New Measures of the Output Gap Based on the Forward-Looking New Keynesian Phillips Curve

by

Arabinda Basistha

West Virginia University

and

Charles R. Nelson[*]

University of Washington

This version: December16, 2003

Abstract:

Forward-looking versions of the New Keynesian Phillips curve imply that the output gap, the deviation of the actual output from its natural level due to nominal rigidities, drives the dynamics of inflation relative to expected inflation. We exploit this to set up a bivariate unobserved component model for extracting new estimates of the output gap in the US. The Phillips curve helps us to distinguish between the output gap and a purely transitory component other than the gap. The estimates suggest that the purely transitory component is small and, therefore, the entire transitory component well approximates the gap. The gap estimates are large and persistent even after allowing for correlated trend and cycle shock. Finally, we augment our benchmark model to use the information in the unemployment rate about the gap. The estimates confirm the presence of a large and persistent cyclical component.

Key Words: Output gap; Phillips curve; Inflation; Unemployment Rate; Unobserved components model.

JEL Classification: E31, E32, E50.

---

[*] Correspondence: Charles Nelson, Box 353330, Dept. of Economics, University of Washington, Seattle, WA - 98195. Email: cnelson@u.washington.edu. The authors would like to thank Fred Joutz, Chang-Jin Kim, Richard Startz and Eric Zivot for helpful suggestions and discussions. Usual disclaimers apply.

1. Introduction

Recent developments in the New Keynesian theory of business cycles provide a precise definition of the output gap. Gali (2003) defines the output gap as: "the deviation of output from its equilibrium level in the absence of nominal rigidities". Theoretical developments on the basis of this definition suggest a forward-looking Phillips curve; current inflation depends on future inflationary expectations and the current output gap. The objective of this paper is to derive estimates of the output gap exploiting the implication that inflation contains information about the gap, given a measure of expectations. We cast the model in state-space form, treating the gap as an unobserved state variable to be estimated using the Kalman filter.

The traditional approaches equate the gap with the deviation of output from a statistical measure of trend. Statistical 'de-trending' procedures typically impose strong priors on the smoothness of the trend or cycle, and generally assume that trend and cycle shocks are uncorrelated. These restrictions lack support in theory, and moreover tend to shape the estimated components. Moreover, the definition of the gap does not rule out transitory fluctuations in equilibrium output which are not due to nominal price rigidities. Instead of imposing smoothness or a restrictive correlation structure, our approach is to exploit the information contained in forward-looking price setting behavior while allowing for a non-gap transitory component of output.

In section 2, we present a brief review of the related literature. We lay out our benchmark model and present our primary results in section 3. In section 4 we augment our benchmark model using the unemployment rate and present estimates of the gap. We summarize and conclude in section 5.

2. Gap Measurement: A Brief Review of the Literature

The history of measurement of the business cycle goes back to the seminal works of Mitchell (1927) and Burns and Mitchell (1946) who focused on the timing of recessions, episodes which they interpreted to be deviations from a full-employment level of output. Since then, the literature can be broadly categorized into two groups, statistical and economic, with sub-categories within them and interactions between them. There are two major sub-categories of statistical approaches to the decomposition of output into trend and cycle components, which generally are assumed to correspond to potential output and gap respectively. One approach imposes smoothness on either the trend or the cycle, while the other does not impose prior smoothness on either component, at least directly, but 'lets the data speak for itself' through a time series model.

The simplest and still widely-used method of obtaining a smooth measure of trend is to fit a polynomial in time to output, the residual being the estimated cycle. The filter of Hodrick and Prescott (1997) imposes smoothness but not determinism on the trend. A third approach extracts an estimate of the cycle by passing the data through a filter that pre-specifies the relevant frequencies for the cycle and thus its persistence. For example, the approximate band-pass filter of Baxter and King (1999) defines the cycle as having spectral power in the range between 6 quarters and 32 quarters. Murray (2003) has shown that in the case of stochastic trend the band-pass filter leaves some of the trend shock in the estimated cycle.

Statistical approaches that 'let the data speak' are model-based and require identification of a stochastic trend component. The Beveridge-Nelson (1981) (hereafter 'BN') decomposition is based on modeling first differences as an ARMA model, the trend being identified as the long-horizon forecast, which must be a random walk. The unobserved components (hereafter UC) model associated with the seminal work of Harvey (1985), Watson (1986), and Clark (1987) imposes the restriction of zero correlation between the shocks to the cycle and trend, the latter assumed to be a random walk (with varying growth rate in some specifications). The BN decomposition yields small, less persistent cycles whereas the UC decomposition yields large, more persistent cycles. Morley, Nelson and Zivot (2003) (hereafter 'MNZ') show that the latter is due to the assumption that trend and cycle shocks are uncorrelated, demonstrating the strong influence of statistical assumptions on trend-cycle decompositions. Blanchard and Quah (1989) identify supply and demand shocks according to whether their long run effect is permanent or transitory, respectively. Canova (1998), while providing a comprehensive survey of all the de-trending methods, shows that empirical macroeconomic results can be quite sensitive to which method is used.

Turning to economic approaches, one measures the gap relative to “potential output’ based on an aggregate production function. CBO (1995) outlines a large-scale multi-sector growth model for estimating potential output. Recently, Gali and Gertler (1999) suggested real unit labor cost (or labor income share) as a good approximation for the output gap. They argue that using this proxy for the gap provides significant empirical support for the forward-looking Phillips curve.

Efforts towards blending the statistical with the economic approach have resulted primarily in estimating multivariate forms of the unobserved components model. Kuttner (1994) uses a bivariate model of inflation and output, assuming that the transitory component of output is the gap variable in the inflation equation. Gerlach and Smets (1999) take a similar approach for EU data, but use the real interest rate as a driving variable for the cycle. Both of these take the standard random walk trend and uncorrelated shocks assumptions from the UC approach to complete their model. Apel and Jansson (1999) use a similar bivariate model of inflation and unemployment to extract an estimate of cyclical fluctuations in output. Our approach differs in allowing the gap to differ from cycle, and relaxes the restriction that trend and cycle shocks are uncorrelated. Clark (1989) studied trend-cycle decompositions of the unemployment rate and output in a multi-country study. Roberts (2001) does a similar study for the US using output, inflation and hours. They found that the assumption of zero correlation was reasonable for the U.S.

A closely related but different strand of research has been on measuring the natural rate of unemployment or the NAIRU. The approaches to measure the unemployment gap and the NAIRU have also varied between statistical and economic. Important contributions on this area have been made by Blanchard and Katz (1997), Gordon (1997, 1998), Laubach (2001), Salemi (1999), Staiger, Stock and Watson (1997b, 2001), Stiglitz (1997) among others. However, Staiger, Stock and Watson (1997a) point out that it is very difficult to measure the NAIRU precisely.

Research on the forward-looking Phillips curve dates at least to Taylor (1979, 1980) whose approach is based on staggered wage contracts. Calvo (1983) provides an alternative staggered pricing model based on random chance of price adjustment. Rotemberg (1987) presents a similar model with quadratic cost price adjustment. Recent theoretical work on derivation of the "New Keynesian" Phillips curve is primarily based on Calvo (1983) type nominal rigidity assuming forward-looking, optimizing, monopolistically competitive producers. A number of recent researchers (see Gali and Gertler (1999), Goodfriend and King (1997), Rotemberg and Woodford (1997), Sbordone

(2002) among others) have used Calvo (1983) type of nominal rigidity to derive the forward-looking Phillips curve from an optimizing model.

Empirical estimation of the forward-looking Phillips curve has not been an unqualified success. Roberts (1995) estimates a forward-looking model of the Phillips curve. Fuhrer (1997) provides evidence against the forward-looking pricing behavior. Fuhrer and Moore (1995) also argue in favor of the presence of substantial backward-looking behavior in estimating the inflation equation. Roberts (1997) provides support for the role of inflationary expectations in estimating Phillips curve. He used survey data for inflationary expectations. Gali and Gertler (1999) also estimated a "hybrid" Phillips curve containing both forward-looking and backward-looking components using GMM. They show the "hybrid" model provides a good fit for the empirical Phillips curve, and that is our starting point for estimating the output gap in this paper.

3. The Phillips Curve in State-Space Form and Estimates of the Gap

3.1 The Model

The forward-looking New Keynesian Phillips curve based on optimizing behavior by forward-looking, monopolistically competitive producers takes the form[1]:

(1) $$\pi_t = \beta E_t \pi_{t+1} + \delta g_t + z_t,$$

where π_t is the inflation rate, g_t is the output gap due to nominal rigidities, z_t is the direct supply shock to inflation rate, and $E_t \pi_{t+1}$ is the unobservable aggregate expectation of inflation in period $t+1$ based on period t information. Theory suggests that β is

[1] See Gali and Gertler (1999), Sbordone (2002) for a derivation of this equation based on Calvo (1983) type of pricing. Also see Goodfriend and King (1997), Rotemberg and Woodford (1997) and Yun (1996) on this topic.

approximately one and δ is positive. Empirical research shows that lagged inflation has considerable explanatory power as an added variable in these models, leading researchers to consider ‘hybrid’ Phillips Curve models that are both forward- looking and backward-looking. Whether the apparent role of lagged inflation is due to error in measuring expectations, to non-rational adaptive expectation formation, or to price rigidities not fully captured by the model may never be resolved, nor is the explanation essential for purposes of extracting the estimate of the gap.

Our approach acknowledges that neither inflation expectations nor the gap is directly observed, and to treat each as a state variable in a state-space representation of the Phillips curve, rather than to simply replace either with measured proxies. The pay-off from this approach comes from using the Kalman filter to extract the estimated gap implied by the behavior of inflation. In particular, the part of actual inflation that is not related to the gap is treated as the state variable implicit in the measurement equation:

(2) $$\pi_t = \tilde{\pi}_t + \delta g_t .$$

This non-gap part of inflation, $\tilde{\pi}_t$, is partially observable through its linear projection on observable variables, including survey expectations of inflation as advocated by Roberts (1997, 1998), denoted π_t^{se}, and lagged actual inflation. The state equation is then:

(3) $$\tilde{\pi}_t = \beta_0 + \beta_1 \pi_t^{se} + \beta_2 \pi_{t-1} + u_t$$

where u_t, is a composite of both unobserved variables that play a role in expected inflation and z_t, the direct supply shock in equation (1). Allowing for possible serial correlation in the error term, we specify

(4) $$u_t = \phi_\pi u_{t-1} + \varepsilon_{\pi,t}\,;\ \varepsilon_{\pi,t} \sim N(0, \sigma_\pi^2) \text{ and } |\phi_\pi| < 1.$$

Turning now to the decomposition of output, we depart from conventional specifications that identify any deviation from trend as belonging to the gap by allowing equilibrium output to have both a permanent ‘trend’ component and a transitory stationary component. Thus, output, Y_t, consists of three unobserved components as follows. P_t reflects the impact of permanent shocks on the equilibrium level of output; w_t allows for transitory shocks to equilibrium output (‘weather’) and thus does not enter the Phillips curve equation; and the gap, g_t, is the stationary component of output associated with nominal rigidities in the economy. The measurement equation for output is then:

(5) $$Y_t = P_t + w_t + g_t ,$$

Completing the specification of the state variables, g_t is assumed to be a stationary AR(2) process, following Harvey (1985), Watson (1986), Clark (1987), and Harvey and Jaeger (1993), to allow for periodicity in the spectral density function of g_t. In the absence of any literature on estimating the non-gap transitory component w_t, we specify it to be AR(1). Finally, the trend component of equilibrium output, denoted P_t, is a random walk component with a (constant) drift m. Gathering these together, we have three more state equations given by:

(6) $$\begin{aligned} P_t &= m + P_{t-1} + e_{P,t} \\ g_t &= f_{g,1} g_{t-1} + f_{g,2} g_{t-2} + e_{g,t} \\ w_t &= f_w w_{t-1} + e_{w,t} \end{aligned}$$

where $e_{P,t} \sim N(0, s_P^2)$, $e_{g,t} \sim N(0, s_g^2)$, $e_{w,t} \sim N(0, s_w^2)$, respectively.

The four shocks in the system, three defined above plus the shock to inflation, have among them six covariances and we restrict two of them to identify the model. First, we restrict $s_{pg} = 0$ by assuming that the survey data responders providing p_t^{se} are sufficiently informed about g_t. This has the effect of separating the two stationary unobserved components of inflation. Second, the two transitory components are assumed mutually orthogonal, $s_{gw} = 0$, thus separating the two stationary components of output. However, it is not necessary to restrict the covariance between trend and cycle shocks as in the standard UC approach. The above restrictions, together with the influence of the gap on both inflation and output, turned out to be adequate to identify the gap. The variance-covariance matrix to be estimated is then:

$$(7) \qquad Cov(e_{P,t}, e_{g,t}, e_{p,t}, e_{w,t}) = \begin{bmatrix} s_P^2 & s_{Pg} & s_{Pp} & s_{Pw} \\ s_{gP} & s_g^2 & 0 & 0 \\ s_{pP} & 0 & s_p^2 & s_{pw} \\ s_{wP} & 0 & s_{wp} & s_w^2 \end{bmatrix}.$$

Summarizing the state-space formulation of the Phillips Curve model, equations (2) and (5) are the measurement equations, relating observed inflation and output respectively to state variables, then (3), (4) and (6) constitute the state equations that specify 'laws of motion' for the unobserved variables. Parameters to be estimated are the coefficients of survey expectations and lagged inflation, AR coefficients for the state variables, and the second moments of the shocks. We estimate the parameters using the maximum likelihood method and then use the Kalman filter to produce estimates of the unobserved components.

3.2 The Data

We use quarterly US time-series from 1960:1 to 2003:1 taken primarily from the Federal Reserve Economic Database ('FRED'). Output is the log of annualized real GDP in 1996 (chained) dollars. Following Kuttner (1994), the quarterly inflation was computed using the seasonally adjusted CPI (urban) data and was annualized. The survey measure for inflationary expectations is from the Michigan Consumer Survey and is the mean response of the consumer to the question "What will be the percentage of price rise in the next 12 months?" Figure 1 provides the graph of the actual inflation series measured from CPI-U and the inflationary expectation survey data, the persistence of the difference supports our specification that allows for serial correlation and a non-zero intercept.

3.3 Estimation Results and the Measure of the Output Gap

We present our estimation results of Model 1 (represented by equations (2) – (6)) in Table 1[2]. The estimate of trend growth rate m is around 3.2 percent annually. The estimated response of inflation to the gap is 0.27, indicating a flat-sloped Phillips curve. This is close to the estimate reported by Rudebusch (2002) who also used the Michigan survey of inflation expectations but the CBO measure of the gap. The estimates also show negative correlation between the gap shock and shocks to the permanent component (r_{Pg}), a mildly negative correlation between the permanent shock and the conglomerate inflation shock (r_{Pp}), a negative correlation between the permanent shock and the non-

[2] We used the approximate maximum likelihood method as outlined in Kim and Nelson (1999) (pp. 26) with BFGS algorithm in GAUSS 6.0. The two-sided or smoothed measure of the output gap has been derived following the fixed-interval algorithm outlined in Harvey (1994) (pp. 87).

gap transitory shock (r_{Pw}), and, finally, a positive correlation between the inflation shock and the non-gap transitory shock (r_{pw}).

The result of negative correlation between permanent and transitory shocks is very much in accordance with the results of MNZ, but we find more persistent output gap dynamics. The estimated periodicity of cyclical fluctuations (corresponding to the peak of the spectral density function of g_t) is approximately 4.5 years in our model, while MNZ report only 2.4 years. This contrast highlights the role inflation plays in identifying the persistence of the output gap, the MNZ decomposition being univariate, based on output alone. It also strengthens Kuttner (1994), Apel and Jansson (1999) and Roberts (2001) approach of using the inflation rate as a source of additional information about the gap.

The variation in non-gap 'weather' transitory component is estimated to be about 25 percent of the total transitory variation. We do a Wald test to investigate whether the variation in non-gap transitory component is a significant portion of the total transitory variation. A test-statistic value of 1.53 implies we could not reject the null hypothesis that it is zero $(H_0 : s_w = 0)$. We do acknowledge that Wald test may not give accurate results when the null hypothesis is on the lower limit of the parameter space. However, in such cases the bias is in favor of rejection. We also found the estimate of s_w to be sensitive to the starting values of the parameters.

We then restricted our Model 1 by dropping this component which implied dropping four parameters. Reestimating the model did not result in significant change of log-likelihood value - the loss in log-likelihood is not significant for even one parameter. The correlation between the gap shock and the trend shock is strongly and significantly negative. The estimates of the gap parameters show similar persistence and a cyclical period of 4.1 years.

We present the smoothed estimates of the output gap, the non-gap transitory component and the natural rate of output (defined as the real output minus the output gap or the level of output associated with the flexible price level) in Figure 2. The estimates of the gap pick the shaded NBER recession periods quite efficiently. The estimates of the natural rate suggest a moderately big size of the random walk component in the equilibrium rate fluctuations as does the estimate of the standard deviation of the random walk component in Table 1.

Just how different is our output gap measure from the other measures found in the empirical literature? In Table 2 we present the correlations between our two-sided output gap measure from Model 1 ('GAP 1'), and the gap measured by five other popular methods: a) announced CBO potential output, b) the Hodrick-Prescott filter ('HP'), c) quadratic time trend ('Time trend'), d) the Watson (1986) UC decomposition, using the one-sided Kalman filter and, e) MNZ's one-sided Beveridge-Nelson decomposition. The diagonal elements in Table 2 are the standard deviations of the corresponding gap measure.

In Figure 3 we present the graphs of the corresponding estimates along with our smoothed estimate of the gap. It shows that our gap measure is less persistent than the CBO gap, the Time trend gap and the UC gap. But it is bigger in size and more persistent than the MNZ gap. However, our smoothed estimates have higher correlation with the Hodrick-Prescott gap. Overall, inclusion of information from inflation data to measure the output gap gives us a moderate picture about the persistence and the size of the gap.

4. Unemployment Rate and the Output Gap

In this section, we extend a stripped down version of Model 1 to add unemployment rate. Based on our results of section 3, we drop the non-gap transitory component since it does not appear to play an important role but burdens the data with four additional parameters. We also make the shock to the non-gap inflationary component serially uncorrelated. So, our equations (3) and (4) are now represented as:

$$(8) \qquad \tilde{\boldsymbol{p}}_t = \boldsymbol{b}_0 + \boldsymbol{b}_1 \boldsymbol{p}_t^{se} + \boldsymbol{b}_2 \boldsymbol{p}_{t-1} + \boldsymbol{e}_{p,t}$$

We follow Clark (1989) in augmenting our model to include unemployment rate. We define the unemployment rate to be a sum of the natural rate (N_t) and the unemployment gap $(g_{u,t})$:

$$(9) \qquad U_t = N_t + g_{u,t}$$

The unemployment gap is assumed to be driven by the current and lagged output gap, a representation of Okun's Law used in Clark (1989):

$$(10) \qquad g_{u,t} = \boldsymbol{g}_0 g_t + \boldsymbol{g}_1 g_{t-1}$$

Following Clark (1989), Gordon (1998), Apel and Jansson (1999), the natural rate of unemployment, N_t, is assumed to follow a simple random walk.

$$(11) \qquad N_t = N_{t-1} + \boldsymbol{e}_{N,t}$$

However, we allow the variance covariance matrix of the shocks to be completely general.

$$(12) \qquad Cov(\boldsymbol{e}_{P,t}, \boldsymbol{e}_{g,t}, \boldsymbol{e}_{p,t}, \boldsymbol{e}_{N,t}) = \begin{bmatrix} \boldsymbol{s}_P^2 & \boldsymbol{s}_{Pg} & \boldsymbol{s}_{Pp} & \boldsymbol{s}_{PN} \\ \boldsymbol{s}_{gP} & \boldsymbol{s}_g^2 & \boldsymbol{s}_{pg} & \boldsymbol{s}_{gN} \\ \boldsymbol{s}_{pP} & \boldsymbol{s}_{pg} & \boldsymbol{s}_p^2 & \boldsymbol{s}_{pN} \\ \boldsymbol{s}_{PN} & \boldsymbol{s}_{gN} & \boldsymbol{s}_{pN} & \boldsymbol{s}_N^2 \end{bmatrix}$$

Completing the specification, equations (2), (8), (9), (10), (11) and equations (5) and (6) after dropping the non-gap transitory component, we get our Model 2 as:

$$
\begin{aligned}
&\textit{Measurement equations}:\\
&p_t = \tilde{p}_t + d g_t\\
&Y_t = P_t + g_t\\
&U_t = N_t + g_0 g_t + g_1 g_{t-1}
\end{aligned}
$$

(Model 2)

$$
\begin{aligned}
&\textit{Transition equations}:\\
&P_t = m + P_{t-1} + e_{P,t}\\
&g_t = f_{g,1} g_{t-1} + f_{g,2} g_{t-2} + e_{g,t}\\
&\tilde{p}_t = b_0 + b_1 p_t^{se} + b_2 p_{t-1} + e_{p,t}\\
&N_t = N_{t-1} + e_{N,t}
\end{aligned}
$$

We present the estimates of Model 2 in Table 3. The estimates of the drift and the Phillips curve slope are similar to the estimates in section 3. The Okuns' Law coefficients are negative and significant. The estimates of the autoregressive coefficients of the cycle imply a periodicity of 5 years, a marginal rise over the estimates in Model 1. In contrast to the Clark (1989) results, the correlation between the trend and the cycle shocks are negative and significant. As expected, the shocks to the trend and the natural rate of unemployment are negatively correlated. The positive correlation between the gap shock and the natural rate shock is consistent with the above results on correlation.

The two-sided filtered estimates of the gap and the trend are in Figure 4 confirming a moderately sized random walk component in the trend and a persistent gap picking up the NBER recessions. In the last row of Table 2, we compare our two sided gap estimates ('Gap 2') to other estimates of the gap. The size of the standard deviation of is now bigger than UC gap, HP gap and MNZ gap but lower than the CBO gap and time trend gap. The estimates of the correlation to other gaps are higher than the estimates with respect to ‘Gap 1’. In figure 5 we compare ‘Gap 2’ to other estimates of the gap. The bottom right panel compares ‘Gap 1’ and ‘Gap 2’ thereby highlighting the role of unemployment in increasing the size of the gap.

In Figure 6, we present the estimates of the natural rate of unemployment along with estimates of unemployment gap. The estimates of the natural rate show a fairly volatile natural rate of unemployment but the size of the shock (0.271) is exactly equal to the largest value Gordon (1998, pp. 313) used to compute the natural rate. The unemployment gap shows significant upward pressure to unemployment during the recessions. With no change in the natural rate, the unemployment gap pushes up the unemployment rate on an average by 0.5 (in percentage points) during each quarter in recession. During a recession of one year, the unemployment rate will rise by two percentage points.

5. Conclusion

We have presented a new set of results on the output gap in this paper which are based on blending the theoretical definition of the output gap in a forward-looking New Keynesian Phillips Curve with a statistical decomposition. We find that the output gap is moderately persistent and negatively correlated with the stochastic trend. We also show the non-gap transitory component is not significantly important. We further use the information present in the unemployment rate to confirm the large size and moderate persistence of the gap.

References:

Apel, Mikael and P. Jansson (1999); “A Theory-consistent System Approach for Estimating Potential Output and the NAIRU”, *Economics Letters*, 64 (3), 271-275.

Baxter, M. and R. G. King (1999); “Measuring Business Cycles: Approximate Band-Pass Filters for Economic Time Series”, *Review of Economics and Statistics*, 81(4), 575-593.

Beveridge, S. and C. Nelson (1981); “A New Approach to the Decomposition of Economic Time Series into Permanent and Transitory Components with Particular Attention to the Measurement of the Business Cycle”, *Journal of Monetary Economics*, 7, 151-174.

Blanchard, O. and D. Quah (1989); “The Dynamic Effects of Aggregate Demand and Supply Disturbances,” *American Economics Review*, 79, 655-73.

Blanchard, Olivier, and Lawrence F. Katz (1997); "What We Know and Do Not Know About the Natural Rate of Unemployment," *Journal of Economic Perspectives*, 11, 51-72.

Burns, A.F. and W.A. Mitchell (1946); “Measuring Business Cycles”, *NBER*, New York.

Calvo, G.A. (1983); "Staggered Prices in a Utility-Maximizing Framework," *Journal of Monetary Economics* 12, 983-998.

Canova, F. (1998); “Detrending and Business Cycle Facts”, *Journal of Monetary Economics*, 41, 475-512.

Clark, Peter K. (1987); “The Cyclical Component of US Economic Activity”, *Quarterly Journal of Economics*, 102, 797-814.

Clark, Peter K. (1989); “Trend Reversion in Real Output and Unemployment”, *Journal of Econometrics*, 40, 15-32.

Congressional Budget Office (1995): “CBO’s Method for Estimating Potential Output”, *CBO Memorandum*.

Fuhrer, J.C., (1997); "The (Un)Importance of Forward-Looking Behavior in Price Specification," *Journal of Money, Credit and Banking*, 29, 338-350.

Fuhrer, J.C. and G. Moore (1995); "Inflation Persistence", *Quarterly Journal of Economics*, CX, 127-159.

Gali, Jordi and M. Gertler (1999); “Inflation Dynamics: A Structural Econometric Analysis”, *Journal of Monetary Economics*, 44 (2), 195-222.

Gali, Jordi (2003); “New Perspectives on Monetary Policy, Inflation and the Business Cycle”, in *Advances in Economic Theory* edited by M. Dewatripont, L. Hansen, and S. Turnovsky, vol. III, 151-197, Cambridge University Press.

Gerlach, S and F. Smets (1999); “Output Gaps and Monetary Policy in the EMU area”, *European Economic Review*, 43, 801-812.

Goodfriend, M. and R. G. King (1997); "The New Neoclassical Synthesis and the Role of Monetary Policy", *NBER Macroeconomics Annual*, 12, 231-283.

Gordon, Robert J (1997); "The Time-Varying NAIRU and its Implications for Economic Policy", *Journal of Economic Perspectives*, 11, 11-32.

Gordon, Robert J, (1998); “Foundations of the Goldilocks Economy: Supply Shocks and the Time-Varying NAIRU,” *Brookings Papers on Economic Activity*, 2, 297-346.

Harvey, A. C. (1985); “Trends and Cycles in Macroeconomic Time Series”, *Journal of Business and Economic Statistics*, 3, 216-27.

Harvey, A. C. and A. Jaeger (1993); “Detrending, Stylized Facts and the Business Cycle,” *Journal of Applied Econometrics*, 8 (3) 231-47.

Harvey, A. C. (1994); “Time Series Models”, Second Edition, *MIT Press*.

Hodrick, R. J., and E. C. Prescott (1997); “Postwar U.S. Business Cycles: An Empirical Investigation”, *Journal of Money, Credit, and Banking*, 29 (1), 1-16.

Kim, Chang-Jin and Charles R. Nelson (1999); “State-Space Models with Regime Switching”, First Edition, *MIT Press*.

Kuttner, Kenneth N. (1994); “Estimating Potential Output as a Latent Variable”, *Journal of Business and Economic Statistics*, 12, 361-368.

Laubach, Thomas (2001), "Measuring the NAIRU: Evidence from Seven Economies," *The Review of Economics and Statistics*, 83, 218-231.

Mitchell, W.A. (1927); “Business Cycles: The Problem and Its Setting”, *NBER*, New York.

Morley, J., Nelson, C. and E. Zivot (2003); “Why Are Beveridge-Nelson and Unobserved-Component Decompositions of GDP So Different?”, *Review of Economics and Statistics*, 85, 235-243.

Murray, Christian (2003); “Cyclical Properties of Baxter-King Filtered Time Series”, *Review of Economics and Statistics*, 85, 472-76.

Roberts, John (1995); "New Keynesian Economics and the Phillips Curve," *Journal of Money, Credit and Banking*, 27, 975-984.

Roberts, John (1997); "Is Inflation Sticky?" *Journal of Monetary Economics*, 39, 173-196.

Roberts, John (1998); "Inflation Expectations and the Transmission of Monetary Policy," unpublished.

Roberts, John (2001) "Estimates of the Productivity Trend Using Time-Varying Parameter Techniques", *Contributions to Macroeconomics*: Vol. 1: No. 1, Article 3.

Rotemberg, J.J. (1987); "The New Keynesian Microfoundations", *NBER Macroeconomics Annual*, 2, 69-104.

Rotemberg, J.J. and M. Woodford (1997); "An Optimization-Based Econometric Framework for Evaluation of Monetary Policy," *NBER Macroeconomics Annual*, 12, 297-346.

Rudebusch, Glenn (2002); “Assessing Nominal Income Rules for Monetary Policy with Model and Data Uncertainty,” *Economic Journal*, 112, 402-432.

Salemi, Michael K (1999); "Estimating the Natural Rate of Unemployment and Testing the Natural Rate Hypothesis," *Journal of Applied Econometrics*, 14, 1-25.

Sbordone, Argia (2002); "Prices and Unit Labor Costs: A New Test of Price Stickiness", *Journal of Monetary Economics*, 49 (2), 265-292.

Staiger, Douglas, James H. Stock, and Mark W. Watson (2001), "Prices, Wages and the U.S. NAIRU in the 1990s," in *The Roaring Nineties: Can Full Employment Be Sustained?*, ed., Alan B. Krueger and Robert Solow, New York: The Russell Sage Foundation and The Century Foundation Press.

Staiger, Douglas, James H. Stock, and Mark W. Watson (1997a), "How Precise are Estimates of the Natural Rate of Unemployment?" in *Reducing Inflation: Motivation and Strategy*, eds. C.D. Romer and D.H. Romer, Chicago: University of Chicago Press, 195-246.

Staiger, Douglas, James H. Stock, and Mark W. Watson (1997b), "The NAIRU, Unemployment and Monetary Policy," *Journal of Economic Perspectives*, 11, 33-50.

Stiglitz, Joseph (1997), "Reflection on the Natural Rate Hypothesis," *Journal of Economic Perspectives*, 11, 3-10.

Taylor, J.B. (1979); "Staggered Wage Setting in a Macro Model", *American Economic Review*, 69 (2), 108-113.

Taylor, J.B. (1980); "Aggregate Dynamics and Staggered Contracts", *Journal of Political Economy*, 88, 1-24.

Watson, M. W. (1986); “Univariate Detrending Methods with Stochastic Trends,” *Journal of Monetary Economics*, 18, 49-75.

Yun, T. (1996); "Nominal Price Rigidity, Money Supply Endogeneity, and Business Cycles," *Journal of Monetary Economics*, 37, 345-370.

Table 1: The Parameter Estimates in Model 1

Parameters	*Model 1*	*Model 1 (Restricted)*	
The Trend Drift and the Phillips Curve Slope			**Wald Test**
m	0.793 (0.09)	0.798 (0.08)	$H_0 : \{s_w = 0\}$
d	0.269 (0.15)	0.181 (0.08)	***W = 1.529***
The Autoregressive Coefficients			
$f_{g,1}$	1.615 (0.17)	1.524 (0.15)	
$f_{g,2}$	-0.741 (0.16)	-0.674 (0.14)	
f_w	0.542 (0.27)	-	
f_p	-0.017 (0.03)	-0.019 (0.25)	
The Non-Gap Coefficients of Phillips Curve			
b_0	-1.305 (0.26)	-1.333 (0.29)	
b_1	1.037 (0.09)	1.022 (0.14)	
b_2	0.162 (0.07)	0.185 (0.11)	
The Standard Deviations of the Shocks			
s_P	1.218 (0.28)	1.042 (0.22)	
s_g	0.451 (0.30)	0.698 (0.28)	
s_p	1.103 (0.07)	1.120 (0.07)	
s_w	0.454 (0.37)	-	
The Correlations of the Shocks			
r_{Pg}	-0.564 (0.32)	-0.870 (0.18)	
r_{Pp}	-0.290 (0.23)	0.018 (0.07)	
r_{Pw}	-0.752 (0.20)	-	
r_{pw}	0.697 (0.29)	-	
Log Likelihood	**-322.904**	**-324.782**	

Note: The standard errors in the parentheses and are computed using the delta method.

Table 2: The Correlation - Standard Deviation Matrix of Different Output Gap Measures

	CBO	HP	Time trend	UC	MNZ	Gap 1	Gap 2
CBO	2.59						
HP	0.76	1.59					
Time trend	0.87	0.69	2.99				
UC	0.93	0.68	0.81	1.64			
MNZ	0.09	0.14	0.11	0.21	0.49		
Gap 1	0.41	0.62	0.51	0.37	0.15	1.40	
Gap 2	0.62	0.71	0.75	0.57	0.28	0.82	2.45

Table 3: The Parameter Estimates in Model 2

Parameters	*Model 2*	*Parameters*	*Model 2*
The Trend Drift, the Phillips Curve Slope and the Okun's Law Coefficients			
m	0.812 (0.05)	g_0	-0.401 (0.06)
d	0.252 (0.07)	g_1	-0.127 (0.06)
The Autoregressive Coefficients			
$f_{g,1}$	1.489 (0.24)		
$f_{g,2}$	-0.621 (0.19)		
The Non-Gap Coefficients of Phillips Curve			
b_0	-1.286 (0.21)		
b_1	1.039 (0.09)		
b_2	0.151 (0.07)		
The Standard Deviations of the Shocks			
s_P	0.853 (0.21)		
s_g	0.645 (0.31)		
s_p	1.120 (0.06)		
s_N	0.271 (0.08)		
The Correlations of the Shocks			
r_{Pg}	-0.635 (0.29)	r_{PN}	-0.693 (0.16)
r_{Pp}	0.203 (0.09)	r_{pN}	-0.127 (0.10)
r_{pg}	-0.305 (0.10)	r_{gN}	0.979 (0.03)
Log Likelihood	**-123.875**		

Note: The standard errors in the parentheses and are computed using the delta method.

Figure 1: Inflation and Inflationary Expectation from Michigan Survey

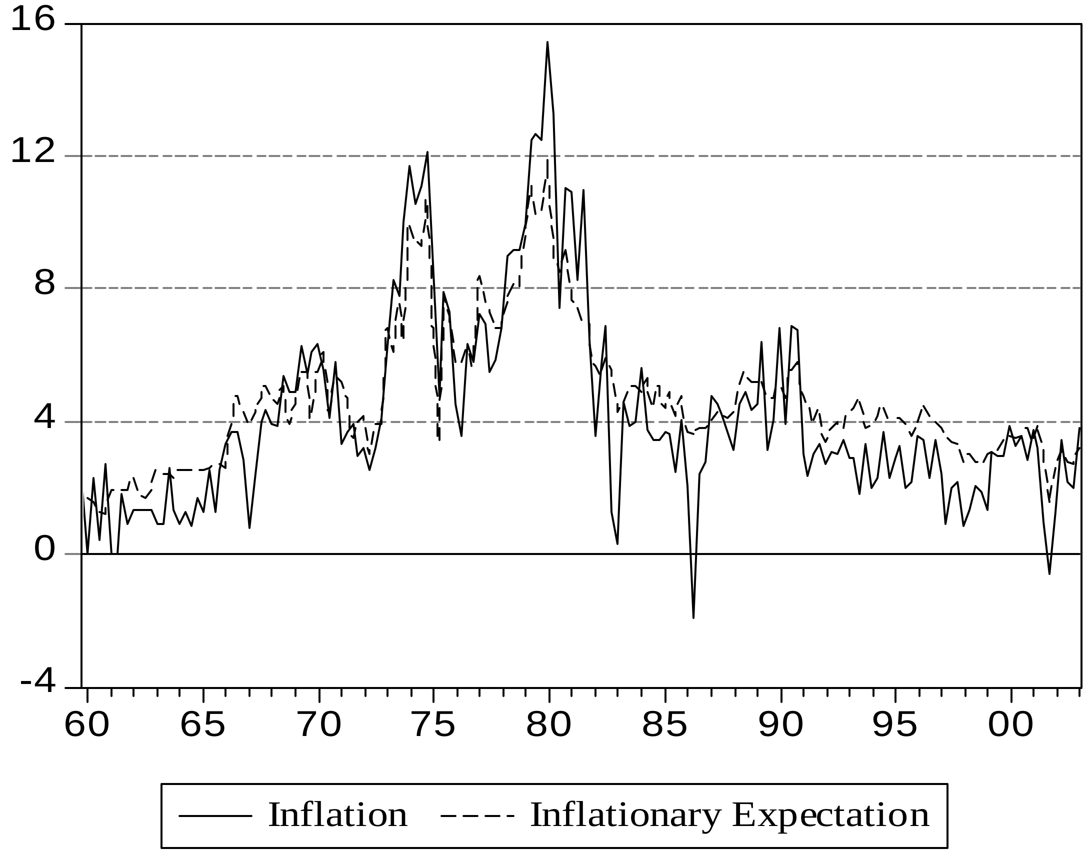


Figure 2: Smoothed Measures of the Output Gap, the Non-Gap Transitory Component and the Natural Rate of Output in Model 1

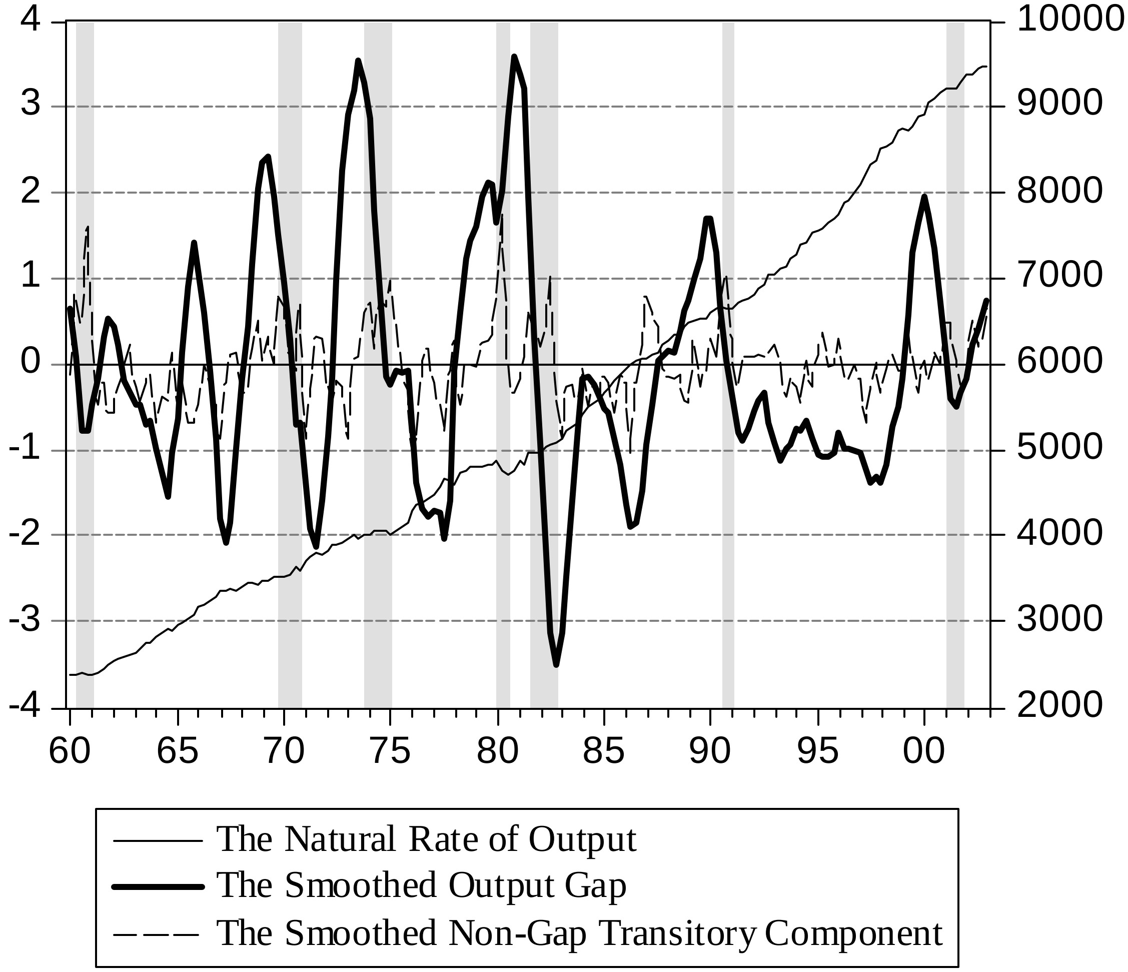


Figure 3: Comparing Different Measures of the Output Gap with Model 1 Gap

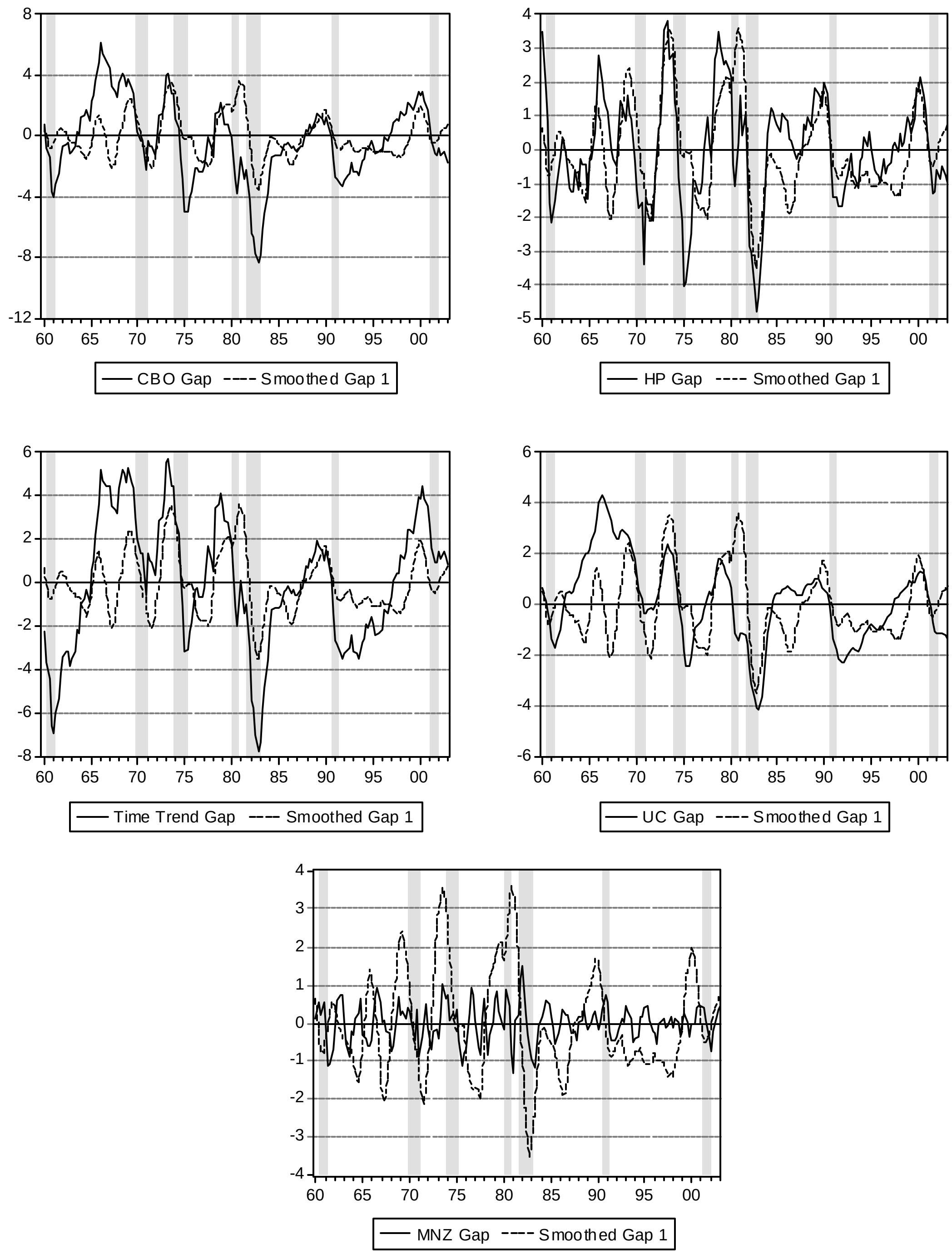


Figure 4: Smoothed Measures of the Output Gap and Natural Rate from Model 2

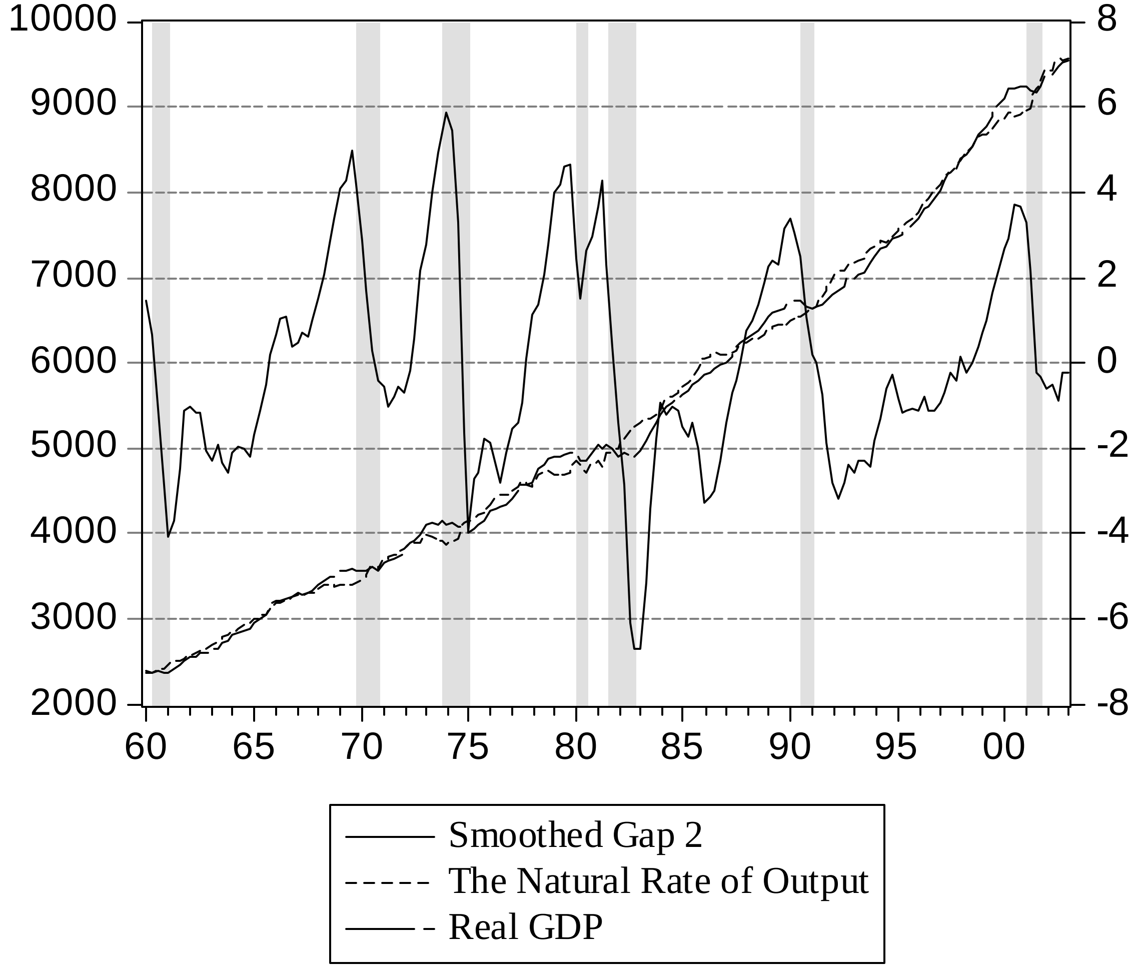


Figure 5: Comparing Different Measures of the Output Gap with Model 2 Gap

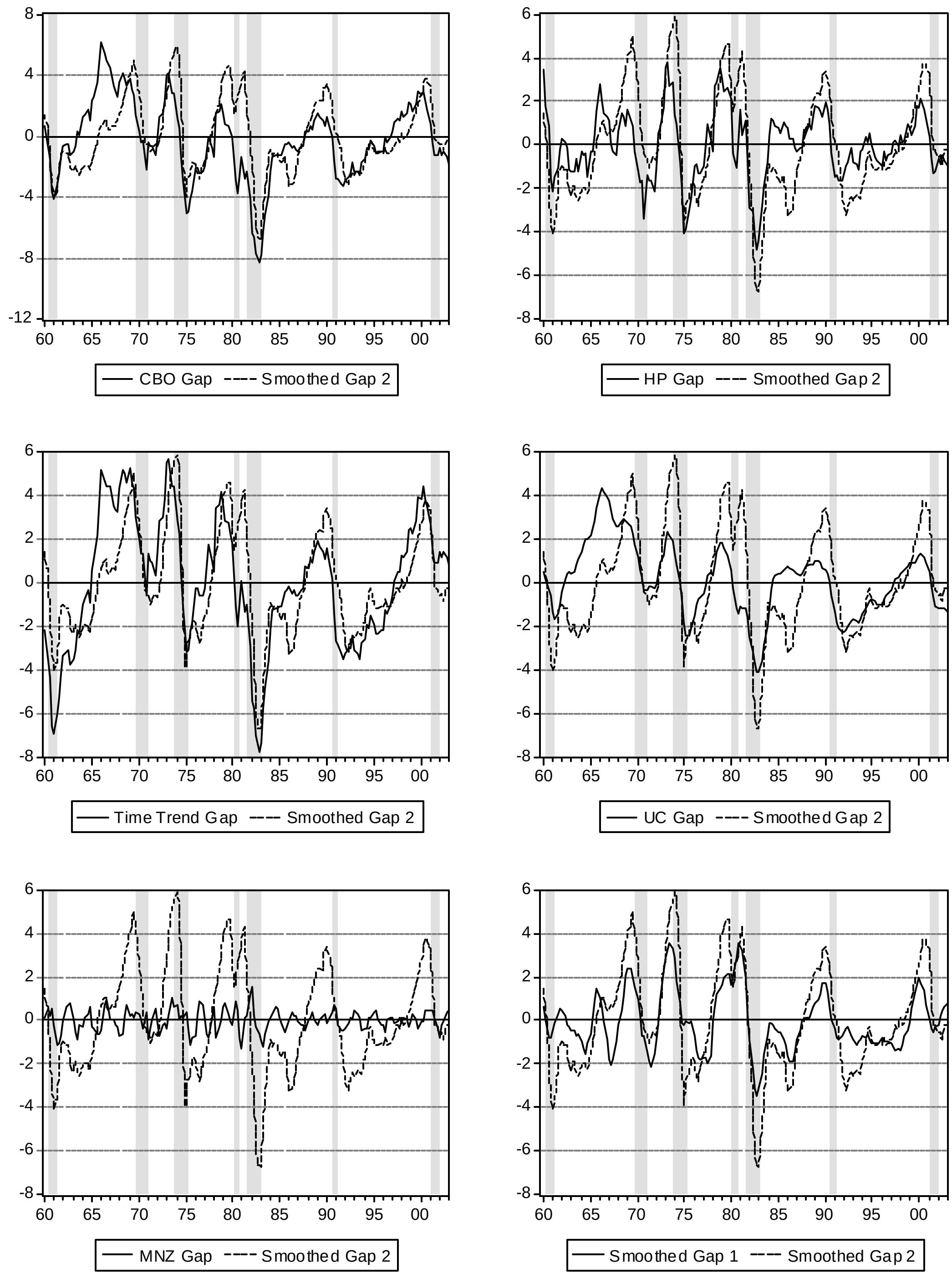
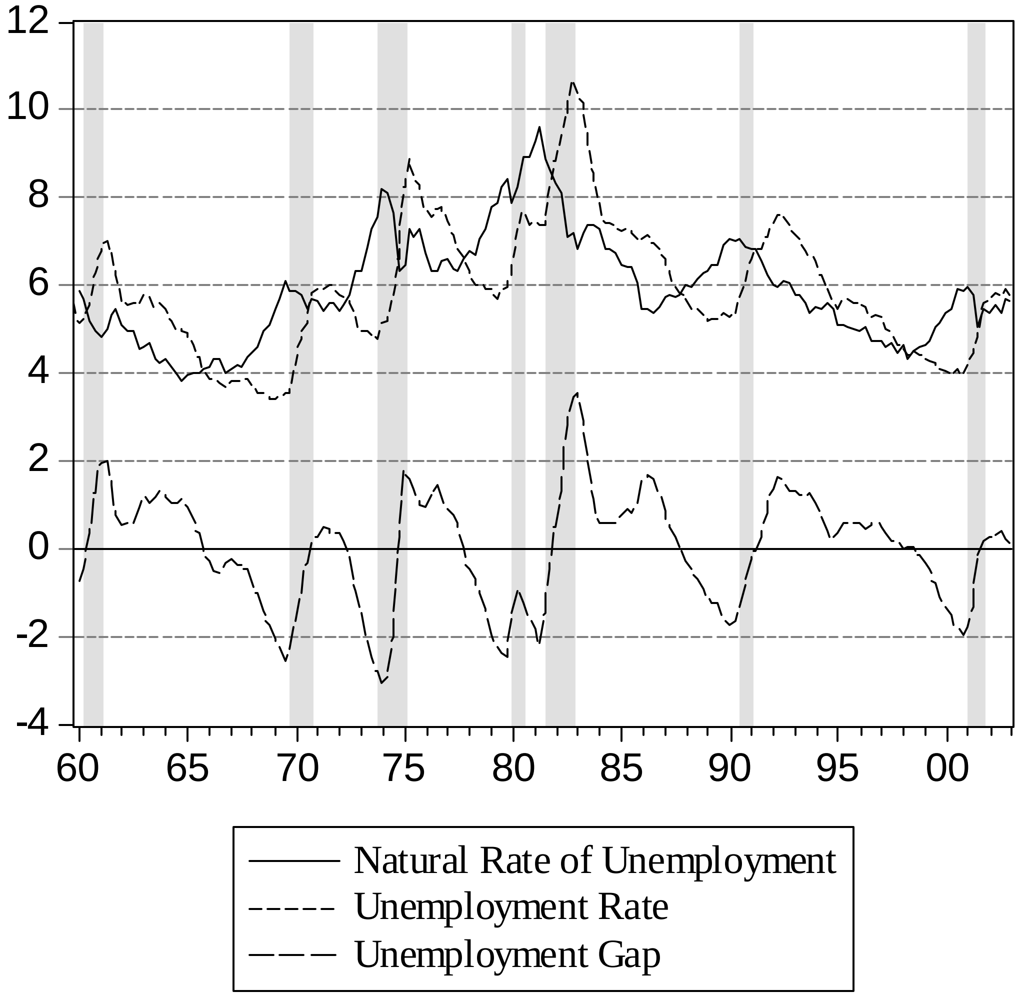


Figure 6: The Natural Rate and the Gap Estimates of Unemployment



Appendix: Estimates of the Smoothed Gap from Model 2

Date	Gap 2	Date	Gap 2	Date	Gap 2	Date	Gap 2
1960:1	1.439	1971:1	-0.572	1982:1	-1.429	1993:1	-2.570
1960:2	0.654	1971:2	-1.032	1982:2	-2.855	1993:2	-2.308
1960:3	-1.063	1971:3	-0.772	1982:3	-6.072	1993:3	-2.293
1960:4	-2.863	1971:4	-0.546	1982:4	-6.698	1993:4	-2.454
1961:1	-4.051	1972:1	-0.670	1983:1	-6.702	1994:1	-1.825
1961:2	-3.692	1972:2	-0.191	1983:2	-5.156	1994:2	-1.319
1961:3	-2.457	1972:3	0.552	1983:3	-3.385	1994:3	-0.603
1961:4	-1.120	1972:4	2.177	1983:4	-1.760	1994:4	-0.267
1962:1	-0.996	1973:1	2.792	1984:1	-0.909	1995:1	-0.858
1962:2	-1.176	1973:2	4.007	1984:2	-1.231	1995:2	-1.151
1962:3	-1.151	1973:3	4.934	1984:3	-1.045	1995:3	-1.136
1962:4	-2.054	1973:4	5.393	1984:4	-1.133	1995:4	-1.063
1963:1	-2.315	1974:1	5.883	1985:1	-1.510	1996:1	-1.115
1963:2	-1.900	1974:2	5.466	1985:2	-1.709	1996:2	-0.778
1963:3	-2.347	1974:3	3.276	1985:3	-1.418	1996:3	-1.124
1963:4	-2.552	1974:4	-1.651	1985:4	-1.994	1996:4	-1.086
1964:1	-2.131	1975:1	-3.923	1986:1	-3.281	1997:1	-0.892
1964:2	-1.947	1975:2	-2.706	1986:2	-3.136	1997:2	-0.703
1964:3	-2.015	1975:3	-2.558	1986:3	-2.979	1997:3	-0.229
1964:4	-2.227	1975:4	-1.765	1986:4	-2.319	1997:4	-0.408
1965:1	-1.687	1976:1	-1.855	1987:1	-1.401	1998:1	0.145
1965:2	-1.134	1976:2	-2.447	1987:2	-0.712	1998:2	-0.224
1965:3	-0.513	1976:3	-2.777	1987:3	-0.398	1998:3	-0.008
1965:4	0.193	1976:4	-2.095	1987:4	-0.032	1998:4	0.364
1966:1	0.664	1977:1	-1.556	1988:1	0.750	1999:1	0.704
1966:2	1.028	1977:2	-1.427	1988:2	0.978	1999:2	1.007
1966:3	1.092	1977:3	-0.939	1988:3	1.380	1999:3	1.644
1966:4	0.409	1977:4	0.118	1988:4	1.892	1999:4	2.158
1967:1	0.478	1978:1	1.123	1989:1	2.290	2000:1	2.656
1967:2	0.732	1978:2	1.390	1989:2	2.364	2000:2	2.924
1967:3	0.621	1978:3	2.046	1989:3	2.318	2000:3	3.723
1967:4	1.004	1978:4	2.770	1989:4	3.153	2000:4	3.645
1968:1	1.504	1979:1	4.004	1990:1	3.390	2001:1	3.313
1968:2	2.063	1979:2	4.183	1990:2	3.084	2001:2	2.196
1968:3	2.850	1979:3	4.620	1990:3	2.463	2001:3	-0.216
1968:4	3.358	1979:4	4.628	1990:4	1.071	2001:4	-0.298
1969:1	4.052	1980:1	2.424	1991:1	0.199	2002:1	-0.575
1969:2	4.288	1980:2	1.525	1991:2	0.000	2002:2	-0.499
1969:3	4.992	1980:3	2.634	1991:3	-0.738	2002:3	-0.868
1969:4	4.172	1980:4	2.988	1991:4	-1.861	2002:4	-0.254
1970:1	2.894	1981:1	3.670	1992:1	-2.792	2003:1	-0.221
1970:2	1.673	1981:2	4.291	1992:2	-3.200		
1970:3	0.292	1981:3	2.297	1992:3	-2.804		
1970:4	-0.426	1981:4	0.375	1992:4	-2.405		