

## The Time-Varying NAIRU and its Implications for Economic Policy

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**T**he relationship between inflation and unemployment is central to the conduct of monetary policy. More than 35 years ago, Paul Samuelson and Robert Solow (1960) coined the term “Phillips curve” at the 1959 AEA meetings to describe that relationship, reacting to the publication of Phillips’s (1958) seminal article a year earlier. A few years later, Milton Friedman (1968) coined the term “natural rate of unemployment,” which more recently has come to be known by the acronym “NAIRU,” standing for the *Non-Accelerating Inflation Rate of Unemployment*. If a unique NAIRU exists, then the Phillips curve tradeoff is vertical at that unemployment rate. The Federal Reserve cannot make the actual unemployment rate differ from the NAIRU in the long run, but it can maintain a stable rate of inflation if it succeeds in setting the actual unemployment rate equal to the NAIRU. If instead of maintaining a stable rate of inflation, the Fed desires to reduce the inflation rate toward zero or some other target, then it needs to keep the actual unemployment rate above the NAIRU. Whether the goal is steady inflation or lower inflation, the Fed needs to know the value of the NAIRU.

For many years it was reasonable to assume that the NAIRU was 6.0 percent. I tested that assumption repeatedly by running dynamic simulations of regression equations that predicted the rate of inflation, using an assumed NAIRU of 6.0 percent and other explanatory variables with their lags. These simulations were dynamic, since the estimates for one time period then created the lagged values of the inflation rate needed for estimates of inflation in future time periods (that is, no information on the actual inflation rate was used for the period of the simulation). Such simulations

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were capable of tracking the inflation rate accurately for many years after the end of the regression sample period—for example, regressions using pre-1987 data could accurately predict inflation for the period 1987–1994 without any appreciable drift. Such postsample simulations provided evidence that the NAIRU had remained at 6.0 percent.<sup>1</sup> The substantial acceleration of inflation that occurred in 1988–89, when the unemployment rate fell below 6.0 percent for a period of three years, is consistent with the view that the NAIRU was at 6.0 percent or above as recently as 1988–89.

However, the NAIRU is not carved in stone. In Friedman's (1968) interpretation, the NAIRU is "ground out" by the set of "Walrasian" microeconomic relations in the economy, including the structure and institutions of product and labor markets, and these relations can change. Numerous factors have changed since 1988–89 in a way that may have reduced the NAIRU. Labor unions are weak, and their penetration in the labor force continues to decline. Manufacturers have been under intense pressure from consumers and foreign competitors to restrain price increases. The rest of the industrial world has experienced a sluggish recovery, and ample foreign capacity exists to provide supplies to U.S. manufacturers. Steady price declines in the computer and high-tech sectors are beginning to put downward pressure on the economywide inflation rate. Some business executives argue that the economy has changed drastically in the last 10 years; as General Electric's John F. Welch, Jr., recently stated (Stevenson, 1996): "There is no inflation . . . there is no pricing power at all."

The Fed also acts as if it accepts that the NAIRU can move. In early 1994, for example, the Fed implicitly believed that the NAIRU was around 6.0 percent and sharply raised short-term interest rates when it correctly predicted that the actual unemployment rate was about to fall below 6.0 percent. But for most of 1995 and early 1996, the Fed then allowed short-term interest rates to drift down slightly when inflation did not accelerate in response to an average unemployment rate well below 6.0 percent. The absence of an acceleration of inflation in 1995–96 suggests that the NAIRU may have fallen below 6.0 percent.

Has the NAIRU in fact declined? If so, from what level a decade ago to what level today? Surprisingly, macroeconomists have thus far provided no answer to this question that can be taken off the shelf by policymakers. In contrast to feverish research activity in the 1960s and 1970s, remarkably little research has been conducted on the U.S. inflation process in the past decade, so little that King and Watson (1994) comment on the "quiescence" of the field. The interpretation of the lack of attention to quantification of the inflation-unemployment tradeoff, and of the current value of the NAIRU, differs considerably among macroeconomists.

<sup>1</sup> The inflation equation was developed in a series of papers, including Gordon (1970, 1975, 1977a and 1982b). King and Watson (1994) have called this approach the "Gordon-Solow model," citing the first of my papers and Solow's 1969 book. To determine whether the inflation relationship has changed, I have maintained unchanged the set of variables, lag lengths and other features of the equation introduced in Gordon (1982b) and Gordon and King (1982). The most recent assessments of the performance of this equation are contained in Gordon (1990a, 1994).

Some have focused on other topics because they believe the U.S. inflation process is so stable, and the models developed in the early 1980s work so well, that there have been no behavioral mysteries to solve. Other macroeconomists have turned away because they believe that searching for a link between NAIRU and inflation has constituted a failed and unproductive line of research.

In the interpretation of King and Watson (1994, p. 160), many “Keynesian economists” have continued to view the Phillips curve as an essentially intact structural relation, once the original econometric models of the 1960s were amended “to represent supply shocks and build in a zero long-run tradeoff.” Once this task had been accomplished (as in Gordon, 1977a), there was no agenda warranting continued research, except periodically checking that the relation remained stable. Indeed, King and Watson (p. 160) note that indeed “the remarkable feature of the Phillips curve in the post war period was its *stability*.”

Across the street from the Keynesians are the neoclassical and monetarist economists. Some of them have dismissed the Phillips curve as “econometric failure on a grand scale” (Lucas and Sargent, 1978), since the long-run negative correlation between inflation and unemployment predicted by the models of the late 1960s contrasted with the distinctly positive correlation in the data of the 1970s. At that point, many neoclassical economists stopped paying attention to empirical work on the Phillips correlation and either did not notice or did not take seriously the new breed of post-1975 Phillips curve estimates that incorporated a vertical long-run tradeoff and included supply shock variables. Instead of taking inflation as the variable to be determined by their models, neoclassical economists turned to real theories of aggregate output fluctuations in which the behavior of inflation was neither explored nor explained. Implicitly, the price level was left as a residual—that is, as the level of nominal GDP (in turn often equal to the money supply plus a stochastic error term) divided by whatever level of real GDP was determined by the model. This treatment was the diametric opposite to that implied in the Phillips curve approach, in which an equation is specified to determine the inflation rate, while the growth rate of real GDP is implicitly a residual equal to the rate of nominal GDP growth minus the rate of inflation.

The NAIRU is meaningful only within a well-specified model of the inflation process. In the next section, I will describe the mainstream “triangle model” of the inflation process that incorporated and resurrected the Phillips curve from what Lucas and Sargent (1978) had called the “wreckage” of the 1960s and early 1970s. Then, instead of assuming a value for the NAIRU and testing the validity of that assumed value in dynamic simulations, this paper adapts an explicit econometric technique that allows a time-varying NAIRU to be estimated. We emerge with a set of alternative NAIRU estimates for the 1955–1996 period that differ only moderately from each other depending on which inflation index and sample period is used. I then use preferred versions of the inflation equation, together with alternative hypothetical paths for the actual unemployment rate, to simulate the inflation rate in future years. The paper concludes by examining implications for the past and future conduct of monetary policy.

Several important topics lie outside of the agenda of this paper. First, it is concerned with the U.S. inflation process and does not treat the quite different behavior of inflation and unemployment in Europe or Japan. Second, it estimates the time-varying NAIRU within the context of the “triangle” model of the inflation process developed in my previous work; it does not develop such a model from scratch. Third, it asks which unemployment rate should be the Fed’s target but does not inquire into the methods by which the Fed should attempt to accomplish that goal—that is, it does not study the channels of monetary policy that link changes in the short-term interest rate to subsequent lagged responses of output, income, employment and unemployment.

To preview the main conclusions, the alternative estimates all support the conclusion that the NAIRU has declined substantially since 1988–89, opening up the opportunity for the Fed to maintain a lower unemployment rate than was feasible then. As we shall see, the NAIRU has exhibited pronounced cycles over the postwar period, albeit within a surprisingly narrow range. Further, the consequences of a mistake by the Fed that reduces the actual unemployment rate a full percentage point below the NAIRU are surprisingly modest; the inflation rate accelerates by only 0.3 percent per year for every point that the actual unemployment rate remains below the NAIRU.

## The “Triangle” Model of Inflation

The “Phillips curve” has become a generic term for any relation 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. In the 1970s, the simple Phillips relation was amended by incorporating supply shocks and a zero long-run tradeoff.<sup>2</sup> What emerged was an interpretation of the Phillips curve that I call the “triangle” model of inflation—a label summarizing the dependence of the inflation rate on three basic determinants: inertia, demand and supply.

For example, a general specification of this framework would be

$$\pi_t = a(L)\pi_{t-1} + b(L)D_t + c(L)z_t + e_t.$$

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

Usually, this equation will include several lags of past inflation rates. If the sum

<sup>2</sup> Schultze (1975) and Gordon (1975) also introduced explicit variables to isolate the effect of food and energy prices and price controls on the U.S. inflation rate.

of the coefficients on these lagged inflation values equals unity, then there is a “natural rate” of the demand variable ( $D_t^N$ ) consistent with a constant rate of inflation.<sup>3</sup> While the 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.

Among the demand variables that have been entered as proxies for  $D_t$  are the “output gap,” defined as the log ratio of actual to natural (or potential) real GDP, the “unemployment gap,” defined as the difference between the actual and natural rate of unemployment (or NAIRU), and the rate of capacity utilization.<sup>4</sup> The 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 is allowed to vary over time. Using the unemployment rate as a predictor of inflation can be justified by findings like those of King and Watson (1994), who find that unemployment causes inflation in the Granger-causation sense, by preceding it in time.

Although the focus here is on using the unemployment gap to predict inflation, the ultimate exogenous demand factor in this model is “excess nominal GDP growth,” which is the extent to which growth of nominal GDP exceeds the growth of potential output. In turn, excess nominal GDP growth in any time period, together with the inflation rate calculated from the triangle model’s inflation equation, will determine the change in the output gap, which in turn will determine the change in the unemployment gap. By treating excess nominal GDP growth as exogenous, the triangle model focuses on the inflation process without the distraction of building a model of the determinants of aggregate demand. Admittedly, this simplification sweeps two-thirds of macroeconomics under the rug. Moreover, it ignores channels by which inflation feeds back into the determination of nominal GDP.

We are interested in estimating the NAIRU, which is the unemployment rate that is consistent with steady inflation. 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 that is consistent with steady inflation *in the absence of supply shocks*. To put it another way, if the inflation rate suddenly exhibits a “spike” that is entirely explained by the supply shock variables, then the “no-supply-shock” NAIRU measures the unemployment rate that *would be* compatible with steady

<sup>3</sup> The intuition behind this point may be clarified by considering the simple case where there is only one lag of inflation; then, obviously, a stable inflation rate means that the coefficient on the inflation rate in the previous period must be equal to 1. The same intuition holds more generally with several lags of inflation.

<sup>4</sup> “Okun’s Law” holds that the unemployment gap and the output gap are closely related. Consider an Okun’s Law equation relating the unemployment gap to current and lagged values of the log ratio of actual to natural real GDP:  $U_t - U_t^N = \theta(L)\log(Y_t/Y_t^N) + \epsilon_t$ . Empirically the sum of the  $\theta$  coefficients has been around  $-0.5$  for most of the postwar period, although in the 1990–95 subinterval that sum has been close to  $-1.0$ .

inflation in the absence of those supply shocks. Without this qualification, then 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.

The traditional Phillips curve specification of the 1960s and early 1970s included only lagged inflation and the unemployment rate, and omitted supply shocks. This created an obvious problem of omitted variables, since supply shocks can create an extraneous positive correlation between inflation and unemployment. Thus, the failure to include supply shocks means that unemployment explains a smaller share of the variation of the inflation rate; in fact, the coefficient on unemployment in such a regression will be biased toward zero and is likely to produce unreliable predictions in periods when supply shocks are absent. To the extent that supply shocks are included in the equation but are imperfectly measured, and there is contemporaneous feedback from inflation to nominal GDP, using the unemployment gap (or the output gap) as a proxy for the demand variable will yield a coefficient that is biased toward zero. The more accurately the influence of supply shocks is measured, the smaller the bias (Gordon, 1990b, Table 1, p. 1121).<sup>5</sup>

Inflation depends on both the level and change in the demand variable, whether the unemployment gap or the output gap is used as the demand variable.<sup>6</sup> 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. Time series equations that do not allow for the change effect, whether by entering it directly or by allowing the level of the gap to enter with one or more lags, are misspecified. The change effect is particularly important in explaining macroeconomic price behavior in the 1930s, a result that I have found previously and that Romer (1996) has recently validated.

Two final issues concerning the triangle model involve the role of wage changes and the role of expectations. After all, the original Phillips article was about the relation between wage changes and unemployment, and later formulations added a term for expected inflation. But the triangle model as summarized here has no expectations and no wages. These are issues of substantive significance.

The omission of expectations is deliberate. Much attention was diverted in the late 1960s and early 1970s to the interpretation of the lagged effect of prices on wages as reflecting adaptive lags in the formation of expectations. Since then, it has become clear that price and wage inertia is compatible with rational expectations. The speed of price adjustment and the speed of expectation formation are two different issues. Price adjustment can be delayed by wage and price contracts, and by the time needed for cost increases to percolate through the input-output table,

<sup>5</sup> Alternatively, estimates of the triangle-type inflation that use nominal GDP as a proxy for the demand ( $D_t$ ) variable will yield a coefficient on nominal GDP that is biased away from zero.

<sup>6</sup> I first noted the importance of the rate-of-change effect in Gordon (1977a, pp. 270–271).

and yet everyone can form expectations promptly and rationally based on full information about the aggregate price level. The role of the lagged inflation terms is to capture the dynamics of inertia, whether related to expectation formation, contracts, delivery lags or anything else.

The omission of wages in the triangle model is deliberate as well. The earlier fixation on wages was a mistake. The relation of prices to wages has changed over time; for example, labor's share in national income exhibits a strong upward movement between the mid-1960s and early 1970s that has not been adequately explained. The Fed's goal is to control inflation, not wage growth, and models with separate wage growth and price markup equations do not perform as well as the equation above, in which wages are only implicit.<sup>7</sup> By treating the relationship of inflation to unemployment, rather than of wage change to unemployment, the triangle approach returns to the framework of the original Samuelson and Solow article (1960) that coined the term "Phillips curve" and plotted U.S. data on the inflation-unemployment quadrant. The earliest credit for ignoring wages is claimed by Irving Fisher (1926 [1973]), whose neglected article discovered the Phillips curve in the form of a relationship between the unemployment rate and price changes, not wage changes.

## Implications of the Triangle Model

The triangle model generates several clear implications for how to think about inflation, unemployment and the relation between them.

First, in the long run, inflation is always and everywhere an excess nominal GDP phenomenon. Supply shocks will come and go. What remains to sustain long-run inflation is steady growth of nominal GDP in excess of the growth of natural or potential real output.

Second, supply shocks can cause a positive correlation between inflation and the unemployment gap. The observation that the Phillips curve correlation between inflation and unemployment was positive rather than negative in the 1970s is consistent with the triangle model, due to its explicit treatment of supply shocks such as the rise and eventual fall of oil prices.

Third, since supply shocks do influence the inflation rate, targeting the no-supply-shock NAIRU, or the equivalent level of natural or potential real GDP, will lead to difficulties. For example, in a decade like the 1970s with significant, serially correlated and adverse supply shocks, attempting to push unemployment down to a previously determined natural rate will lead to an acceleration in nominal GDP

<sup>7</sup> For a complete set of wage equations for both the United States and for Germany, using the same general specification as in this paper, see Franz and Gordon (1993). That paper determined that the U.S. wage NAIRU for 1990 was 6.2 percent, almost exactly the same as estimated in this paper for the GDP deflator by the time-varying approach described below.

growth as the central bank is forced to accommodate the inflation caused by the supply shocks, and hence it will lead to a permanent acceleration of inflation.

Fourth, growth in the money supply is not a unique cause of inflation. What matters is excess nominal GDP growth, which depends not just on the rate of monetary growth but also in the growth in the velocity of money. In a literal sense, the triangle model predicts inflation without using information on the money stock. In an economic sense, this implies that any long-term effect of money growth on inflation operates through channels that are captured by the real excess demand variables.

Fifth, in the short run, fluctuations in excess nominal GDP growth lead to clockwise loops on a diagram plotting the unemployment gap on the horizontal axis versus inflation on the vertical axis. For example, an increase in excess nominal GDP growth will first show up as a reduction in the unemployment gap, moving left on the diagram, and then in a rise in inflation, an upward movement. The loops come from inertia, the fact that because current inflation depends partly on past values of inflation, it will respond slowly to a change in the unemployment gap.

Sixth, the triangle model is resolutely Keynesian. Prices are prevented by inertia and by the finite Phillips curve adjustment coefficient from mimicking changes in nominal GDP growth. However, the triangle model does not incorporate the implication that King and Watson (1994) attribute to their “Keynesian” straw man that “unemployment is dominated by aggregate demand disturbances.” Instead, both demand and supply shocks influence both the inflation rate and the unemployment rate.

Seventh, since excess nominal demand is the ultimate cause of inflation, a sensible anti-inflation policy should target this variable in a direct way. One straightforward approach would be for monetary policy to target excess nominal GDP growth itself. Such a policy, advocated by a number of prominent economists, insures that the economy has a “nominal anchor” that prevents an acceleration of inflation and represents a compromise response to adverse supply shocks, which would then cause an increase in both unemployment and inflation rather than just in one or the other.

## **Validation of the Triangle Model**

The textbook version of the triangle model came first, and the econometrics and theory followed. A diagrammatic version of the model originated in a classroom handout that Rudiger Dornbusch developed at the Chicago Business School in early 1975. I laid out the basic equations in 1976, in a paper presented at the AEA meetings (Gordon, 1977b). The econometric version, developed in the late 1970s, was validated in 1981–87 when the “sacrifice ratio” experienced by the economy—that is, the percentage loss in output associated with the deceleration of inflation that occurred—corresponded almost exactly to what had been predicted in advance on



the basis of parameters estimated through the end of 1980.<sup>8</sup> Versions of the equation estimated through 1987 in postsample dynamic simulations tracked quite precisely the acceleration of inflation observed in 1987–1990 and the deceleration of inflation that occurred in 1990–93.

The positive performance of the triangle model stands in sharp contrast to the shambles in which the Phillips curve literature found itself in the mid-1970s. A central point of departure for Lucas's new classical revolution was the failure of the 1960s Phillips curve. In the language of Lucas and Sargent (1978, pp. 49–50), "[T]hat these predictions were wildly incorrect, and that the doctrine on which they were based is fundamentally flawed, are now simple matters of fact . . . the task which faces contemporary students of the business cycle [is] that of sorting through the wreckage . . . of that remarkable intellectual event called the Keynesian Revolution." The triangle model was in print in its present form before Lucas and Sargent wrote those lines; it has survived and thrived, while empirical attempts by Robert Barro (1978) and others to validate the new classical proposition of policy ineffectiveness have failed, running aground on the bedrock that inflation inertia exists, and markets do not clear quickly enough to avoid a substantial medium-run impact of nominal demand shocks on output and unemployment.<sup>9</sup>

## **Estimating a Time-Varying NAIRU**

For almost two decades, a time series for the NAIRU has been published in my macroeconomics textbook. The series starts with a NAIRU of a bit more than 5 percent in the late 1950s, and then it climbs very gradually through the 1960s and 1970s. My procedure, following Perry's (1970) innovation, was to use a demographic adjustment to the unemployment rate to reflect the rising share of teenagers and females in the labor force during that era. However, when I tested in the late 1980s to see whether the demographic changes of the 1980s (notably a reduced share of teenagers in the labor force) had reduced the NAIRU accordingly, I found that it had not (Gordon, 1990a). Without any justification other than its empirical performance, I arbitrarily set the textbook NAIRU equal to 6.0 percent for the entire period after 1978. The NAIRU series that combines the demographic adjustment through 1978 with an assumption that the NAIRU is constant at 6.0 percent thereafter is henceforth called the "textbook NAIRU series."

<sup>8</sup> Gordon and King (1982, Table 5) computed a sacrifice ratio of 6.2 from their econometric version of the triangle model. Using the data available at the time, the cumulative deviation of actual from potential output during the period 1980–87 was 26.2 percent, and inflation was reduced by 4.1 percentage points from 1979–1980 to 1985–86, for an actual sacrifice ratio of 6.4.

<sup>9</sup> Gordon (1982a) shows that the new classical policy ineffectiveness proposition can be nested in a general model of price adjustment and can be rejected in the presence of inflation inertia.

### The Basic Framework

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:

$$\pi_t = a(L)\pi_{t-1} + b(L)(U_t - U_t^N) + c(L)z_t + e_t$$

$$U_t^N = U_{t-1}^N + \epsilon_t$$

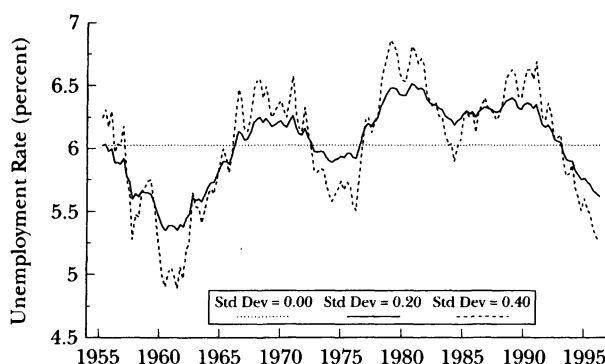
In this formulation, the error term  $\epsilon_t$  in the second equation is well behaved, with a mean of zero and a standard deviation of  $\sigma_\epsilon$ . When this standard deviation  $\sigma_\epsilon = 0$ , then the natural rate is constant. When the standard deviation  $\sigma_\epsilon$  is positive, 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. This model is a standard “stochastic time-varying parameter regression model” that can be estimated using maximum likelihood methods described by Hamilton (1994). The methodology was previously applied to the issue of the NAIRU, using a different specification of the inflation equation, by King, Stock and Watson (1995) and Staiger, Stock and Watson (1996).

The following are the key elements of the inflation equation. The sample period is 1955:2–1996:2, or 165 quarters. All right-hand-side variables are allowed to enter with lags.<sup>10</sup> Supply shock variables include changes in the relative price of imports and the change in the relative price of food and energy.<sup>11</sup> Dummy variables are included for the “on” and “off” effects of the Nixon price controls during 1971–75. These dummy variables, and indeed all the other variables, are defined exactly the same as in all my papers starting with Gordon (1982b). Also included as an explanatory variable is the difference between productivity growth and its trend, reflecting the fact that, while most of any cyclical increase or decrease in

<sup>10</sup> Lag lengths are chosen to be identical to those in Gordon (1990a). The only smoothing condition imposed on the lag distributions involves the lagged dependent variable, where 24 lagged terms enter. Rather than estimating 24 unconstrained coefficients, the lagged dependent variable is entered as a series of four-quarter moving averages of rates of change; for example, the first variable is a four-quarter average of lags  $t-1$  to  $t-4$ , the next  $t-5$  through  $t-9$ , and so on. The coefficients on the individual moving averages are unconstrained. Exclusion tests indicate that the moving averages representing lags 13 through 24 enter with a significance level of better than 1 percent in the three equations displayed in Table 1 and are thus highly significant. The coefficients on lags 13 through 24 represent 21 percent of the total lagged effect in the equation for the GDP deflator, 34 percent of the total effect for the PCE deflator, and 25 percent of the total effect for CPI-U-X1.

<sup>11</sup> The food-energy effect is defined as the difference of the rate of change of the chain-weighted consumption deflator minus the rate of change of the chain-weighted consumption deflator net of food and energy. Chain-weighted deflators are available back to 1959 and are linked to the implicit deflator prior to 1959. An additional supply shock variable, the change in sensitive raw materials prices, BCD series 99, was tested and found to be insignificant, with a  $t$ -ratio below 1. See Gordon (1994, footnote 7). Also, the change in the real effective exchange rate, included in previous papers, was found to be insignificant in all versions estimated for this paper and therefore is excluded in the results presented here.

Figure 1

**TV-NAIRU for GDP Deflator with Alternative Standard Deviations**

productivity is reflected in a movement in profits in the same direction, a small fraction remains to influence the inflation rate in the opposite direction.<sup>12</sup>

I calculate three alternative NAIRU series using three alternative price indexes. One is the chain-weighted GDP deflator, the basic deflator concept in the National Income and Product Accounts since early 1996. A second is the chain-weighted deflator for personal consumption expenditures (PCE). The third is the inflation rate of the Consumer Price Index concept called “CPI-U-X1.”<sup>13</sup> All three series exhibit the same basic cycles of acceleration and deceleration in the inflation rate. However, some differences exist. For example, in the supply shock episodes of 1974–75 and 1979–1981, the CPI inflation rate accelerates earliest and rises highest. On average, consumer price inflation was more rapid than GDP inflation from 1987 to 1994.

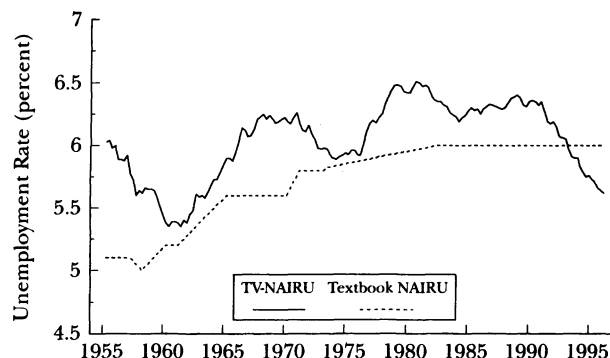
**The Smoothness Problem**

As indicated above, an assumption must be made about the size of the standard deviation of the error term in the equation for the NAIRU ( $\sigma_\epsilon$ ), and this choice will determine how much the NAIRU is allowed to move from quarter to quarter. An assumption of  $\sigma_\epsilon = 0$  implies a completely constant NAIRU series of 6.0 percent, as shown by the dotted horizontal line in Figure 1. At the other extreme, an assumption of  $\sigma_\epsilon = 0.4$  allows the NAIRU to be highly variable, as shown by the line with the long dashes in Figure 1. In between is a series drawn as a solid line based on an assumed

<sup>12</sup> The productivity deviation variable was first introduced in exactly the same form in Gordon (1970). The productivity deviation is defined as the growth rate of the log ratio of actual nonfarm private output per hour to a loglinear piecewise trend running through 1950:Q2, 1954:Q4, 1963:Q3, 1972:Q2, 1978:Q3, 1987:Q3 and 1994:Q3. The 1987–1994 growth rate of this trend is 1.07 percent per annum.

<sup>13</sup> The CPI-U-X1 is the same as the CPI for urban consumers, called “CPI-U,” except that it extends the post-1983 treatment of the CPI shelter component (based on rental equivalence) back to 1967 and thus eliminates the pre-1983 error in the treatment of housing in the conventional CPI that leads to a substantial exaggeration of the inflation rate, particularly during 1977–1981.

Figure 2

**Textbook NAIRU and TV-NAIRU for GDP Deflator***(standard deviation = 0.20)*

standard deviation of 0.2. Which of these (or other) possible assumptions about the standard deviation should we make?<sup>14</sup> The most sensible standard deviation may not be the same for every variable or topic. If the NAIRU is viewed, to paraphrase Friedman, as “ground out” by the microeconomic structure and behavior of the economy, then it should shift slowly. This is especially true since the concept of the NAIRU being estimated here is the unemployment rate consistent with steady inflation *in the absence of supply shocks*. From this view, the zig-zags in the series assuming a standard deviation of 0.4 appear implausible; why should the no-supply-shocks NAIRU jump up and down from quarter to quarter? In essence, I propose using a “smoothness” prior: the NAIRU can move around as much as it likes, subject to the qualification that sharp quarter-to-quarter zig-zags are ruled out.

As shown in Figure 1, a standard deviation ( $\sigma_e$ ) of 0.2 accomplishes this result, allowing a NAIRU series that exhibits substantial movements but just avoids sharp quarter-to-quarter zig-zags. It declines from 6.0 percent in the mid-1950s to a minimum of 5.3 percent around 1962, rises to a plateau of about 6.2 percent between 1967 and 1972, declines briefly between 1972 and 1975, then exhibits a hump of about 6.5 percent between 1978 and 1982, and then drifts down gradually to 5.6 percent by mid-1996.

Figure 2 compares our preferred time-varying NAIRU series based on a standard deviation of 0.2 with the textbook NAIRU series described above. The new series is substantially higher than the textbook series until the last three years, indicating that prior to 1993 the textbook series provided too optimistic a view of the economy’s ability to maintain a given unemployment rate without suffering the consequence of accelerating inflation.

<sup>14</sup> This problem is analogous to the choice of a smoothness parameter for the Hodrick-Prescott filter so often used to detrend time series variables.

Figure 3

Unemployment Gaps, Textbook NAIRU and Alternative TV-NAIRUs

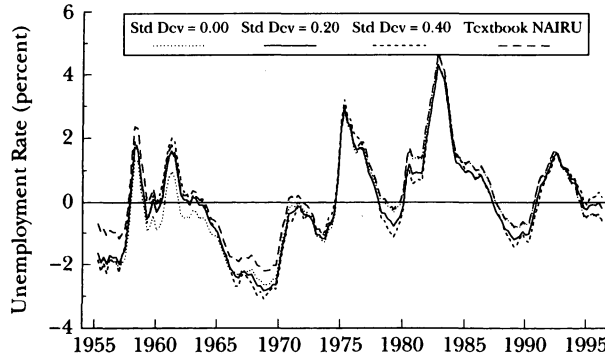
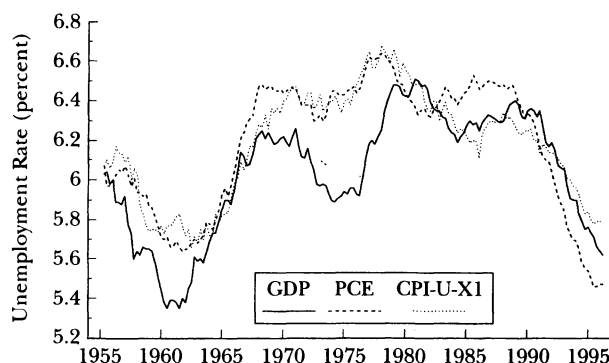


Figure 3 compares the unemployment gaps implied by the textbook NAIRU series in comparison with the various time-varying NAIRU series. We see that all the time-varying NAIRU series indicate substantially more excess demand than the textbook series in 1955–57, 1965–1970 and 1979–1980. For 1995–96, the time-varying NAIRU series corresponding to a standard deviation of 0.2 indicates somewhat less excess demand than the textbook series. I have previously argued that the behavior of inflation in the 1988–89 expansion and 1990–91 recession period was consistent with the textbook NAIRU assumption of 6.0 percent (Gordon, 1994). But Figures 2 and 3 show that the textbook NAIRU performs well after 1987 *simply because during that interval it happens to be quite close to the time-varying NAIRU*.

Staiger, Stock and Watson (1996, p. 2; this issue) have cast doubt on the enterprise of estimating the NAIRU, concluding that “a typical 95% confidence interval for the NAIRU in 1990 is 5.1 percent to 7.7 percent. . . . This imprecision suggests caution in using the NAIRU to guide monetary policy.” It is true that the different unemployment gap series displayed in Figure 3 look almost the same, are very highly correlated and result in inflation equations that fit about as well as each other. By standard statistical criteria, they cannot be distinguished from the other. However, the smoothness criterion proposed above is a way to cut through some of this ambiguity by using an economic rather than a statistical criterion to choose between alternative NAIRU series.

Staiger, Stock and Watson (this issue) argue that there are two sources of uncertainty in estimates of the NAIRU: uncertainty over the proper model (for example, the specification and the smoothness parameter) and then, given the proper model to estimate, uncertainty about the estimated parameters in the inflation equation. I consider only one “proper model,” one that has performed with remarkable reliability over the past 15 years, and ignore the issue of parameter uncertainty on the grounds that the parameters in this model have remained relatively stable over many years during which new data have accumulated.

*Figure 4***TV-NAIRUs for Alternative Price Indexes***(standard deviation = 0.20)***Estimated Equations and Implications**

To build some intuition about the results of regressions like these, consider some explicit findings presented in Figure 4 and in Table 1.

Figure 4 shows three estimates of the time-varying NAIRU, all assuming a standard deviation of 0.2 but based on three different price indexes: the GDP deflator, the PCE deflator and the CPI-U-X1. The time-varying NAIRU series for the PCE deflator and CPI-U-X1 are quite close to each other prior to 1980; the CPI-U-X1 series for the NAIRU is lower from 1980 to 1990 and higher after 1990. By mid-1996 a substantial gap had opened up between the NAIRU for CPI-U-X1 (5.8 percent) and for the PCE deflator (5.4 percent), with the NAIRU for the GDP deflator in between (5.6 percent). Prior to 1980, the NAIRU for the GDP deflator was generally lower than that for the two consumption price indexes, by as much as half a percentage point in the mid-1970s.

Table 1 presents the results of regressions that use the same three price indexes: the GDP and PCE deflators, and the CPI-U-X1. Estimated sums of coefficients on the inflation inertia variable are very close to unity, while those on the unemployment gap are always highly significant and of the correct sign.<sup>15</sup> The significance of the various supply variables differs, but with two exceptions of insignificant coefficients, they all have the correct sign. A one percentage point excess of productivity growth above trend reduces inflation by somewhat less than 0.1 percent. A one percentage point increase in the relative price of imports raises domestic GDP inflation by 0.09 percent, not far from the average share of imports in GDP during the sample period. About

<sup>15</sup> No constant is included. This is an essential element of the approach if the demand variable is defined as a deviation from the NAIRU, that is, the "unemployment gap"  $U_t - U_t^N$ .

Table 1

**Estimated Equations for Quarterly Change in Alternative Deflators,  
1955:2–1996:2**

<i>Variable</i>	<i>Lags</i>	<i>GDP</i> (1)	<i>PCE</i> (2)	<i>CPI-U-X1</i> (3)
ΔChain-Weight GDP deflator	1–24	1.01 <sup>b</sup>	1.01 <sup>b</sup>	1.01 <sup>b</sup>
Unemployment Gap	0–4	–0.61 <sup>b</sup>	–0.68 <sup>b</sup>	–0.58 <sup>b</sup>
ΔProductivity deviation	0–1	–0.07 <sup>a</sup>	–0.02	0.01
ΔRelative Import Price	1–4	0.09 <sup>b</sup>	0.14 <sup>b</sup>	0.05 <sup>a</sup>
ΔRelative Price Food-Energy	0–4	0.24	0.66 <sup>b</sup>	0.92 <sup>b</sup>
Nixon “on”	0	–1.65 <sup>b</sup>	–2.04 <sup>b</sup>	–2.41 <sup>b</sup>
Nixon “off”	0	1.97 <sup>b</sup>	–0.25	1.39 <sup>a</sup>
$\bar{R}^2$		0.87	0.89	0.90
S.E.E.		0.88	0.88	0.89
S.S.R.		109.5	109.6	110.5

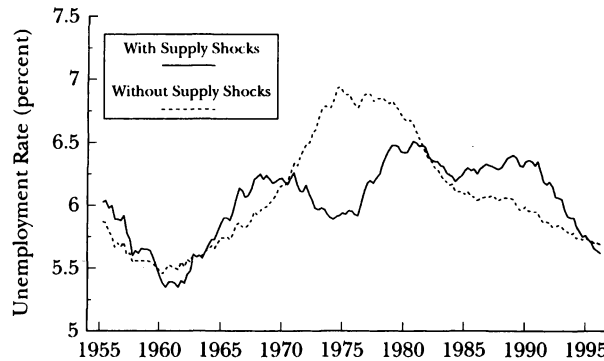
<sup>a</sup> Indicates that coefficient of sum of coefficients is significant at 5 percent level.

<sup>b</sup> Indicates that coefficient of sum of coefficients is significant at 1 percent level.

one-quarter of the food-energy relative price effect feeds through to inflation in the GDP deflator, two-thirds for the PCE deflator and more than 90 percent for CPI-U-X1. The Nixon “on” and “off” dummy variables continue to be essential elements in explaining the dynamics of price behavior during the 1971–75 period, although the “off” variable is small and insignificant in the PCE deflator equation. Taken as a group, the inclusion of the supply side variables makes a substantial difference, especially during the 1973–1981 period, which is influenced by adverse supply shocks. The estimates of the time-varying NAIRU would be much higher during those years if the contribution of the supply shock variables to inflation were to be ignored. This is shown in Figure 5, where the dashed line indicates the alternative NAIRU series that would be estimated if all supply shock variables (including the Nixon control variables) were excluded from the estimation. As shown there, it would have taken a much higher unemployment rate of about 7 percent during the last half of the 1970s to avoid an acceleration of inflation, whereas in the 1980s the alternative NAIRU would have been lower, reflecting the benign influence of falling real oil and import prices in pushing down the rate of inflation.

One way of exploring the stability and accuracy of results like these is to use the equations as the basis for dynamic simulations of particular historical periods. This process begins by estimating an alternative set of coefficients for a sample period beginning as before in 1955:2 but truncated in the third quarter of 1987, and then using these coefficients to form an estimate of inflation for the fourth quarter of 1987. Then, that estimate for 1987:4 is used in turn as a basis for forecasting the following quarter, and so on for the following decade, feeding back the *estimated* values of lagged inflation after 1987:3 rather than the actual values. Over the time period from 1987–1996, the root-mean-squared error of the simulation in

Figure 5

**GDP Deflator-Based TV-NAIRUs With and Without Supply Shocks**

forecasting the rate of inflation is 0.7 at an annual rate, actually smaller than the standard error of estimate of 0.9 percent (this presumably reflects the smaller variance of inflation during the simulation period than during the sample period). The mean error is about 0.25 percent at an annual rate, meaning that the actual inflation rate is on average one-quarter of a percentage point above the simulated inflation rate during 1987–1996. But in the last two years of the simulation (1994–96), the mean error is only 0.07 percent, indicating no “drift” in the simulated inflation rate away from the actual inflation rate over the near-decade duration of the simulation. The fact that it is possible to estimate inflation in 1994–96 based on pre-1987 data illustrates how stable the structure of the inflation process seems to have been during 1987–1996 from the perspective of the pre-1987 period.

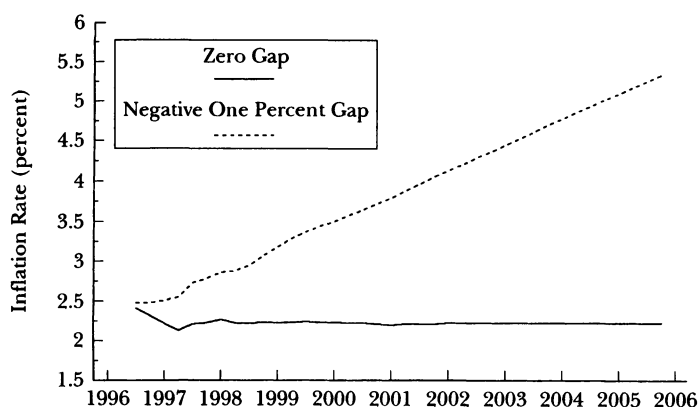
Recently, both Eisner (1996) and Akerlof, Dickens and Perry (1996) have suggested that the linear specification of the inflation equation is incorrect. Eisner argues that the Phillips curve is concave, that is, flatter when the unemployment rate is below the conventional NAIRU and steeper when the unemployment rate is above the conventional NAIRU. Akerlof, Dickens and Perry (1996) argue for the opposite nonlinearity, a convex Phillips curve that becomes much flatter when inflation is low and unemployment is above the conventional NAIRU. I have tested each possibility by allowing the coefficients on the unemployment gap to be different at low vs. high unemployment rates, or at low vs. high inflation rates. None of these differences is statistically significant, indicating that the short-run Phillips curve is resolutely linear, at least within the range of inflation and unemployment values observed over the 1955–1996 period.

Another set of concerns relates to the particular sample period chosen. For example, why should the Fed base its estimate of the current NAIRU on more than 40 years of previous data? Why is not the more recent past, say the last 20 years, a more relevant interval for which to estimate the inflation equation? Splitting the sample period at the first quarter of 1975 results in a sharp jump in the estimated NAIRU at



*Figure 6*

**Future Simulations, Four-Quarter Moving Averages of Inflation Rate**



the break point; the NAIRU for 1955–1974 is between 0.1 and 0.5 percentage points lower than the full-sample estimate, and the NAIRU for 1975–1996 ranges between 0.0 and 0.3 percentage points higher than the full-sample estimate. However, for the purposes of conducting current monetary policy, it is reassuring that the NAIRU estimate for the second quarter of 1996 is identical in the full-sample and split-sample alternatives. It is also true that a dynamic simulation for 1987–1996 based only on the data since 1975 predicts more accurately than the full-sample results in Table 1.

How rapidly would inflation accelerate if the Fed, either by accident or design, allowed unemployment to fall one percentage point below the NAIRU? To simplify, assume that no supply shocks occur. Figure 6 displays the results of two simulations. The first, which yields steady inflation at a rate of 2.2 percent, is based on the assumption that the unemployment gap remains at zero forever, beginning in 1996:3. The alternative simulation allows the gap to decline to  $-1.0$  percent in the five quarters beginning with 1996:3, and to remain at  $-1.0$  percent forever; this generates a slow acceleration of inflation that starts immediately and reaches 5.3 percent by the year 2005. The most notable aspect of this result is the slowness of the acceleration; after the year 2000 inflation accelerates by only 0.32 percent per year. The slow pace of this acceleration reflects the role of the lags in the effects of both inflation and the unemployment gap on the current rate of inflation.<sup>16</sup>

<sup>16</sup> Readers of earlier drafts questioned this result and assumed that in the long run the rate of inflation should accelerate by the sum of coefficients on the unemployment rate, for example, 0.61 for the GDP deflator. However, a bit of simple algebra shows that this assumption is correct only if the lagged inflation rate enters with a single annual lag. If there are two annual lags with equal weights, the long-run acceleration is the 0.61 coefficient divided by 1.5. With three annual lags, the divisor is 2.0. The simulated acceleration is an accurate reflection of the estimated coefficients on lagged inflation, which stretch out over six years.

## Conclusion

The inflation process in the United States is one of the most important macroeconomic phenomena in the world, but it is also one of the best understood. In contrast to the gyrations of inflation in many other countries, the U.S. inflation process is dominated by inertia. Inflation changes little from year to year, and any deviation of the actual unemployment rate from the NAIRU has only small consequences in the short run. The best recent example is the 1988–1990 period, when unemployment was on average about one percentage point below the 6.2 percent estimated NAIRU, and the GDP deflator accelerated over the three years 1987–1990 from 3.1 to 4.4 percent. This implies a response of inflation of a bit less than half a point per one percentage point that unemployment remains below the NAIRU for a single year. This is very similar to the pace of inflation's response to the –1 percent unemployment gap displayed in Figure 6.

Because the U.S. inflation process has been so stable, and is so well characterized by the triangle model of inflation developed in the late 1970s and early 1980s, that model has performed extremely well in dynamic postsample simulations extending out for up to a decade after the end of the sample period. In such simulations, the model has proven capable of tracking the disinflation of the early and mid-1980s, the acceleration of inflation of the late 1980s, and the subsequent deceleration of inflation in the 1990s. Those empirical successes were achieved despite the fact that in previous research, the NAIRU inserted into the model was assumed arbitrarily to be constant at 6.0 percent for the entire period after 1978 rather than estimated econometrically. The reason that my previous assumption that the NAIRU was fixed at 6.0 percent performed so well in tracking the acceleration and deceleration of that period seems to be that the estimated time-varying NAIRU was fairly close to 6.0 percent during the expansion of the late 1980s and recession of 1990–91.

What would it take to reject the hypothesis that there is a NAIRU and therefore a vertical long-run Phillips curve? Formally, an inflation equation with a sum of coefficients on lagged inflation of unity and a significant negative sum of coefficients on the unemployment gap validate the NAIRU concept. Less formally, wild gyrations of the estimated NAIRU over a range too wide to be explained by microeconomic changes in market structure and institutions would lead to skepticism about the NAIRU concept. Within the postwar experience of the United States, the modest fluctuations in the NAIRU seem plausible in magnitude and timing. When applied to Europe or to the United States in the Great Depression, however, fluctuations in the NAIRU seem too large to be plausible and seem mainly to mimic movements in the actual unemployment rate. This paper is about the postwar United States, for which the NAIRU hypothesis works very well, and simply leaves open for further research the deeper reasons why the hypothesis does not seem to characterize the U.S. Great Depression or the recent years of high unemployment in many European countries.

This paper rejects the recent argument that the band of statistical uncertainty surrounding the NAIRU is so broad as to render the concept useless for the conduct of policy. We propose an economic criterion based on smoothness, rather than a

statistical criterion, to choose among alternative NAIRU estimates for any given measure of inflation. The recent suggestion of Staiger, Stock and Watson (1996) that the NAIRU for the year 1990 could range from 5.1 to 7.7 percent makes no economic sense. If the NAIRU had been 5.1 percent since 1987, inflation would not have accelerated during 1987–1990, since the actual unemployment rate never fell below 5.1 percent in any calendar quarter. If the NAIRU had been 7.7 percent in the period since 1987, inflation would not have decelerated during 1990–93, since the actual unemployment rate never rose above 7.7 percent in any calendar quarter. The fact that the inflation rate for the GDP deflator was roughly constant during the six quarters from the end of 1994 to the beginning of 1996, when the actual unemployment rate was approximately constant at 5.6 percent, suggests that the time-varying NAIRU for the GDP deflator during those six quarters was very close to 5.6 percent (our point estimate for 1996:2).

What evaluation of past and current monetary policy is implied by this new research on the NAIRU? According to our new time-varying NAIRU measures, there was considerably more excess demand in 1955–57 and 1965–1970 than implied by the previous textbook NAIRU series (see Figure 3), suggesting that monetary policy was even more overly expansionary in those periods than was previously thought. The new time-varying NAIRU series also boosts modestly the extent of estimated excess demand in 1979–1980 and 1988–1990. However, the new series implies that monetary policy in 1995–96 has been almost precisely on target, with an average unemployment rate during the seven quarters 1994:4–1996:2 of 5.6 percent, only slightly below the average estimated time-varying NAIRU of 5.7 percent for the GDP deflator in that interval. If the Fed considers its goal as the stabilization of the rate of change of the PCE deflator rather than the GDP deflator, then the estimated average time-varying NAIRU during the same interval was 5.5 percent, implying that monetary policy was just slightly too restrictive in 1995–96.

The time-varying NAIRU by any measure has declined in the 1990s. This raises an issue of whether the Fed can run an easier monetary policy to encourage a faster expansion, with little fear of triggering inflation. The new time-varying NAIRU series allows a new series for potential output to be created, measuring the real GDP that can be produced each quarter when the economy is operating at the time-varying NAIRU. Since the time-varying NAIRU declined from about 6.2 percent in 1990 to 5.6 percent in mid-1996, this potential output series grows at about 0.1 percentage point per year faster (that is, 2.1 percent per annum rather than 2.0 percent) than would be implied by a NAIRU fixed at 6.0 percent.<sup>17</sup> Thus, caution is advised regarding

<sup>17</sup> As support for this statement, I have estimated an Okun's Law equation similar to that in note 4. In doing so, I invert the equation to regress the unknown output gap on current and leading values of the unemployment gap implied by the new TV-NAIRU series based on the GDP deflator and a standard deviation of 0.2. I allow the sum of coefficients on the unemployment gap to differ during 1990–96 from their values in 1972–1990. I calculate the fitted output gap, and then compute a trial value of potential output as actual real GDP minus the fitted output gap. The final potential output series is a 12-quarter centered moving average of the trial series.

the advice of “growth hawks” that the U.S. economy could grow at 3 percent or more per annum if only the Fed’s monetary policy were less restrictive. The decline in the NAIRU is not nearly enough to allow potential real output growth to take off from its present level of about 2 percent to 3 percent or higher. Moreover, the decline in NAIRU is a one-time event; it can make room for the economy to have faster noninflationary growth for a few years, but not in perpetuity.

If the Fed’s current deliberations about interest rate changes are intended to influence the actual unemployment rate roughly one year from now, should the Fed extrapolate the recent decline in the NAIRU into the future, or should the Fed set its estimate of the NAIRU one year hence equal to the current value? The time-varying NAIRU derived here is a random walk and thus is just as likely to increase over the subsequent year as to continue to decrease. There is no information about future inflation available beyond that contained in the lagged values of the explanatory variables in the inflation equation that are already used to derive the NAIRU.

While the time-varying NAIRU technique does not provide a magic crystal ball that allows the Fed to see into the future, it makes two valuable contributions to the conduct of monetary policy. First, it quantifies in a systematic way the Fed’s belief that the NAIRU must have fallen in the 1990s, because as of mid-1996, inflation had not accelerated as it did in 1988–1990. Second, it highlights the differences in the time-varying NAIRU series implied by alternative inflation indexes and forces the Fed to take a stand on what inflation concept it is trying to stabilize.

Estimated movements in the NAIRU over time naturally raise the question as to which factors caused these movements. The two especially large changes in the NAIRU, as shown in Figure 4 for all three alternative price indexes, are the increase between the early and late 1960s and the decrease in the 1990s. The late 1960s were a time of labor militancy, relatively strong unions, a relatively high minimum wage and a marked increase in labor’s share in national income. The 1990s have been a time of labor peace, relatively weak unions, a relatively low minimum wage and a slight decline in labor’s income share. Other factors that may have contributed to weaker demand and increased supply in product and labor markets include global competition and immigration of unskilled labor. A final factor that is beginning to play a significant role in lowering the NAIRU is the growing share of computer output in both GDP and personal consumption;<sup>18</sup> by mid-1996 the rapidly declining prices of computers were subtracting about half a percentage point from the growth rate of the deflators and roughly 0.4 percent from the time-varying NAIRUs estimated in this paper.

<sup>18</sup> In the year ending in 1996:2, the implicit deflator for business purchases of computers declined 23 percent and for consumer purchases of computers declined 35 percent. If one subtracts nominal and real computer output from both nominal and real GDP, one can calculate an alternative implicit deflator for the noncomputer part of the economy. In the four quarters ending in 1996:2, this rose 0.7 percentage points faster than the implicit deflator for all of GDP including computers. Using this alternative ex-computer implicit GDP deflator results in a NAIRU for 1996:2 of 6.0 percent rather than the 5.6 percent estimated in this paper. The same technique adds about 0.4 percent to the NAIRU estimated for the PCE deflator. Computers make no difference to the CPI-U-X1, which still uses obsolete 1982–84 expenditure weights for consumer purchases of computers and thus gives them close to a zero weight.

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