Inflation and Unemployment in the New Economy: Is the Trade-off Dead or Alive?*

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I. Introduction

The miracle of U. S. economic performance between 1995 and mid-2000 was a source of pride at home, of envy abroad, and of puzzlement among economists and policymakers.1[1] The Federal Reserve presided over quarter after quarter of output growth so rapid as to break any speed limit previously believed to be feasible. As the unemployment rate inched ever lower, reaching 3.9 percent in several months between April and October, 2000, the Fed reacted with a degree of neglect so benign that late in the year 2000 short-term interest rates were barely higher than they had been five years earlier and long-term interest rates were considerably lower.[2]

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1. Lawrence Summers spoke for many economists and policymakers recently when he characterized this widespread puzzlement as "paradigm uncertainty." See Business Week, "The Economy: A Higher Safe Speed Limit," April 10, 2000, p. 242.

2. The peak Federal funds during the expansion, 6.5 percent reached during September-December, 2000, was barely higher than the 6.0 percent reached during the spring of 1995, while the 30-year government bond rate over the same period fell from 7.6 percent to 5.8 percent.

The Two Surprises: Inflation and Productivity Growth

What made the Fed so cooperative in promoting rapid economic growth? Clearly it was the continuing surprise that, despite the steady decline in the unemployment rate, the inflation rate refused to accelerate, at least during 1996-98, as the Phillips-curve inflation-unemployment tradeoff would have predicted. In fact, until 1998 overall "headline" inflation (including food and energy prices) decelerated rather than accelerated. From then until late 2000 headline inflation accelerated, indeed, more than doubling for both the Consumer Price Index (CPI) and the deflator for Personal Consumption Expenditures (PCE), but the Fed dismissed this as irrelevant to its mission, attributing the post-1998 acceleration of inflation as entirely due to higher energy prices rather than excess aggregate demand. The benign behavior of inflation in the late 1990s poses the main question addressed by this paper, can inflation in the late 1990s be explained by the mainstream model of inflation that was developed in the late 1970s, or is a new model or approach required? Did the Phillips curve shift its position or even disappear entirely?

The second change of behavior was the post-1995 revival of productivity growth. This contributed to the late 1990s economic boom both directly and indirectly. The direct effect was to boost the growth rate of potential output. That is, for any given growth in labor input and hence in labor-market tightness, the acceleration of productivity growth (from 1.4 percent per annum in 1972-95 to 2.6 percent during 1995-2000) added 1.2 percent to potential output growth and hence to the rate of actual output growth that could be achieved with a given amount of inflationary pressure. The indirect effect was more subtle. An acceleration of productivity growth that is not matched by an equal acceleration of real wage growth will, by definition, reduce labor's income share, thus putting downward pressure on inflation for any given degree of labor-market tightness. The indirect channel would be symmetric with and opposite to the upward pressure on labor's share that occurred at the time of the earlier post-1972 productivity growth slowdown. As in the earlier case, the impact of the indirect channel would be expected to be temporary, and eventually real wage growth would be expected to accelerate by the same amount as productivity change if labor's share is constant in the long run.

Alternative Interpretations of Low Inflation

Those debating the sources of low inflation in the late 1990s can be divided up into two groups, those arguing that "The Phillips Curve is Dead" and those defending the previous mainstream view that "The Phillips Curve is Alive." In turn the "Dead" group consisted of two sub-groups. The first announced that a revolution had occurred and a "New Economy" had arrived, in which the rapid growth of production of high-tech products, many of which enjoyed continuing declines in prices, had rendered obsolete previous capacity constraints associated with the Phillips curve, while globalization provided low-tech products in endless quantities at ever-lower prices.[3] The second sub-group argued on econometric grounds that the NAIRU (Non-Accelerating Inflation Rate of Unemployment), natural rate hypothesis, and short-run Phillips curve had never existed, even prior to 1995.[4]

The growing group of papers defending the Phillips curve as "Alive" generally adopt some combination of the mainstream (or "triangle") inflation model developed in Gordon (1982) and Gordon-King (1982), combined with an allowance for the NAIRU to vary over time (the TV-NAIRU), as developed by Gordon (1995, 1997, 1998) based on pioneering research by Staiger-Stock-Watson (1997).[5] In this work a central explanation of low inflation in the late 1990s becomes a significant decline in the NAIRU between the late 1980s and late

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3. The "New Economy" advocates were led by Edward Yardeni, then Chief Economist of Deutsche Morgan Grenfell. A skeptical view of this approach as of early 1998 was provided in "Too Triumphalist by Half," *Economist*, April 25, 1998, p. 29.

4. A leading proponent of this view was our late colleague Robert Eisner. For instance, see his "The Economy is Booming. So Why Are Economists Glum?" *Wall Street Journal*, July 29, 1998, editorial page. See also Levy (1997). More recent advocates of the dead Phillips Curve include Clement (2001) and Glassman (2002).

5. See also Stock and Watson (1999).

1990s that these papers explain only partially, if at all.[6] Beyond that common ground, recent papers differ in their emphasis on various components of the mainstream model, or additional elements, as having special explanatory power in the late 1990s. Gordon (1998) emphasizes a set of beneficial supply shocks, particularly the relative prices of food, energy, and imports that are in the original 1982 mainstream specification, as well as two additional supply elements, the behavior of the relative price of computers and medical care services.[7] Ball-Moffitt (2001), Koenig (2000), Brayton-Roberts-Williams (1999), and Staiger-Stock-Watson (2001) emphasize the role of the productivity growth revival in holding down inflation, in some papers working directly and in others working through an increase in profit margins made possible by the lag of real wage acceleration behind productivity acceleration.[8]

The Contribution of This Paper

A straightforward motivation for this paper is that four years have elapsed since the final data quarter used in the "Goldilocks" paper (Gordon, 1998), and much has changed since then, mainly in the direction of making low inflation

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6. Explanations of the declining NAIRU based on structural changes in the labor market, discussed below in Part VI, are contributed by Katz and Krueger (1999) and the U. S. Congressional Budget Office (2002).

7. Rich-Rissmiller (2000) confirm Gordon's emphasis on the importance of import prices, and Alquist-Chinn (2002) create an additional link between productivity and inflation working through the Euro-Dollar exchange rate and import prices.

8. A separate role for expectations based on survey evidence, not much discussed in the other papers, is the main theme of Driver-Greenslade-Preise (2000).

harder to explain. While headline inflation doubled between early 1998 and mid-2000, which would seem to revive the Phillips curve, much of this was due to the behavior of food and energy prices rather than excess aggregate demand. Perhaps the single most important event that has made it easier to explain low inflation the late 1990s has been the role of data revisions in reducing the inflation rate recorded in previous data for 1978-95.[9] Thus lagged inflation is lower in 1995 than before, making it that much easier to explain low inflation after 1995.

Working in the opposite direction are at least three factors that should have made low inflation more difficult to explain and thus to tilt the debate in favor of those who have declared the Phillips Curve to be dead:

(1) The actual unemployment rate remained between 3.9 and 4.2 percent for the period between August, 1999 and December, 2000, thus well below even the lowest TV-NAIRUs estimated in 1997-98. This should have put substantial upward pressure on the inflation rate.

(2) The beneficial supply shocks emphasized in Gordon (1998) all lost much of their force after early 1998. In addition to the upsurge of food-energy

9. In October 1999 the revised NIPA incorporated "backcasting" of methodological improvements in price measurement that reduced the inflation rate for 1978-95 by roughly 0.3-0.4 percent at an annual rate throughout that period. Also, Stewart-Reed (1999) released a "research series" CPI that re-estimated the growth rate of the CPI on a consistent methological basis for the 1978-99 period. Both of these improved data sources are utilized throughout this paper and explain some of the difference in results as contrasted to Gordon (1997, 1998). For instance, the peak level of the TV-NAIRU in the new data tends to be lower than in the old data in the 1980s. These new data sources also eliminate the need to discuss measurement inconsistency, which was treated as a fifth "supply shock" in Gordon (1998).

prices during 1998-2000, the rapid decline of computer prices lasted only through 1999 and became less rapid in 2000, and after a convergence of medical care inflation with aggregate inflation in 1996-98, there was an acceleration of medical care inflation in 1999-2001. Finally, the most important single beneficial supply shock, the decline in relative import prices, nearly came to a halt, with a decline of only 1.0 percent at an annual rate between 1998:Q2 and 2001:Q2. [10]

(3) The emphasis in previous papers, e.g., Ball and Moffitt (2001), on the role of the productivity growth revival involve a phenomenon that should be inherently temporary. While real wage growth may lag behind a productivity growth revival for a period of time, that period is not infinite. By the end of the 1990s the productivity revival was widely perceived and discussed, and real wage growth should have responded. Indeed, one measure of nominal wage growth, for compensation per hour, jumped from 2.5 percent in 1995 to 6.5 percent in 2000. Further, to the extent that the productivity revival and lagged real wage reaction worked through a surge in profits that allowed firms to postpone price increases, the national income (NIPA) measure of the profit share of GDP peaked in 1997 and fell thereafter, consistent with the hypothesis that wages began to catch up to productivity growth.

The basic question of this paper is whether low inflation in the 1995-2001 period can be explained by the mainstream triangle/TV-NAIRU approach that dates back to 1982, or whether the empirical evidence has killed the Phillips Curve, which still retains its role as a central concept throughout macroeconomics, from policymaking to textbooks.[11] To preview our conclusions, three improvements in the 1982 specification are required to explain why inflation was so low in the 1995-2001 period. First, the NAIRU must be allowed to vary, as has been apparent since 1997. Second, consideration of computer and medical care prices needs to be added, as in Gordon (1998) to the list of supply shocks previously consisting of the relative prices of food-energy and import prices. Third, the previous treatment of productivity growth can be improved in a direction that supports its important role in subduing inflation in the late 1990s.

Unique Features of this Research Approach

The reader new to this literature may notice several aspects of the approach to inflation research that are relatively unusual in the more general context of empirical macroeconomic studies. First, a prime emphasis is on *continuity*. After inflation research was thoroughly shaken up by the U. S. inflation acceleration of the late 1960s and inflation spikes of 1973-75, a new paradigm had emerged by 1980 across the board in macro theory, empirical research, and even elementary textbooks, which treated shocks to aggregate demand and supply symmetrically.

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10. In contrast, the decline between 1995 and 1998 was at an annual rate of 5.0 percent.

11. Mankiw (2000) informs us that the Phillips Curve tradeoff remains one of the ten lead-off economic "principles" in his best-selling principles of economics text.

The correlation between inflation and unemployment could be just as equally negative or positive, depending on the source of the shocks and the length of adjustment lags. Since then, my specification of inflation dynamics, developed in 1977-80 and published in two papers in 1982, has become widely used. This paper, along with previous papers, attempts to maintain the 1982 specification intact and explore marginal changes that improve our understanding, rather than "reinventing the wheel" in each succeeding paper. In this paper the "original" 1982 specification is subjected to a close examination to examine the validity of its relatively long lag lengths, its treatment of productivity growth, and its sensitivity to splits in the sample period, as well as to produce the TV-NAIRUs that are implied by the original specification and numerous alternatives.

Second, a missing element in most inflation research but maintained here is the insistence that every alternative specification must be subjected to *post-sample dynamic simulations*. In every equation explaining price or wage behavior, a dominant explanatory variable is lagged price and/or wage change. Accordingly, any paper in this literature runs the risk of concluding (without realizing it or saying so) that "inflation was low because inflation was low." In this paper, the test of each alternative version is its mean error when the sample period is truncated at 1995 and a dynamic simulation is created in which the lagged inflation (and/or wage change) variable is calculated via the predictions of the equation rather than using actual lagged inflation data. Any such simulation can, and often does, drift significantly away from the actual data, since it is prevented from using the "help" of the actual data on lagged inflation. Frankly, we are baffled as to why post-sample dynamic simulations have not become a standard part of diagnostics in empirical macroeconomics, at least for those topics in which the lagged dependent variable plays an important role.

Third, in a point that dates back to Stock's discussion of Gordon (1998), a complementary question to be raised about the late 1990s, in addition to why inflation was so low, is why the unemployment rate fell by so much while the rate of capacity utilization did not rise. This is an additional question to untangle about the late 1990s that receives relatively little emphasis in the contemporary literature.

Plan of the Paper

The paper begins in Part II with a brief review of the "triangle" approach to explaining inflation behavior, combining the natural rate hypothesis, a role for supply shocks and inertia, and a time-varying natural rate of unemployment or TV-NAIRU. Part III then documents the behavior of inflation and the quite different behavior of several wage indexes.

Part IV discusses issues of specification, including the role of the "traditional" supply shocks, including changes in real import prices and in the real price of food and energy. The role of the post-1995 productivity growth revival in holding down inflation is also examined, as are questions of truncating the lag lengths used in previous versions of this research. Part V presents the basic results, including time series of the TV-NAIRUs for both the inflation rate and changes in unit labor cost, and discusses the sensitivity of results to variable definitions, lag lengths, definitions of the productivity effect, and sample splits. As discussed above, primary emphasis in assessing results is placed on dynamic simulations that truncate the sample period at the end of 1995 and allow the lagged dependent variable to be created endogenously for the 1996-2001 period for different versions of the data and specification.[12] Part VI provides quantitative evidence on the role of the traditional food-energy and import supply shocks, the role of the "new" shocks involving computers and medical care prices, and also a discussion of labor-market aspects of the decline in the TV-NAIRU. Finally, Part VII summarizes and considers the future.

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12. In Gordon (1998) the sample period was truncated in 1992:Q4 and the dynamic simulations were calculated for 1993:Q1 through the end of the data set in 1998:Q2. The initial motivation for allowing the NAIRU to vary over time was pointed out in Gordon (1994,1995), where dynamic simulations based on the 1982 specification over the simulation period 1987-94 had begun to drift away from the actual values in the last few quarters of 1994.

II. Combining the "Triangle" Model with the TV-NAIRU

The "Phillips curve" has become a generic term for any relationship between the *rate of change* of a nominal price or wage and the *level* of a real indicator of the intensity of demand in the economy, such as the unemployment rate. The Phillips-curve tradeoff set in a context of the "natural rate hypothesis" dates back to the theoretical work of Friedman (1968) and Phelps (1968) and to a large body of empirical work in the 1970s. Most important for the interpretation of the late 1990s, the natural-rate Phillips curve was augmented in the mid-1970s (Gordon, 1975, 1977, 1984) to incorporate the adverse or beneficial role of supply shocks. This research emphasized the parallel deterioration during the 1970s of both inflation and unemployment caused by adverse food and oil shocks, soon dubbed "stagflation." Thus, in applying the natural-rate-cum-supply-shocks Phillips curve to an interpretation of the U. S. economic miracle of the late 1990s, we are continuing a line of research that traces its roots back more than 25 years.

Henceforth as shorthand we shall refer to this view of the inflation process as the "triangle" model, standing for the mutual three-way interplay of demand, supply, and inertia.[13] In its original incarnation of the early 1980s the triangle model was developed with a natural rate of unemployment or NAIRU that was

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13. The term "triangle model" was first used in Gordon (1983). The origins of the triangle model and additional perspective are provided in Gordon (1997). Stock (1998, p. 3) cites Gordon (1982) as the source of the framework that he, Staiger, and Watson (1997, 2001) have used in their own estimation of the TV-NAIRU.

either constant or allowed to change only in response to demographic shifts in the labor market.[14] Subsequently the work of Staiger, Stock, and Watson (1997) led the way in developing techniques to allow the NAIRU to vary over time. This time-varying "TV-NAIRU" approach was incorporated into the triangle model by Gordon (1997, 1998). Subsequently Eller (2000) re-examined the specification of the triangle approach and developed a streamlined approach to estimating the triangle/TV-NAIRU model by shortening the lags and redefining the productivity variable that appeared in the original triangle model.[15]

A general specification of the triangle framework is:

$$p_t = a(L)p_{t-1} + b(L)D_t + c(L)z_t + e_t . \qquad \textbf{(1)}$$

Lower-case letters designate first differences of logarithms, upper-case letters designate logarithms of levels, and L is a polynomial in the lag operator. The dependent variable p_t is the inflation rate. Inertia is conveyed by the lagged rate of inflation p_{t-1}. D_t is an index of excess demand (normalized so that $D_t=0$

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14. In particular teenagers have always been viewed as having a higher "natural" rate of unemployment than adults, so that the increase in the number of baby-boom teenagers in the period 1963-79 and the subsequent decrease during 1979-90 was translated into an increase and subsequent decrease in the NAIRU.

15. A productivity deviation variable has been incorporated in Gordon's research since his initial paper (1970).

indicates the absence of excess demand), z_t is a vector of supply shock variables (normalized so that $z_t=0$ indicates an absence of supply shocks), and e_t is a serially uncorrelated error term.

Usually, equation (1) will include several lags of past inflation rates, reflecting the influence of several past years of inflation behavior on current price setting, through some combination of expectation formation and overlapping wage and price contracts.[16] If the sum of the coefficients on these lagged inflation values equals unity, then there is a "natural rate" of the demand variable (D^N_t) consistent with a constant rate of inflation.[17] Subsequently we will supplement (1) with alternative versions that explain wage changes, with and without two-way feedback between prices and wages. The basic equations estimated in this paper use current and lagged values of the unemployment gap as a proxy for the excess demand parameter D_t, where the unemployment gap is defined as the difference between the actual rate of unemployment and the natural rate, and the natural rate (or NAIRU) is allowed to vary over time.

Using the unemployment rate as a predictor of inflation can be justified by

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16. In the triangle approach there is no explicit attempt to separate the role of expectations and explicit or implicit contracts in contributing to the "inertia effect" represented by the long lags. In fact,we have always believed that expectations adjust quite rapidly, especially to identifiable discrete events like oil shocks, and that most of the inertia effect represents staggered overlapping Taylor-type price and contracts. See Driver-Greenslade-Pierse for an attempt to introduce an explicit survey-based expectations variable explicitly into the "triangle model of Gordon 1997, 1998" (p. 15).

17. While the estimated sum of the coefficients on lagged inflation is usually roughly equal to unity, that sum must be constrained to be exactly unity for a meaningful "natural rate" of the demand variable to be calculated.

the findings of King and Watson (1994), who find that unemployment causes inflation in the Granger-causation sense, by preceding it in time.[18] Alternatively, the capacity utilization rate can be used as a proxy for the excess demand parameter D_t , and the natural rate of the capacity utilization rate (NAIRCU) can also be allowed to vary through time.

The structure of the triangle model, with its distinction between demand and supply shocks, suggests a particular conception of the NAIRU. The standard concept is the "no-supply-shock" NAIRU, that is, the unemployment rate which is consistent with steady inflation *in the absence of supply shocks*. If the inflation rate suddenly exhibits a "spike" that is entirely explained by the z_t supply shock variables in equation (1), then the "no-supply-shock NAIRU" measures the unemployment rate that *would* be compatible with steady inflation in the absence of those supply shocks ($z_t = 0$). Without this qualification, the NAIRU would jump around as supply shocks arrived and departed, which is not what most economists are trying to convey when they speak of the natural rate of unemployment.

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18. Inflation depends on both the level and change in the demand variable. I first noted the importance of the rate-of-change effect in Gordon (1977, pp. 270-1). The rate of change effect is automatically allowed to enter as long as the gap variable is entered with more than one lag; in other words, if the gap variable is entered as, say, the current value and one lagged value, this contains precisely the same information as entering the current level and change from the previous period. The change variable is incorporated in this and earlier papers by including the current and four lagged values of the unemployment rate; the zig-zag in the current and lagged coefficients incorporates the change effect, whereas the significant sum of coefficients incorporates the level effect.

Allowing the NAIRU to Vary over Time

The estimation of the time-varying NAIRU combines the above inflation equation, with the unemployment gap serving as the proxy for excess demand, with a second equation that explicitly allows the NAIRU to vary with time:

$$p_t = a(L)p_{t-1} + b(L)(U_t - U^N_t) + c(L)z_t + e_t , \tag{2}$$

$$U^N_t = U^N_{t-1} + h_t , Eh_t = 0, var(h_t) = t^2 \tag{3}$$

In this formulation, the disturbance term h_t in the second equation is serially uncorrelated and is uncorrelated with e_t. When this standard deviation $\tau_\eta = 0$, then the natural rate is constant, and when τ_η is positive, then the model allows the NAIRU to vary by a limited amount each quarter. If no limit were placed on the ability of the NAIRU to vary each time period, then the time-varying NAIRU would jump up and down and soak up all the residual variation in the inflation equation (2).

The Interaction of Wage and Price Behavior

Primary attention in recent discussions of the time-varying NAIRU has been devoted to equations explaining price inflation, because this is the inflation concept of most direct relevance for monetary policy. However, the rate of change of wages has, ever since Keynes' *General Theory*, been believed to play a central role in aggregate supply behavior.

One direct indicator of the role of wages in the inflation process is provided by labor's share in national income. The change in labor's share (s_t) is by definition equal to the growth rate of the real wage $(w_t - p_t)$ minus the growth rate of labor's average product (q_t):

$$s_t = w_t - q_t - p_t \tag{4}$$

It can be shown (Gordon, 1990; Franz-Gordon 1993) that changes in labor's share become a source of "cost push" that is on an equal footing with any other type of supply shock; an increase in labor's share pushes upward on the rate of inflation at any given level of the unemployment gap.

The well-known stability of labor's share in the United States since the early 1970s suggests that wage behavior has not played much of an independent role in the inflation process. Nevertheless, it is informative to create estimates of the NAIRU corresponding to the same dynamic estimation framework developed above. A straightforward analogy of our basic inflation equation (2 above) is an equation explaining changes in wage rates (w_t) relative to trend productivity (q^*_t) by its own lagged values and the same set of demand and supply variables that enter into the price equation. The difference between the growth rates of wage rates and trend productivity is often called the growth rate of "trend unit labor cost" or TULC $(w\text{-}q^*)$.

$$(w\text{-}q^*)_t \;=\; g(L)(w\text{-}q^*)_{t-1} \;+\; b(L)(U_t\text{-}U^N_t\,) + c(L)z_t + e_t\,. \qquad \textbf{(5)}$$

As originally suggested by Sims (1987), the identification of a wage equation that is separate from the price equation is problematic. One approach would be to include different sets of demand and supply terms as explanatory variables in the wage equation from those included in the price equation. However, this is implausible *a priori*, since any variable relevant as a determinant of price change may also be relevant for participants in the wage-setting process, and vice-versa for prices. Another approach is to restrict the contemporaneous coefficient of wages on current prices or prices on current wages, but this is arbitrary as well. In this paper we estimate the time-varying NAIRU based on (5), which is a direct analogy to (2) and includes the same explanatory variables based on the notion that the same variables are relevant for wage behavior that are relevant for price behavior. However, (5) is restrictive in that it does not allow for feedback from prices to wages or vice-versa. In this paper we are particularly interested in whether wage changes were restrained by the beneficial supply shocks that reduced the rate of price inflation, and whether price changes were restrained by factors that limited wage changes, e.g., improved efficiency or flexibility in the operation of the U. S. labor market. An alternative wage equation, which leaves open the relative importance of wage-wage and price-wage feedback, can be written as follows:

$$(w\text{-}q^*)_t = g(L)(w\text{-}q^*)_{t-1} + h(L)(p)_{t-1} + b(L)(U_t\text{-}U^N_t) + c(L)z_t + e_t . \quad \textbf{(6)}$$

This equation (6) is identical to (5) except for the addition of the lagged price inflation terms. A simple method of estimating the relative importance of lagged wage and price inflation is to transform (6) by adding and subtracting *h(L)* times the lagged TULC terms:

$$(w\text{-}q^*)_t = [g(L)+h(L)](w\text{-}q^*)_{t-1} - h(L)(w\text{-}q^*\text{-}p)_{t-1} + b(L)(U_t\text{-}U^N_t) + c(L)z_t + e_t . \quad \textbf{(7)}$$

The sum of the *g(L)* and *h(L)* coefficients can be constrained to sum to unity, which imposes the natural rate hypothesis, while the freely estimated sum of coefficients *(Sh)* indicates the weight on lagged prices in the determination of trend unit labor cost, while *1-Sh* indicates the weight to be applied to "wage-wage" feedback. Henceforth we shall call the *w-q*-p* term the change in "trend labor share" (hereafter TLS: note that this term differs from the change in labor's share in (4) above only through the replacement of actual productivity change *q* by trend productivity change θ*). By analogy, feedback from wages to prices can be estimated by the "dual" to (7):

$$p_t = [g(L)+h(L)]p_{t-1} + h(L)(w\text{-}q^*\text{-}p)_{t-1} + b(L)(U_t\text{-}U^N_t) + c(L)z_t + e_t, \qquad \textbf{(8)}$$

where the change in TLS appears with a positive sign, in contrast to the negative sign in (7). To summarize, we have four sets of equations to estimate, all containing the unemployment gap and the same set of supply shock terms, and differing only in the dependent variable, lagged dependent variable, and lagged trend labor cost term:

	Dependent variable	*Lagged dependent variable*	*Trend Labor Share?*
(A)	price change	price change	no
(B)	TULC change	TULC change	no
(C)	price change	price change	yes
(D)	TULC change	TULC change	yes

The first section of empirical results in this paper focusses on the reduced-form inflation equations in line (A). The discussion of lag lengths, sample splits, and productivity variables is limited the the line-A equations. Then, once specification details are established for line (A), we provide parallel results using the identical specification for the other three versions in lines (B), (C), and (D).

III. The Recent Behavior of Price and Wage Inflation

The behavior of postwar U. S. inflation experience is familiar. Here we summarize the overall evolution of inflation since 1960 and then focus more closely on price and wage behavior since 1987.

The Overall Behavior of Inflation

Figure 1 displays the four-quarter changes in the deflator for GDP, for Personal Consumption Expenditures (PCE), and the new CPI-RS, the research series that eliminates most aspects of measurement inconsistency in the CPI back to 1978.[19] Clearly visible are the demand-driven acceleration of inflation in the late 1960s, the effect of price controls during the high-demand period 1972-73, the "twin peaks" related to the oil shocks of 1974-75 and 1979-81 as well as the end of price controls in 1974, the collapse of oil prices in 1986, the mild demand pull of the late 1980s, and the "valley" of inflation in 1997-98 connected with the beneficial supply shocks. Inflation doubled or more than doubled between 1998 and 2000, mainly because of oil prices, increasing most for the CPI and least for the GDP deflator.

The more recent period is highlighted in Figure 2, which limits the display

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19. See Stewart-Reed (1999). CPI data prior to 1978 are obtained by ratio-linking the official CPI-U to the CPI-RS.

to 1987-2001 and to the two consumption deflators, both "headline" (including food and energy) and "core" (excluding those two sectors). The role of supply shocks is clearly visible in 1997-2001, with both headline measures falling below the corresponding core measure in 1998 and then surging upward in 1999-2000 before falling back in late 2001. There was a mild but steady acceleration in the core CPI between 1999 and 2001, while the core PCE accelerated in 2000 before declining in 2001. Figure 2 dramatizes the puzzle of low inflation in the late 1990s, since all the inflation measures were much lower than in 1987-90, even though the unemployment rate in 2000 fell to a low of 3.9 percent, in contrast to its 1989 minimum of 5.1 percent.

The behavior of three measures of core inflation is displayed for the full 1960-2001 period in Figure 3. The core PCE inflation rate has been below the CPI inflation rate for almost every year since 1966. Between 1978 and 1994 the methodology-consistent CPI-RS corresponds closely to the PCE deflator, but since 1994 the CPI-RS has converged to the official CPI (by design, since the shrinking gap shows the effect of measurement improvements in the official CPI) while a substantial gap has opened up between the PCE deflator and the CPI-RS. Prior to 1978 differences between the CPI and PCE deflator are primarily due to the treatment of housing costs that are eliminated after 1978 in the CPI-RS.[20]

20. The complexities of this topic have led to a mistake in this paper. We should have ratio-linked the CPI-RS at 1987 not to the official CPI-U but to the experimental CPI-U-X1 that imposes a single method of measuring housing costs back to 1967. This lapse will be corrected in the next version of the paper.

Changes in Specified Quarters

For the period 1987-2001, Table 1 exhibits measures of price and wage change, for seven inflation measures and four wage series. Also shown are the levels in specified quarters of the civilian unemployment rate, the rate of capacity utilization, and the growth rate of labor productivity. The quarters chosen are those in which the unemployment rate was declining through the NAIRU (1987:Q4 and 1994:Q4), quarters which marked the business cycle peak (1990:Q2 and 2000:Q4), and the most recent quarter in our data (2001:Q4). The "tightness" measures in the first two lines refer to the level in that particular quarter, whereas all the rates of change refer to changes over four quarters ending in that particular quarter.

Between 1994 and 2000 the unemployment rate declined by three times as much as between 1987 and 1990. In contrast, the rate of capacity utilization reveals a reduction in cyclical tightness in the more recent period 1994-2000, in contrast to no change in tightness during the earlier 1987-90 expansion. This sharp contrast between the extent of tightness indicated by the unemployment rate versus the rate of capacity utilization is a continuing theme of the current paper.

The next section of Table 1 displays four-quarter rates of change for various price deflators. Here the main contrast is between the change in the price indexes in the demand-driven expansions of 1987-90 and 1994-2000. We note that two of the seven price indexes (PCE and core PCE) had declining rates of inflation in 1987-90. This is exactly the same as in 1994-2000, when two of the seven had declining rates of inflation (core PCE and core CPI-U). The sense in which inflation was surprisingly low in the late 1990s now comes into sharper focus: much of the surprise occurred in 1997-98, and the resurgence of headline inflation in 1999-2000 eliminated at least some of the surprise. Further, the main sense in which the *change* in the inflation rate in 1994-2000 looks different than 1987-1990 is not in *absolute* terms but rather *relative* to the much greater decline in unemployment in the later than in the earlier period. Yet, in the context of the 1994-2000 decline in the rate of capacity utilization, one could propose the opposite puzzle as to why inflation did not decelerate over this period.

The bottom section of Table 1 displays changes for four wage indexes, the Employment Cost Index including fringe benefits (ECI-TC), the same excluding fringe benefits (ECI-WS), Compensation per Hour (CPH), and Average Hourly Earnings (AHE). The first of these (ECI-TC) is the best and most comprehensive index, being based on a wage survey that covers the entire private economy and which eliminates the effects of shifts in employment mix across industry and occupation categories. ECI-WS is identical except for excluding the fringe benefits component of ECI-TC. The compensation index CPH is inferior, since it is a raw index of compensation divided by hours, and is influenced by any change in industry or occupation mix, by changes in the importance of overtime premiums, and by changes in the importance of sales commissions that are sensitive to the business cycle. AHE excludes non-wage types of compensation and is less volatile than CPH although still is subject to mix effects.

In contrast to the price indexes, the wage indexes display a uniform acceleration for every index in both periods, 1987-90 and 1994-2000. The two ECI indexes accelerated less in 1994-2000 than in 1987-1990, whereas the CPH and AHE indexes accelerated considerably more. In addition, productivity growth accelerated much more in 1994-2000 than in 1987-90, dampening some of the pressure of wage acceleration on inflation.

In the recession period between 2000:Q4 and 2001:Q4, all the price indexes decelerated substantially except for the two core CPI measures. Among the wage indexes, the CPH and AHE indexes decelerated rapidly while the two ECI measures were flat. Productivity growth also decelerated.

IV. Specification Issues

The starting point of this research is a particular version of the reduced-form inflation equation (2 above) that we will call the "original" specification. The set of variables and lag lengths have been left unchanged since Gordon (1982), so that the robustness of the triangle model and its specific 1982 implementation could be reassessed as new data emerged in the 1980s and 1990s, without any "fiddling" to meet new challenges presented by new data.[21] Until the mid-1990s, this specification was regularly re-estimated as new data emerged and was subjected to dynamic simulations for five or six years after the end of the sample period of the regression equation, e.g., an equation estimated to 1987:Q4 was subjected to a dynamic simulation through 1994:Q4.[22] Unlike many postwar macroeconomic relationships that had "gone off the rails" soon after the original article was written, this particular implementation of the triangle model seemed to work very well until 1994. Soon thereafter, however, actual inflation began to drift down relative to predicted inflation. While this could have been due to many causes, the most appealing solution was to abandon the previous assumption of a fixed NAIRU and instead allow explicit estimation of the time-varying (TV) NAIRU.

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21. The specification published in Gordon (1982) was originally presented at a Brookings conference in November 1980 and is thus more than two decades old.

22. The most recent of these post-sample simulation exercises that remained on track was Gordon (1994). Subsequently the actual inflation rate began to drift down below the predicted values that assumed a fixed NAIRU, and this led to the development of the TV-NAIRU version of the model in Gordon (1997). Yet in neither Gordon (1997) nor Gordon (1998) was any attempt made to test the significance of the variable definitions and lag lengths that had been left unchanged since 1980.

Details of the Original Specification

The longstanding "original" specification includes the gap between the actual unemployment rate and the NAIRU, as well as the lagged dependent (inflation) variable. If the coefficients on the lagged dependent variable sum to unity, then this specification has the interpretation of the "natural-rate Phillips curve." Maintaining consistency since the late 1970s, this specification is augmented with four variables that are interpreted as supply shocks (the *z* variables in (1) and (2) above), namely the change in the relative import price, relative food-energy price, productivity deviation, and dummy variables for the effect of the 1971-74 Nixon-era price controls.[23] Lag lengths were originally specified in Gordon (1982) and have not been changed since then. The only change in the original specification made in this paper is that the previous log-linear piecewise productivity trend is replaced by a productivity trend estimated with the Hodrick-Prescott filter.[24]

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23. The relative import price variable is defined as the rate of change of the non-oil import deflator minus the rate of change of the dependent variable, e.g., PCE deflator or GDP deflator. The relative food-energy variable is defined as the difference between the rates of change of the overall PCE deflator and the "core" PCE deflator. The productivity deviation is the difference between the actual growth rate of output per hour in the nonfarm business sector and its trend, where a log-linear trend was interpolated between benchmark quarters in previous papers and is explained by a HP trend in this paper. The Nixon control variables remain the same as originally specified in Gordon (1982). Lag lengths are shown explicitly in Table 3.

24. Unlike the standard H-P parameter of 1600, which yields a trend that is implausibly volatile over the business cycle, we used a parameter of 6400. This avoids any tendency for the productivity growth trend to turn negative during recessions. We have previously argued that the H-P parameter of 1600 creates an implausibly volatile series for potential GDP during the Great Depression decade of the 1930s.

Going Beyond the Original "Triangle" Specification

Since the long lag lengths in the original 1982 specification often appear as arbitrary and implausible, we take explicit steps in this paper to shorten the lag lengths and also to change the treatment of productivity change. This work was originally reported in Eller (2000) and is updated here.

The specification used by Gordon (1982, 1998) includes six years of inflation lags, the current period plus one year of lags on the food and energy shock and the unemployment gap, one year of lags (but not the current period) on the import price shock, and the current period plus one lag on the productivity deviation variable. Due to the long lags, when the specification attempts to explain low inflation during the late 1990s, it is "handicapped" by incorporating high inflation in the late 1980s and early 1990s due to the dynamic interaction of its long lag lengths. But perhaps these lag lengths exaggerate the influence of inflation almost a decade ago on the current behavior of economic agents. Shortening these lags might provide a better model to interpret inflation in the late 1990s. This leads to our alternative "truncated" specification as discussed below.

To test whether the original specification could be simplified, we used the full sample period (1962:1-2001:Q4), but we also checked goodness-of-fit statistics within the overall time period, particularly looking at the sum of squared residuals (SSRs) during 1990-2000. We then tested to see if particular lags on inflation or on the supply shock variables could be omitted without losing predictive power. For the full sample 1962-2001, and for the sample period before 1990, the long lags remained significant, and thus could not be pared down or truncated. However, when we looked at the residuals within the 1990-2000 sub-period, it appeared that the specification could be simplified. Not only could the longest lags on the lagged dependent (i.e., inflation) variable be removed, but also the lags on the supply shock variables could be shortened as well. During this time period the long lags on inflation could be shortened from six to three years of lags, the lags on the food and energy shock variable could be shortened to the current time period and one lag, the import price variable could be shortened to just two lags, the unemployment gap could be specified as the current period and the change in the unemployment gap, and the lag on the productivity deviation variable could be omitted.[25]

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25. Blocks of inflation lags were assessed in a stepwise fashion, each time running a Chow test of the simplified specification versus the standard Gordon specification. The Chow tests showed that for the time period of 1990-2001, the inflation lags from quarters 13-24 could be removed without losing predictive power. The supply shocks were removed in a similar fashion by running the regression with only the current quarter and one lag (or as just two lags in the case of imports), and then comparing the results with the original Gordon specification, again using a Chow test. The lags on each supply shock were tested individually, and then the removal of all of the supply shock lags simultaneously was tested against the original specification. The Chow test showed that the longer supply shock lags could be removed. In order to control for any possible interaction between the long lags on inflation and the supply shock lags, the same set of tests on the supply shocks were run, this time against the version of the specification that contained the full supply shock lags, but only 12 quarters of inflation lags. The Chow test again showed that the lags on the supply shocks could be removed. Finally, the simplified specification (with the shortened supply shocks and only 12 quarters of inflation lags) was tested against the original specification. The Chow test between the simplified TV-NAIRU specification and the standard TV-NAIRU specification revealed that the all of these lags could be removed without impairing the

As the long lags were removed, the short lags became a very good predictor of inflation. The fact that inflation was low in the late 1990s is best explained in this model by the fact that inflation in the preceding quarter was low. Therefore, it is not necessary for the TV-NAIRU to decline as much in order to explain the low actual inflation rate. However, when long lags are included, the NAIRU is forced to decline when inflation is low, because the inflation of six years ago is still included in the model. With long lags, when the model is trying to figure out why inflation is so low in 1996, it must also consider the fact that inflation was high back in 1990, thus the model believes that the NAIRU must have shifted to account for this change.

The *Economic Report of the President* (February 2000, pp. 90-91) discusses a mechanism by which the productivity revival may have held down the inflation rate. The *ERP*=s hypothesis is that workers are unable immediately to incorporate productivity increases into real wage increases due to an information and recognition lag. Although in retrospect the productivity growth revival began in late 1995, it was not recognized until, at the earliest, 1998. Figure 4 in the top right frame shows plots of changes in nonfarm business productivity over eight quarters and over twenty quarters. The eight-quarter moving average is the shortest moving-average length in which a post-1995 productivity growth revival becomes visible.

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specification.

To reflect the *ERP*=s hypothesis that real wage growth lags productivity growth during a systematic acceleration or deceleration in the productivity trend, we have constructed a variable based on the difference of two moving averages of nonfarm business productivity, namely the difference between an eight-quarter and a 20-quarter moving average of nonfarm productivity growth. The shorter moving average reflects the trend in productivity, while the longer moving average reflects the hypothetical movement of real wages. The particular combination of eight and 20-quarter moving averages emerged from extensive testing as the best-fitting combination of numerous alternative combinations. In periods where this "8-20" difference is positive, inflation should be reduced relative to the prediction of the other variables in the equation, including lagged inflation, the unemployment gap, and the various supply shocks. The bottom left frame of Figure 4 shows that the 8-20 productivity variable is positive in 1983-1984 and 1992-93 as well as 1994-2000, all of which were periods of decelerating inflation, and is predominately negative in the late 1960s and the early 1970s, which were periods of accelerating inflation. We will return below to the issue of alternative treatments of the post-1995 productivity growth acceleration.

The "Smoothness" Issue in Estimating the TV-NAIRU

Recall that an important aspect of estimating the TV-NAIRU is the need to restrict the variance (τ) of the error term in the NAIRU equation (3 above). Two approaches have been used in the past. Stock and Watson (1999) allow τ to be estimated, while Gordon=s (1997, 1998) "smoothness" criterion states that τ should be selected to be as high as possible subject to the qualification that there are no short-term quarter-to-quarter reversals in the NAIRU, and he previously used a τ of 0.09 in his 1998 paper. Revisiting this issue, we have examined five versions of the TV-NAIRU based on both the original and truncated specifications, using PCE inflation as the dependent variable, and based on different values τ of .05, .1, .15, .2, and .25. We believe that the estimated TV-NAIRU that corresponds to $\tau = .15$ uses the largest value of τ that is still acceptable by the "smoothness" criterion that rejects as implausible volatile short-term reversals in the estimated TV-NAIRU.

Data

Here we note several data issues that matter for the results of this and other papers investigating the stability and shifting of the Phillips curve. First, the U. S. national accounts ("NIPA") were subject to major revisions announced in October, 1999. Compared to the inflation data used in Gordon (1998) and earlier papers, the new U. S. data for the GDP and PCE deflators register an inflation rate that is lower on average by roughly 0.4 percentage points per annum during the entire period 1978-95. Thus the triangle model has an "easier" time explaining low inflation in the late 1990s with the new inflation data, since the inertia (lagged dependent variable) component of the inflation explanation projects substantially lower inflation after 1995. Second, the output and productivity growth data were revised upward by the same amount that the inflation data were revised down for the 1978-95 period, so that a higher rate of productivity growth is subtracted from (unrevised) wage growth in constructing the trend unit labor cost variable needed for the wage equations. Thus the growth in trend unit labor cost fed through to the late 1990s by the inertia variables is lower in the wage equations, just as in the inflation equations.

Third, in this paper the original specification uses the Hodrick-Prescott filter rather than piecewise linear trends to measure the productivity trend needed to calculate the productivity deviation variable. Fourth, previous research used a somewhat unsatisfactory import price variable that excluded oil imports during 1968-84 but not before or after. This has now been replaced by a price index that consistently refers to non-oil imports for the entire post-1967 portion of the sample period. Fifth, there were sharp and discontinuous downward spikes in the PCE deflator in the single quarter 2001:Q3 and in the GDP deflator in the single quarter 2001:Q4. Since we believe these changes in the NIPA deflators are spurious and do not represent the fundamental behavior of inflation, we have created "World Trade Center" (WTC) dummy variables, one for each deflator in the single quarter listed above.[26] Since the NIPA treatment of insurance had no impact on the CPI, no WTC dummies are entered in the CPI equations nor in the various wage equations..

The results for wages use three different wage indexes, the ECI-TC, ECI-WS, and the CPH indexes that are listed in the bottom section of Table 1. Our primary attention is to the first of these indexes, since the latter is highly volatile and is contaminated by mix effects when the industry and occupational composition of compensation changes. The only reason to include results for the CPH series is that it is consistently constructed throughout the postwar period, whereas the ECI-TC series dates back only to 1980, and it is necessary to backcast the ECI-TC from 1980 to 1960 with a series that has a different concept and methodology.[27]

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26. The sharp drop in the PCE deflator in 2001:Q3 was caused by the bizarre treatment of insurance prices in the national accounts. Essentially all insurance benefits paid out, either in that quarter and in future quarters, were treated as a reduction in the price rather than real quantity of insurance. "In the NIPA's, insurance expenditures are defined as premiums net of benefits payable, and the large benefit payments resulting from the September 11th attacks were treated as a reduction in the net price of insurance." See "The Terrorist Attacks of September 11th as Reflected in the National Income and Product Accounts," *Survey of Current Business*, November 2001, pp. 2-3. Many of the insurance benefits were to be paid by foreign firms and were included in imported services; because imports are included in PCE but excluded from GDP, the treatment of the terrorist attacks caused a bounce-back in import prices in 2001:Q4 that had a corresponding negative impact on the GDP deflator.

27. For details see Gordon (1998), p. 332.

V. Estimated Coefficients and TV-NAIRUs

We now report on the estimated coefficients in the equations explaining changes in the GDP and PCE deflators, as well as the CPI-RS, using both the original and truncated specifications. Subsequently we shall examine the sensitivity of the deflator results to alternative productivity variables, and then turn to results in which wage changes are the dependent variable. Then we shall compare the estimated TV-NAIRUs for the differing dependent variables.

How Much of a Surprise was Inflation in the Late 1990s?

Before turning to the estimated equations, we begin by asking how large was the puzzle of low inflation in the late 1990s, using the original 1982 specification that forces the NAIRU to be constant rather than declining after 1995:Q4. As is done throughout this paper, we use the technique of dynamic simulation to generate the values of the lagged dependent variable endogenously.[28] Errors are reported in the left portion of Table 2 for the 24 quarters ending 2001:Q4 and in the right portion for the four quarters ending in 2001:Q4. Clearly, the original specification substantially understates inflation,

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28. As indicated above, dynamic simulations have been used as a primary testing device over the past 20 years, usually covering a period of roughly six years or 24 quarters at the end of the period of available data. Gordon (1994) ran simulations over the period 1987-93 and Gordon (1998) over the period 1993-98.

both in the 1996-2001 interval and especially in 2001. Note that these simulation results use the actual values of all the other explanatory variables besides the lagged dependent variable and hence include the effect of food, energy, and import prices in the simulation results.

In contrast, the bottom section of Table 2 shows that errors are much smaller, almost negligible, for the two ECI wage indexes adjusted for trend productivity (w-θ* in the above notation). The volatile CPH series generates large errors, and these change signs across sub-periods of 1995-2001. Henceforth we will devote little attention to the CPH series and note that explaining the behavior of wage changes does not appear to require a declining post-1994 TV-NAIRU. Looking at the data in Tables 1 and 2 more broadly, two issues appear to create ambiguity regarding the late 1990s inflation surprise. First, the surprise occurred in the context of the Phillips-curve acceleration to be expected in response to declining unemployment. But there was no surprise with respect to capacity utilization, which declined rather than increased despite the vigorous expansion of aggregate demand. Second, the surprise refers to prices but not to trend unit labor costs.

Equations for Price Inflation

Table 3 displays the estimated coefficients for equation (2) for the three price indexes and two specifications (original and truncated). Recall that these are the reduced-form equations explaining quarterly inflation rates by the lagged dependent variable (the inertia effect), by the unemployment gap, and by the set of supply-shock variables, but without the wage feedback effect present in equation (8) above. The first two columns display the results for the GDP deflator with the original and truncated specifications, respectively, and then the next two sets of columns report the results for the PCE deflator and the CPI-RS. The sum of coefficients on the inflation equations is always very close to unity, as in previous research. The inclusion of lags 13-24 (years four through six) is strongly significant at the one percent level. The sum of unemployment gap variables is around -0.6 in the original specification and -0.4 to -0.5 in the truncated specification. The fact that the slope of the Phillips curve is roughly one-half validates a stylized fact first noticed in the 1960s and provides evidence of the stability of the Phillips curve.

Of the supply shocks, the change in the relative import price and relative food-energy effect is consistently significant in all four columns with plausibly sized positive coefficients. As expected, the coefficients on the food-energy variable are much higher in the equations for the PCE deflator and CPI-RS than for the GDP deflator, because imported energy is a part of PCE but not of GDP. A puzzle that we have not resolved is why the coefficients with both specifications for the non-oil import deflator are lower in the PCE equations than in the GDP equations, when the relationship should be the opposite. Both the productivity deviation and alternative productivity acceleration variables are significant in most versions with the expected negative signs, indicating that an acceleration of productivity growth of 1.0 percent holds down inflation by between 0.09 and 0.31 percent X the remaining 0.69 to 0.91 percent implicitly raises profit margins. The coefficients for the Nixon control variables are as expected in the original specification, but the post-controls rebound effect ("Nixon off" coefficient) is small and insignificant for the PCE deflator.

The bottom of the table displays results of post-sample dynamic simulations, which truncate the sample period at 1995:Q4. The alternative equations with the original specification overpredict the rate of inflation over the 24 quarters 1996:Q1-2001:Q4 by an average of 0.24 to 0.49 percent at an annual rate, while the truncated specification underpredicts inflation by between 0.01 and 0.57 percent. The simulation performance of the truncated specification for the four quarters of 2001 is much better than in the original specification. Comparing Tables 2 and 3, where the former holds the NAIRU constant after 1995 and the latter allows it to decline, we see that the declining post-1995 NAIRU reduces the simulation error for the original specification in the four quarters of 2001 by about half a percentage point.

The Productivity Effect

A leading hypothesis to explain low inflation in the late 1990s is the impact of the post-1995 revival in productivity growth. However, there are many different ways of specifying the response of inflation to a productivity growth upsurge or slowdown. Alternative variables are displayed in Figure 4. The original specification uses the deviation of productivity growth from trend, where the trend is now computed with the HP filter. Even when plotted as a four-quarter moving average, this series is highly volatile, capturing the very short-run cyclical movements of productivity but not its medium-term behavior. The upper-right frame shows the eight-quarter and 20-quarter moving averages developed by Eller (2000); his preferred productivity variable is the difference between the eight and 20-quarter moving averages as shown in the lower left frame. This is not as volatile as the original productivity deviation, but it still mainly picks up cyclical events, namely the temporary acceleration of productivity in the early stages of economic expansions, e.g., 1971-73, 1976-77, 1983-84, and 1992.

A different approach is suggested in the lower right frame. Here the HP trend is contrasted with a 10-year moving average of the HP trend. The difference between these two variables, which we will call the HP10 productivity measure, evolves smoothly and clearly captures the influence of the post-1995 revival as well as the earlier slowdown, which has a negative value from 1969 to 1983. Table 4 displays coefficients and simulation values for all three productivity variables for all three price indexes, using both the original and truncated specifications. Our selection criterion is based entirely on the original specification, which will be used throughout the rest of the paper, because of the superior fit of the original specification and the continued significance of the long lags, even when the sample period is split in half (see below). Looking only at the original specification in Table 4, the fit of the new HP10 is about the same for the GDP deflator, slightly better for the PCE deflator, and somewhat worse for the CPI-RS. However, the simulation errors are uniformly smaller with the HP10 variable for all three price indexes. In particular, the simulation error for 2001, six years after the end of the sample period, is only -0.27 for the GDP deflator (left column, next to bottom row). The HP10 productivity variable is used throughout the rest of the paper, since it does the best job of representing the influence of the post-1995 productivity revival in holding down inflation, while also providing a roughly similar fit in the productivity slowdown period of the 1970s and early 1980s.

Sample Split

The original specification was developed more than 20 years ago and needs to be subjected to skepticism and testing, some of which was carried out in the form of the truncated specification above. Another obvious test is to split the sample in half (1962-80 and 1981-2001) to determine whether the original triangle specification is stable. There are two interesting aspects of this experiment. First, the original specification survives the sample split with flying colors, with a t (21,114) ratio of 1.16, compared to the critical five percent value of 1.66. The equivalent figure for the truncated specification is 1.60, still short of the critical five percent value of 1.66.

Another interesting aspect of the sample split is that the unusually long lags 13-24 on the lagged dependent variable remain significant at the one percent significance level in both sub-periods of the original specification, 1962-80 and 1981-2001. Thus it is not true, as I once speculated informally, that the long lags were an artifact of the 1950s and 1960s, perhaps because of the importance of union wage contracts, and had evaporated by the time of the "twin peaks" of inflation in the 1970s and 1980s when inflation showed itself capable of such sharp non-inertial ups and downs.

Is the Phillips Curve Dead?

Using the framework developed thus far, it is possible to assess the widespread belief, most popular during the 1997-98 period of decelerating inflation, that the Phillips curve is dead, i.e., that the slope on the Phillips curve had decreased in absolute value from some negative number to zero. With current data we replicated the test published by Stock in his comment on Gordon (1998). To test for a shift in the Phillips curve coefficient in 1994:Q1, we created a

0,1 dummy, equal to zero for 1962-93 and unity for 1994-2001. This dummy, multiplied by both the set of current and lagged values of the unemployment gap, was entered into the original specification for the GDP deflator, i.e., into the specification for which the results are displayed in the first column of Table 3. If the Phillips curve had disappeared, we would expect the interactive dummies to have coefficients equal to and of the opposite sign to that shown in Table 3, i.e., +0.66, for the unemployment gap. However, the estimated coefficients for the interactive dummy on the unemployment gap, while having the correct sign, was an insignificant 0.26 (the significance level was 0.25). Changing the date of the time break to 1995:Q4 yields a coefficient on the interactive dummy at 0.25 with a similarly low significance level of 25 percent. Corresponding to this finding is that the sum of squared residuals in the inflation equation increases substantially if the unemployment gap is arbitrarily set to zero for the entire period after 1993:Q4 or alternatively after 1995:Q4.

Results Replacing the Unemployment Gap by the Utilization Gap

Table 5 displays the coefficients with the original specification when the unemployment gap is replaced by the difference between the rate of capacity utilization and its own NAIRU concept, which we call the "NAIRCU". A result of this part of our study is that the TV-NAIRCU is virtually constant throughout the last 40 years, providing the appearance that inflation behavior is more stable relative to capacity utilization than to the unemployment rate. The coefficients in Table 5 are comparable to those in Table 2 for the original specification. The sum of coefficients on the utilization gap is strongly significant and about one-third of the equivalent sum of coefficients on the unemployment gap, reflecting the much greater volatility of capacity utilization than of the unemployment rate.[29] The goodness-of-fit statistics for the capacity utilization gap substantially worse than in the original specification for the unemployment gap, but the predictive performance of tracking inflation in the late 1990s is much better, at least for the full 1996-2001 dynamic simulation period. Because the rate of capacity utilization collapsed in 2001, these equations predicted that inflation should have declined much more than it did, and so all the simulation errors for 2001 underpredict inflation (i.e., the actual inflation rate was higher than the predicted value).

Equations for Changes in Trend Unit Labor Cost

The behavior of wage inflation is examined using the specification in equation (5) above, in which the quarterly change in trend unit labor cost is the dependent variable and no feedback from price indexes is allowed. The tests are carried out only for the original specification and for the three different wage

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29. Over our sample period the rate of capacity utilization has varied from 72 to 92 percent, a range of 20 percentage points, whereas the unemployment rate has varied between 3.5 and 10.5 percent, a range of 7 percentage points, about one-third as large.

series ECI-TC, ECI-WS, and CPH (converted into trend unit labor cost by subtracting a single labor productivity trend growth rate based on the Hodrick-Prescott filter).

Some consideration of the HP10 productivity variable in the wage equations is required. Symmetry requires including every variable in the price index equations as well in the equations for trend unit labor cost. However, since the HP trend in productivity change is subtracted out from the left-hand side variable, it is not surprising that the coefficient on a transformation of the same variable has a coefficient of -1.0 or above in these equations displayed in Table 6. Another difference with the price index equations in Table 3 is that the wage equations in Table 6 display much smaller effects of the Nixon-era price controls, not surprisingly since these were controls on prices rather than wages.

The dynamic simulation results in the bottom section of Table 6 support the initial verdict of Table 2, that the behavior of wages in the 1990s has been much less "surprising" than the behavior of price indexes. The mean error in dynamic simulations for all three measures of wages in 2001 (the next to the bottom line in Table 6) are close to zero, even for the CPH wage measure which otherwise is very volatile and has a poor fit. The slope of the Phillips curve across the six columns of Table 3 is a bit steeper than in the price equations, with sums of coefficients on the unemployment gap in the relatively narrow range of -0.63 to -0.84, again highly significant at the one percent level. The relative food-energy variable is positive and significant, indicating a spillover to wage behavior of a variable normally thought to be relevant only to price behavior, while the relative import price variable is zero and significant for all three wage series.

Wage-Price Feedback

Until this point in the paper, all results have been reduced-form equations in which actual inflation is explained by lagged inflation and other demand and supply variables, while actual trend unit labor cost has been explained by its own lagged values and the same set of demand and supply variables. However, as shown in equations (7) and (8) above, it is possible to study the symmetric reverse feedback between wages and prices by including the change in the trend income share of labor in either a price or wage equations. The results summarizing the inclusion of the feedback effects are displayed in Table 7.

Recall from equation (8) that a properly signed wage feedback term in a price equation would be positive, and that a properly signed price feedback term in a wage equation would be negative as in equation (7). The results in Table 7 can be summarized by scanning the third column, showing the significance level in an exclusion test of the feedback term, or alternatively by comparing the sum of squared residuals (SSR's) in the various lines of the right-hand column.

Wage feedback is highly significant for the GDP deflator and the CPI-RS, but not for the PCE deflator. Price feedback is highly significant in the wage equation when the GDP deflator is used as the feedback variable, but not when the PCE or CPI-RS are used as the feedback variable, and in these cases the sign of the sum of coefficients is incorrect, positive rather than negative. While the results are mixed, they validate the attention to feedback summarized in equations (7) and (8), but not in the form of independently specified wage push and price mark-up equations that were universal in the pre-1980 empirical inflation literature.[30] A major caveat on this attention to feedback effects is that all the post-sample simulation results for 1996-2001 in Table 7 exhibit substantially larger errors for the feedback versions than for the corresponding no-feedback versions, although the deterioration in fit of the simulations is very minor for the GDP deflator with labor-share feedback from the ECI-TC and for the TULC-TC version with CPI feedback. Clearly, if our only interest is in explaining low inflation in the late 1990s, we can dispense with the wage feedback issue.

Estimated TV-NAIRUs

Corresponding to each of the specifications reported in Tables 3 and 6 is a TV-NAIRU, and these are displayed in Figures 5 and 6. In Figure 5 we view the actual unemployment rate plotted against the TV-NAIRUs estimated with the original specification for the GDP and PCE deflators, as well as the CPI-RS. These

30. In Gordon's research dating back to 1970 and 1977, the effect of producer, i.e., GDP prices on wages has always been stronger than that of consumer prices, suggesting a demand-pull mechanism on wages rather than a push from indexation to the cost of living.

differ from the TV-NAIRUs estimated with the same specification in Gordon (1998) in several respects, presumably reflecting some combination of the extensive data revisions in the NIPA since 1998 and also the addition of 14 extra quarters to the sample period. First, they are less variable between 1970 and 1990 and a bit lower throughout. The TV-NAIRU for the PCE deflator does not move above or below the range of 5.8 to 6.5 in the entire period between 1961:Q1 and 1993:Q4, but by 2001:Q4 had declined to 5.4 percent. The TV-NAIRU for the GDP deflator displays similar behavior, declining by the end of our sample period to 5.5 percent.

The range of varying estimates of the decline in the TV-NAIRU in the 1990s is displayed in figure 6. The steepest dive among the five plotted TV-NAIRU's is for the CPI-RS, declining from a peak of 6.32 percent in 1990:Q1 to 5.15 percent in 2001:Q1. The other price indexes decline less, and the final estimated value of the TV-NAIRU in 2001:Q4 ranges from 5.15 percent for the CPI-RS, 5.36 percent for the PCE deflator, 5.48 percent for the GDP deflator, 5.71 percent for the trend unit labor cost based on the ECI-TC wage series, and 6.03 percent based on the CPH wage series.

The "TV-NAIRCU"

In Figure 7 we display the "natural rate" concept for the rate of capacity utilization that we label the "TV-NAIRCU". This is plotted for all three price indexes examined in this paper, the GDP and PCE deflators and the CPI-RS price index. The graph displays the high volatility of the actual rate of capacity utilization in contrast to the near-constancy of the TV-NAIRCUs for all three price indexes, together with a near-zero dispersion of the TV-NAIRCU across the three price indexes. The TV-NAIRCU for the GDP deflator is slightly lower than for the PCE deflator, just as the TV-NAIRU for the GDP deflator in Figure 5 is slightly higher, indicating that it requires slightly more economic "slack" to maintain constant inflation in the GDP deflator than in the PCE deflator.

The contrasting results for the TV-NAIRU and TV-NAIRCU pose a puzzle about the nature of the U. S. macroeconomic miracle of the late 1990s. As a result of a technological acceleration in computer technology, followed by a computer-led investment boom, the U. S. economy appeared to be awash in capital and capacity, hence keeping the capacity utilization rate relatively low, but was short of labor, thus forcing down the unemployment rate. This imbalance between the product and labor markets provides one interpretation of the differing time paths of the TV-NAIRU and TV-NAIRCU in the 1990s. These generalizations need to be qualified to the extent that the capacity and utilization data cover only manufacturing, mining, and utilities, about 30 percent of the economy. The uncovered 70 percent could have experienced an unobserved increase in utilization (e.g., hotel occupancy rates and airline load factors) while facing a tight labor market.

VI. The Role of Beneficial Supply Shocks

We have already shown in Table 2 that prediction errors for inflation are higher during the 1996-2001 period when the NAIRU is artificially held constant than when it is allowed to decline. A similar experiment can quantify the role of the food-energy and import price supply shocks. The original specification is re-estimated to end the sample period in 1995:Q4 instead of 2001:Q4, and then dynamic simulations are carried out for the 1996-2001 post-sample interval. These simulations artificially hold the value of the NAIRU constant during 1996-2001, as in Table 2, and also set all the supply shock variables equal to zero instead of their actual values. Thus we would expect the simulations to yield substantially faster predicted inflation, since the TV-NAIRU is held constant instead of declining and the predominately beneficial supply shocks are suppressed, than a similar simulation using the actual values of these variables (for which statistics are reported in the bottom sections of Tables 3 and 6).

The results of the "surprise" computations are provided in Table 8, which shows the actual and fitted values of equation (2) estimated with the same three price indexes as in Table 3 and 4, and the actual and fitted values of equation (5) for the three wage indexes as in Table 6. As would be expected, the first three lines in Table 8 show substantial simulation errors, with the overprediction of inflation ranging from -1.55 to -1.99 percent per annum in the four quarters ending in 2001:Q4, in contrast to a range of -0.47 to -0.76 in Table 4 (using the same HP10 productivity change variable). This difference, e.g., -1.08 percent for the GDP deflator, represents the combined effect of the declining TV-NAIRU and the beneficial net impact of supply shocks in holding down inflation after 1994:Q4.

How much of this improvement in fit is provided by the declining TV-NAIRU and how much by the influence of the supply shocks? The answer is provided in Table 9, which exhibits simulation errors that incorporate the actual (declining) values of the TV-NAIRU after 1995:Q4 but alternatively exclude and include the influence of the import-price and food-energy-price effects. To continue using the example of the GDP deflator, the combined effect of the two supply shock variables is to reduce the prediction error for the four quarters ending in 2001:Q4 from -1.14 to -0.26. The remaining reduction of the prediction error from -1.55 in Table 8 to -1.14 in Table 9 was by inference achieved by allowing the TV-NAIRU to decline instead of holding it at its value of 1995:Q4. Thus for the GDP deflator the role of the supply shocks, mainly the import price effect, is more than twice as large as the effect of the declining TV-NAIRU.

VII. Supply Shocks and Other Sources of the Decline in the TV-NAIRU

Thus far the paper has provided a partial answer to the basic question, "why was inflation so low in the late 1990s?" By estimating equations in which supply shocks enter and in which the NAIRU is allowed to vary over time, we have succeeded in matching the actual behavior of late-1990s inflation quite closely.

The Role of Food-Energy and Import Price Shocks

The best measure of the supply-shock effects is the set of mean errors for dynamic simulations of the inflation equations over the period 1996:Q1-2001:Q4 in the bottom section of Table 4. The mean error using the original specification and the HP10 productivity variable is a relatively small -0.30, -0.22, and -0.24 for the GDP deflator, PCE deflator, and CPI-RS, respectively. The achievement is almost as impressive as the dynamic simulations proceed over their six year period, especially for the GDP deflator where the error in the four quarters of 2001 is only -0.27 percent, although the PCE and CPI versions register larger errors for 2001 of -0.57 and -0.76, respectively. The actual and simulated values for the GDP deflator are compared in Figure 8, which displays the actual values for the GDP deflator, the predicted values through 1995, and the simulated values for 1996-2001.

If there are remaining simulation errors in 2001, why does this methodology not estimate an even lower TV-NAIRU for the year 2001 than the results of Tables 4 and 9? An intuitive answer is that the simulation errors rely on coefficients estimated only through the end of 1995, not the end of 2001, while the estimated TV-NAIRUs are estimated through 2001 in equations that incorporate small shifts in coefficients (when the 1962-2000 sample is compared to the 1962-1995 sample) that help improve the prediction of inflation during 1996-2001 without requiring a further decline in the TV-NAIRU.

The wage equations perform substantially better than than the inflation equations, and in the bottom section of Table 6 have simulation errors for the four quarters of 2001 of virtually zero X 0.04 for the ECI-TC index, 0.09 for ECI-WS, and -0.03 for the CPH index. Figure 9 displays predicted and simulated values for the first of these, the ECI-TC. The prediction error zigs and zags between negative and positive during 1996-2001 but ends up right on track.

The Role of Computer and Medical Care Prices

The late 1990s were characterized by two phenomena that helped to hold down inflation and thus help to solve the puzzle posed at the beginning of this paper, why was U. S. inflation so low in the late 1990s. The first was an acceleration in the rate of deflation of computer prices that began at the end of 1995 and continued until late 1998 for total computers and through 2001 for consumption computers, as shown in the bottom section of Table 10. Medical care inflation also helps to contribute to low inflation in the late 1990s. From 1985 to 1995 medical care inflation was running at roughly double the overall rate of inflation in the GDP and PCE deflators but in 1996-98 exhibited a sharp deceleration, nearly converging with the overall rate of inflation. This cessation of inflation pressure from medical care, which represents fully 15 percent of consumption expenditures, provided the equivalent of a beneficial supply shock by removing one source of upward pressure on the inflation rate. In turn, the behvaior of medical care prices can be traced to a truly exogenous institutional event, the "managed care revolution" associated with the growth of Health Maintenance Organizations (HMO's) over this period.

The impact of computer and medical care prices is documented in Table 11. Each number displayed in the top two sections shows the effect on the inflation rate of removing that component of spending from total GDP or PCE. "Tech" refers to the computer hardware, software, and communications equipment. The beneficial impact of these sectors in holding down inflation occurred between the 1991-95 and 1996-98 periods; the combined effect of tech and medical care was to cause inflation to decelerate between those two intervals by 0.3 percentage points for the GDP deflator and 0.5 percentage points for the PCE deflator. The bottom section of Table 11 shows that removing both sectors raises the TV-NAIRU in 1996-98 by 0.1 points for the GDP deflator and 0.3 points for the PCE deflator.

Thus the combined effect of tech and medical care is to provide a partial explanation for the decline in the TV-NAIRU in the mid 1990s. Notice that the effect is reversed during 1999-2001 for the GDP deflator but remains largely intact for the PCE deflator.

Labor Market Sources of the Falling TV-NAIRU

Numerous other structural changes in the American economy help to explain the large decline in the TV-NAIRU. Katz and Krueger (1999) studied changes in the labor market that might explain the decline in the TV-NAIRU during the 1990s. The contributions to this decline emphasized by Katz and Krueger (1999, p. 64) were demographic shifts toward older workers (0.4 points), improved labor market efficiency due to the growth of the temporary help industry (a range centering on 0.2 points), the tripling of the prison population since the mid-1980s that has moved some young males from unemployed status to prison (0.17 points), and a generalized structural shift towards lower bargaining power for workers, related to the decline in unionization (perhaps 0.05 points). This list could perhaps be supplemented by the role of legal and illegal immigration in boosting the supply of workers, both at the unskilled end and also through the well-known influx of computer engineers and programmers from Taiwan, India, and other countries.[31]

31. See U. S. Congressional Budget Office (2002) for an assessment that is complementary to that of Katz and Krueger.

VII. Conclusion

The ongoing testing and validation of the "triangle" model of inflation dynamics was once described as "one of the great successes of postwar macroeconometrics."[32] With remarkably few changes from its 1982 origins, the "original" specification is able to explain why inflation was so low in the late 1990s, using the demanding testing method of dynamic simulation, with errors in 2001 X six years after the end of the sample period X of close to zero for both price changes and wage changes. In the conclusion we concentrate on the explanation of the behavior of the GDP deflator and say nothing further about the wage equations for the basic ECI-TC wage index, which has been shown in Table 6 and Figure 9 to remain on track throughout the post-1995 period.

The conclusions of this paper are that low inflation in the late 1990s can be completely explained by a decline in the NAIRU, due largely to structural changes in labor markets, and to a set of beneficial supply shocks that have effects that are quantified in this paper. This overall conclusion is decomposed in Table 12, which displays the factors that explain why inflation was so low in the final year of the data period, the four quarters ending in 2001:Q4. As shown in line 8, actual inflation for the GDP deflator was for these four quarters was 1.83 percent, whereas a naive forecast of inflation for the same period would have been much

32. A comment made by Robert E. Hall in the conference discussion of Gordon (1995).

higher, 3.68 percent, based on a constant TV-NAIRU (at the level of 1995:Q4), and no influence of productivity change or supply shocks. That creates a gap between actual and predicted of 1.85 percentage points, a substantial chasm to bridge.

The first set of explanations is presented in line 2 of Table 12. Fully two-thirds of the error of 1.85 points is explained by the combined effect of the traditional supply-shock variables in the original specification, with most of the work being done by the relative price of imports. The contribution of the productivity growth revival is surprisingly small, presumably because the HP10 productivity variable is constructed to return to zero several years after a major productivity shock in either direction. The small WTC dummy effect offsets the food-energy effect that, in this sub-period, works against explaining why inflation was so low.

The next contribution to the explanation is the decline in the TV-NAIRU. Post-1995 simulations with a fixed NAIRU (as in Table 2) and a TV-NAIRU (as in Table 4) provide the contribution of -0.37 to the predicted value, bringing the overall error down from 1.85 point with a fixed NAIRU and without supply shocks, to 0.64 with supply shocks, to 0.27 when supply shocks are included and the NAIRU is allowed to vary over time. Simulations on the official GDP deflator compared to the GDP deflator stripped of computer and medical care prices reduce the unexplained residual from 0.27 to 0.23.

The hypothesis that "The Phillips Curve is Dead" has been rejected, both in statistical tests that allow the coefficient on unemployment in the inflation equation to shift toward zero in the 1990s, and in the continuing evidence of a strong and robust positive relationship between the inflation rate and the rate of capacity utilization as an alternative measure of economywide "tightness." Further, the doubling between 1998 and 2000 of headline inflation in both the PCE deflator and the CPI are consistent with the view that inflation was temporarily held down, particularly in 1997-98, by a set of beneficial supply shocks.

These beneficial shocks form the crux of our explanation of why inflation was so low. Two sources of shocks appear directly in the inflation equation, changes in the relative prices of imports and of food and energy. Falling real import prices, partly caused by the 1997-98 Asian crisis, were a particularly potent source of low U. S. inflation in the late 1990s. Energy prices fell and then jumped, explaining part but not all of the post-1998 upsurge in headline inflation. Computer and medical care prices also qualify as beneficial supply shocks in the late 1990s. The rate of computer deflation accelerated during the 1995-99 interval, while medical care inflation dropped sharply in the mid-1990s as a result of the managed care health revolution. The post-1995 productivity revival counts as a fifth beneficial supply shock, and it enters our basic equation as the difference between the 8-quarter and 20-quarter change in productivity growth. Thus an acceleration in productivity growth directly holds down inflation during a transition period to a steady-state of more rapid productivity growth.

Our equations for the GDP and PCE deflators are estimated with two specifications in this paper, one "original specification" which retains the long lags characteristic of Gordon's work on inflation since the late 1970s, and a "truncated specification" that shortens the lags and attempts to improve on the way in which an acceleration or deceleration of productivity growth enter the price-setting process. We have found that the original specification still fits better over a sample period spanning the last 40 years, even when the sample period is split between the 1962-81 and 1982-2001 intervals.

In this paper we have placed considerable emphasis on the stability of the NAIRU concept that we have developed for the rate of capacity utilization ("TV-NAIRCU"). The contrast between the unchanging TV-NAIRCU and the sharply declining TV-NAIRU requires a reconciliation. We have pointed to some combination of rapid capacity growth made possible by a technological acceleration in computer production, together with improvements in labor market performance emphasized by Katz and Krueger, in explaining this difference in behavior.

In one sense we may have overexplained why inflation in the late 1990s was so low. Inflation was low because the rate of capacity utilization was low, and the decline in the actual unemployment rate was largely offset by a decline in the NAIRU. Beneficial supply shocks, especially falling real import prices and moderate energy prices through early 1999, help to explain why inflation did not accelerate even when the actual unemployment rate dropped below the "no-shock" NAIRU. Clearly, computer prices and medical care prices helped to push down the TV-NAIRU in the mid-to-late 1990s.

In contrast to some of the contemporary research on inflation issues, this paper develops a unified framework in which price and wage inflation are treated symmetrically. The paper shows throughout that there was no puzzle to be explained about "why wage change was so low" in the 1990s, and the final results of the paper in Table 12 show that the remaining puzzle about low inflation in 2001 was only two-tenths of a percentage point.

Caveats and Afterthoughts

While this paper has been able to explain wage behavior almost perfectly and price behavior within a margin of 0.2 as an annual rate of change, there are, as always, several research issues that remain to be investigated. First, all of our results have been based on a single demand variable, the gap between the actual and natural unemployment rates (or NAIRU). That gap measures substantial excess demand in the U. S. economy in the late 1990s, while an alternative measure of tightness, the rate of capacity utilization, suggests that the extent of aggregate demand tightness was unchanged in 1995-99 and then diminished in 2000-2001. Future research should explore the possibility of developing an optimal blend of the two demand-tightness measures, the unemployment gap and the capacity utilization gap.

The future outlook for inflation is mixed. The single most important factor arguing for optimism is the powerful inertia effect, which still stretches back over six years and suggests that the low inflation rates observed during 1996-2001 will hold down actual inflation in the interval 2002-2007. The research reported here suggests that the most important single factor holding down U. S. inflation in the late 1990s was the strong dollar and its impact in reducing the relative price of imports. The possibility of a collapse in the foreign exchange value of the dollar is thus the most important negative aspect of the inflation outlook. While the effects of medical care and computer inflation are quite small in these results, this might not be true in the future. The media and newspapers have been full of articles predicting a future explosion in medical care costs that has not yet shown up in the economywide deflators but might do so soon. Perhaps offsetting this is the ongoing decline in computer prices, which, to those of us who have purchased new computers in the last few months, seems to be faster than ever.

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TABLE 1
Basic Data for Selected Quarters, 1987:Q4-2001:Q4

Variable	1987:Q4	1990:Q2	1994:Q4	2000:Q4	2001:Q4
A. "Tightness," Level in Quarter					
1. Civilian Unemployment Rate	5.8	5.3	5.6	4.0	5.6
2. Capacity Utilization Rate	82.9	82.8	84.0	80.7	74.6
Four-quarter rates of change					
B. Price Variables					
1. GDP Deflator	3.2	3.8	2.1	2.4	1.9
2. PCE Deflator	4.4	4.0	2.1	2.6	1.3
3. Core PCE	4.4	4.3	2.3	1.9	1.6
4. CPI-U	4.4	4.6	2.6	3.4	1.9
5. Core CPI-U	4.2	4.8	2.8	2.5	2.7
4. CPI-R	4.1	4.2	2.1	3.4	1.8
5. Core CPI-R	4.0	4.4	2.2	2.5	2.7
C. Wage and Productivity Variables					
1. ECI Total Compensation	3.6	5.4	3.0	4.1	4.1
2. ECI Wages & Salaries	3.7	4.6	3.0	3.8	3.9
3. Compensation per Hour	3.7	5.7	2.2	7.8	3.9
4. Average Hourly Earnings	3.1	4.1	2.6	4.3	3.9
5. Output per Hour	1.0	1.5	1.1	2.6	2.1

Sources BLS and BEA web sites.

TABLE 2
Actual and Simulated Values of Price and Wage Changes, Using Alternative Indexes and Constant NAIRU[a]

Units as indicated

	Dynamic simulation errors		*2001:Q4 results*[b]		
Index	*Root mean-squared error*	*Mean error*	*Actual*	*Simulated*	*Error*
GDP deflator	0.95	-0.61	1.83	3.00	-1.17
PCE deflator	1.00	-0.65	1.29	2.85	-1.56
CPI-RS	1.16	-0.76	1.85	3.50	-1.65
Trend unit labor cost					
ECI-total compensation	0.68	0.07	1.79	1.48	0.31
ECI-wages and salaries	0.71	0.12	1.39	1.62	-0.23
Compensation per hour	2.04	0.52	0.05	2.39	-2.34

Source: Author's calculations.

a. Specification of equations given by equation (1) in text; sample period is 1962:Q1 - 1995:Q4. Dynamic simulation is from 1996:Q1 to 2001:Q4. Details of variables and lag lengths are in Tables 2 and 6.

b. Four-quarter percent changes.

c. The TV-NAIRUs were calculated for the full 1962:Q1 - 2001:Q4 sample period, and then held constant at their respective 1995:Q4 level. The 1995:Q4 values of the TV-NAIRU are as follows:
GDP - 5.75, PCE 5.56, CPI-RS 5.73, ECI-TC 5.68, ECI-WS 5.99, CMH 5.96.

TABLE 3

Estimated Equations for Quarterly Change in Price Variables, Original Specification, 1962:Q1 - 2001:Q4

Variable	Lags	GDP deflator		PCE deflator		CPI-RS	
		Orig	Trunc	Orig	Trunc	Orig	Trunc
1. Lagged Dependent Variable[a]	1-24	1.00**		1.00**		0.99**	
2. Lagged Dependent Variable[a]	1-12		0.99**		0.99**		0.99**
3. Unemployment Gap	0-4	-0.66**		-0.62**		-0.59**	
4. Unemployment Gap	0-1		-0.48**		-0.37**		-0.51**
5. Relative Import Price	1-4	0.11**		0.10**		0.07**	
6. Relative Import Price	1-2		0.08**		0.04**		0.05**
7. Relative Food-Energy	0-4	0.54**		1.01**		1.09**	
8. Relative Food-Energy	0-1		0.34**		0.90**		1.20**
9. Productivity Deviation	0-1	-0.13*		-0.09		-0.18**	
10. Productivity Accel (8-20)	0		-0.23		-0.25*		-0.31**
11. Nixon Controls "on"	0	-1.26**	-1.29*	-1.77**	-1.49**	-2.00**	-2.11**
12. Nixon Controls "off"	0	1.35*	1.31*	0.17	-0.08	1.37*	1.35**
13. 2001:Q3 dummy	0			-1.78*	-1.39		
14. 2001:Q4 dummy	0	-1.45	-0.91				
R^2		0.91	0.89	0.93	0.92	0.92	0.91
S.E.E		0.79	0.86	0.73	0.78	0.83	0.88
S.S.R.		83.90	109.13	72.79	89.23	94.04	114.56
Dynamic Simulation[b]							
1996:Q1-2001:Q4							
Mean Error		-0.39	0.01	-0.49	0.21	-0.41	0.57
Root Mean-Squared Error		0.72	0.57	0.84	0.57	0.84	0.89
2001:Q1-2001:Q4							
Mean Error		-0.67	-0.03	-1.00	0.09	-1.05	0.47
Root Mean-Squared Error		1.03	0.53	1.45	0.84	1.35	0.88

Notes: (*) indicates that coefficient or sum of coefficients is significant at 5 percent level; (**) at 1 percent level.

Lagged dependent variable is entered as the four-quarter moving average for lags 1, 5, 9, 13, 17, and 21, respectively.

Dynamic simulations are based on regressions for the sample period 1961:Q1-1995:Q4 in which the coefficients on the lagged dependent variable are constrained to sum to unity.

TABLE 4
Estimated Equatrions for Quarterly Change in Price Variables, Alternative Measures of Productivity, 1962:Q1 - 2002:Q4

		GDP Deflator		PCE Deflator		CPI-RS	
	Lags	Original	Trunc	Original	Trunc	Original	Trunc
Productivity Deviation	0-1						
Coefficient		-0.13*	-0.12	-0.10	-0.09	-0.18**	-0.17*
S.S.R.		83.90	107.82	72.80	90.85	94.04	113.68
Dynamic Simultation (1996:Q1-2001:Q4)							
Mean Error		-0.60	0.05	-0.49	0.16	-0.41	0.61
Root Mean-Squared Error		0.93	0.55	0.84	0.60	0.85	0.94
Dynamic Simultation (2001:Q1-2001:Q4)							
Mean Error		-1.08	0.10	-1.00	-0.06	-1.05	0.49
Root Mean-Squared Error		1.42	0.48	1.46	0.95	1.35	0.94
Productivity Acceleration (8-20)	0						
Coefficient		-0.22*	-0.23	-0.24*	-0.25*	-0.32**	-0.31**
S.S.R.		84.08	109.13	71.59	89.24	94.66	114.56
Dynamic Simultation (1996:Q1-2001:Q4)							
Mean Error		-0.38	0.01	-0.45	0.21	-0.33	0.57
Root Mean-Squared Error		0.74	0.57	0.79	0.57	0.79	0.89
Dynamic Simultation (2001:Q1-2001:Q4)							
Mean Error		-0.60	-0.04	-0.93	0.09	-0.91	0.47
Root Mean-Squared Error		1.00	0.62	1.35	0.57	1.29	0.93
Trend Productivity Deviation (10 year av)	0						
Coefficient		-0.50	0.06	-0.75**	-0.04	-0.57*	0.09
S.S.R.		84.33	110.95	70.83	91.87	97.25	117.24
Dynamic Simultation (1996:Q1-2001:Q4)							
Mean Error		-0.30	-0.36	-0.22	-0.69	-0.24	-0.75
Root Mean-Squared Error		0.68	0.79	0.64	1.08	0.74	1.18
Dynamic Simultation (2001:Q1-2001:Q4)							
Mean Error		-0.27	-0.70	-0.49	-1.52	-0.76	-1.87
Root Mean-Squared Error		0.75	1.02	0.84	1.97	1.16	2.02

TABLE 5

Estimated Equations for Quarterly Change in Price Variables, Original Specification, 1962:Q1 - 2001:Q4

Variable	Lags	GDP deflator Orig	PCE deflator Orig	CPI-RS Orig
1. Lagged Dependent Variable[a]	1-24	0.98**	0.98**	0.99**
2. Capacity Util. Gap	0-4	0.20**	0.14**	0.16**
3. Relative Import Price	1-4	0.06*	0.03	0.01
4. Relative Food-Energy	0-4	0.46**	0.70**	0.70**
5. Productivity trend - 10 ave.	0	0.21	-0.14	-0.06
6. Nixon Controls "on"	0	-0.86	-1.22*	-1.41*
7. Nixon Controls "off"	0	1.02	0.13	1.48*
8. 2001:Q3 dummy	0		-0.76	
9. 2001:Q4 dummy	0	-0.57		
R^2		0.88	0.91	0.90
S.E.E		0.90	0.82	0.91
S.S.R.		109.16	91.76	114.20
Dynamic Simulation[b]				
1996:Q1-2001:Q4				
Mean Error		0.22	0.08	0.09
Root Mean-Squared Error		0.78	0.66	0.76
2001:Q1-2001:Q4				
Mean Error		1.33	0.79	0.70
Root Mean-Squared Error		1.23	1.06	1.06

Notes: (*) indicates that coefficient or sum of coefficients is significant at 5 percent level; (**) at 1 percent level.

Lagged dependent variable is entered as the four-quarter moving average for lags 1, 5, 9, 13, 17, and 21, respectively.

Dynamic simulations are based on regressions for the sample period 1961:Q1-1995:Q4 in which the coefficients on the lagged dependent variable are constrained to sum to unity.

TABLE 6

Estimated Equations for Quarterly Change in Trend Unit Labor Cost Variables, Original Specification, 1962:Q1 - 2001:Q4

Variable	Lags	ECI-TC	ECI-WS	Comp/Hour
1. Lagged Dependent Variable[a]	1-24	1.00**	1.01**	1.02**
2. Unemployment Gap	0-4	-0.63**	-0.63**	-0.84**
3. Relative Import Price	1-4	0.01	-0.01	-0.02
4. Relative Food-Energy	0-4	0.29*	0.30*	0.61*
5 Productivity Trend - 10 ave	0	-1.16**	-1.55**	-1.47*
6. Nixon Controls "on"	0	-0.88	-0.88	-0.71
7. Nixon Controls "off"	0	0.50	0.30	1.02
R^2		0.91	0.91	0.66
S.E.E		0.83	0.73	1.79
S.S.R.		92.35	72.6	428.83
Dynamic Simulation[b]				
1996:Q1-2001:Q4				
Mean Error		0.02	0.32	0.34
Root Mean-Squared Error		0.66	0.74	1.96
2001:Q1-2001:Q4				
Mean Error		0.04	0.09	-0.03
Root Mean-Squared Error		0.36	0.50	2.06

Notes: (*) indicates that coefficient or sum of coefficients is significant at 5 percent level; (**) at 1 percent level.

Lagged dependent variable is entered as the four-quarter moving average for lags 1, 5, 9, 13, 17, and 21, respectively.

Dynamic simulations are based on regressions for the sample period 1961:Q1-1995:Q4 in which the coefficients on the lagged dependent variable are constrained to sum to unity.

TABLE 7

Coefficients and Significance Levels for Addition of Trend Labor Share Variable, Alternative Dependent Variables, 1962:Q1 - 2001:Q4

	Sum of Coefficients, Lags 1-8	Signif. Level of Sum	Signif. Level, Excl. Test	S.E.E.	SSR	Simulation Results 1996:Q1 - 2001:Q4 RMSE	ME
1. GDP Deflator, no LS term	-.--	-.--	-.--	0.79	84.33	0.68	-0.30
2. GDP Deflator, with LS term	0.14	0.25	0.00	0.71	64.54	0.76	-0.38
3. PCE Deflator, no LS term	-.--	-.--	-.--	0.73	72.80	0.84	-0.49
4. PCE Deflator, with LS term	0.07	0.47	0.80	0.75	70.66	1.00	-0.68
5. CPI-RS, no LS term	-.--	-.--	-.--	0.83	94.04	0.84	-0.41
6. CPI-RS, with LS term	0.16	0.15	0.00	0.77	75.66	0.98	-0.67
7. TULC-TC, no LS term	-.--	-.--	-.--	0.83	92.35	0.36	0.04
8. TULC-TC, LS for GDP deflator	-0.02	0.91	0.01	0.76	71.18	1.20	-0.85
7. TULC-TC, LS for PCE deflator	0.30	0.15	0.08	0.78	76.33	0.88	-0.53
8. TULC-TC, LS for CPI-RS	0.23	0.19	0.17	0.82	84.94	0.63	-0.07

Sources and Methods:

Specification of equations given by (1), (7), and (8) in text, sample period 1962:Q1-2001:Q4. Details of variables and lag lengths are as in Tables (3) and (6).

TULC-TC stands for Trend Unit Labor Cost based on data for the ECI, Total Compensation.

TABLE 8

Four-Quarter Averages of Actual Values, Post-1995:Q4 Simulated Values, and Simulation Errors, Using Fixed NAIRU and Supressing Supply Shocks

	1996:Q1-2001:Q4		Four Quarters Ending 2001:Q4		
Dependent Variable	**RMSE**	**ME**	**Actual**	**Simulated**	**Error**
Original Specification					
1. GDP Deflator	1.57	-1.25	1.83	3.38	-1.55
2. PCE Deflator	1.26	-0.83	1.29	2.85	-1.56
3. CPI	1.56	-0.84	1.85	3.84	-1.99
4. TULC-TC	0.73	0.18	1.79	0.71	1.08
5. TULC-WS	0.78	0.45	1.39	0.40	0.99
6. TULC-Comp/Hour	2.14	0.89	0.05	1.63	-1.58

Sources and Methods:

Specification of equations given by (1) in text, sample period 1962:Q1-2001:Q4.

Simulated values are calculated by assuming that the values of all supply-shock variables are set equal to zero for 1996:Q1-2001:Q4 and that the value of the TV-NAIRU is set at the constant 1995:Q4 value throughout 1996:Q1-2001:Q4.

Details of variables and lag lengths are the same as in Tables (3) and (6).

TULC stands for Trend Unit Labor Cost; RMSE stands for root-mean squared error; ME stands for mean error.

TABLE 9

Four-Quarter Averages of Actual Values, Post-1994:Q4 Simulated Values, and Simulation Errors, Using TV-NAIRU and Supressing Supply Shocks

	1996:Q1-2001:Q4		Four Quarters Ending 2001:Q4		
Dependent Variable	**RMSE**	**ME**	**Actual**	**Simulated**	**Error**
1. GDP Deflator					
Actual Values	0.68	-0.30	1.83	2.10	-0.28
Omitting Food-Energy Effect	0.69	-0.20	1.83	1.85	-0.02
Omitting Import Price Effect	1.39	-1.39	1.83	3.22	-1.39
Omitting Both Effects	1.34	-1.04	1.83	2.97	-1.14
2. PCE Deflator					
Actual Values	0.64	-0.22	1.29	1.78	-0.49
Omitting Food-Energy Effect	0.81	-0.09	1.29	1.80	-0.51
Omitting Import Price Effect	1.11	-0.86	1.29	2.60	-1.31
Omitting Both Effects	1.17	-0.73	1.29	2.62	-1.33
3. CPI-RS					
Actual Values	0.73	-0.23	1.85	2.48	-0.63
Omitting Food-Energy Effect	1.15	-0.07	1.85	2.53	-0.68
Omitting Import Price Effect	1.04	-0.70	1.85	3.12	-1.27
Omitting Both Effects	1.35	-0.53	1.85	3.17	-1.32

Sources and Methods:

Specification of equations given by (x) in text, sample period 1962:Q1-2001:Q4. Post-sample simulations are carried out for 1996:Q1 to 2001:Q4 and compute the lagged dependent variable endogenously.

Details of variables and lag lengths are the same as in Table (x).

Table 10
Data on Computers, Higher Tech, and Medeical Care, Selected Quarters
Average Percent

Item	1979:1-1985:4	1985:1-1990:4	1991:1-1995:4	1996:1-1998:4	1999:1-2000:2	2000:3-2001:4
Nominal expenditure shares						
Total Computers in GDP	0.89	1.01	0.87	1.00	0.99	1.00
Consumption of computers in PCE	0.05	0.17	0.26	0.35	0.38	0.36
Total IT in GDP#	-	0.76	1.03	1.94	2.80	3.37
Consumption of IT in PCE#	-	0.05	0.08	0.62	0.96	1.01
Medical care goods and services in GDP	7.07	8.46	10.35	10.33	10.11	10.31
Medical care goods and services in PCE	11.15	12.90	15.49	15.47	14.96	14.95
Four-quarter rates of percentage change of deflators						
GDP Deflator	6.3	3.3	2.5	1.7	1.6	2.3
PCE Deflator	6.5	3.8	2.7	1.7	2.0	2.1
Total Computers	-17.0	-16.0	-18.1	-22.0	-11.9	-16.0
Consumption of Computers	-15.4	-11.8	-20.3	-33.0	-25.8	-27.7
Total Software*#	-	-0.3	-2.0	-3.1	1.5	2.0
Consumption of Software in PCE*#	-	-11.1	-19.4	-25.1	-5.0	-3.6
Total Communications*^	-	-	-	-4.5	-4.7	-4.2
Consumption of Communication in PCE*^	-	-	-	-6.2	-9.0	-8.9
Medical Care Goods and Services	8.6	6.6	4.8	2.3	2.6	2.9

*Shares combined to calculate IT measurements above
^data unavailable before 1997
#data unavailable before 1988

Table 11
Effects of Computers, Medical Care, and IT on inflation and the TV-NAIRU, Selected Quarters
Average Percent Change

Item	1979:1-1985:4	1985:1-1990:4	1991:1-1995:4	1996:1-1998:4	1999:1-2000:2	2000:3-2001:4
GDP Deflator, impact of Stripping						
Tech	0.2	0.2	0.2	0.4	0.2	0.3
Medical care goods and services	-0.2	-0.3	-0.3	-0.1	-0.1	-0.1
Both components	0.0	-0.1	0.0	0.3	0.2	0.1
PCE deflator, impact of stripping						
Tech	0.0	0.0	0.1	0.2	0.2	0.2
Medical care goods and services	-0.3	-0.4	-0.4	-0.1	0.0	-0.2
Both components	-0.3	-0.4	-0.4	0.1	0.2	0.0
TV-NAIRU for GDP deflator						
Official	5.9	6.0	6.1	5.6	5.4	5.5
Deflator stripped of						
Tech	6.0	6.1	6.1	5.6	5.4	5.4
Medical care goods and services	5.9	6.0	6.2	5.6	5.4	5.4
Both components	5.9	6.0	6.2	5.7	5.5	5.5
TV-NAIRU for PCE deflator						
Official	5.8	6.2	6.0	5.5	5.4	5.3
Deflator stripped of						
Tech	5.8	6.2	6.1	5.7	5.5	5.5
Medical care goods and services	5.7	6.1	6.1	5.7	5.5	5.4
Both components	5.7	6.1	6.1	5.8	5.6	5.5

Table 12. Decomposition of the Inflation Surprise in the GDP Deflator

	2001:Q4
1. Predicted inflation, constant NAIRU, constant real prices of food, energy, and imports (rows 3 - 2c)	4.25
2. Contribution of traditional supply shocks	
a. Food and energy prices	0.25
b. Import prices	-1.15
c. Productivity	-0.57
d. WTC effect	-0.30
e. Total	-1.78
3. Predicted inflation with actual behavior of supply shocks and constant NAIRU	2.47
4. Effect of the estimated decline in the TV-NAIRU	-0.37
5. Predicted inflation with actual behavior of supply shocks and actual TV-NAIRU	2.10
6. Error term in simulation of inflation (rows 7 - 5)	-0.28
a. Medical Care, Computers, and IT	-0.04
b. Unexplained	-0.24
7. Actual inflation, four quarter change	1.83

Figure 1. Four Quarter Moving average in GDP, PCE, and CPI-RS

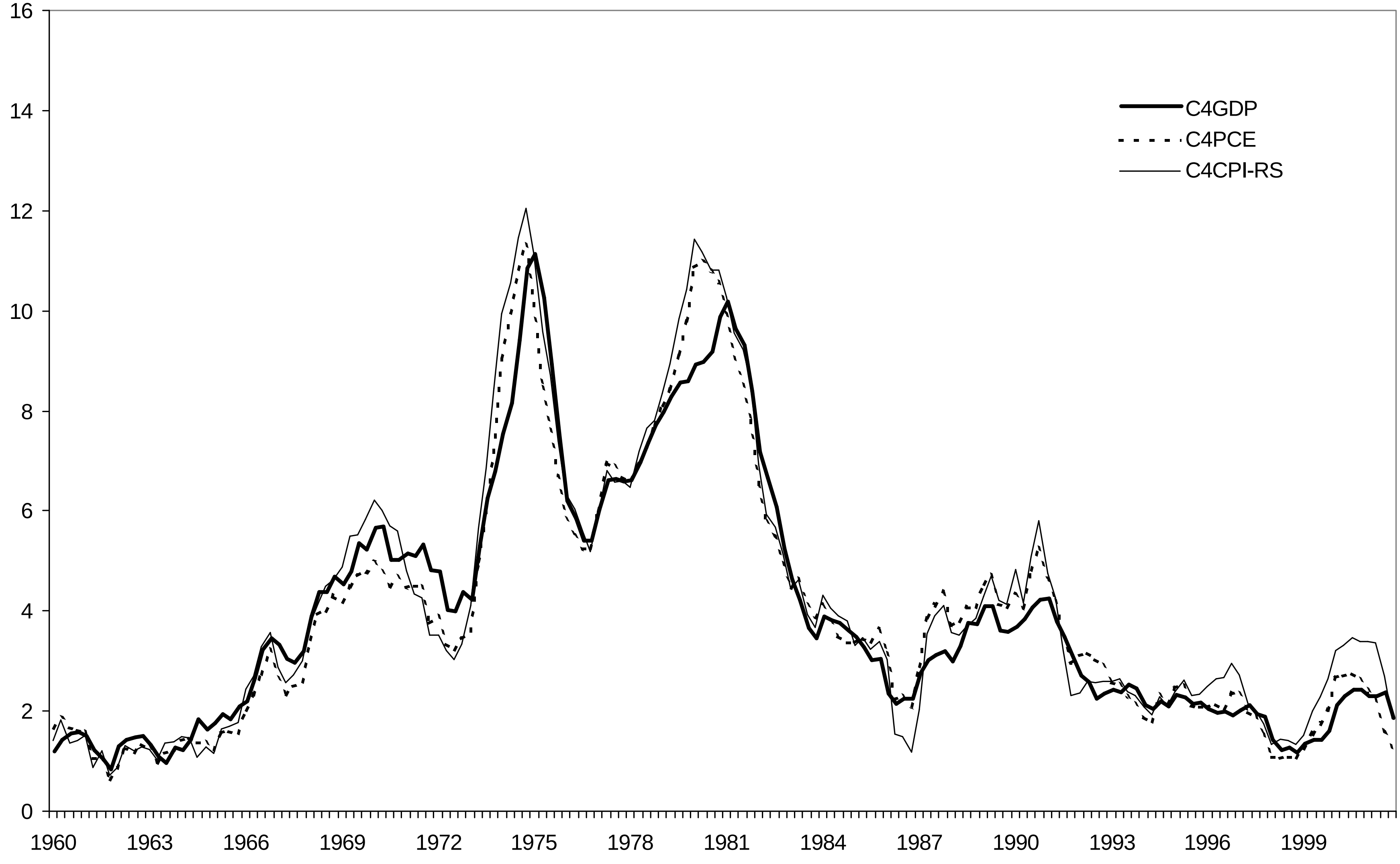

Figure 2. Four Quarter Moving average in PCE, CPI-RS, Core PCE and Core CPI-RS

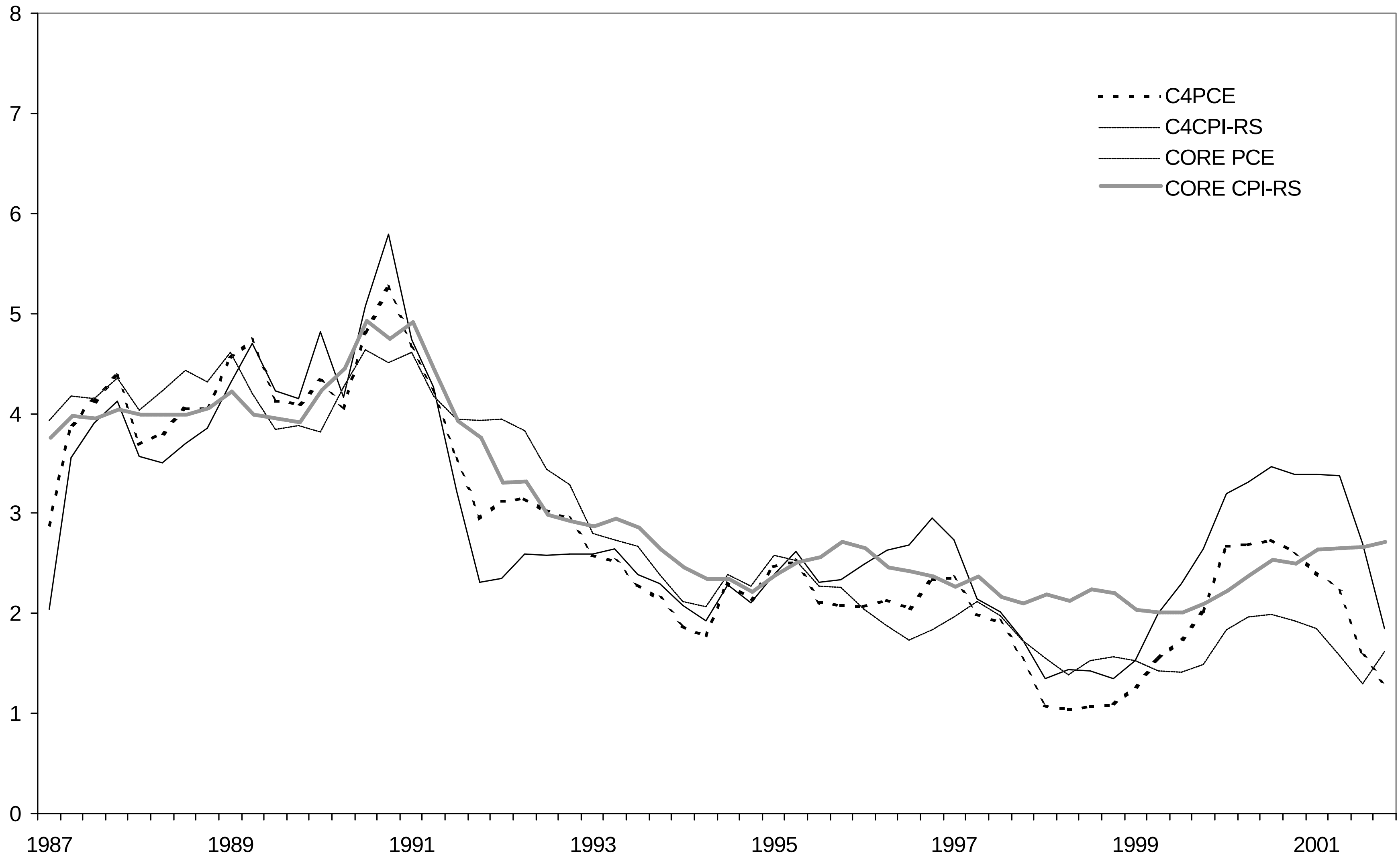

Figure 3. Four Quarter Moving average in Core PCE, Core CPI-RS, and Core CPI

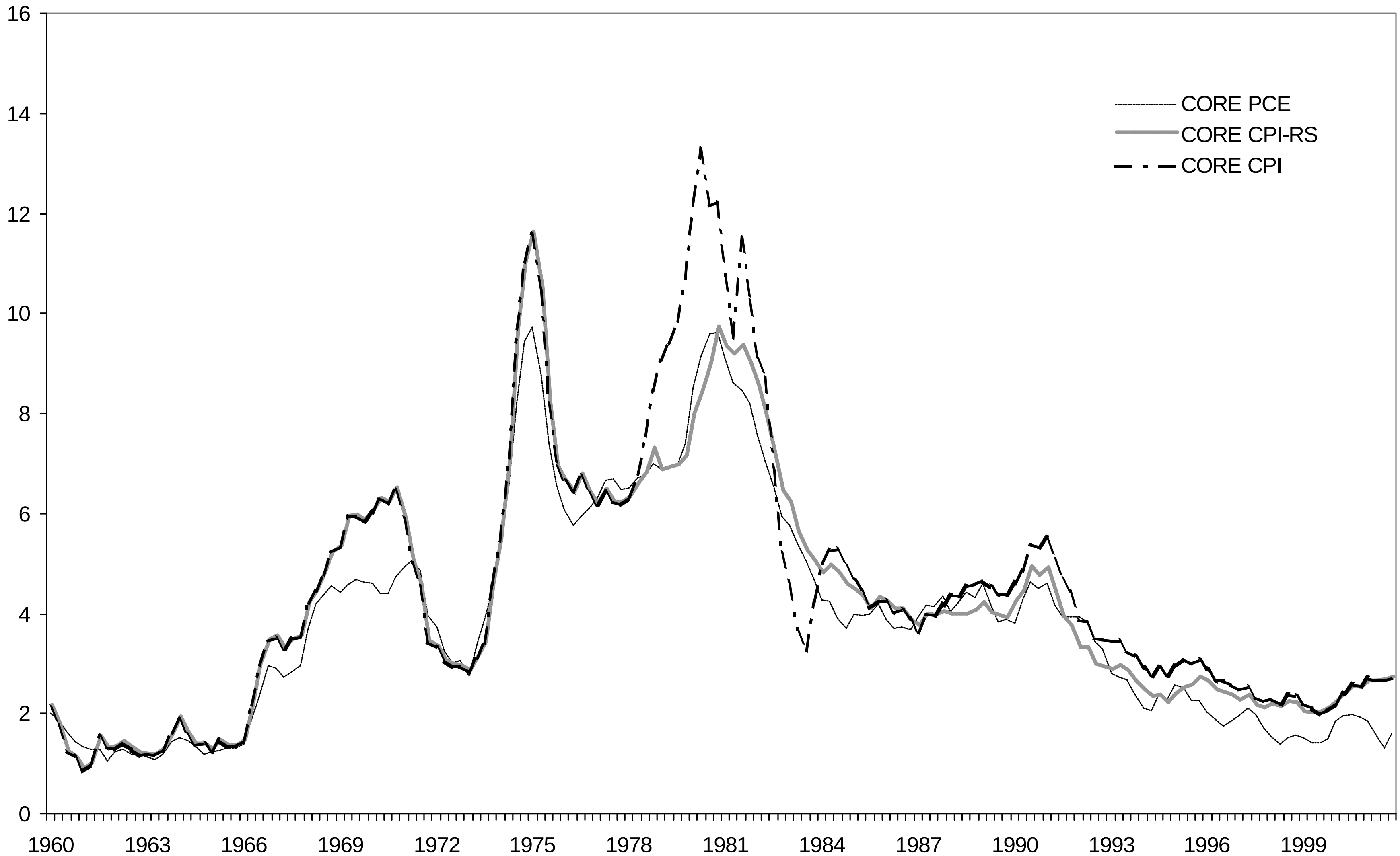

Figure 4. Alternate Treatments of Productivity

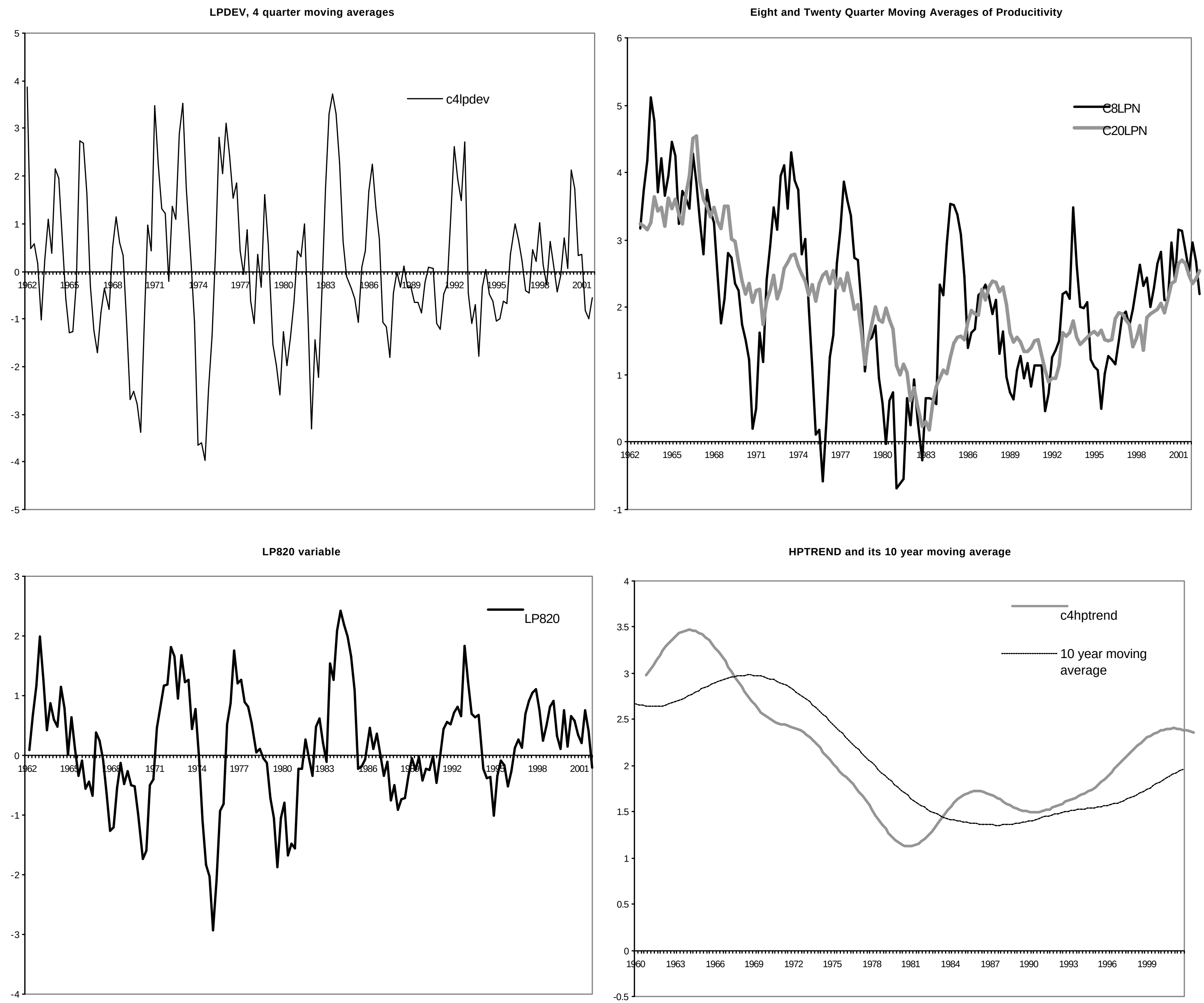

Figure 5
Actual Unemployment and TV-NAIRUs for PCE, GDP, and CPI-RS, Original Specification, 1961-2001

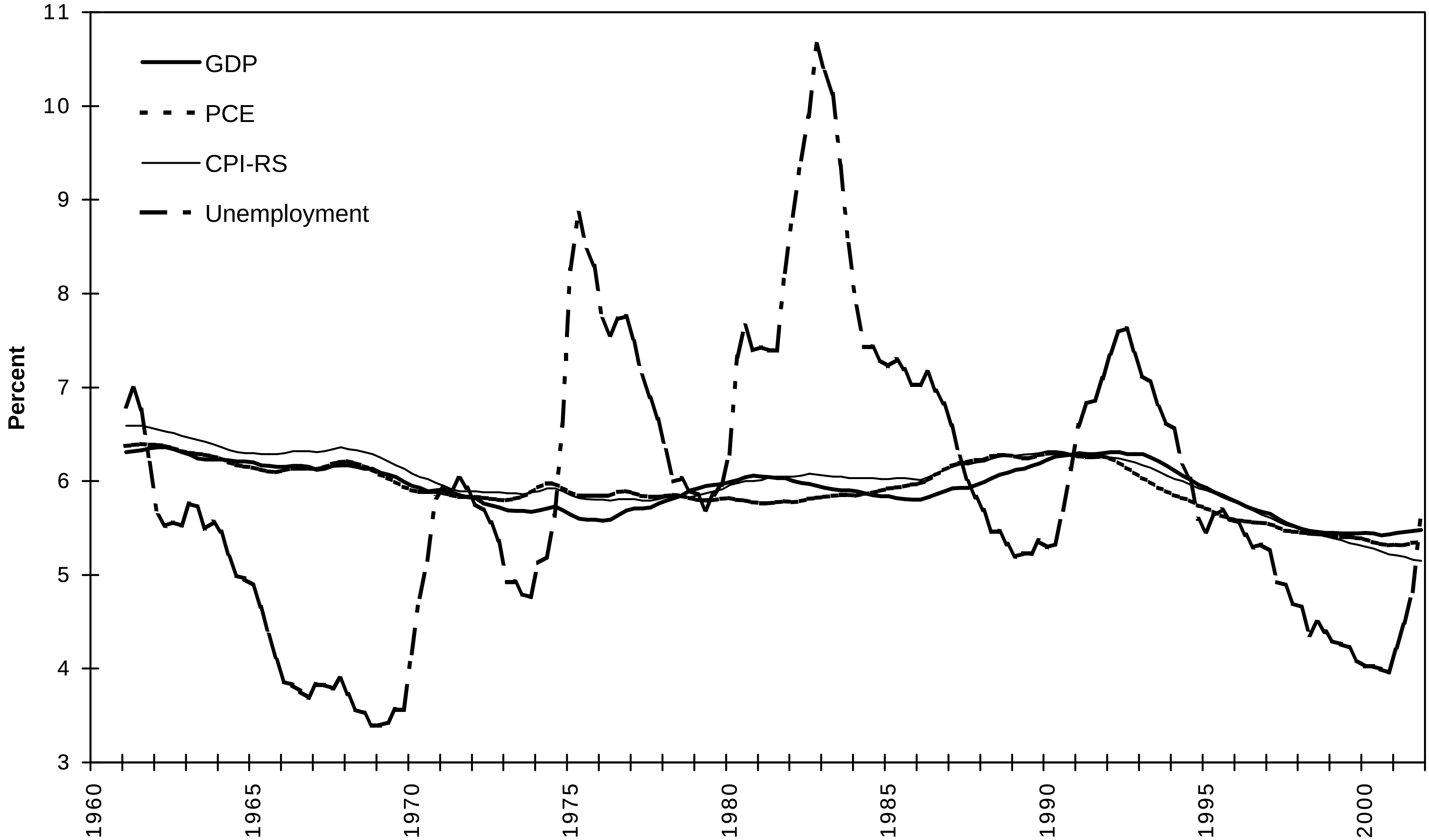

Figure 6
Time-Varying NAIRUs for GDP, PCE, CPI-RS, ECI-TC, and Compensation per hour, Original Specification, 1961-2001

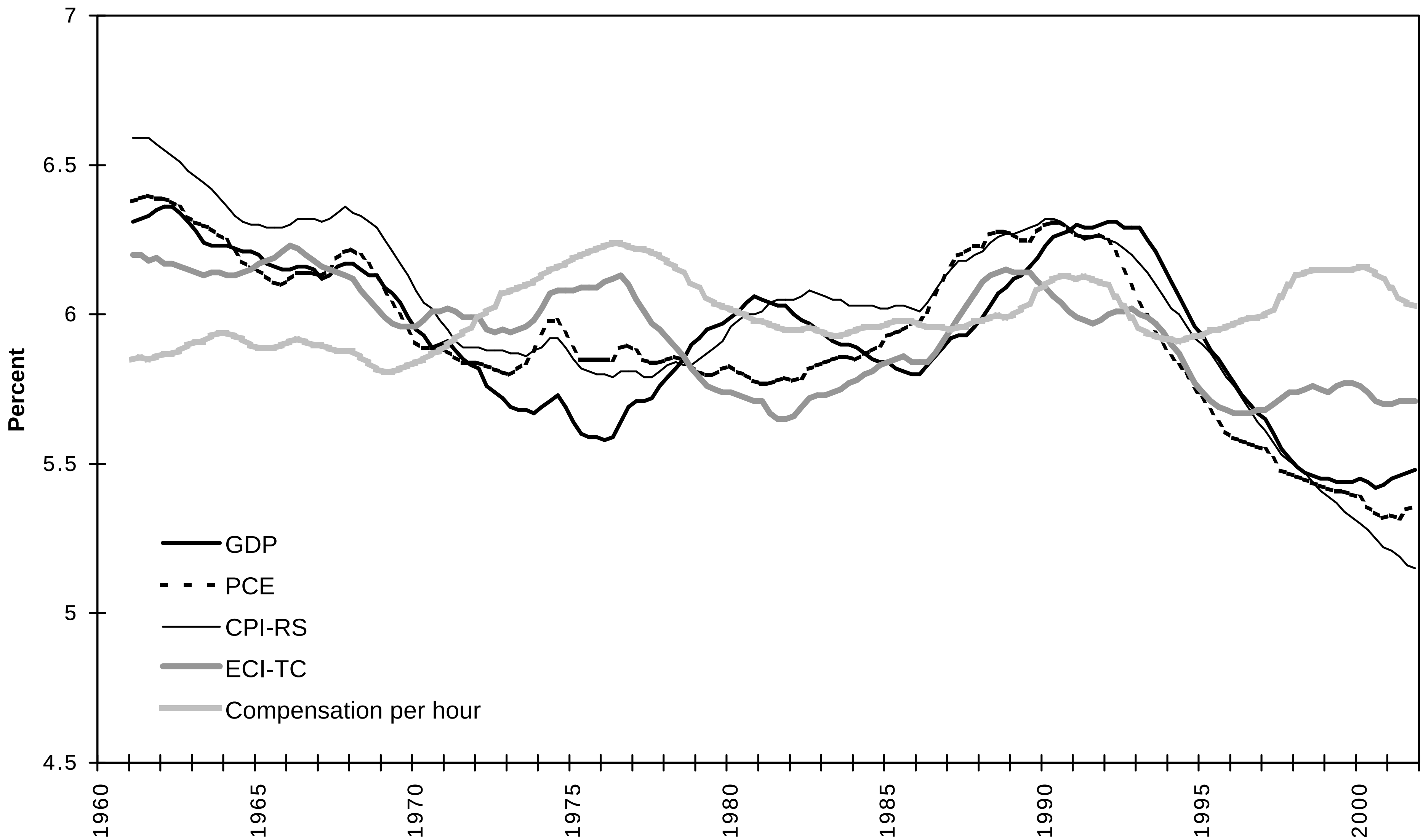

Figure 7. Time-Varying NAIRCUs for GDP, PCE, and CPI-RS, Original Specification, 1961-2001

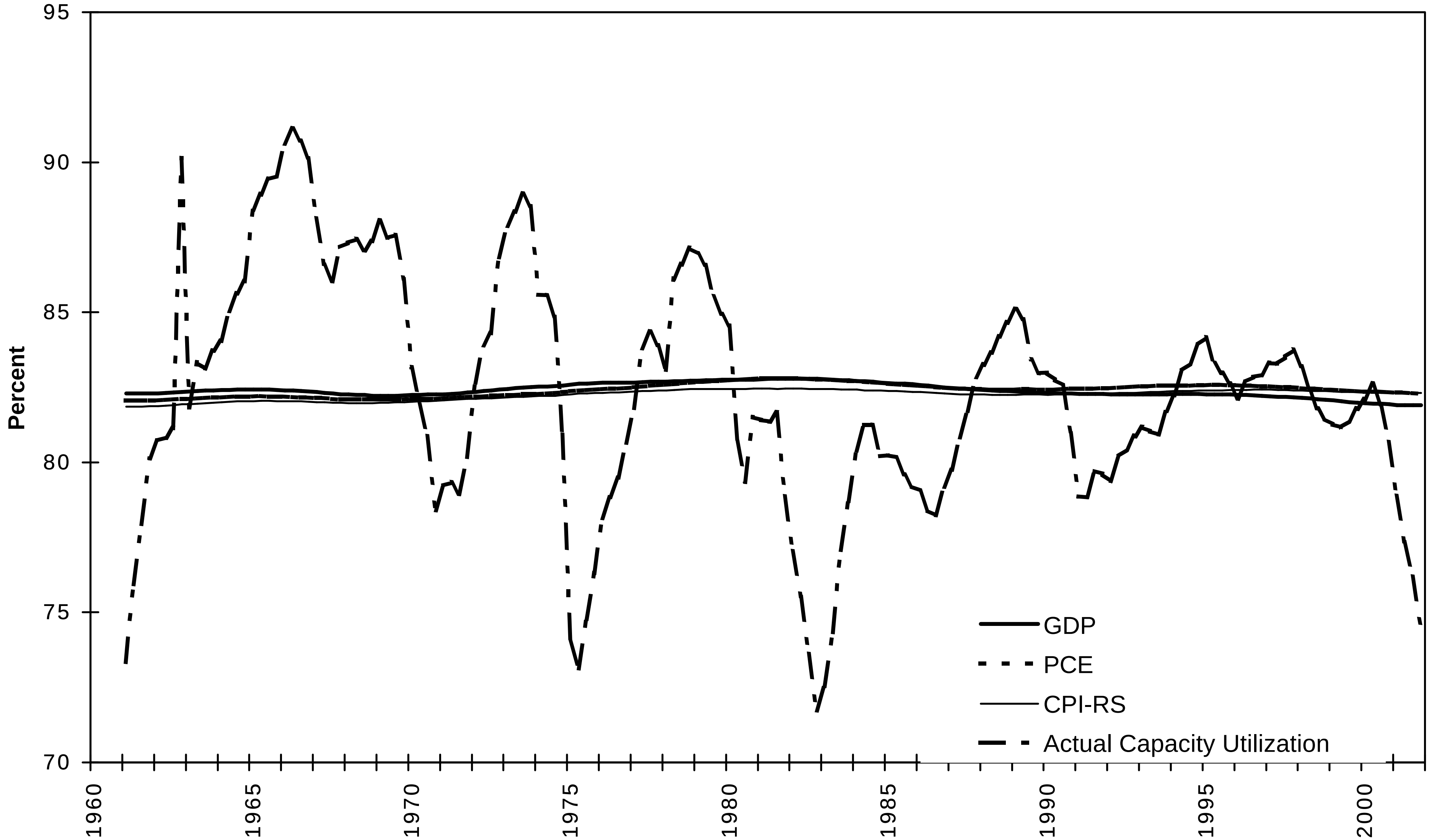

Figure 8. Actual and fitted values for GDP, four quarter moving average, 1962-2001, dotted line marks beginning of simulation

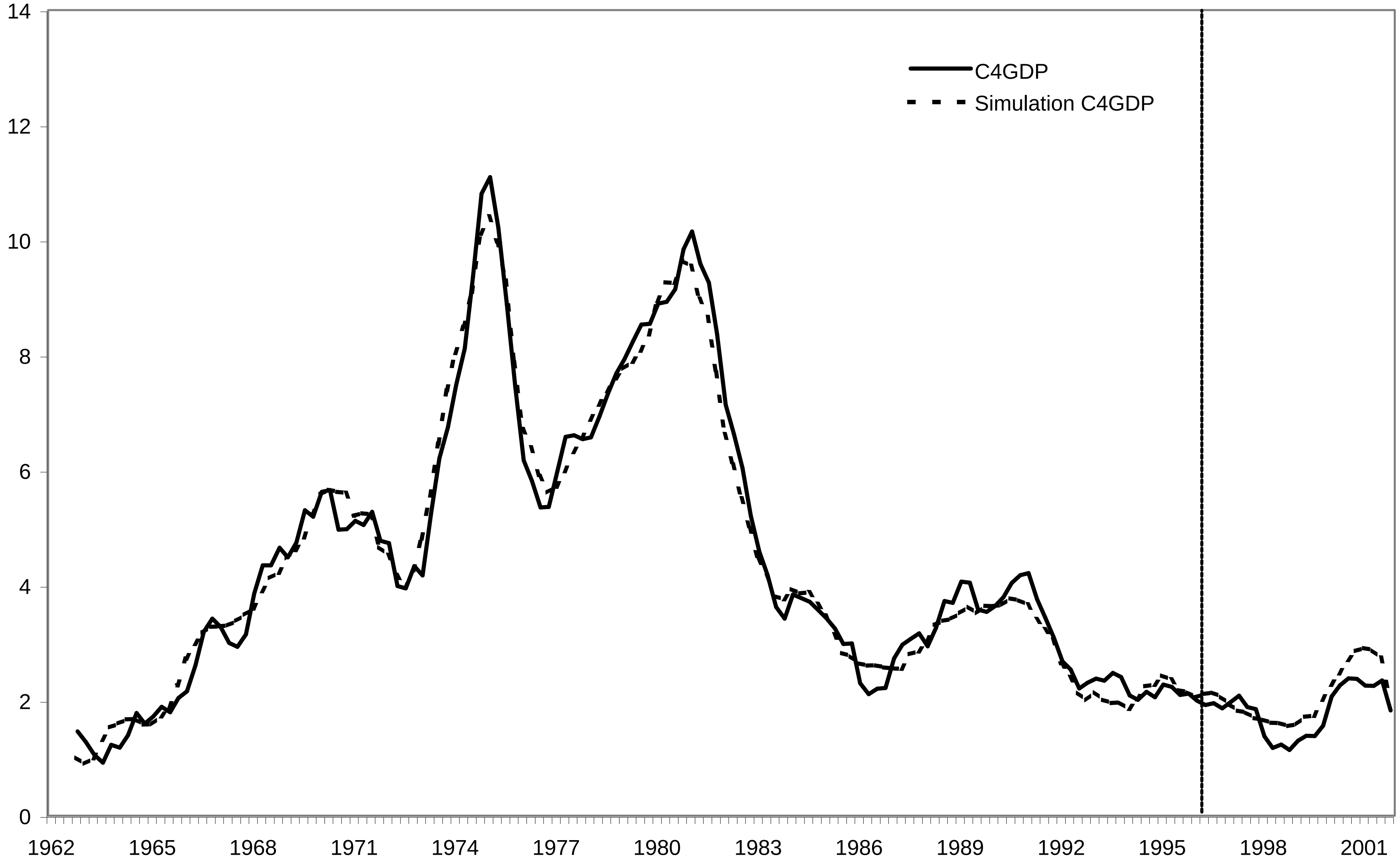

Figure 9. Actual SULC-TC and fitted values for SULC-TC, four quarter moving average, dotted line marks beginning of simulation