US over 1968-2005. Both inflation expectations survey data and a rational expectations approximation are used to capture expectations. We find that forward-looking behavior plays a smaller role during the high and volatile inflation regime to 1981 than in the subsequent period of moderate inflation, providing support for the empirical coherence of sticky prices models over the last two decades. A further break in the intercept of the NKPC is identified around 2001 and this may be associated with monetary policy in the recent period.

Keywords: New Keynesian Phillips Curve, inflation survey forecasts, inflation inertia, structural breaks, monetary policy

JEL Classification: E31, E37, E52, E58

“The theories usually stop short, however, of specifying models of aggregate supply that are intended to hold generally”.

---David Romer
Advanced Macroeconomics, 2006, p. 257

1. Introduction

Recent empirical studies of the New Keynesian Phillips Curve (NKPC) have found very different results as to the extent of forward- versus backward-looking behavior. For example, Gali and Gertler (1999), Sborndone (2002; 2005), and Gali, Gertler, and Lopez-Salido (2005) find a predominant role for future expected inflation, while Fuhrer and Moore (1995), Fuhrer (1997), Rudebusch (2002), Linde (2005), Roberts (2005), and Rudd and Whelan (2005) find the backward-looking component to be more important. Resolving this issue is, nonetheless, crucial for understanding the driving process for inflation, namely whether it is driven only by the expected discounted sum of current and future values of the output gap (as advocated by Gali and Gertler 1999), or whether lagged inflation also pressures inflation (as in Fuhrer 1997). More importantly, different inflation behaviors can lead to strikingly distinct results in assessing monetary policy and hence may render very different policy recommendations. For example, Ball (1999) and Svensson (1999b) find that nominal income growth targeting is destabilizing in a backward-looking model, whereas McCallum (1999) and McCallum and Nelson (1999) draw the opposite conclusion using a forward-looking model.

Despite the burgeoning number of studies on the NKPC, little attention has been given to potential structural changes in the relationship. In particular, over the long span of the post-1960s, both monetary policy and the economic performance in the U.S. have experienced considerable changes. The impact of these is illustrated in Figure 1, which depicts the evolution of the quarterly U.S. GDP deflator inflation (at an annualized rate) and the U.S. monetary policy instrument, the Federal Funds Rate (FFR), over 1960Q1-2005Q4. This shows a progressive rise in inflation rose from 1970 to the beginning of the 1980s and the subsequent decline. The FFR exhibits similar patterns, reflecting the responses of monetary policy to inflation. Indeed, in a forward-looking monetary policy framework, Clarida, Gali, and Gertler (2000) formally document that the response of the FFR to inflation (and the output gap) differs under the Federal Reserve chairmanships of Paul Volcker and Alan Greenspan compared with the pre-Volcker era.

Because the NKPC is an important ingredient in monetary policy analysis (e.g. Clarida, Gali, and Gertler 1999), it is plausible that shifts in monetary policy regimes and changes in the transmission of monetary policy could induce structural shifts in the NKPC. A growing literature in the univariate context, including Alogoskoufis and Smith (1991), Taylor (2000), Cogley and Sargent (2001), Willis (2003), Levin and Piger (2004), and Zhang (2006), points to a significant reduction in inflation persistence since the early 1980s. Such a decline in persistence may influence firms' pricing behavior (Taylor, 2000) and in turn affect the short-run dynamics of the aggregate supply curve.

The purpose of this paper is to characterize the nature of possible structural changes in the NKPC over time. In doing so, our analysis focuses on NKPC estimates that use observed inflation survey data to measure inflation expectations. By using a range of inflation forecast series (the Survey of Professional Forecasters, the Michigan Survey and the Greenbook forecasts), we aim to capture peoples' responses to economic performance and hence to more accurately measure inflation expectations than approaches explicitly based on rational expectations; see also Roberts (1995). Our approach is supported by recent studies that present evidence in favor of using observed inflation forecasts as measures of inflation expectations in monetary policy analysis (Croushore, 1993). Nevertheless, we also check the robustness of our results by employing a rational expectations approach.

To preview our results, we find that forward-looking behavior plays a smaller role during the high and volatile inflation regime of the 1970s than over recent decades. Therefore, a predominant role for inflation expectations, with corresponding empirical support for sticky prices models, applies only for the most recent period of moderate inflation and low inflation persistence. The role of structural breaks is further emphasized by our finding (when survey inflation expectations are used) that the intercept of the NKPC experiences an additional break around 2001.

This paper is organized as follows. Section 2 discusses the relevant literature, focusing on the debate concerning forward- versus backward-looking behavior in the NKPC. Section 3 outlines the economic model and the econometric structural break tests methodology used. In section 4 we document the timing and nature of structural changes in the NKPC, employing observed inflation forecasts and using a dynamic model that is free from serial correlation, while Section 5 checks the robustness of these results to the use of the more common "stylized" NKPC model and to employing a rational inflation expectations approximation. Section 6 then discusses the implications of our empirical findings and section 7 provides concluding remarks.

2. Literature Review

Recent theoretical contributions by Fuhrer and Moore (1995), Roberts (1995), Fuhrer (1997), Yun (1996), Goodfriend and King (1997), Clarida *et al*. (1999), Gali and Gertler (1999), Jensen (2002), Mankiw and Reis (2002), Woodford (2003), and Christiano, Eichenbaum and Evans (2005), among others, have advanced understanding of the New Keynesian short-run aggregate supply curve as a fundamental ingredient in monetary policy analysis. This literature emphasizes the important distinction between models that incorporate a dominant forward-looking behavior and those that do not.

The typical micro-founded NKPC can be expressed as

$$\pi_t = \pi_t^e + \alpha_y y_t \tag{1}$$

where π_t is the rate of inflation, y_t denotes the output gap or real marginal cost, and π_t^e is the inflation that would prevail if output were at its natural rate (i.e. the output gap is zero) and supply shocks are absent; π_t^e is sometimes known as core or underlying inflation (Romer 2006, p. 255). A fundamental distinction of the NKPC from the traditional Phillips curve lies in the formulation of π_t^e. In particular, Gali and Gertler (1999) elegantly propose that core inflation in the micro-founded NKPC is given by

$$\pi_t^e = \alpha_f E_t \pi_{t+1} + \alpha_b \pi_{t-1} \tag{2}$$

where $E_t \pi_{t+1}$ denotes expected inflation for period t+1 given information available up to period t. Combining (1) with (2), the "New" Keynesian short-run aggregate supply curve is

$$\pi_t = \alpha_f E_t \pi_{t+1} + \alpha_b \pi_{t-1} + \alpha_y y_t, \quad 0 \le \alpha_f \le 1, 0 \le \alpha_b \le 1, \text{ and } \alpha_y > 0. \tag{3}$$

In addition, recent literature of inflation targeting, notably Svensson (1999a; 1999b; 2000), suggests a more general specification for core inflation π_t^e taking account of a specific inflation target, viz

$$\pi_t^e = \alpha_f E_t \pi_{t+1} + \alpha_b \pi_{t-1} + \alpha^* \pi^* \tag{4}$$

where π^* denotes the constant inflation target of the central bank[1].

When $\alpha_f = 0$ and $\alpha_b = 1$, (3) becomes the well-known adaptive expectations Phillips curve with dominant inflation stickiness. Alternatively, $\alpha_f = 1$ and $\alpha_b = 0$ gives rise to the purely forward-looking NKPC with price stickiness, which implies that inflation is driven by

[1] In Svensson's (2000) setup, the forward-looking coefficient is set to zero.

the expected discounted sum of current and future values of the real variable y_t only. On the other hand, if both α_f and α_b are non-negligible, the implied inflation process becomes

$$\pi_t = \alpha_b \sum_{i=1}^{\infty} \alpha_f^{i-1} \pi_{t-i} + \alpha_y \sum_{i=1}^{\infty} \alpha_f^{i-1} E_t y_{t+i-1} \tag{5}$$

in which lagged inflation also drives inflation.

Given the crucial role of α_f and α_b, it is not surprising that these parameters have attracted increasing attention in recent literature. For example, Ball (1993; 1994) and Fuhrer (1997) suggests that the NKPC with a large value of α_f is at odds with the costly disinflation experience in the U.S. On the other hand, Jensen (2002), Rudebusch (2002), Walsh (2003b), Svensson and Woodford (2003; 2004), McCallum and Nelson (2004; 2005), and Svensson (2005) all suggest that a good monetary policy targeting rule under one set of parameter values can be a dismal one under alternative values of the forward- and backward-looking parameters. As discussed in Roberts (2005), by employing a monetary policy analysis framework incorporating a purely forward-looking NKPC, Rotemberg and Woodford (1997) find that an optimized monetary policy rule should maintain a high degree of interest rate smoothing in conjunction with a small response to the output gap. In contrast, Levin, Wieland and Williams (1999) show that in a Phillips curve model with a dominant role for inflation inertia, the optimized policy rule ought to have a moderate interest rate smoothing but a large response to the output gap.

Consequently, recent literature, including Rudebusch (2002) and Walsh (2003a), emphasizes the importance of empirical evidence on the forward- and backward-looking components in the NKPC. There is, however, also a considerable debate in relation to this empirical evidence. In particular, Gali and Gertler (1999) and Gali *et al*. (2005) employ Generalized Method of Moments (GMM) in conjunction with rational expectations to estimate (3) with unit labor cost as the measure of marginal cost, and conclude that inflation inertia is much less important than suggested by Fuhrer and Moore (1995) and Fuhrer (1997) over the period since 1960. Sbordone (2002, 2005) estimates a closed form solution of the NKPC and derives results consistent with Gali and Gertler (1999), apparently confirming the dominant role of forward-looking behavior in the NKPC.

Rudd and Whelan (2005), however, question these findings. They argue that the small lagged inflation coefficient obtained by Gali and Gertler (1999) is induced by an omitted variable problem in conjunction with the use of instrumental variables (IV). By estimating an alternative closed form inflation equation, Rudd and Whelan (2005) find the backward- rather than the forward-looking behavior predominates in inflation dynamics. Earlier work by Fuhrer and Moore (1995), Fuhrer (1997), as well as recent empirical studies of Rudebusch (2002), Estrella and Fuhrer (2002, 2003), Adam and Padula (2003), Fuhrer and Olivei (2004), Fuhrer (2005), Linde (2005), and Zhang, Osborn and Kim (2006) provide generally consistent evidence with Rudd and Whelan (2005).

Despite intensive empirical investigation of the NKPC, potential changes in behavior over different regimes have received little attention. However, with the profound structural changes in the U.S. economy (Willis 2003) and monetary policy (Judd and Rudebusch 1998, Brainard and Perry 2000, and Clarida *et al*. 2000), there are several reasons why the dynamic process of the NKPC may also have changed over the past half century. For example, Willis (2003) shows that changes since the beginning of the 1980s in the U.S. economy, including the labor, goods and capital markets, are likely to affect firms' pricing behavior. Since the micro foundations imply that α_f and α_b are functions of "deep" parameters relevant to firms' pricing behavior, changes in such behavior may induce shifts in the aggregate NKPC.

Perhaps more importantly, monetary policy influences inflation through a policy transmission mechanism, and hence any shift in the conduct of monetary policy may affect inflation dynamics. Indeed, Clarida *et al*. (2000) show that the systematic change in monetary policy at the end of the 1970s led to a low and less volatile inflation regime. Brainard and Perry (2000) also propose that different monetary policy reactions in the U.S. since the 1960s may induce shifts in price adjustment equations. In addition, Taylor (2000) suggests that the reduction of firms' pricing power over the most recent two decades is positively correlated with the (low) level of inflation, indicating the interaction between monetary policy and short-run inflation dynamics. The results in Taylor (2000) also imply that the structural change of the U.S. economy discussed by Willis (2003) may be correlated with shifts in monetary policy.

By investigating the structural stability of the NKPC, the aim of this paper is to provide a better understanding of inflation dynamics and further insight into the ongoing debate on sticky inflation and sticky prices models in relation to the US. In doing so, we extend the small group of papers that estimate the NKPC using observed inflation forecasts (including Roberts 1995, Adam and Padula 2003) to consider the possibility of structural breaks occurring at one or more unknown time points.

3. Methodology

Here we first discuss the form of the NKPC model employed in our empirical analysis, before considering the econometric methodology of the structural break tests.

3.1 The Economic Model

The NKPC model can be derived from an economic environment similar to that of Calvo (1983), in which firms are assumed to revise their prices in any given period with a fixed probability 1 - θ. 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) further assume that the backward-looking firms adjust their price using

$$p_t^B = p_{t-1}^* + \pi_{t-1} \tag{6}$$

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, quarterly inflation is relatively noisy, so that backward-looking agents may consider a weighted average of past inflation rather than the stylized single lag in (6), so that

$$p_t^B = p_{t-1}^* + \rho(L)\pi_{t-1} \tag{7}$$

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 $\rho(1) = 1$. For quarterly models, q = 4 appears reasonable and allows the possibility that firms look back up to a year.

Using (7) in conjunction with the usual assumptions in Calvo's (1983) model, it is shown in the appendix that the NKPC model has the form

$$\pi_t = c_0 + \alpha_f E_t \pi_{t+1} + \alpha_b \pi_{t-1} + \sum_{i=1}^{3} \alpha_{\Delta bi} \Delta\pi_{t-i} + \alpha_y y_t + \eta_t \tag{8}$$

where the constant term c_0 reflects the steady-state inflation rate and η_t captures random factors which also affect inflation, such as supply shocks. Notice that the representation in (8) summarises the impact of past levels of inflation on current inflation through the single coefficient α_b, which facilitates later structural change tests[2].

As shown in Zhang, Osborn and Kim (2006), (8) in general is free of serial correlation and appears sufficient to characterize the empirical NKPC relationship for the U.S. over the

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[2] Obviously, (8) is equivalent to a representation that includes four lags in the levels of inflation. Compared to that representation, α_b is equal to the sum of the four lagged inflation coefficients.

1960-2005 period. Therefore, in what follows we focus on (8) as our baseline specification of the NKPC. However, as a robustness assessment, we also consider the stylized model with a single lag of inflation, namely

$$\pi_t = c_0 + \alpha_f E_t \pi_{t+1} + \alpha_b \pi_{t-1} + \alpha_y y_t + \eta_t \,. \tag{9}$$

3.2 Econometric Methodology

As already noted, shifts in monetary policy are well documented in the postwar period. For instance, 1979Q3 is the start of the Volcker-Greenspan era during which monetary policy differed significantly from the previous regime; see Clarida *et al.* (2000). While the link between monetary policy and inflation makes it plausible that such changes may lead to structural breaks in the parameters of the NKPC, any such effect and its timing depends on the behavior of economic agents. Since the dates of potential change points in the NKPC are therefore unknown, we perform break tests using the methodology developed by Andrews (1993) and Andrews and Ploberger (1994), taking into account the possibility of multiple breaks through the Bai and Perron (1998, 2003) repartition procedure.

Prior to examining these tests, several econometric issues should be noted. First, inflation forecasts may be influenced by information relating to the current period. For example, the forecasts from the Survey of Professional Forecasters (SPF) are generally obtained in the middle of the quarter and hence are likely to be correlated with the supply shocks represented by η in (8). In addition, y_t is also likely to be correlated with the contemporaneous noise, since demand shocks may influence both variables. More importantly, as will be evident in the empirical estimation, Durbin-Wu-Hausman specification tests indicate that in most cases OLS is not consistent because the null hypothesis that $E_t\pi_{t+1}$ and y_t can be treated as exogenous is rejected at conventional levels of significance. Therefore, we use IV, or more generally the Generalized Method of Moments (GMM) estimator.

The baseline IV set used in estimating (8) consists of two lags of each of inflation expectations, the output gap, unemployment rate, growth rate of money aggregate (M2), and the short-term interest rate. Since the NKPC in (8) is generally free of significant serial correlation in empirical estimations, lagged inflation values on the right-hand-side of (8) are used as instruments for themselves. In addition, the baseline estimations are verified through the IV serial correlation test (Davidson and MacKinnon, 1993, and Godfrey, 1994), Hansen's

(1982) *J*-test for overidentifying restrictions, and the Stock and Yogo (2003) generalized *F*-test for weak IV.

Based on the preceding design, we carry out formal unknown structural break tests. Specifically, write the NKPC model in vector notation as

$$Y = X_1\beta_1 + X_2\beta_2 + \eta \tag{10}$$

where Y consists of observations on inflation, π_t, and the matrix of explanatory variables in (8) is $X = [X_1\ X_2]$. Our focus of interest is the coefficients α_f, α_b that represent forward- and backward-looking behavior in (8), together with the intercept whose changes may capture shifts in the inflation target, or its perception by agents, through (4). In this case the stability test relates to the coefficient subvector $\beta_2 = (c_0,\ \alpha_f, \alpha_b)'$, although other subvectors are also considered in our analysis. The break date is indexed by $\tau \in [0,1]$, which splits the entire sample into two subsamples, say $s1 = \tau T$ and $s2 = (1-\tau)T$, where T refers to the total sample size available for estimation.

Denoting observations relating to the first subsample by the superscript $s1$, the IV estimate for β_2 over s1 is given by

$$\tilde{\beta}_2^{s1} = [W_2^{s1}{}' M_{W_1}^{s1} W_2^{s1}]^{-1} W_2^{s1}{}' M_{W_1}^{s1}\, y^{s1} \tag{11}$$

where $M_{W_1}^{s1} = I_{s1} - P_{W_1}^{s1}, W_i^{s1} = P_Z^{s1} X_i^{s1}\ (i = 1, 2)$, Z denotes the matrix of observations for the instrumental variables and P is the projection matrix for the observations indicated, for example $P_X = X(X'X)^{-1}X'$. The IV estimator for the second subsample $s2$ is defined analogously to (11). In addition, the heteroscedasticity consistent (HCCME) covariance matrix estimates for β_2 over the separate subsamples are computed by

$$\tilde{V}(\tilde{\beta}_2^{si}) = (W^{si}{}'W^{si})^{-1} W^{si} \tilde{\Omega}^{si} W^{si} (W^{si}{}'W^{si})^{-1} \quad i = 1, 2, \tag{12}$$

where $\tilde{\Omega}^{si} = diag(\tilde{\eta}^{si}\tilde{\eta}^{si}{}')$ and $\tilde{\eta}^{si}$ are the residuals for the corresponding subsample.

Given τ, the *Wald* statistic for testing the null hypothesis $\beta_2^{s1} = \beta_2^{s2}$ is

$$Wald_T(\tau) = [\tilde{\beta}_2^{s1} - \tilde{\beta}_2^{s2}]'[\tilde{V}(\tilde{\beta}_2^{s1}) + \tilde{V}(\tilde{\beta}_2^{s2})]^{-1}[\tilde{\beta}_2^{s1} - \tilde{\beta}_2^{s2}]. \tag{13}$$

The Andrews-Ploberger *Sup-Wald* statistic for testing a break at an unknown point is then computed as the maximum value of *Wald*-statistic in (13) over all possible break points (e.g. $\tau \in [0.15,\ 0.85]$). The associated exponential-*Wald* statistics, given by

$$ExpWald = \ln \int_{\tau_{\min}}^{\tau_{\max}} \exp[0.5 Wald_T(\tau)] d\tau \ , \tag{14}$$

are also reported, as Hansen (2000) suggests these may be preferred in dynamic models in the presence of structural changes in marginal distributions[3]. Note that, in the context of the stylized NKPC model (9), these statistics are implemented with the Newey-West (fixed bandwidth) HAC matrix using the Bartlett kernel, in order to account for serial correlation that may be present in this case. We apply *Sup-Wald* and *ExpWald*, with asymptotic *p*-values computed using the method of Hansen (1997).

In order to capture possible multiple breaks, we sequentially apply the structural breaks tests to subsamples and perform the refined (repartition) procedure suggested by Bai and Perron (1998, 2003). That is, if the null hypothesis of stability is rejected, then a break point is estimated as the date corresponding to the *Sup-Wald* statistic and the sample is divided into two subsamples at this date. The stability tests are then applied to each subsample to estimate any additional breaks[4]. If multiple structural break points are indicated, their dates are refined (re-estimated). For example, suppose two break dates ($\tilde{k}_i, i = 1, 2$) are identified and $\tilde{k}_1 < \tilde{k}_2$. Then $\tilde{k}_1$ is re-estimated using the subsample [1, $\tilde{k}_2$], and, likewise, $\tilde{k}_2$ is refined using the subsample [$\tilde{k}_1$, T]. The resulting estimate has the same convergence rate as in the case of simultaneous estimation of multiple breaks. Because the limiting distribution of the simultaneous multiple breaks approach is unclear in the linear GMM context[5], the sequential refinement procedure is particularly appealing for our case.

4. Analysis Using Observed Inflation Forecasts

4.1 The Data

Empirical NKPC investigations involve series for inflation, π_t, inflation expectations, $E_t\pi_{t+1}$, and a measure of the output gap y_t. To evaluate structural changes in the context of a standard measure of inflation and to facilitate comparisons with the literature, we measure

[3] We also computed the average-*Wald* statistic of Andrews and Polberger (1993, 1994). However, these provided qualitatively similar results to the other statistics and hence are not reported.

[4] In principle, this procedure is repeated until no further breaks are identified. However, the total sample size available and the number of instruments used make it infeasible to repeat the partitioning more than once in our application.

[5] We thank Pierre Perron for pointing this out to us.

inflation by the annualized quarterly growth rate of the GDP deflator (that is 400 times the first difference of the log GDP deflator). The output gap is obtained from the estimates of real potential GDP published by the Congressional Budget Office.

We employ four different inflation forecasts in the analysis of this section, namely the one-quarter and one-year ahead median forecasts from the SPF (denoted SPF1Q and SPF1Y respectively), the Greenbook one-quarter-ahead forecasts (Greenbook), and one-year-ahead general price inflation forecasts from the Michigan survey (Michigan)[6]. With the exception of the Michigan forecasts, all specifically relate to GDP inflation[7]. Figure 2 plots the four inflation forecasts, where the data are lined up according to the quarter in which the forecasts are collected. This figure suggests similar general patterns amongst these survey data series, although (not surprisingly) there are some differences in detail.

As the SPF data is based on professional forecasters, the Greenbook forecasts are prepared within the Fed, while the Michigan survey aims to capture the views of the general public, these series represent different groups of agents with (presumably) different information sets and hence their use ensures the relative robustness of our investigation. The sample sizes in our empirical estimations are dictated by the availability of the four inflation forecasts, which cover 1968Q4-2005Q4, 1970Q1-2005Q4 for the one-quarter and one-year ahead (respectively) SPF forecasts, 1968Q3-1999Q4 and 1968Q3-2005Q2, respectively, for Greenbook and Michigan. Note, in particular, that the final Greenbook forecast is made in 1999, due to their five year publication lag.

4.2 Structural Break Test Results

Table 1 summarizes the results of the Andrews-Ploberger unknown structural break tests for the NKPC model (8) using each of the four inflation forecasts as the measure of inflation expectations. In the context of (10), Overall, (c_0, α_f, α_b) and $\alpha_{\Delta b}$ define the relevant subvector β_1 for joint stability tests, while the other results refer to individual tests for the indicated coefficients. All tests are performed over the central 70% of the sample (or subsample) observations available for estimation[8]. The columns under *p*-Sup, and *p*-Exp denote *p*-values associated with the corresponding Andrews-Ploberger test statistics for the

[6] Due to the lack of a quantitative question, earlier Michigan survey data (e.g. prior to 1967) may be of distinctly lower quality (Rudebusch, 2002) and hence the Michigan data (mean values) employed here starts from 1968Q3 as in Rudebusch (2002).

[7] For the SPF data, before 1992Q1, the forecasts correspond to GNP deflator inflation.

[8] The searching intervals for these tests corresponding to the different inflation forecasts vary slightly, but are mostly from the mid-1970s to the mid-1990s.

null hypothesis of no structural change, while the column labeled Date reports the estimated break date corresponding to the *Sup-Wald* statistic.

As can be seen from the whole sample results in Table 1, *p*-values for the break test statistics testing overall model stability are always highly significant, with the two statistics providing similar results. That is, the NKPC is statistically unstable over 1968-2005 and the strongest evidence of change relates to the intercept, forward- and backward-looking inflation coefficients[9]. Further, the break date estimates corresponding to these parameters cluster around 1975 or 1981.

The remaining columns investigate the possibility of multiple breaks and implement the Bai and Perron (1998, 2003) refinement procedure. Specifically, break tests are computed on subsamples taking 1975Q1 and 1981Q1 as the break dates. However, the number of observations available prior to 1975Q1 make it infeasible to apply the tests to this subsample. Further, it should be noted that, after allowing for lags, there are generally less than 45 observations available before 1981 for estimation. With seven regressors and 15 instruments, the asymptotic Andrews-Ploberger tests may suffer from substantial distortions in this case. This issue is particularly serious for the overall test, and hence results are also not reported for this test over the pre-1981 sample.

With the exception of results using Greenbook forecasts, all other cases in Table 1 indicate the presence of multiple breaks in the NKPC. When Greenbook inflation forecasts are used, the evidence points to a 1975 break, but there is little indication of further breaks when the post-1975 subsample is considered[10]. However, the Overall and/or (c_0, α_f, α_b) results with the other forecast series typically indicate a break in the NKPC in 1981, with the post-1981 subsample finding a further break between 2000 and 2002. Thus, three possible breaks are revealed in these cases, namely around 1975, 1981 and 2000.

Recognising the possibility of breaks in 1975 and 2000, the final set of results in Table 1 reassesses the evidence for a mid-sample break. Whether the whole sample, or the post-1975 or 1975-2000 subsamples are used, the 1981 break appears to be a robust result for all cases except the Greenbook forecasts[11,12].

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[9] It might be noted that the *p*-values associated with α_y in regressions using SPF1Q and SPF1Y may be unreliable since the implied break date 2000Q1 corresponds to the polar point in the search interval.

[10] The 1996Q2 break indicated for the output gap coefficient may be unreliable, as it occurs at an extreme of the searching interval.

[11] This break is also indicated by graphs of the value of the sequential *Wald* statistic computed for the whole

The dating of other breaks is more difficult. Conditioning on the 1981 break, the evidence for a break in 1975 largely disappears, with the exception of when the SPF1Y forecasts are employed. On the other hand, the structural break tests over the post-1981 subsample consistently suggest a further break around the beginning of the 2000s, which confirms evidence found for a break around this period in some tests for the post-1975 period. Nevertheless, this potential break is close to the end of the searching intervals[13], which entails further investigation of whether the break is induced by the unreliable estimates near the extreme of the sample.

For this investigation, we condition on a break in 1981 and estimate the NKPC (8) recursively by GMM, starting with an initial (10-year) sample period of 1981Q2-1990Q1. Figure 3 displays the recursive estimates for α_f, α_b and the intercept using each of the four inflation forecast series in conjunction with the CBOGAP. From these graphs, it is evident that α_f, in general dominates α_b before 2001, with this being particularly clear when the SPF1Q or the Michigan survey is used. However, when the recursive sample incorporates observations after 2001 (not applicable to the Greenbook data though), a distinct reduction occurs in the estimates of α_f while a sizable increase occurs in α_b. The last graph in Figure 3 plots recursive estimates of intercept, which exhibits an apparent upward trend from 2001.

Although the precise date of the potential break is not always clear from Table 1, the recursive estimates of Figure 3 confirm the end of 2000 as the appropriate break date. Therefore, we define dummy variables based on a change point in 2001Q1 to investigate the nature of this structural break, with results shown in Table 2 using the subsample 1981Q2-2005Q4[14]. Since there is no evidence that the coefficients $\alpha_{\Delta bi}$ suffer a post-1981 structural break, these are restricted to be constant over the period. Where no further restrictions are imposed in Panel A, the results do not provide clear evidence on which coefficients change, presumably due to short subsample available post-2001 and the associated collinearity induced by the multiplicative dummy variables. Panel B imposes the

sample, which indicate two break dates, in 1975 and 1981. These are, however, not shown to conserve space.

12 Using SPF1Q, the 1975-2000 results are unclear about a 1981 break. Nevertheless, this date is supported by the whole sample and post-1975 results.

13 Searching interval is 70% of the (sub)sample, so that the end-dates for searching in this case are 2002Q4 for SPF data 1997Q1 for Greenbook data, and 2001Q4 for Michigan data.

14 Dummy tests are implemented by using GMM with corresponding augmentations; see the notes to Table 2.

convex restriction $\alpha_f + \alpha_b = 1$ in order to alleviate the collinearity[15], and these results clearly indicate that the structural shift in 2001Q1 can be associated with the intercept term of (8).

Therefore, the next subsection investigates the nature of changes in the NKPC when breaks in the coefficients are recognized at the beginning of 1981 and (for the intercept) in 2001. Although a 1975 break would be more appropriate for the Greenbook forecasts, we use 1981 for ease of comparison across all forecast series.

4.3 Subsample Estimates

Table 3 reports GMM estimates of the NKPC model (8) over pre- and post-1981 periods for intercept, forward- and backward-looking inflation coefficients and the output gap, in conjunction with relevant diagnostic statistics. The diagnostic test statistics indicate that the specification is free from significant serial correlation and the IV choice is valid and strong in most cases. In addition, the Durbin-Wu-Hausman statistics (heteroscedasticity robust) in the last column confirm the need for GMM estimation, since the null hypothesis of consistency of OLS in estimating (8) is typically rejected at conventional levels (although this is not the case for Greenbook data or the Michigan series over the pre-1981 period).

Panel A provides evidence that the backward-looking behavior plays a more important role than the forward-looking component before 1981, with this effect being strongest when the SP1Y and Michigan forecasts are used. Panel B shows corresponding estimates post-1981 conditional on the break in the intercept in 2000Q1, without and with the restriction $\alpha_f + \alpha_b = 1$ imposed respectively. From these results, and conditional on the intercept shift, forward-looking behavior is, in general, predominant over the post-1981 period while the backward-looking element appears quantitatively less important. The most dramatic change in these coefficients between Panels A and B occurs when inflation expectations are measured using the Michigan survey results. In addition, the estimates indicate a significant increase in the intercept after 2001.

In summary, the estimates of α_f and α_b in Table 3 suggest that the backward-looking behavior is strong over 1968-1981, while the outlook for inflation plays a much more important role after 1981. The next section assesses the robustness of these findings.

[15] The null hypothesis of the convex restriction in general cannot be rejected at conventional levels of significance.

5. Robustness Analysis

The robustness of our results in Section 4 is checked in two ways, firstly by using the stylized NKPC model (9) in conjunction with observed inflation forecast series and secondly by applying a rational expectations approximation in the context of the more general dynamic specification of (8).

5.1 Evidence from the Stylized Model

As discussed in Zhang *et al*. (2006), empirical estimations for the stylized formulation of the NKPC (9) generally manifest serial correlation, which invalidates lagged values of inflation as instruments. Therefore, we employ a baseline IV set for the stylized NKPC, which includes two lags of each of survey inflation, the output gap, unemployment rate, and short term interest rate while it does not incorporate lagged inflation.

As in section 4.2, we implement the Andrews-Ploberger structural break tests and the results (not reported here) suggest that in general, the pattern and timing of the structural breaks in (9) are similar to those for (8). That is, 1975, 1981, and 2001 appear to be three possible structural break dates, with the 1981 date generally significant when the 1975 break is recognised, but the converse is not the case. Dummy variable tests for the post-1981 subsample are again used to investigate the nature of the break in 2001, with results (after imposition of the convex restriction) indicating a significant intercept break at that date[16].

Table 4 provides subsample estimates for the stylized NKPC before and after 1981. Panel A shows that the backward-looking behavior in the stylized model (9) dominates before 1981 while the forward-looking component is quantitatively very small in all cases, and statistically insignificant at conventional levels when either form of SPF forecast is used. For the post-1981 period, the results in Panel B provide results reinforce those embedded in Panel B of Table 3: that is, conditioning on an intercept break in (9) in 2001, inflation expectations play a more important role than inflation inertia. For instance, the coefficient estimates on SPF1Q and Michigan are higher than 0.90, and the estimates on SPF1Y are close to 0.70 after 1981, while the estimates for α_b are less than 0.35. Indeed, in all cases the latter coefficients are not statistically significant (at 5%) in the post-1981 period.

It is worth noting that in the estimations for the stylized NKPC model, the IV serial

[16] However, using the Michigan data, a break in the forward/backward looking coefficients is also significant when the convex restriction is imposed.

correlation test (up to order four) often rejects the null hypothesis of no serial correlation for the post-1981 subsample. Thus the standard errors reported in Table 4 are Newey-West HAC-robust. For the IV choice, the overidentifying restrictions tests indicate the null hypothesis of valid moment conditions cannot be rejected at conventional levels. However, the Stock and Yogo's (2003) weak IV statistic suggests that the instruments here are much less strong than the baseline IV set for model (8), which is unsurprising since lagged inflation is not included here[17].

Therefore, the analysis of the stylized model using survey inflation forecasts reinforces the conclusion that backward-looking behavior is quantitatively more important over the pre-1981 period while forward-looking behavior plays a more dominant role over the post-1981 era. Moreover, we also find a significant intercept break in 2001 for the stylized formulation of the NKPC.

5.2 Rational Expectations Approximation

Rather than using observed inflation forecasts, it is more common to examine the NKPC using a rational expectations approximation, as in Gali and Gertler (1999) or Gali *et al.* (2005). These authors propose that this model should be estimated using real marginal cost rather than an output gap variable and argue that lagged inflation quantitatively plays a negligible role while future inflation is predominant. Here we investigate the structural stability of the NKPC under a similar setup to that in Gali and Gertler (1999) and Gali *et al*. (2005). However, our analysis is based on the model in the form of (8), which mitigates concerns about serial correlation and hence the validity of lagged inflation as instruments.

For GMM estimation and the structural break analysis, we initially employ the same IV sets as in Gali and Gertler (1999) and Gali *et al*. (2005), denoted by GG-1999IV and GGL-2005IV respectively[18]. The projections of actual future inflation on the corresponding IV set are used to measure inflation expectations, which gives rise to exactly the same coefficient estimates as obtained when $E_t\pi_{t+1}$ is replaced by π_{t+1} in (8). However, as discussed in Zhang *et al*. (2006), this renders more accurate inference than treating π_{t+1} itself as the

[17] Although the estimations over pre-1981 in Table 4 appear serially uncorrelated, serially correlation presents if lagged inflation is incorporated in the baseline IV set. Therefore, we do not include lagged inflation in the IV for the stylized model.
[18] GG-1999IV includes four lags of each of the following variables: inflation, output gap, labor income share, wage inflation, commodity price inflation, and long-short interest rate spread; GGL-2005IV includes four lags of inflation, and two lags of labor income share, output gap, and wage inflation.

inflation expectation[19]. In addition, since Gali and Gertler (1999) emphasize the importance of labor income share of the non-farm business sector as the real driving variable, we also provide empirical results using the labor income share (denoted NFB-LS) in addition to those with the output gap.

Panel A of Table 5 reports results of the Andrews-Ploberger structural break tests using the two sets of instruments, in conjunction with CBOGAP and the labor income share, and using the central 50% of the sample as the search interval[20]. In most cases, there is strong evidence of a structural break in α_f and α_b in 1981, in particular for regressions estimated using GGL-2005IV. Structural break tests over subsamples separated by the 1981 break do not, however, provide statistical evidence of further breaks. Further, Table 5 provides little evidence of a break in the intercept in 1981. However, it should also be noted that under the rational expectations approximation, the IV sets in both Gali and Gertler (1999) and Gali *et al*. (2005) are generally weak, as indicated by the Weak IV statistics in Panel B of Table 5, in particular during the post-1981 sample.

Having identified a break in 1981, subsample estimates of the forward- and backward-looking coefficients for the pre- and post-1981 periods are shown in Panel B of Table 5. For the GG-1999IV, estimates of the forward-looking coefficient are 0.48 and 0.57 before 1981, while both increase to 0.70 or more after 1981. Conversely, the point estimates of the backward-looking coefficient drop from around 0.45 to 0.28 or less after 1981. Further, the estimate on lagged inflation in the pre-1981 regression using the labor income share is effectively equal to that on future inflation, which indicates that Gali and Gertler's (1999) proposal that inflation inertia plays a negligible role in the NKPC with labor share may not be applicable during this period.

Although GGL-2005IV produces different estimates for the key coefficients and the estimates of α_f are larger than α_b pre-1981, the general pattern of the changes in the forward- and backward-looking behaviors is similar to that based on GG-1999IV. For instance, using the labor income share, the point estimate for α_f is 0.57 before 1981 but increases to above 1.0 during the post-1981 era. On the other hand, the coefficient estimate for backward-looking behavior drops from 0.43 to a small (negative) value.

Our analysis of the structural stability of the NKPC under a rational expectations

[19] This arises because treating π_{t+1} as the inflation expectation series gives rise to a measurement error problem.
[20] Using the central 70% often leads to extreme points of the search interval as the break point, and estimates in this case are unreliable.

assumption does not extend to the stylized model, because the model generally suffers from autocorrelation and this invalidates the instrument sets GG-1999IV and GGL-2005IV, as both include lagged inflation.

6. Discussion of the Empirical Results

6.1 The Structural Change in 1981

The current study provides empirical evidence of structural changes in the importance of inflation inertia and inflation expectations in the NKPC relationship around 1981. This finding has several important implications.

First, our empirical results suggest that models of price stickiness and inflation stickiness should be distinguished over different regimes. It follows that the evaluation of different monetary policy rules should consider sample periods relevant to the specific rules. For instance, Ball (1999) employs the Phillips curve of inflation stickiness in conjunction with the simple dynamic aggregate demand equation

$$y_t = -\beta r_{t-1} + \lambda y_{t-1} + \varepsilon_t \tag{15}$$

where r denotes the deviation of the real interest rate from its steady state level and ε_t is white-noise. Assuming $\alpha_f = 0$ and $\alpha_b = 1$ in the NKPC, Ball shows that a nominal income monetary targeting rule can induce infinite variances for both inflation and output. McCallum (1999) and McCallum and Nelson (1999), however, set $\alpha_f = 1$ and $\alpha_b = 0$ and conclude (through simulations) that Ball's finding is confined to the setup incorporating the purely backward-looking inflation equation.

The empirical findings in the current study suggest that Ball's (1999) analysis and policy recommendation may be applicable to the high and volatile inflation regime of 1968-1981 while the proposal of McCallum (1999) and McCallum and Nelson (1999) appears more appealing over the most recent two decades since the empirical results show that forward-looking behavior has been more dominant after 1981.

In addition, the finding of structural change in the forward- and backward-looking behaviors of inflation in 1981 also lends some insight on the optimization-based monetary policy rule analysis as in Rotemberg and Woodford (1997) and Levin *et al*. (1999), who find opposite results for an optimized policy rule under different degrees of forward- and backward-looking behaviors in the NKPC.

Moreover, our results indicate that forward- and backward-looking behavior in the NKPC may be closely related to the degree of inflation persistence, since the timing of the breaks identified in this paper are in line with changes in inflation persistence documented in Taylor (2000), Willis (2003), and Zhang (2006). This may imply that during highly persistent inflation periods, past inflation contains more relevant information for firms' pricing behavior than the future prospects for the economy. From this perspective, the finding here is also in agreement with Erceg and Levin (2003) who suggest that inflation inertia is not an inherent characteristic of the US economy but varies with the stability and credibility of the monetary policy regime. Erceg and Levin use calibration to show that a NKPC model with little inflation inertia can account for the dynamics of the output gap and inflation during the Volcker-Greenspan period (after 1984).

Therefore, changes in inflation dynamics, and specifically forward- versus backward-looking behavior, may be closely associated with different monetary policies pursued before and after the Volcker-Greenspan era. Clarida *et al*. (2000) find that, associated with differing anti-inflation stances of the Federal Reserve, before the Volcker-Greenspan years the Fed appears very reluctant to respond to changes in expected inflation while during the Volcker-Greenspan era the Fed is typically highly responsive to fluctuations in inflation expectations. Interestingly, the empirical results in the current study suggest that changes in the monetary policy rule may also have induced changes in the forward- and backward-looking behaviors in inflation dynamics, given the coincidence of the timing.

The results in this paper emphasize the importance of inflation expectations over the most recent two decades, which is consistent with several recent contributions. For example, in a system of New Keynesian equations, Ireland (2004) shows that the coefficient estimate on lagged inflation of the NKPC is statistically insignificant over 1980Q1-2003Q1, although his interest is the importance of technology shocks in accounting for the behavior of aggregate fluctuations. Bindelli (2005) also finds no backward-looking pricing behavior over 1987Q4-1999Q4. Although Fuhrer (1997) is not able to reject the null hypothesis that inflation dynamics over 1979-1994 are purely backward-looking at conventional levels of significance, his coefficient estimates suggest greater weight on forward-looking behavior over this period than when the sample commences in 1966.

6.2 Intercept Break in 2001

A novel finding in the current study is the structural change in the constant term in 2001, when the NKPC is estimated using observed inflation forecast series. The timing of this identified break coincides with the mild recession in the U.S. economy in 2001 and the devastating events of September 11 and may reflect a significant, although temporary, monetary policy shift triggered by a number of important events.

According to the Monetary Policy Report to Congress by the Board of Governors of the Federal Reserve System in February 2001, the Federal Open Market Committee (FOMC) recognized signs of a moderation in the growth of economic activity and decreased the target FFR rate by 0.5 percentage point in January 2001. The Fed further lowered the FFR in subsequent months to in order to prevent tightening the economy. Despite the FFR reductions, the weakness in economic activity was still widespread and the 9/11 terrorist attacks then exacerbated an already fragile economy. The Monetary Policy Report to Congress in February 2002 indicates that the economic fallout of the catastrophe led the FOMC to further cut the target FFR immediately after the attack. Consequently, the short-term interest rate (the FFR) was pulled down by nearly 5 percentage points from 6.4% in 2000Q4 to 1.8% by the end of 2001 and was held at a historically low level until 2004, as evident in Figure 1.

These changes of monetary policy in the early 2000s may affect the aggregate supply curve through the associated policy transmission mechanism, and hence induce a structural shift in the NKPC. Indeed, as noted in Section 2 and seen in (4), the inflation target directly enters the intercept of the NKPC. If agents perceive that monetary policy has changed (albeit temporarily) such that the Fed had a higher implicit inflation target in the early 2000s than in the 1990s, then a higher level of inflation will result, which is compatible with the increase in the intercept found in Tables 3 and 4.

7. Conclusions

The specification of the New Keynesian Phillips Curve with both inflation expectation and inflation inertia has recently provoked a fierce debate as to the degree of forward- and backward-looking behaviors, with little consensus after years of investigation. Given the profound variations in US inflation performance over the past half decade, however, it is plausible that the relevant importance of the forward- and backward-looking behaviors may have changed over time. Therefore, this paper is designed to investigate the nature of structural stability in short-run inflation dynamics over 1968-2005.

The paper presents statistical evidence of a structural change in this relationship around 1981 and shows that the forward-looking behavior emphasized by Gali and Gertler (1999) and Gali *et al*. (2005) appears to play a relatively small role in inflation dynamics over the 1968-1981 period while this behavior becomes more dominant after 1981, and the converse phenomenon applies to the backward-looking behavior which is stressed by Fuhrer and Moore (1995), Fuhrer (1997), Estrella and Fuhrer (2002; 2003), and Rudd and Whelan (2005). The finding here is consistent with recent research of Ireland (2004) and Bindelli (2005), while to some extent lends more insights into the ongoing debate on the importance of backward- and forward-looking behaviors in the NKPC literature.

We argue that changes in the monetary policy rule, as documented in Clarida *et al*. (2000), may contain the seeds of changes in inflation persistence and the changes of the forward- and backward-looking behaviors in inflation dynamics around 1981, as characterized in this paper. Future research linking the change of systematic monetary policy rules and the changes in the pricing behavior of firms is worth exploring. However, this research implies the use of micro data and is beyond the scope of the current study.

In addition, subsample analysis suggests that the steady-state inflation rate may have undergone a structural shift in 2001. This shift may reflect the loosening of monetary policy at the beginning of the 2000s, during which depressed economic activity was exacerbated by the 9/11 terrorist attacks, resulting in changes in economic agents' perception of the central bank's inflation target at that time.

Our results are generally robust to whether observed inflation forecasts are used to measure inflation expectations or whether these are captured through the use of a rational expectations approximation. However, when the Greenbook forecasts of the Fed are employed, the break in the NKPC parameters is dated in 1975 rather than 1981. Since Romer and Romer (2000) find that the Fed has information not available to other agents when producing its inflation forecasts, this series may have different characteristics, and hence may yield different results, from other forecast series. This may be important, since in the NKPC context the properties of aggregate inflation depend on the pricing behavior of individual firms. As these firms do not have access to the extended information set on which

Greenbook forecasts are based, other inflation forecasts may be more relevant in this context than Greenbook forecasts.

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Appendix

Derivation of the Extended New Keynesian Phillips Curve

The following describes the derivation of the extended NKPC, assuming an economic environment similar to Calvo's (1983) model, in which firms are able to revise their prices in any given period with a fixed probability ($1-\theta$). As in Gali and Gertler (1999), we assume both "forward-" and "backward-looking" firms co-exist in the economy with a proportion of ω and $(1-\omega)$ respectively. Nevertheless, we extend the recent pricing behavior of the backward-looking firms to incorporate a weighted process of past inflation, instead of a stylized one lag.

Based on the regular assumptions in Calvo's (1983) model and log-linear approximations, it is possible to obtain the (log) aggregate price level as

$$p_t = \theta p_{t-1} + (1-\theta) p_t^* \tag{A1}$$

where p_t^* is the new price set in period *t*. Let p_t^F be the price set by forward-looking firms and p_t^B the price set by backward-looking firms at *t*. Then the new price (relative to the aggregate price) can be expressed as a convex combination of p_t^F and p_t^B:

$$p_t^* - p_t = (1-\omega)(p_t^F - p_t) + \omega(p_t^B - p_t)\,. \tag{A2}$$

Next, following Woodford (2003, ch.3), the pricing behaviour of the forward-looking firms can be written as

$$p_t^F - p_t = (1-\theta\beta)\sum_{T=t}^{\infty}(\theta\beta)^{T-t} E_t\left[\sum_{j=t+1}^{T}\pi_j + \varsigma y_t\right], \tag{A3}$$

where β denotes a subjective discount factor, ζ is introduced by the procedure of log-linearization (see Woodford for a discussion of economic implications of ζ) , and y_t is real output gap. Iterating (A3) gives

$$p_t^F - p_t = \theta\beta E_t\pi_{t+1} + (1-\theta\beta)\varsigma y_t + \theta\beta E_t(p_{t+1}^F - p_{t+1}) \tag{A4}$$

We assume that firms adjust their pricing behavior by a weighted average of past (say one-year) inflation, viz.

$$p_t^B = p_{t-1}^* + \rho(L)\pi_{t-1} \tag{A5}$$

where $\rho(L) = \rho_1 + \rho_2 L + \rho_3 L^2 + \cdots + \rho_q L^{q-1}$ is polynomial in lag operator with $\rho(1) = 1$.

Combining (A1) - A(5) gives the extended (theoretical) NKPC

$$\pi_t = \alpha_f E_t\pi_{t+1} + \alpha_b(L)\pi_{t-1} + \alpha_y y_t \tag{A6}$$

where

$$\alpha_f = \theta\beta\psi^{-1} \tag{A7}$$

$$\alpha_b(L) = \omega\{\theta + (1-\theta)\rho(L) - (1-\theta)\theta\beta\rho_\Delta(L)]\}\psi^{-1} \tag{A8}$$

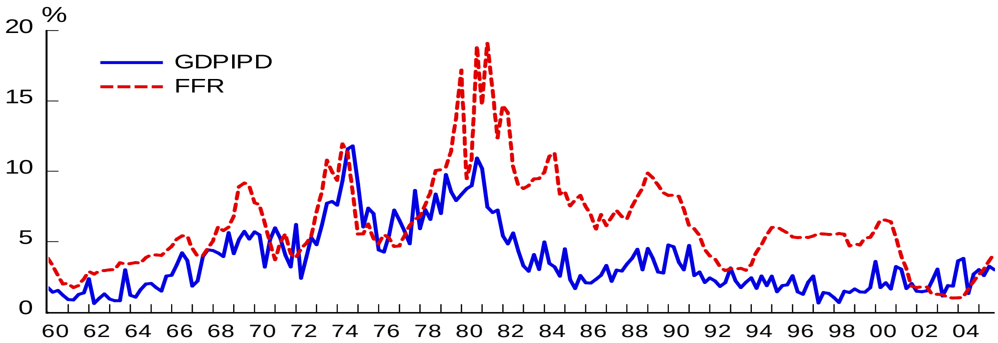
$$\alpha_y = (1-\omega)(1-\theta)(1-\beta\theta)\varsigma\psi^{-1} \tag{A9}$$

$$\psi = \theta(1+\omega\theta\beta) + \omega(1-\theta)(1+\theta\beta\rho_1) \tag{A10}$$

$$\rho_\Delta(L) = \rho_2 + \rho_3 L + \rho_4 L^2\,. \tag{A11}$$

Reparametrizing (A6) and taking account of a stochastic error yields the NKPC model (8), which is used for empirical estimation in the paper.

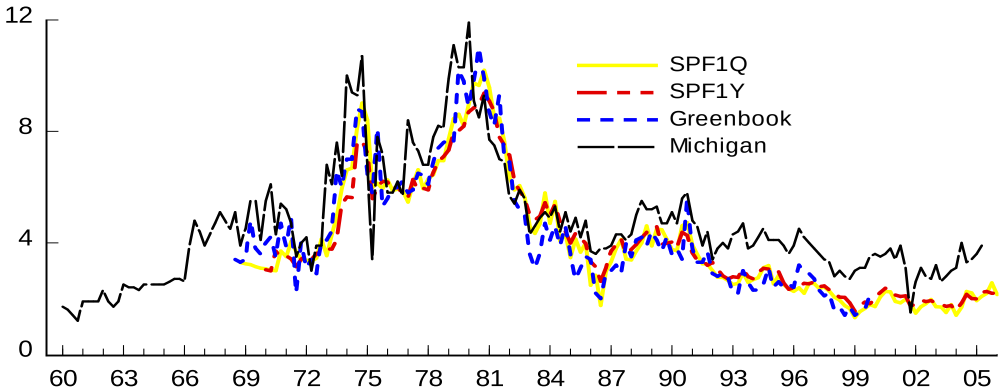
Figure 1. The U.S. GDP Deflator Inflation and Federal Funds Rate



Notes**:** Sample spans 1960Q1-2005Q4. The Federal Funds Rate is that effective at end-of-quarter.

Data source: Economic Data-FRED, Federal Reserve Bank of St. Louis.

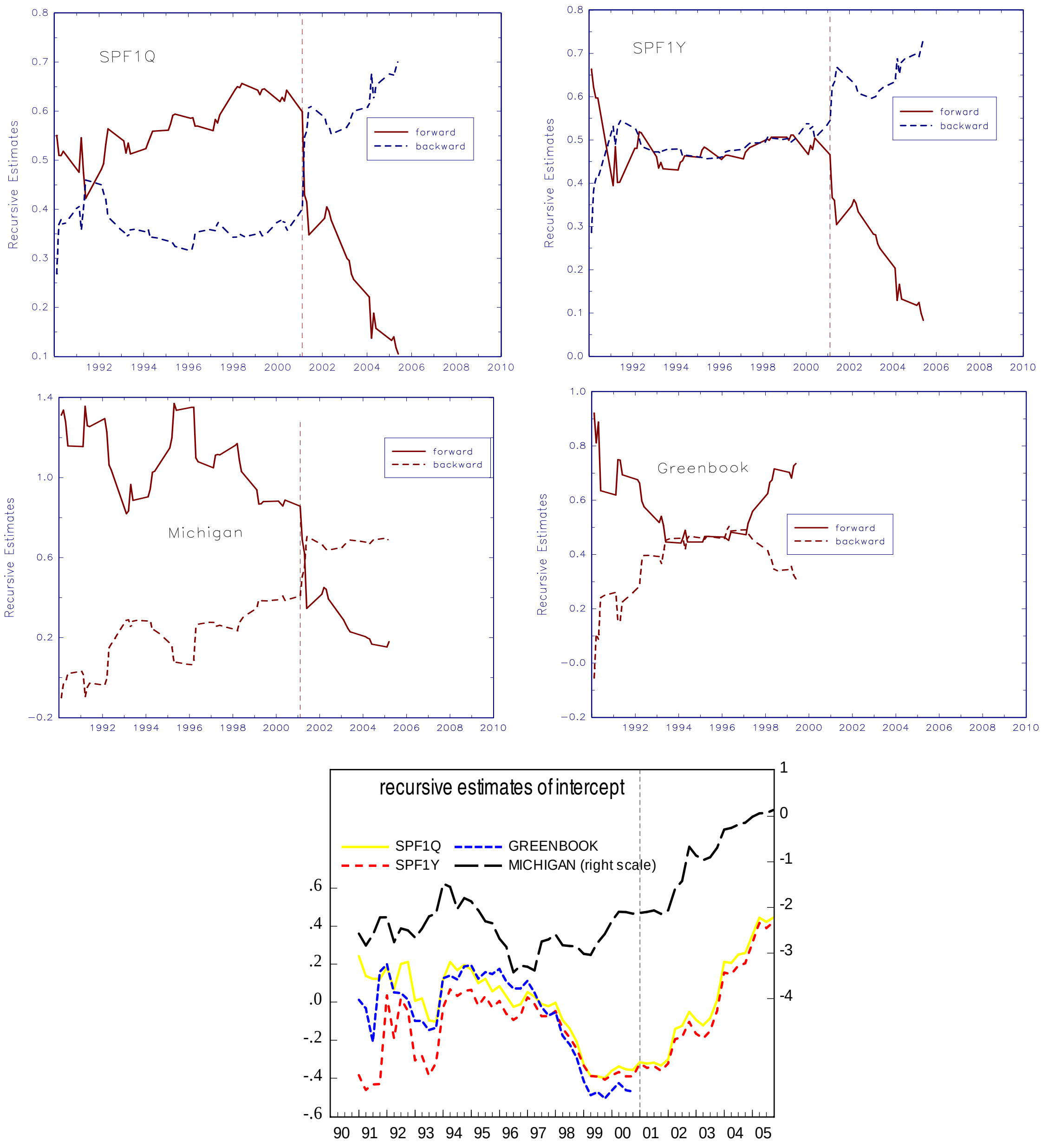
Figure 2. Observed Inflation Forecasts



Notes: SPF1Q, SPF1Y, Greenbook, and Michigan in the figure denote the SPF one-quarter-ahead GDP (before 1992Q1, GNP) inflation forecasts, the SPF one-year-ahead GDP (before 1992Q1, GNP) inflation forecasts, Greenbook quarterly GDP inflation forecasts, and the general price inflation forecasts (one-year-ahead) from the Michigan survey.

Data sources: the first three series of forecasts are obtained from the website of the Federal Reserve Bank of Philadelphia while the Michigan data is collected from the website of Survey of Consumers of the University of Michigan.

Figure 3. Recursive GMM Estimates of the NKPC using Post-1981 Data



Notes: Estimates reported relate to (8). The recursive estimation starts from 1981Q2-1990Q1; “forward” and “backward” denote estimates of α_f and α_b respectively.

Table 1
Andrews-Ploberger Tests (GMM) for the NKPC Using Survey Inflation Forecasts

		Whole Sample			Pre-1981Q1			Post-1981Q1			Post-1975Q1			1975Q2-2000Q4		
		p-Exp	***p-Sup***	**Date**	***p-Exp***	***p-Sup***	**Date**	***p-Exp***	***p-Sup***	**Date**	***p-Exp***	***p-Sup***	**Date**	*p-Exp*	*p-Sup*	Date
SPF1Q	Overall	0.000	0.000	1981.1	---	---	---	0.107	0.075	2000.4	0.000	0.000	1981.3	0.000	0.000	1997.1
	(c_0, α_f ,α_b)	0.000	0.000	1975.1	0.351	0.288	1975.3	0.061	0.026	2002.2	0.000	0.000	2000.4	0.335	0.268	1997.1
	Intercept	0.029	0.013	1981.1	0.188	0.168	1975.2	0.022	0.015	2002.2	0.000	0.000	2000.4	0.200	0.195	1983.2
	α_f	0.000	0.000	1975.1	0.064	0.081	1975.2	0.042	0.021	2000.4	0.000	0.000	2000.4	0.162	0.124	1981.1
	α_b	0.000	0.000	1981.1	0.029	0.017	1975.3	0.121	0.090	2000.4	0.000	0.000	1981.1	0.124	0.088	1981.1
	$\alpha_{\Delta b}$	0.074	0.037	1983.3	0.206	0.299	1976.2	0.818	0.923	1991.1	0.300	0.403	1983.3	0.840	0.915	1982.3
	α_y	0.001	0.001	2000.1	0.654	0.836	1975.2	0.034	0.023	2002.2	0.000	0.000	2000.1	0.887	0.992	1982.3
SPF1Y	Overall	0.000	0.000	1976.1	---	---	---	0.024	0.024	2001.3	0.000	0.000	1981.2	0.000	0.000	1981.2
	(c_0, α_f ,α_b)	0.005	0.001	1981.1	0.053	0.055	1975.3	0.040	0.015	1986.1	0.000	0.000	1981.1	0.023	0.007	1981.1
	Intercept	0.159	0.068	1981.1	0.041	0.024	1975.3	0.021	0.011	2002.2	0.000	0.000	2000.4	0.082	0.034	1981.1
	α_f	0.001	0.001	1981.1	0.001	0.002	1975.3	0.036	0.015	2000.4	0.000	0.000	1981.1	0.027	0.010	1981.1
	α_b	0.000	0.000	1981.1	0.004	0.004	1975.3	0.127	0.100	2000.4	0.000	0.000	1981.1	0.001	0.001	1981.1
	$\alpha_{\Delta b}$	0.181	0.121	1984.1	0.177	0.341	1976.4	0.838	0.766	1991.1	0.476	0.631	1984.1	0.708	0.856	1981.1
	α_y	0.007	0.006	2000.1	0.666	0.767	1973.2	0.030	0.019	2002.2	0.000	0.001	2000.1	0.562	0.579	1981.1
Greenbook	Overall	0.000	0.000	1975.1	---	---	---	0.000	0.000	1997.1	0.122	0.093	1979.4	0.122	0.093	1979.4
	(c_0, α_f ,α_b)	0.000	0.000	1975.1	0.640	0.808	1975.4	0.000	0.000	1997.1	0.152	0.130	1996.1	0.152	0.130	1996.1
	Intercept	0.000	0.000	1975.1	0.829	0.767	1971.1	0.255	0.261	1996.1	0.191	0.247	1983.3	0.191	0.247	1983.3
	α_f	0.000	0.000	1975.1	0.873	0.763	1971.1	0.049	0.034	1996.1	0.110	0.073	1996.1	0.110	0.073	1996.1
	α_b	0.000	0.000	1975.1	0.772	0.767	1971.1	0.127	0.075	1996.1	0.096	0.062	1996.1	0.096	0.062	1996.1
	$\alpha_{\Delta b}$	0.004	0.001	1975.1	0.252	0.479	1978.1	0.828	0.933	1991.1	0.700	0.710	1980.3	0.700	0.710	1980.3
	α_y	0.111	0.058	1982.2	0.361	0.457	1976.2	0.672	0.747	1984.4	0.007	0.002	1996.2	0.007	0.002	1996.2
Michigan	Overall	0.001	0.001	1976.2	---	---	---	0.000	0.000	2001.4	0.018	0.024	2000.4	0.015	0.013	1980.1
	(c_0, α_f ,α_b)	0.046	0.040	1981.1	0.862	0.867	1972.2	0.000	0.000	2001.4	0.027	0.025	1981.1	0.031	0.012	1980.2
	Intercept	0.011	0.006	1975.1	0.792	0.896	1975.2	0.051	0.023	2000.4	0.013	0.018	1998.2	0.423	0.456	1981.3
	α_f	0.009	0.007	1981.1	0.556	0.514	1975.2	0.005	0.002	2001.4	0.026	0.031	1981.1	0.355	0.319	1981.1
	α_b	0.004	0.003	1975.1	0.424	0.262	1975.2	0.274	0.284	1991.1	0.025	0.009	1981.1	0.143	0.157	1991.1
	$\alpha_{\Delta b}$	0.360	0.440	1990.2	0.101	0.164	1976.2	0.961	0.897	1991.1	0.746	0.605	1991.1	0.794	0.793	1991.1
	α_y	0.052	0.089	1997.1	0.787	0.955	1976.2	0.032	0.038	2000.3	0.038	0.022	2000.1	0.199	0.119	1981.1

Notes: The whole sample is 1968Q4-2005Q4, 1970Q1-2005Q4 for the one-quarter and one-year ahead (respectively) SPF forecasts, 1968Q3-1999Q4 and 1968Q3-2005Q2, respectively, for Greenbook and Michigan. The estimated equation is given by (8). The baseline IV set for the NKPC includes two lags of each of inflation forecasts, short-term interest rate (3-month Treasury bill rate), the output gap, unemployment rate, and M2 growth, plus the lags of inflation included in the model (and a constant). *p-Exp* and *p-Sup* denote *p*-values of Andrews-Ploberger Exp- and Sup-Wald tests for the null of stability; Date corresponds to the point at which the maximum *Wald*-statistic is achieved. The structural break tests are implemented over central 70% of the underlying samples. A heteroskedasticity-consistent covariance matrix (HCCME) is used for all tests.

Table 2
Dummy Tests for the NKPC using Survey Inflation Forecasts: Post-1981

Panel A. Unrestricted

$$\pi_t = c_0 + \alpha_f E_t \pi_{t+1} + \alpha_b \pi_{t-1} + \sum_{i=1}^{3} \alpha_{\Delta bi} \Delta\pi_{t-i} + \alpha_y y_t + c_0^d d_t + \alpha_f^d d_t E_t \pi_{t+1} + \alpha_b^d d_t \pi_{t-1} + \alpha_y^d d_t y_t + \varepsilon_t$$

	$\tilde{c}_0^d$	$\tilde{\alpha}_f^d$	$\tilde{\alpha}_b^d$	$\tilde{\alpha}_y^d$	**All**	$\alpha_f^d = \alpha_b^d = 0$
SPF1Q	2.298	-0.878	0.243	0.078	0.021	0.664
	(2.166)	(1.113)	(0.320)	(0.231)		
SPF1Y	2.354	-0.863	0.169	0.031	0.031	0.872
	(4.074)	(2.042)	(0.339)	(0.320)		
Michigan	1.210	-0.185	0.014	-0.170	0.026	0.972
	(2.676)	(0.789)	(0.257)	(0.232)		

Panel B. Imposing convex restriction $\alpha_f + \alpha_b = 1$

$$\pi_t - \pi_{t-1} = c_0 + \alpha_f (E_t \pi_{t+1} - \pi_{t-1}) + \sum_{i=1}^{3} \alpha_{\Delta bi} \Delta\pi_{t-i} + \alpha_y y_t + c_0^d d_t + \alpha_f^d d_t (E_t \pi_{t+1} - \pi_{t-1}) + \alpha_y^d d_t y_t + \varepsilon_t$$

	$\tilde{c}_0^d$	$\tilde{\alpha}_f^d$	$\tilde{\alpha}_y^d$	**All**
SPF1Q	0.976	0.235	-0.028	0.002
	(0.404)	(0.332)	(0.185)	
SPF1Y	0.883	0.130	-0.061	0.004
	(0.415)	(0.316)	(0.193)	
Michigan	0.347	-0.088	-0.121	0.020
	(0.494)	(0.249)	(0.167)	

Notes: Lag order is four in all regressions. HCCME standard errors are reported in parentheses. The dummy variable d_t is set to zero before 2001Q1 and unity otherwise. The IV set is the baseline IV set *Z* (see Table 1) and *Zd* (that is, *Z* multiplied by the dummy variable). All denotes the *p*-value for a joint significance test for the coefficients on all dummy variables.

Table 3
Subsample Estimates of the NKPC Using Survey Inflation Forecasts

Panel A. Pre-1981

	$\tilde{c}_0$	$\tilde{\alpha}_f$	$\tilde{\alpha}_b$	$\tilde{\alpha}_y$	p-auto	p-over	Weak IV	Hausman
SPF1Q	0.195	0.472	0.596	0.293	0.497	0.112	6.875	0.002
	(1.074)	(0.189)	(0.273)	(0.145)				
SPF1Y	-0.346	0.399	0.763	0.336	0.951	0.022	7.023	0.006
	(1.186)	(0.218)	(0.284)	(0.168)				
Greenbook	0.071	0.433	0.633	0.279	0.388	0.083	5.574	0.102
	(1.101)	(0.177)	(0.275)	(0.143)				
Michigan	-0.025	0.395	0.623	0.132	0.241	0.100	1.962	0.491
	(0.949)	(0.166)	(0.258)	(0.176)				

Panel B. Post-1981: $\pi_t = c_0 + \alpha_f E_t \pi_{t+1} + \alpha_b \pi_{t-1} + \sum_{i=1}^{3} \alpha_{\Delta bi} \Delta\pi_{t-i} + \alpha_y y_t + c_0^d d_t + \varepsilon_t$

	$\tilde{c}_0$	$\tilde{c}_0^d$	$\tilde{\alpha}_f$	$\tilde{\alpha}_b$	$\tilde{\alpha}_y$	p-auto	p-over	Weak IV	Hausman
SPF1Q	-0.318	1.099	0.760	0.207	0.159	0.850	0.567	6.798	0.012
	(0.329)	(0.328)	(0.334)	(0.322)	(0.056)				
SPF1Y	-0.322	0.970	0.567	0.408	0.159	0.914	0.620	24.007	0.009
	(0.329)	(0.295)	(0.262)	(0.245)	(0.050)				
Michigan	-1.726	0.909	0.797	0.367	0.104	0.833	0.651	3.891	0.025
	(0.815)	(0.283)	(0.308)	(0.209)	(0.052)				
Greenbook	0.501	---	0.536	0.134	0.854	0.52	0.088	1.643	0.111
(-1999Q4)	(0.375)		(0.400)	(0.068)					
<u>With convex restriction</u>									
SPF1Q	-0.411	1.146	0.782	0.218	0.170	0.847	0.643		
	(0.182)	(0.310)	(0.321)	(0.321)	(0.043)				
SPF1Y	-0.394	1.006	0.583	0.417	0.167	0.908	0.700		
	(0.176)	(0.274)	(0.245)	(0.245)	(0.040)				
Michigan	-0.913	0.656	0.549	0.451	0.091	0.910	0.644		
	(0.327)	(0.207)	(0.189)	(0.189)	(0.054)				

Notes: Pre-1981 refers to samples from the available starting dates for each inflation forecast series to 1980Q4, with the equation estimated in Panel A given by (8). For the post-1981 period in Panel B, the reported estimates are conditional on a 2001Q1 intercept break (except for Greenbook). The dummy variable d_t is set to zero before 2001Q1 and unity otherwise. HCCME-robust standard errors are reported in parentheses. p-auto, p-over, Weak IV, and Hausman refer to p-values of IV serial correlation test (up to order four), Hansen's (1982) J-test, Stock and Yogo's (2003) weak IV test (as a rule of thumb, a statistic larger than 4.66 can be deemed an indication of strong IV at the 5% level and 30% bias of OLS over IV estimator), and Durbin-Wu-Hausman test (with the null of consistency of the OLS estimator; HCCME robust), respectively. In the lower panel, IV set includes the baseline IV plus d_t.

Table 4
Subsample Estimates of the Stylized NKPC Using Survey Inflation Forecasts

Panel A. Pre-1981

	$\tilde{c}_0$	$\tilde{\alpha}_f$	$\tilde{\alpha}_b$	$\tilde{\alpha}_y$	*p*-auto	*p*-over	Weak IV	Hausman
SPF1Q	0.010	0.221	0.836	0.209	0.270	0.332	2.145	0.170
	(0.708)	(0.172)	(0.232)	(0.078)				
SPF1Y	-0.066	0.262	0.819	0.215	0.482	0.350	1.938	0.001
	(0.643)	(0.220)	(0.234)	(0.094)				
Michigan	0.090	0.360	0.625	0.047	0.206	0.370	2.202	0.527
	(0.629)	(0.126)	(0.193)	(0.097)				
Greenbook	0.240	0.352	0.660	0.154	0.144	0.272	2.885	0.184
	(0.533)	(0.128)	(0.166)	(0.068)				

Panel B. Post-1981: $\pi_t = c_0 + \alpha_f E_t \pi_{t+1} + \alpha_b \pi_{t-1} + \alpha_y y_t + c_0^d d_t + \varepsilon_t$

	$\tilde{c}_0$	$\tilde{c}_0^d$	$\tilde{\alpha}_f$	$\tilde{\alpha}_b$	$\tilde{\alpha}_y$	*p*-auto	*p*-over	Weak IV	Hausman
SPF1Q	-0.553	1.221	0.992	0.025	0.114	0.075	0.885	2.645	0.000
	(0.239)	(0.237)	(0.190)	(0.192)	(0.036)				
SPF1Y	-0.439	0.948	0.682	0.314	0.100	0.128	0.476	2.464	0.011
	(0.239)	(0.284)	(0.227)	(0.217)	(0.031)				
Michigan	-2.103	0.855	0.908	0.339	0.023	0.006	0.308	1.873	0.030
	(0.811)	(0.293)	(0.293)	(0.181)	(0.027)				
Greenbook	-0.978	---	1.459	-0.348	0.017	0.009	0.600	1.709	0.000
	(0.349))		(0.363)	(0.343)	(0.052)				
<u>With convex restriction</u>									
SPF1Q	-0.506	1.198	0.982	0.018	0.109	0.076	0.933		
	(0.125)	(0.239)	(0.187)	(0.187)	(0.035)				
SPF1Y	-0.451	0.954	0.684	0.316	0.102	0.132	0.604		
	(0.147)	(0.269)	(0.219)	(0.219)	(0.026)				
Michigan	-0.736	0.420	0.451	0.549	0.012	0.003	0.225		
	(0.231)	(0.141)	(0.137)	(0.137)	(0.026)				

Notes: The equation estimated in Panel A is given by (9). The IV set includes two lags of each of survey inflation, output gap, unemployment rate, and short-term interest rate (3-month Treasury bill rate). 4-lag HAC-robust covariance matrix is used. The dummy variable d_t in Panel B takes value zero before 2001Q1 and unity otherwise. *p*-auto and *p*-over refer to *p*-values of IV serial correlation test (up to order four) and Hansen's (1982) *J*-test, respectively.

Table 5
Structural Stability Analysis for the NKPC with Rational Expectations

Panel A. Andrews-Ploberger Tests (GMM): 1968Q1-2005Q4					
		Coefficient	***p-Exp***	***p-Sup***	**Date**
GG-1999 IV	CBOGAP	Overall	0.081	0.365	1981.1
		$(c_0, \alpha_f, \alpha_b)$	0.039	0.155	1981.1
		Intercept	0.785	0.952	1981.1
		α_f	0.024	0.209	1981.1
		α_b	0.054	0.242	1981.1
		$\alpha_{\Delta b}$	0.327	0.258	1994.1
		α_y	0.580	0.959	1981.1
	NFB-LS	Overall	0.027	0.271	1981.1
		$(c_0, \alpha_f, \alpha_b)$	0.003	0.053	1981.1
		Intercept	0.569	0.875	1981.1
		α_f	0.009	0.170	1981.1
		α_b	0.017	0.190	1981.1
		$\alpha_{\Delta b}$	0.151	0.165	1990.2
		α_y	0.059	0.270	1981.1
GGL-2005IV	CBOGAP	Overall	0.000	0.000	1981.1
		$(c_0, \alpha_f, \alpha_b)$	0.000	0.003	1991.1
		Intercept	0.218	0.552	1981.1
		α_f	0.000	0.043	1981.1
		α_b	0.004	0.152	1981.1
		$\alpha_{\Delta b}$	0.745	0.931	1981.3
		α_y	0.022	0.020	1992.3
	NFB-LS	Overall	0.000	0.011	1981.1
		$(c_0, \alpha_f, \alpha_b)$	0.001	0.011	1981.1
		Intercept	0.393	0.628	1981.1
		α_f	0.003	0.071	1981.1
		α_b	0.008	0.146	1981.1
		$\alpha_{\Delta b}$	0.827	0.826	1981.4
		α_y	0.008	0.018	1981.1

Table 5 (continued)

Panel B Subsample Estimates of the NKPC with Rational Expectations							
		$\tilde{\alpha}_f$	$\tilde{\alpha}_b$	$\tilde{\alpha}_y$	*p*-auto	*p*-over	Weak IV
GG-1999 IV							
1968Q1-1980Q4	CBOGAP	0.573	0.429	0.002	0.017	0.204	2.374
		(0.138)	(0.156)	(0.106)			
	NFB-LS	0.479	0.486	0.231	0.056	0.145	1.890
		(0.162)	(0.139)	(0.161)			
1981Q2-2005Q4	CBOGAP	0.700	0.280	0.036	0.181	0.147	1.253
		(0.214)	(0.196)	(0.060)			
	NFB-LS	0.727	0.189	0.033	0.173	0.122	1.380
		(0.191)	(0.144)	(0.054)			
GGL-2005 IV							
1968Q1-1980Q4	CBOGAP	0.684	0.346	-0.011	0.551	0.246	2.517
		(0.212)	(0.214)	(0.141)			
	NFB-LS	0.568	0.428	0.246	0.603	0.308	4.133
		(0.218)	(0.164)	(0.198)			
1981Q2-2005Q4	CBOGAP	1.200	-0.073	0.008	0.941	0.510	0.682
		(0.484)	(0.362)	(0.069)			
	NFB-LS	1.280	-0.097	-0.038	0.945	0.673	1.383
		(0.295)	(0.166)	(0.063)			

Notes: Lag order is four in all cases, with the equation estimated given by (8). The searching interval for the break tests in Panel A is the central 50% of each sample. Inflation expectations are projections of realized future inflation on the IV sets. NFB-LS denotes labor income share of non-farm business sector. GG-1999IV indicates that the instrumental variables used are those of Gali and Gertler (1999), namely four lags of each of inflation, output gap, labor income share, wage inflation, commodity price inflation, and long-short interest rate spread; GGL-2005IV indicates that the IV used are those of Gali *et al*. (2005), namely two lags of each of labor income share, output gap, wage inflation, and four lags of inflation. HCCME standard errors are reported in parentheses. *p*-auto and *p*-over refer to *p*-values of IV serial correlation test (up to order four) and Hansen's (1982) *J*-test, respectively.