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Kim, Chang-Jin and Manopimoke, Pym and Nelson, Charles

Korea University and University of Washington, University of Kansas, University of Washington

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Chang-Jin Kim[*] **Pym Manopimoke**[†] **Charles R. Nelson**[‡]

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Abstract

In this paper, we investigate the nature of structural breaks in inflation by estimating a version of the New Keynesian Phillips curve (NKPC) in the presence of a unit root in inflation. We show that, with a unit root in inflation, the NKPC implies an unobserved components model that consists of three components: a stochastic trend component, a component that depends upon current and future forecasts of real economic activity, and a stationary component which is potentially serially correlated (or a component of inflation that is not explained by the conventional forward-looking NKPC). Our empirical results suggest that, with an increase in trend inflation during the Great Inflation period, the response of inflation to real economic activity decreases and the persistence of the inflation gap increases due to an increase in the persistence of the unobserved stationary component. These results are in line with the predictions of Cogley and Sbordone (2008), who show that the coefficients of the NKPC are functions of time-varying trend inflation.

JEL Codes: C32, E12, E31

Keywords: New Keynesian Phillips Curve, Trend Inflation, Inflation Gap, Unobserved Components Model, Structural Breaks.

[*]Professor, Department of Economics, University of Washington, and Department of Economics, Korea University, e-mail: changjin@u.washington.edu.

[†]Assistant Professor, Department of Economics, University of Kansas, e-mail: pymm@ku.edu.

[‡]Professor, Department of Economics, University of Washington, e-mail: cnelson@u.washington.edu.

1. INTRODUCTION

While New Keynesian Phillips curves (NKPCs) are typically derived and estimated under the assumption that steady-state inflation or long-run trend inflation is close to zero, some authors have recently investigated the implications of non-zero or time-varying trend inflation on the dynamics of inflation within the New Keynesian framework. For example, Ascari (2004) shows that with non-zero trend inflation, both the long-run and the short-run properties of the New Keynesian models based on the Calvo pricing model can change dramatically. Cogley and Sbordone (2008) derive a version of the NKPC that incorporates a time-varying trend rate of inflation. They show that the coefficients of the resulting NKPC are functions of the time-varying trend inflation. Ireland (2007) identifies the source of time-varying trend inflation as changes in the Federal Reserve Bank's implicit inflation target. Both Cogley and Sbordone and Ireland show that time-varying trend inflation contributes as a highly persistent component to post-war U.S inflation dynamics. Furthermore, Cogley, Primiceri and Sargent (2010) show that during the Great Inflation period of the 1970s, both the trend rate of inflation and the persistence of the inflation gap increased considerably.

A number of studies also present evidence about regime changes in U.S. inflation persistence. For example, by estimating a univariate unobserved components model for inflation, Kang, Kim and Morley (2009) find that U.S. inflation persistence underwent two sudden permanent regime shifts in 1970Q3 and 1984Q4. With a stochastic volatility model, Stock and Watson (2007) report similar changes in the ratio of standard deviations for permanent and transitory shocks, which is a key determinant of inflation persistence over long horizons. The occurrence of these break dates is often assumed to have close ties with the U.S. monetary policy regime in place. Murray, Nikolsko-Rzhevskyy and Papell (2009) argues that switches in inflation persistence stems from shifts between stabalizing and destabilizing monetary policy rules as suggested by the Taylor principle. By estimating structural vector autoregressive models with time-varying coefficients, Cogley and Sargent (2002, 2005), Primiceri (2005) and Sims and Zha (2006) study changes in the U.S. postwar inflation dynamics in relation to the degree of monetary policy activism.

In the meantime, dating back to at least Nelson and Schwert (1977), there is substantial empirical evidence that U.S. inflation has a unit root. Based on reduced form unobserved components trend-cycle models of inflation with heteroscedastic shocks, Stock and Watson (2007) investigate the evolving nature of inflation dynamics. Harvey (2011) specifies a bivariate unobserved components model for inflation and real output based on a reduced form Phillips curve, with the lagged inflation terms replaced by a random walk. Lee and Nelson (2007) derive and estimate an unobserved components trend-cycle model for inflation and unemployment, as implied by the NKPC.

In this paper, we investigate the nature of structural breaks in inflation by estimating a version of the NKPC in the presence of a unit root in inflation. We first show that, with a unit root in inflation, the NKPC implies a reduced form unobserved components model of inflation that consists of three components: a stochastic trend component, a component that depends upon current and future forecasts of real economic activity, and a stationary component which is potentially serially correlated. Note that the last component can also be interpreted as the component of inflation that is not explained by the conventional forward-looking NKPC. We then investigate the nature and the implications of structural breaks in the latter two components, with a focus on the sensitivity of inflation to real economic activity and on the persistence of the component of inflation not explained by the conventional forward-looking NKPC. It is not our aim in this paper to directly investigate or identify the sources of structural breaks in these components. Rather, we ask whether the nature of structural breaks in these components is in line with the predictions of Cogley and Sbordone (2008), who derive a version of the time-varying NKPC in which the coefficients are the functions of time-varying trend inflation.

Our empirical results can be summarized as follows. During the Great Inflation period of the 1970s: i) inflation was relatively less sensitive to real activity; ii) there was a surge in the persistence of the unobserved stationary component or the component not explained by the conventional forward-looking NKPC; and iii) there was an upward shift in trend inflation. All these results are consistent with the predictions of Cogley and Sbordone (2008). Based on observing an increased persistence in the unobserved stationary component alone, one cannot rule out the possibility that the backward-looking component or price indexation may have been relatively more important during the Great inflation period. However, when combined with the other two results mentioned above, this interpretation could be erroneous, as implied by Cogley and Sbordone.

The outline of the paper is as follows. In Section 2, we provide model specifications. In particular, we first derive an unobserved components model of inflation as implied by the NKPC, and then explain how structural breaks can be incorporated into the model. In Section 3, we present empirical results. Section 4 provides concluding remarks.

2. SPECIFICATION OF AN EMPIRICAL MODEL

As in Goodfriend and King (2012), we consider the following version of the model due to Woodford (2008) that allows for time-varying trend inflation in the NKPC:

$$\pi_t - \pi_t^* = \beta E_t(\pi_{t+1} - \pi_{t+1}^*) + kx_t + \eta_t \tag{1}$$

where

$$\pi_t^* = \lim_{j\to\infty} E_t(\pi_{t+j}), \tag{2}$$

which is interpreted as the stochastic trend rate of inflation in the sense of Beveridge and Nelson (1981); β denotes the subjective discount factor; $E_t(.)$ refers to expectation formed conditional on information up to time t; x_t is a proxy for real economy activity such as the output gap, unemployment gap, or unit labor costs.

The η_t term, which is potentially serially correlated, is included to capture the importance of lagged inflation or higher order leads of expected inflation beyond $t+1$ in the NKPC.[1] Note that equation (1) is obtained from a log-linearization of the inflation dynamics derived from the Calvo pricing model, assuming that there is full indexation of the non-optimized prices to trend inflation. However, an assumption that the non-optimized prices are indexed to a linear combination of trend inflation and past inflation delivers lags of inflation in the model, as in Smets and Wouters (2003).

Alternatively, Ascari (2004) and Cogley and Sbordone (2008) show that, in the presence of non-zero or time-varying trend inflation, the interaction between trend inflation and nonlinearities in the Calvo model of price adjustment results in additional leads of expected inflation in the NKPC. According to them, ignoring these multi-step expectation terms would lead to serial correlation in η_t, which may be mistakenly attributed to the lagged inflation terms.

We note that it is not our aim in this paper to directly investigate the source of serial correlation in the η_t term. Rather, we investigate the nature and the implications of structural breaks in the Phillips curve given above, with a focus on the structural breaks on the k parameter and the persistence of the η_t term. By iterating equation (1) in the forward direction, we have:

$$\pi_t - \pi_t^* = \lim_{j\to\infty} \beta^j E_t(\pi_{t+j} - \pi_{t+j}^*) + k\sum_{j=0}^{\infty} \beta^j E_t(x_{t+j}) + \tilde{z}_t, \tag{3}$$

where $\tilde{z}_t = \sum_{j=0}^{\infty} E_t(\eta_{t+j})$. Here the $\tilde{z}_t$ term is the component of inflation not explained by the conventional forward-looking NKPC. Note that the first element on the right-hand-side of equation (3) is zero. Furthermore, the $\sum_{j=0}^{\infty} \beta^j E_t(x_{t+j})$ term is a function of x_t. In the case that x_t is not exogenous, it is correlated with $\tilde{z}_t$, resulting in a difficulty in estimation of the model. For feasible estimation of the model, we replace $E_t(x_{t+j})$ with $E_{t-1}(x_{t+j})$ in equation (3). By rearranging terms, we thus obtain the following empirical model for the Phillips curve:

$$\pi_t = \pi_t^* + k\sum_{j=0}^{\infty} \beta^j E_{t-1}(x_{t+j}) + z_t, \tag{3'}$$

where $z_t = k\sum_{j=0}^{\infty} \beta^j (E_t(x_{t+j}) - E_{t-1}(x_{t+j})) + \tilde{z}_t$. The first element of z_t is serially uncorrelated as it is a function of economic agents' revision on expectation of current and future real economic activities. Thus, potential serial correlation in z_t may be due to serial correlation in the η_t term in (1).

In the presence of a unit root in inflation, the π_t^* term, or the long-horizon inflation forecast, follows random walk dynamics, as shown in Beveridge and Nelson (1981). We assume that the x_t and z_t terms can be approximated by finite-order autoregressive (AR) processes. For an AR(2) process for x_t and an AR(1) process for z_t, we have the following unobserved components model which is consistent with the NKPC given in equation (1):

$$\pi_t = \pi_t^* + k \sum_{j=0}^{\infty} \beta^j E_{t-1}(x_{t+j}) + z_t, \tag{4}$$

$$\pi_t^* = \pi_{t-1}^* + v_t, \ \ v_t \sim i.i.dN(0, \sigma_v^2), \tag{5}$$

$$x_t = \phi_1 x_{t-1} + \phi_2 x_{t-2} + u_t, \ \ u_t \sim i.i.d.N(0, \sigma_u^2), \tag{6}$$

$$z_t = \psi z_{t-1} + \varepsilon_t, \ \ \varepsilon_t \sim i.i.d.N(0, \sigma_\varepsilon^2), \tag{7}$$

where u_t and ε_t are potentially correlated, as the z_t term involves a revision on expectation of the current and future real economic activities $(\sum_{j=0}^{\infty} \beta^j (E_t(x_{t+j}) - E_{t-1}(x_{t+j})))$. In the case that trend inflation is exogenous and is mainly driven by the long-run monetary policy of the central bank as in Cogley and Sbordone (2008), we can assume that the permanent shock to inflation is uncorrelated with both the transitory shock to inflation and the shock to output gap. Note that the model is estimated by setting the discount factor β to 0.99.

Incorporating Structural Breaks

We take the results of Kim and Nelson (1999) and McConnell and Perez-Quiros (2000) as establishing the existence of a structural break in 1984Q3 due to the Great Moderation. Building on that stylized fact in our estimation, the dynamics of the output gap in equation (6) is replaced by:

$$x_t = \phi_1 x_{t-1} + \phi_2 x_{t-2} + u_t, \ \ u_t | D_t \sim i.i.d.N(0, \sigma_{u,D_t}^2), \tag{8}$$

$$\sigma_{u,D_t}^2 = \sigma_{u,0}^2 (1 - D_t) + \sigma_{u,1}^2 D_t, \tag{9}$$

where

$$D_t = \begin{cases} 0, & \text{if } t \leq 1984Q3, \\ 1, & \text{otherwise.} \end{cases}$$

However, we do not pretend we know the dates of structural breaks in the dynamics of inflation. Our focus is on the nature of structural breaks in the sensitivity of inflation to current and future real economic activity and in the persistence and the variance of the component not explained by the forward-looking NKPC. Assuming that trend inflation is mainly driven by the long-run monetary policy of the central bank, one can conjecture that the evolution of trend inflation may be smooth and that there may be no abrupt shifts in the variance of the shocks to trend inflation. In order to test whether this is the case, however, we also consider structural breaks in the variance of the shocks to trend inflation.

An appropriate model selection procedure leads us to incorporate two structural breaks with unknown break dates for the dynamics of inflation. We thus employ a three-state Markov-switching model with absorbing states, as in Chib (1998). The conjecture is that the three regimes to be captured by the model are: i) a regime before the Great Inflation started; ii) the Great Inflation regime; and iii) a regime after the Volcker disinflation.[2] The inflation dynamics with structural breaks are given by:

$$\pi_t = \pi_t^* + k_{S_t} \sum_{j=0}^{\infty} \beta^j E_{t-1}(x_{t+j}) + z_t, \tag{10}$$

$$\pi_t^* = \pi_{t-1}^* + v_t, \;\; v_t|S_t \sim i.i.dN(0, \sigma_{v,S_t}^2), \tag{11}$$

$$z_t = \psi_{S_t} z_{t-1} + \varepsilon_t, \;\; \varepsilon_t|S_t \sim i.i.d.N(0, \sigma_{z,S_t}^2), \tag{12}$$

$$S_t = 1, 2, 3$$

where S_t is a first-order Markov-switching variable with the following matrix of transition probabilities:

$$\tilde{P} = \begin{bmatrix} p_{11} & 1-p_{11} & 0 \\ 0 & p_{22} & 1-p_{22} \\ 0 & 0 & 1 \end{bmatrix}, \tag{13}$$

where the $(i,j)-th$ element refers to $Pr[S_t = j|S_{t-1} = i]$.

State-Space Representation of the Model

Notice that u_t, the shock to the observed output gap in equation (8), and ε_t, the shock to the unobserved stationary component of inflation, are potentially correlated with each other. In order to allow for the potential correlation between these two shocks, we employ the following state-space representation of the model:

Measurement Equation

$$\begin{bmatrix} \pi_t \\ x_t \end{bmatrix} = \begin{bmatrix} 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} \pi_t^* \\ z_t \\ x_t^* \\ x_{t-1}^* \end{bmatrix} + \begin{bmatrix} k_{S_t} \sum_{j=0}^{\infty} \beta^j E_{t-1}(x_{t+j}) \\ 0 \end{bmatrix}, \tag{14}$$

where the term $\sum_{j=0}^{\infty} E_{t-1}(x_{t+j})$ can be calculated by:

$$\sum_{j=0}^{\infty} E_{t-1}(x_{t+j}) = e_1' F (I_2 - \beta F)^{-1} \tilde{x}_{t-1}, \tag{15}$$

where $e_1 = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$ $F = \begin{bmatrix} \phi_1 & \phi_2 \\ 1 & 0 \end{bmatrix}$ and $\tilde{x}_{t-1} = \begin{bmatrix} x_{t-1} \\ x_{t-2} \end{bmatrix}$.

Transition Equation

$$\begin{bmatrix} \pi_t^* \\ z_t \\ x_t^* \\ x_{t-1}^* \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \psi_{S_t} & 0 & 0 \\ 0 & 0 & \phi_1 & \phi_2 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} \pi_{t-1}^* \\ z_{t-1} \\ x_{t-1}^* \\ x_{t-2}^* \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} v_t \\ \varepsilon_t \\ u_t \end{bmatrix}, \tag{16}$$

where

$$\begin{bmatrix} v_t \\ \varepsilon_t \\ u_t \end{bmatrix} |S_t, D_t \sim i.i.d.N \left(\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \sigma_{v,S_t}^2 & 0 & 0 \\ 0 & \sigma_{\varepsilon,S_t}^2 & \sigma_{u\varepsilon} \\ 0 & \sigma_{u\varepsilon} & \sigma_{u,D_t}^2 \end{bmatrix} \right). \tag{17}$$

The empirical results that follow in the next section are obtained from estimating the state-space model above by maximum-likelihood methods based on Kim's (1994) approximate Kalman filter.

3. EMPIRICAL RESULTS: THE NATURE OF STRUCTURAL BREAKS IN INFLATION DYNAMICS

For the inflation series, we employ the seasonally adjusted PCE chain-type price index, and we use the CBO (Congressional Budget Office) output gap series as a proxy for real economy activity. The sample covers the period of 1952Q1-2007Q3. The beginning of the sample is chosen to avoid large swings in inflation resulting from the Korean war, and the end of the sample marks the quarter prior to the 2007 financial crisis. All data is taken primarily from the Federal Reserve Economic Database (FRED).

In determining the number of states, we consider model selection based on the Akaike Information Criterion (AIC). Then, we verify our model selection results by checking whether a given model captures most of the serial correlation and heteroscedasticity in the data. This is done by testing the null of no serial correlation in the standardized residuals and their squares. The number of structural breaks thus chosen is two.[3]

For robustness checks, we estimated the model by employing the GDP deflator and the CPI inflation series as well. As the empirical results are qualitatively similar for estimation of the model using PCE inflation, we do not report the results here. We also consider another robustness check to investigate whether our results are sensitive to the assumptions about the output gap process. We estimate a bivariate unobserved components model in inflation and output that is consistent with the NKPC, which allows us to treat the output gap as an unobserved variable. We find that the estimation results from the bivariate unobserved components model is qualitatively similar to those of the model with observed CBO output gap. The estimation results based on the GDP deflator and the CPI inflation series as well as the results for the bivariate unobserved components model are reported in an unpublished Appendix, which is available from the authors upon request.

Table 1 reports parameter estimates of the model based on the PCE inflation. The second column contains the results for the model with structural breaks in the variances of the shocks to both the stochastic trend and stationary components. The third column reports the results for a model in which the shocks to the stochastic trend component is constrained to follow an i.i.d. process. In the fourth column, the results correspond to a model where the stationary component z_t is constrained to be serially uncorrelated and the variance of its shocks are assumed to be constant. Based on log-likelihood ratio tests, we could not reject the null hypothesis that the variance of the permanent shocks is constant for each measure of inflation. Although we fail to reject the null hypothesis that the variance of the transitory shocks are constant and z_t is serially uncorrelated, the results in the second and third columns indicate that serial correlation in z_t is significant as well as the changes in the variance of shocks to z_t across regimes. Thus, all of the discussion that follows is based on the estimates of models with constant variance of permanent shocks and an unconstrained transitory component. The results can be summarized as follows.

First, the estimated transition probabilities imply that the two break dates are the early 1970s and the early 1980s, as illustrated by the estimated regime probabilities in Figure 1. As expected, the second regime roughly coincides with the Great Inflation period. The third regime roughly coincides with the period after the Volcker disinflation.

Second, there is an upward shift in trend inflation during the Great Inflation period. In Figure 2, the estimates of trend inflation and the 90% confidence intervals are depicted against the realized inflation rate. The ups and downs of trend inflation generally coincide with those of actual inflation, even though trend inflation is much smoother than actual inflation. In addition, it can be observed that trend inflation is low and steady in the early 1960s, started to rise in the late 1960s peaking around 6% in the 1970s , fell after the Volcker disinflation of the early 1980s, and remained low and stable around 2% since the early 1990s. This general trajectory of trend inflation is similar to those reported elsewhere (see, e.g., Cogley and Sargent 2002, Ireland 2007, and Cogley and Sbordone 2008).

Third, estimates of the k parameters over the different regimes suggest that inflation was less sensitive to real economic activity in the 1970s than in the other regimes. These results are consistent with those reported in Cogley, Primiceri and Sargent (2010) and Cogley and Sbordone (2008). The former report a decline in the coefficient on real economic activity during the 1970s based on recursive estimation of backward-looking Phillips curves. The latter report the same results based on estimation of a structural model with time-varying trend inflation.

Fourth, the persistence (ψ) and the variance of the unobserved stationary component (z_t) are much higher in the second regime (the Great Inflation) than in the other two regimes. Figure 3 depicts the estimates of the inflation cycle and the inflation gap, where the inflation cycle is defined as the portion of inflation that is driven by current and future economic activity and the inflation gap as the sum of the inflation cycle and the unobserved stationary component. Note that the inflation gap diverges considerably from the inflation cycle during the Great Inflation period, as the result of an increase in the persistence and variance of the unobserved stationary component. Cogley and Sbordone (2008) and Cogley, Primiceri and Sargent (2010) also present evidence that inflation-gap persistence increased considerably during the Great Inflation and that it fell after the Volcker disinflation. As in Cogley and Sbordone, we conjecture that the increase in the persistence and the variance of the unobserved stationary component (i.e. the portion of inflation not explained by the conventional forward-looking NKPC) during the Great Inflation period may reflect a failure to explicitly include additional leads of inflation expectation, the relative weight of which increased with an increase in trend inflation.

However, these results are inconsistent with Stock and Watson (2007), who suggest that higher inflation persistence before the Volcker disinflation can be explained by a higher fraction of the variance of the change in inflation ($\Delta\pi_t$) explained by shocks to the stochastic trend component, rather than shocks to the transitory component which they find to be almost constant. The empirical results from our model suggest the contrary, that is, higher inflation persistence is reflected as an increase in the persistence and variance of the transitory component of inflation not explained by the output gap. We conjecture that the main driver of this difference in results stem from the fact that in the Stock and Watson model, the transitory component of inflation is constrained to be serially uncorrelated. As a result, an increase in overall inflation persistence is forced to show up as increased variability in the shocks to the stochastic trend component.

In the last column of Table 1, we report the estimation results obtained by constraining the transitory component (z_t) to be serially uncorrelated.[4] Note that constraining the z_t component to be serially uncorrelated does not change our results on the estimate of the k coefficient across regimes. That is, inflation is less sensitive to real economic activity in the 1970s than in the other regimes. However, the results show that a high variance of the shocks to the permanent component is responsible for the high variance of inflation in the 1970s, as conjectured. Furthermore, similar to Stock and Watson (2007), we find that constraining the transitory component z_t to be serially uncorrelated results in the stochastic trend component of inflation tracking actual inflation closely, as depicted in Figure 4.

4. SUMMARY AND CONCLUDING REMARKS

Ascari (2004) and Cogley and Sbordone (2008) show that non-zero or time-varying trend inflation results in additional leads of expected inflation in the NKPC. Cogley and Sbordone further show that the coefficients of the NKPC are functions of time-varying trend inflation. In this paper, we first derive a reduced-form model of inflation, as implied by the New Keynesian Phillips curve in the presence of a unit root in inflation. We then investigate the nature of structural breaks in the resulting unobserved components model, which consists of a stochastic trend component, a stationary component, and a component that depends upon current and future expected output gaps.

Our empirical results suggest that, with an increase in trend inflation during the Great Inflation period, the response of inflation to real economic activity decreases and the persistence of the inflation gap increases due to an increase in the persistence of the unobserved stationary component (i.e. the portion of inflation not explained by the conventional forward-looking NKPC). After the Volcker disinflation, the response of inflation to real economic activity increases and the persistence of the unobserved stationary component decreases. These results are all in line with the predictions of Cogley and Sbordone's (2008) model.

The increase in the persistence of the unobserved stationary component during the Great Inflation period may reflect a failure to explicitly include additional leads of inflation expectation, the relative weight of which might have increased with an increase in trend inflation, as suggested by Cogley and Sbordone (2008). One cannot rule out the possibility that the increased persistence of the inflation gap may be due to an increased importance of the backward-looking component. However, there exists no rigorous theory that may justify such time-varying importance of the backward-looking component. The empirical results in this paper could be interpreted as providing indirect evidence in support of Cogley and Sbordone. They show that a purely forward-looking version of the NKPC fits the post-war U.S. data well after accounting for the effects of time-varying trend inflation on the multi-step expectations of inflation.

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LITERATURE CITED

Ascari, Guido. (2004) "Staggered Prices and Trend Inflation: Some Nuisances." *Review of Economics Dynamics,* 7, 642-667.

Beveridge, Stephen, and Charles R. Nelson. (1981) "A New Approach to the Decomposition of Economic Time Series into Permanent and Transitory Components with Particular Attention to Measurement of the 'Business Cycle'." *Journal of Monetary Economics,* 7, 151-174.

Chib, Siddhartha. (1998) "Estimation and Comparison of Multiple Change-Point Models." *Journal of Econometrics,* 86, 221-241.

Cogley, Timothy, and Thomas J. Sargent. (2002) "Evolving Post-World War II U.S. Inflation Dynamics." In *NBER Macroeconomics Annual 2001,* edited by Mark Gertler and Kenneth Rogoff, pp. 331-373. Cambridge MA: The MIT Press.

Cogley, Timothy, and Thomas J. Sargent. (2005) "Drifts and Volatilities: Monetary Policies and Outcomes in Post WWII US." *Review of Economic Dynamics,* 8, 262-302.

Cogley, Timothy, Giorgio E. Primiceri, and Thomas J. Sargent. (2010) "Inflation-Gap Persistence in the US." *American Economic Journal: Macroeconomics,* 2(1), 43-69.

Cogley, Timothy, Argia M. Sbordone. (2008) "Trend Inflation, Indexation, and Inflation Persistence in the New Keynesian Phillips Curve." *American Economic Review,* 98(5), 2101-2126.

Goodfriend, Marvin, and Robert G. King. (2012) "The Great Inflation Drift." In *The Great Inflation: The Rebirth of Modern Central Banking,* edited by Michael D. Bordo and Athanasios Orphanides, Chicago: University of Chicago Press.

Harvey, Andrew C.. (2011) "Modeling the Phillips Curve with Unobserved Components." *Applied Financial Economics,* 21(1-2), 7-17.

Ireland, Peter N.. (2007) "Changes in the Federal Reserve's Inflation Target: Causes and Consequences." *Journal of Money, Credit and Banking,* 39(8), 1851-2110.

Kang, Kyu Ho, Chang-Jin Kim, and James Morley. (2009) "Changes in U.S. Inflation Persistence." *Studies in Nonlinear Dynamics & Econometrics,* 13(4), Article 1.

Kim, Chang-Jin. (1994) "Dynamic Linear Models with Markov-switching." *Journal of Econo-*

metrics, 60(1-2), 1-22.

Kim, Chang-Jin, and Charles R. Nelson. (1999) "Has the US Economy Become More Stable? A Bayesian Approach Based on a Markov-Switching Model of the Business Cycle." *Review of Economics and Statistics*, 81(4), 608616.

Lee, Jaejoon, and Charles R. Nelson. (2007) "Expectation Horizon and the Phillips Curve: The Solution to an Empirical Puzzle." *Journal of Applied Econometrics,* 22, 161-178.

McConnell, Margaret M., and Gabriel Perez-Quiros. (2000) "Output Fluctuations in the United States: What has Changed Since the Early 1980s?" *American Economic Review,* 90, 1464-1476.

Murray, Christian J., Alex Nikolsko-Rzhevskyy, and David H. Papell. (2009) "Inflation Persistence and the Taylor Principle." MPRA Paper No. 11353, University Library of Munich, Germany.

Nelson, Charles R., and G. William Schwert. (1977) "Short-term Interest Rates as Predictors of Inflation: On Testing the Hypothesis that the Real Rate of Interest is Constant." *American Economic Review,* 67(3), 478-486.

Primiceri, Giorgio E.. (2005) "Time Varying Structural Vector Autogregressions and Monetary Policy." *Review of Economic Studies,* 72(3), 821-852.

Sims, Christopher A., and Tao Zha. (2006) "Were There Regime Switches in U.S. Monetary Policy?" *American Economic Review,* 96, 54-81.

Smets, Frank, and Raf Wouters. (2003) "An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area." *Journal of the European Economic Association,* 1(5), 1123-1175.

Stock, James H., and Mark W. Watson. (2007) "Why Has U.S. Inflation Become Harder to Forecast?" *Journal of Money, Credit and Banking,* 39(1), 3-33.

Woodford, Michael. (2008) "How Important is Money in the Conduct of Monetary Policy?" *Journal of Money, Credit, and Banking,* 40(8), 1561-1598.

FOOTNOTES

[1]The η_t term may be interpreted as a "mark-up shock" in the New Keynesian literature. Note that mark-up shocks are typically serially correlated.

[2]Alternatively, we could incorporate two-state Markov-switching parameters into the model instead to allow for recurring states. In such a case, we hypothesize that the parameters during the pre and post Volcker disinflation regimes are the same. Specifically, there would be two regime switches in U.S. inflation dynamics, which can be described as transitions to the Great Inflation regime and back. By estimating both a structural break and a Markov-switching model for the NKPC, we find that the two models deliver results that are qualitatively similar. Estimation results for a two-state Markov-switching model are reported in an unpublished Appendix, which is available from the authors upon request.

[3]For the chosen model, we could not reject the null hypothesis that the standardized residuals and their squares are white noise except for a short disinflationary period in the early 1980s.

[4]We could not reject the null hypothesis of a constant variance for the shocks to the z_t component even at a 10% significance level (the p-value was 0.50). Note that Stock and Watson (2007) also report a fairly stable variance of the shocks to the transitory component, which is constrained to be serially uncorrelated.

Table 1: **Estimation results of the unobserved components NKPC model [1952Q1-2007Q3].**

Parameters	Estimates (Standard error)		
	Unconstrained Model	Model with Constrained Permanent Component	Model with Constrained Transitory Component
		Output Gap Equation	
ϕ_1	1.190** (0.063)	1.191** (0.063)	1.195** (0.063)
ϕ_2	-0.266** (0.063)	-0.266** (0.062)	-0.271** (0.062)
$\sigma_{u,0}$	1.031** (0.067)	1.030** (0.067)	1.028** (0.066)
$\sigma_{u,1}$	0.459** (0.034)	0.460** (0.034)	0.461** (0.034)
		Inflation Equation	
k_1	0.023* (0.011)	0.022* (0.010)	0.021* (0.011)
k_2	0.007 (0.020)	0.006 (0.019)	0.000 (0.018)
k_3	0.014 (0.012)	0.016 (0.012)	0.016 (0.012)
ψ_1	-0.104 (0.174)	-0.076 (0.171)	-
ψ_2	0.907** (0.085)	0.895** (0.089)	-
ψ_3	0.032 (0.158)	0.000 (0.087)	-
σ_ε	-	-	0.809** (0.054)
$\sigma_{\varepsilon,1}$	0.718** (0.093)	0.736** (0.088)	-
$\sigma_{\varepsilon,2}$	1.561** (0.200)	1.546** (0.193)	-
$\sigma_{\varepsilon,3}$	0.866** (0.088)	0.846** (0.074)	-
σ_v	-	0.339** (0.060)	-
$\sigma_{v,1}$	0.376** (0.090)	-	0.340** (0.078)
$\sigma_{v,2}$	0.292 (0.307)	-	1.274** (0.231)
$\sigma_{v,3}$	0.291** (0.097)	-	0.309** (0.085)
$\rho_{\varepsilon,u}$	-0.063 (0.087)	-0.074 (0.084)	-0.101 (0.089)
p_{11}	0.987** (0.013)	0.987** (0.013)	0.987** (0.013)
$BreakDates$	1971Q1	1971Q1	1971Q1
p_{22}	0.975** (0.025)	0.974** (0.026)	0.977** (0.023)
$BreakDates$	1981Q1	1980Q4	1981Q4
$Log-likelihood$	-362.373	-362.586	-364.049

Note: ** and * indicate significance at the 5 and 1 percent levels, respectively.

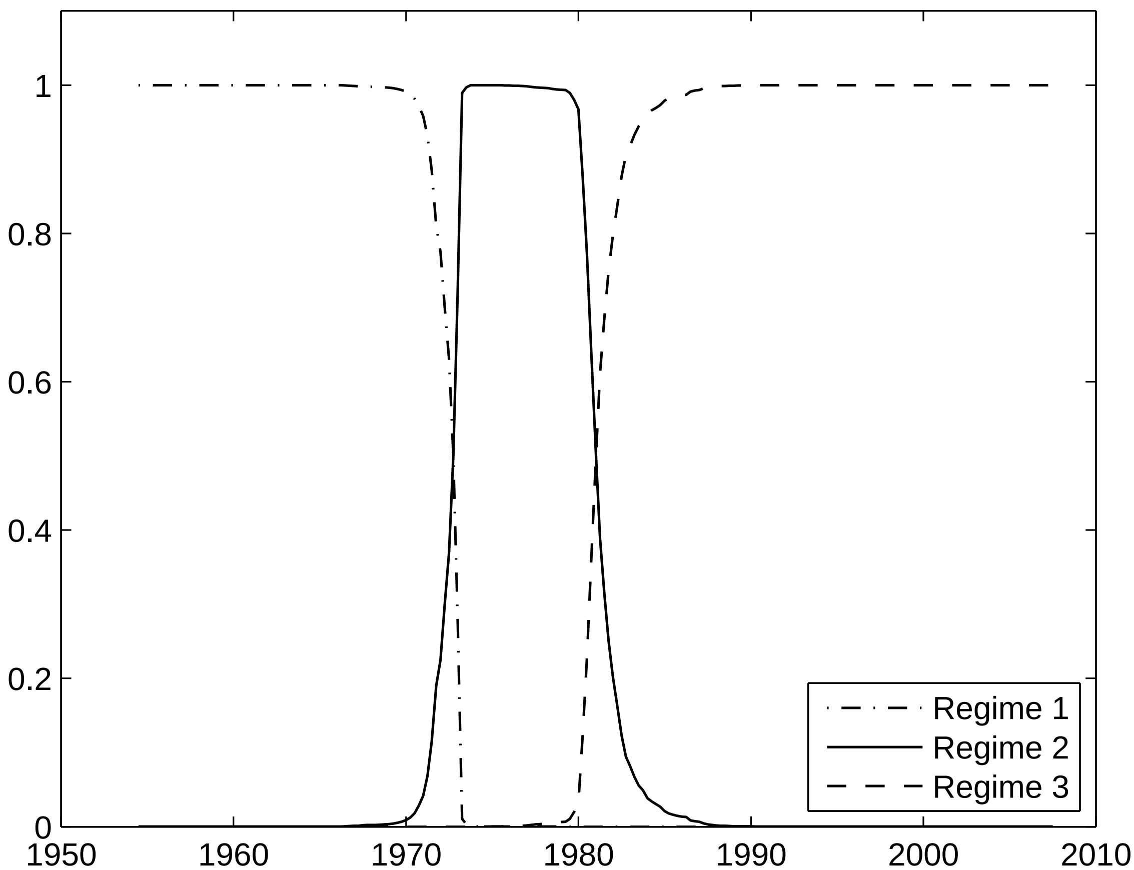

Figure 1: Smoothed probabilities of regimes.

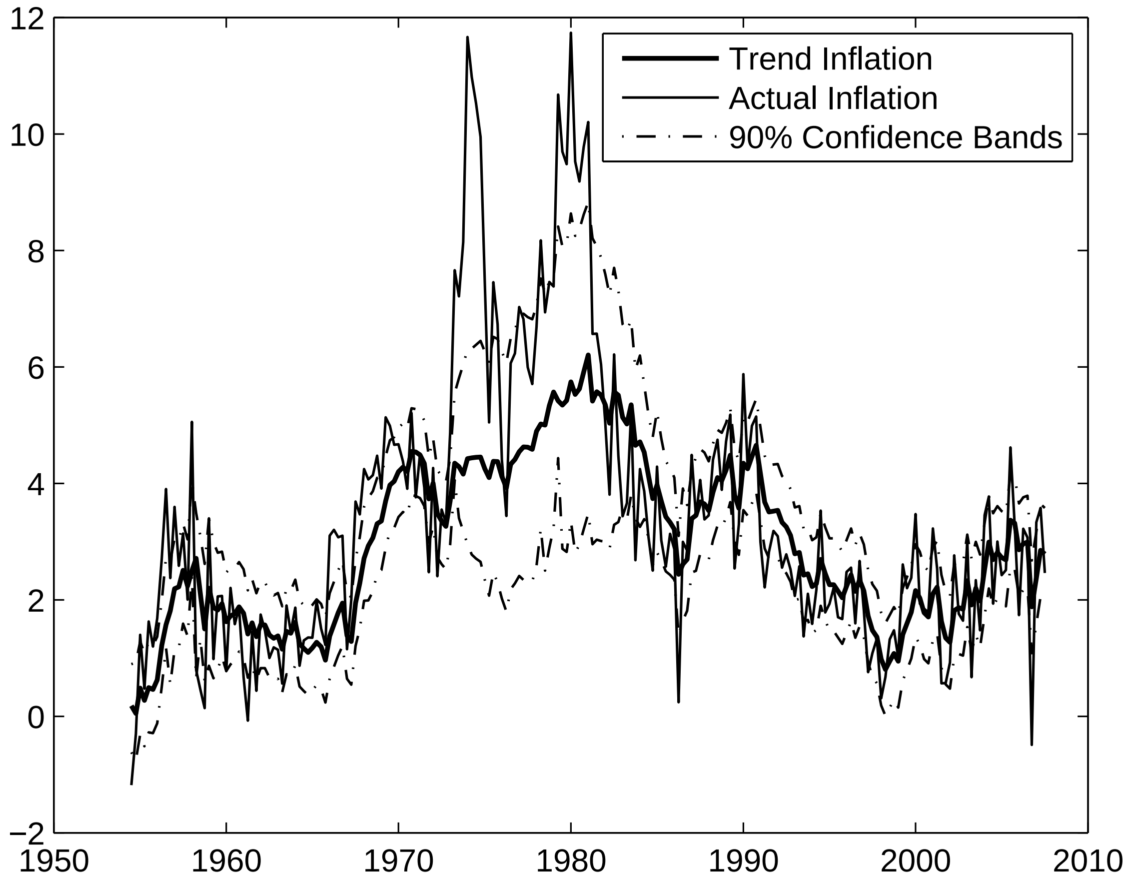

Figure 2: Actual inflation and trend inflation.

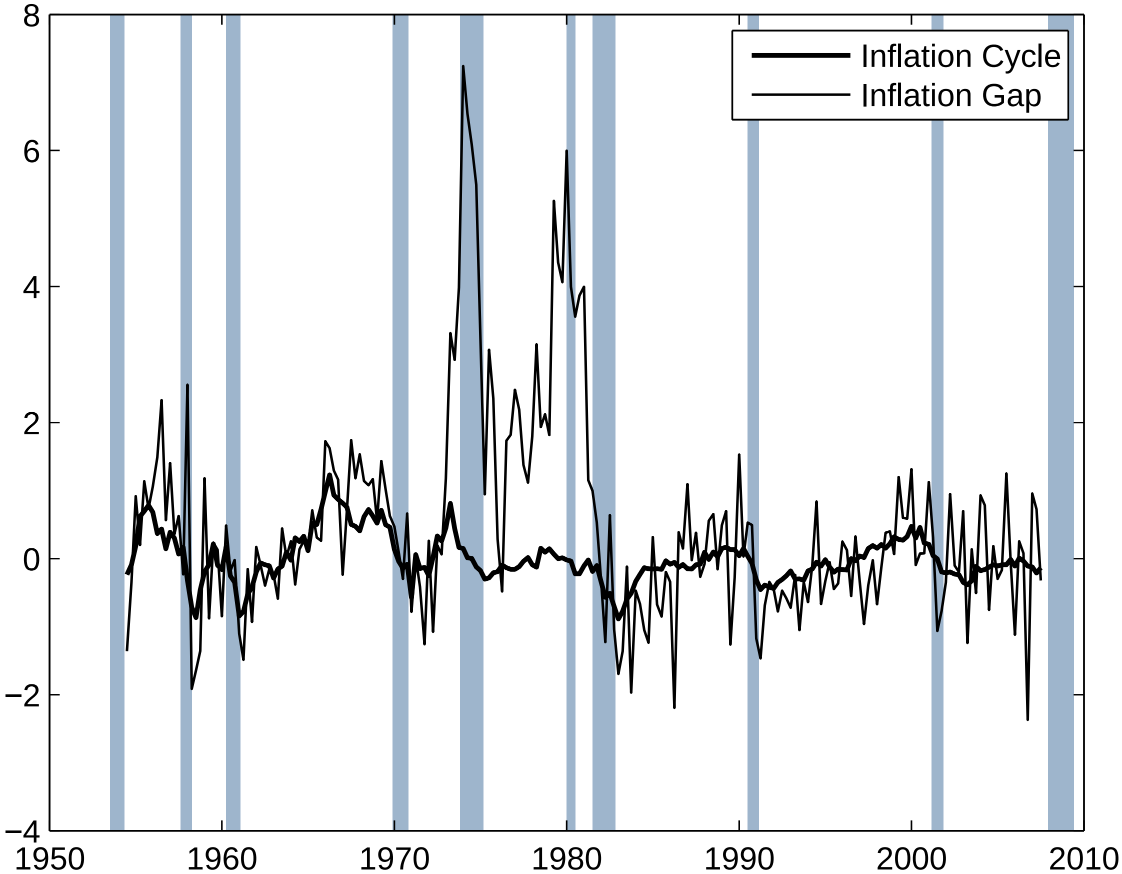

Figure 3: Inflation cycle and inflation gap. Shaded regions correspond to NBER recession dates.

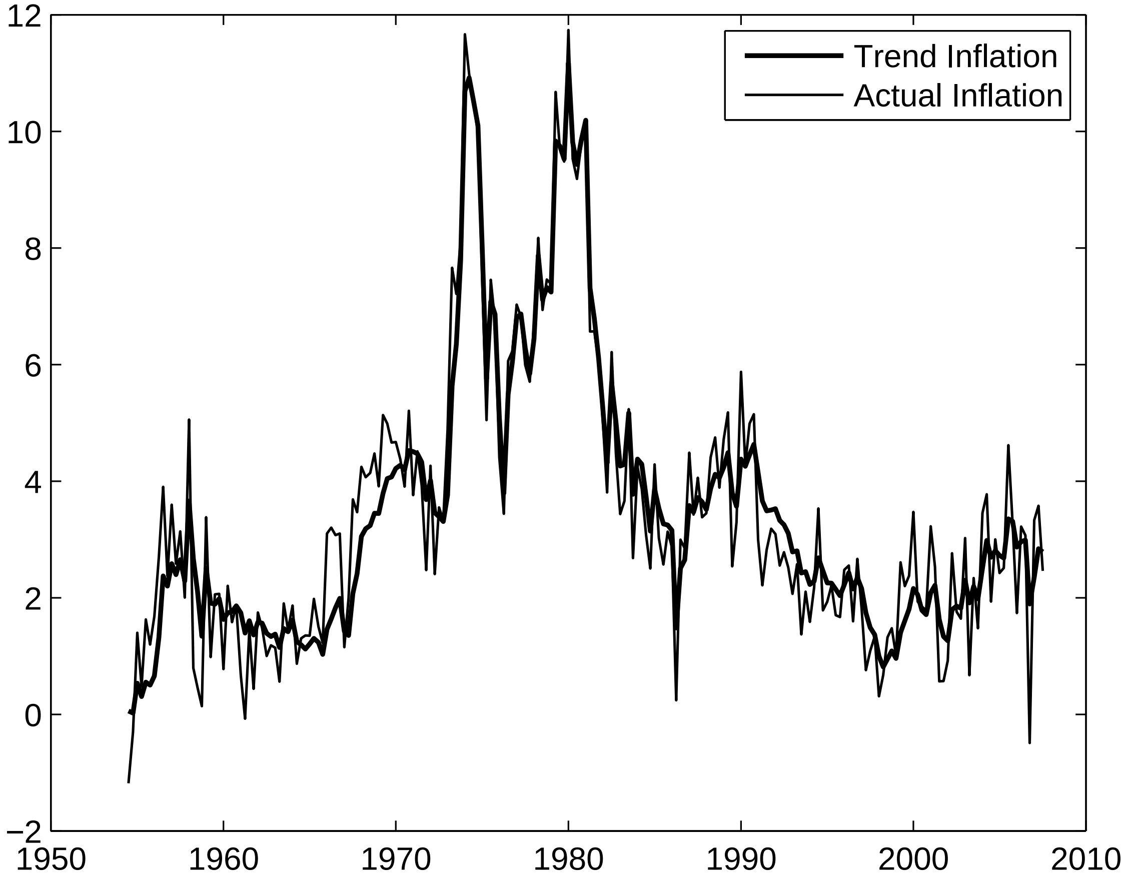

Figure 4: Actual inflation and trend inflation for the unobserved components model with constrained transitory component z_t.