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REESTIMATING THE PHILLIPS CURVE AND THE NAIRU

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ABSTRACT

Recent research indicates that there have been fundamental changes in the way the economy works since the mid-1980s, including a reduction in the volatility of real GDP growth and lower rates of inflation and unemployment. Those changes have the potential to alter the inflation-unemployment tradeoff underlying the Phillips curve relationship and, consequently, the estimate of the NAIRU. This paper presents updated empirical estimates of the Philips curve and the NAIRU and explores the possibility that structural changes in the economy have shifted the underlying relationships. The empirical results suggest that the structure of the Phillips curve has changed during the past 20 or so years. Although full-sample regressions appear to be satisfactory, estimates that allow for the possibility of structural change in the equations suggest a much weaker relationship between inflation and unemployment during the past two decades compared to the early part of the sample. In addition, the results suggest that the level of the NAIRU has declined during the past 20 years.

As part of its annual report on the economic and budget outlook, CBO forecasts many macroeconomic variables, including inflation, the unemployment rate, and GDP growth. An important aspect of the economic forecast is the concept of the natural rate of unemployment, which is the rate of unemployment that corresponds to equilibrium in the labor market (meaning that there is no excess supply of or demand for labor at prevailing wages). CBO uses an estimate of the natural rate for three purposes in its economic forecast: as a guide for the projection of the unemployment rate in the medium term, as a benchmark for the estimate of potential GDP, and as an indicator for use in inflation forecasts.

The natural rate of unemployment is not observable and its somewhat broad definition—equilibrium in the labor market—makes it hard to estimate. Consequently, CBO uses a closely related concept, the nonaccelerating inflation rate of unemployment (NAIRU), which is defined as the rate of unemployment that is consistent with a stable rate of inflation. During business cycle booms, when the unemployment rate is below the level of the NAIRU, labor markets are tight and wage and price inflation tend to rise. During periods of low aggregate demand, when the unemployment rate is above the level of the NAIRU, there is slack in the labor market and inflation tends to fall.

CBO uses a relationship known as the Phillips curve to help forecast inflation and to estimate the NAIRU.[1] Phillips curves describe the observed negative correlation between unemployment and inflation: low rates of unemployment tend to be associated with high rates of inflation and vice versa. Regression equations based on the Phillips curve model changes in inflation as a function of the unemployment rate, among other factors. Such equations (and the NAIRU) performed well as indicators of inflationary pressure during the late 1980s and early 1990s, but failed during the late 1990s when very low rates of unemployment coexisted with low and stable inflation.

The poor forecasting performance of the Phillips curve during the late 1990s might be explained by structural change in the equation. There is evidence of significant changes in the functioning of the U.S. economy during the past 20 or so years. Most notably, the volatility of output growth and inflation has been much lower since the mid-1980s, a phenomenon often referred to as the Great Moderation. In addition, labor markets appear to be functioning differently, with a seeming decline in the natural rate of unemployment.

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1. CBO last described the equations used to estimate the NAIRU in 1994. See "Reestimating the NAIRU," Appendix B in Congressional Budget Office, *The Economic and Budget Outlook: An Update*, August 1994.

This paper reestimates CBO's version of the Phillips curve to determine whether it is still a useful concept for analyzing and forecasting inflation. It also explores the possibility of structural change in the Phillips curve regressions to determine whether the curve shifted during the past 20 or so years and whether the NAIRU declined during the same period.

Results of the empirical estimation reported in this paper suggest that the Phillips curve is a less useful tool for inflation forecasting than it once was. Although regressions using the full data sample (from 1955 through 2007) appear to be satisfactory, estimates that allow for the possibility of structural change in the equations suggest a much weaker relationship between inflation and unemployment during the past 20 or so years compared to the early part of the sample. Indeed, for the period since 1985, the fit of the equations is rather poor and the coefficients are generally smaller in magnitude and less statistically significant.

It's not clear, however, that the lack of significance during the latter part of the sample period indicates that the relationships identified using the early part of the sample no longer hold. Instead, it is possible that the lack of variation in inflation (and other macroeconomic variables) has made it harder for statistical techniques to pick up those effects.

Background

As part of its mandate, CBO is required to produce a macroeconomic forecast, which includes projections of such variables as inflation, unemployment, and GDP growth. An important input into those projections is an estimate of the natural rate of unemployment. Developed 40 years ago by Milton Friedman and Edmund Phelps, the natural rate of unemployment corresponds to equilibrium in the labor market.[2] That is, it is the rate of unemployment that obtains when the demand for labor and the supply of labor are in balance. However, it is not a zero rate of unemployment. Some workers will be unemployed even if there is no excess supply of, or excess demand for, labor.

The U.S. labor market is dynamic, with continual flows of workers into and out of the labor force as well as flows of workers into and out of employment. Business cycle fluctuations are clearly an important source of changes in the unemployment rate but there are other sources as well. Workers may become unemployed if they switch jobs in search of a better match between their skills and the requirements

2. See Milton Friedman, "The Role of Monetary Policy," *American Economic Review*, 1968. Edmund Phelps had the same insight independently; see Edmund Phelps, "Phillips Curves, Expectations of Inflation, and Optimal Inflation Over Time," *Economica*, 1967.

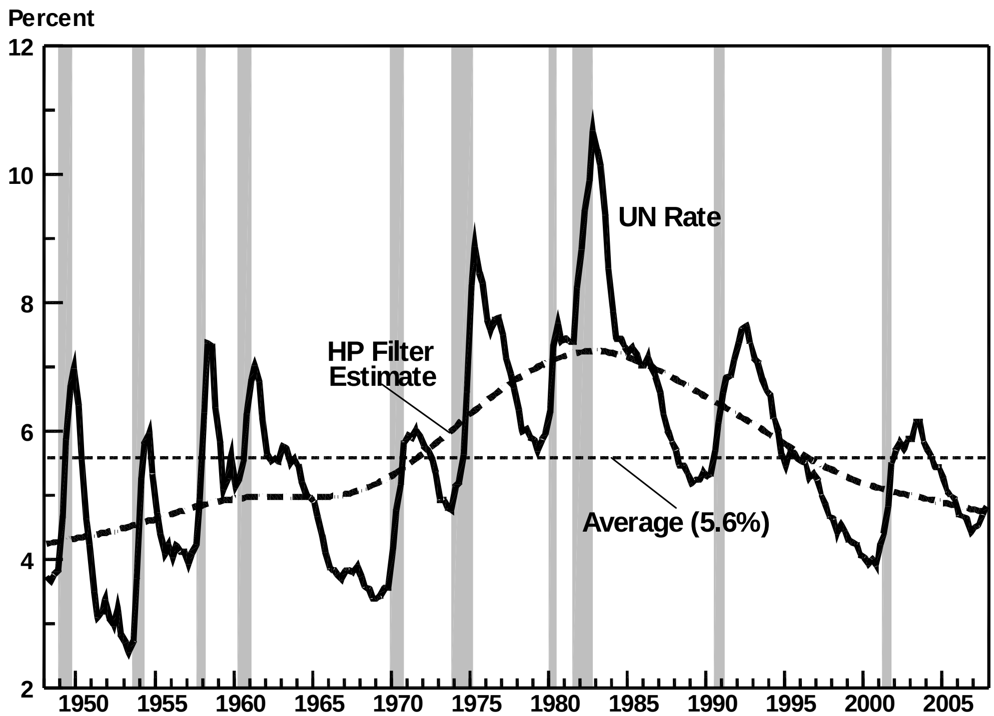
of a job, others may move from an industry in decline to an industry that is expanding, and still others may need to change jobs because they've moved to a new city. In each case, workers may be unemployed for a while as they search for a new job. Consequently, at any given time, some workers will not have jobs and some jobs will be vacant even if the aggregate labor market is roughly in balance. The natural rate of unemployment depends in part on the rate at which vacancies and unemployment simultaneously occur as a result of the microlevel decisions made by individual people and businesses.

In general, a higher rate of structural change or turnover in the economy is associated with a higher natural rate of unemployment. The rate of structural change in the economy is largely determined by the rate of technological change, but it is also influenced by other factors such as openness to international trade, changes in the degree of monopoly power in various industries, and the degree of government regulation. The rate of turnover is primarily determined by the demographic composition of the labor force, especially the proportion of younger workers. These workers typically have higher rates of frictional unemployment, so an increase in the youth share of the labor force is often associated with a higher natural rate of unemployment.[3] The efficiency of the labor market, or the rate at which vacancies are filled, also influences the natural rate of unemployment. If the process of matching job seekers and job openings becomes more efficient, then the natural rate of unemployment is likely to fall.

Economists know about the factors that underlie the natural rate and can make predictions about how it will be affected by changes in different aspects of the labor market, but estimating the level of the natural rate is more difficult. Most simply, one might use a long-run average rate of unemployment as an estimate of the natural rate (see Figure 1). While easy to calculate, this has the clear disadvantage of ignoring specific changes to the natural rate—in practical terms, it would miss the recent developments that may have reduced the natural rate. Alternatively, one could use some sort of interpolation procedure (e.g., connecting points at the mid-points or peaks of business cycles) or a statistical filter (e.g., the Hodrick-Prescott filter or a centered moving average). These would get closer but would still be devoid of economic content, so they wouldn't be able to help predict future movements in the natural rate.

3. Frictional unemployment arises when workers are unemployed temporarily as they search for a job—for example, when a student enters the labor market for the first time, when a person reenters the labor market, or when someone leaves a job to find a new position that is a better match for their skills and interests.

Figure 1. The Unemployment Rate and Estimates of Its Trend, 1948–2007



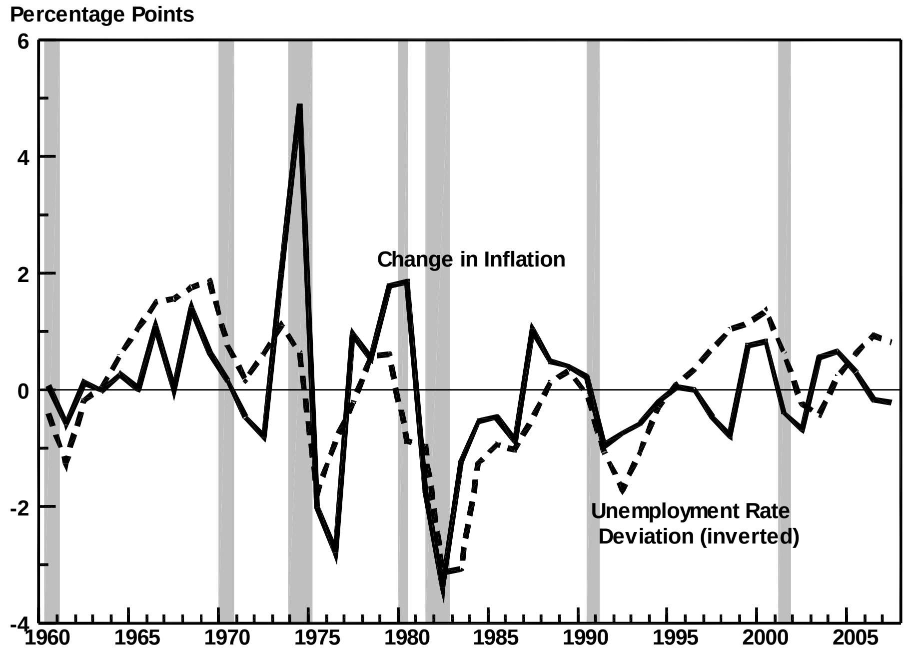
Notes: UN Rate is the civilian rate of unemployment, published by the Bureau of Labor Statistics.

The HP Filter estimate is calculated by applying the Hodrick-Prescott filter to the unemployment rate using a smoothing parameter of 100,000.

The shaded vertical bars on the graphs in this paper indicate periods of recession.

The natural rate of unemployment is closely related to another measure called the nonaccelerating inflation rate of unemployment (NAIRU), which is the rate of unemployment that is consistent with a constant rate of inflation. Although it doesn't relate explicitly to equilibrium in the labor market, the NAIRU is a description of how the economy behaves out of equilibrium. In general, faster economic growth eventually leads to more intensive use of resources (including labor) and thus tighter markets and higher wages and prices. As a consequence, the unemployment rate declines and inflation tends to rise, all else being equal. During recessions, the opposite occurs: slack demand leads to underused resources and less upward pressure on wages and prices. This relationship between inflation and unemployment can be used to provide an estimate of the NAIRU using statistical analysis.

Figure 2. The Unemployment Rate Deviation and the Change in Inflation, 1960–2007



Notes: Change in inflation equals the first difference of annual rate of inflation in the Personal Consumption Expenditure (PCE) price index.

The unemployment rate deviation equals the difference between the married-male unemployment rate and its average during the 1960–2007 period. The unemployment deviation is inverted to better show the correlation with inflation.

One commonly used method is to estimate a Phillips curve, which is an equation that relates the rate of inflation to some measure of aggregate demand, usually the unemployment rate.[4] At root, a Phillips curve follows from the idea that there is a correlation (or tradeoff) between the rates of inflation and unemployment in the short run (see Figure 2). A very simple version of such an equation would be:

4. The original Phillips curve, published in 1958, documented an inverse relationship between wage inflation and unemployment using data from the United Kingdom. Subsequent research has shown that the same relationship holds for price inflation and most empirical investigations of the Phillips curve use price-based equations. See A. W. Phillips, "The Relation Between Unemployment and the Rate of Change of Money Wage Rates in the United Kingdom, 1861-1957," *Economica*, Vol. 25, No. 100 (November 1958), pp. 283-299. This paper uses the married-male unemployment rate because it is better insulated from shifts in the demographic composition of the labor force than is the overall unemployment rate.

(1) $\pi_t - \pi_{t-1}$ = Constant + [$\alpha \bullet UN_t$]

Where π = the rate of inflation, and
UN_t = unemployment rate at time t.

If one were to estimate this equation using regression analysis, one would expect the parameter, α, to be negative if there were a negative correlation between inflation and the unemployment rate. That is, the rate of inflation would tend to rise when the unemployment rate is low and fall when the unemployment rate is high. If this is true, then there must be a rate of unemployment at which there is no tendency for inflation to rise or fall. That's not to say that the rate is stable or that it is precisely estimated, just that it must exist.

The correlation between inflation and the unemployment rate is illustrated in Figure 3, which plots a measure of unanticipated inflation against the married-male unemployment rate. Unanticipated inflation is measured as the growth in the price index for personal consumption expenditures (PCE) minus a 24-quarter moving average of PCE inflation and the data span the period 1953 through 2007. A negative relationship is immediately apparent (the slope of the regression line equals –0.88), though the relationship is noisy—high unemployment rates are associated with declines in inflation, but there are several instances with high unemployment and rising inflation. Clearly this relationship doesn't capture all of the factors that drive changes in inflation.

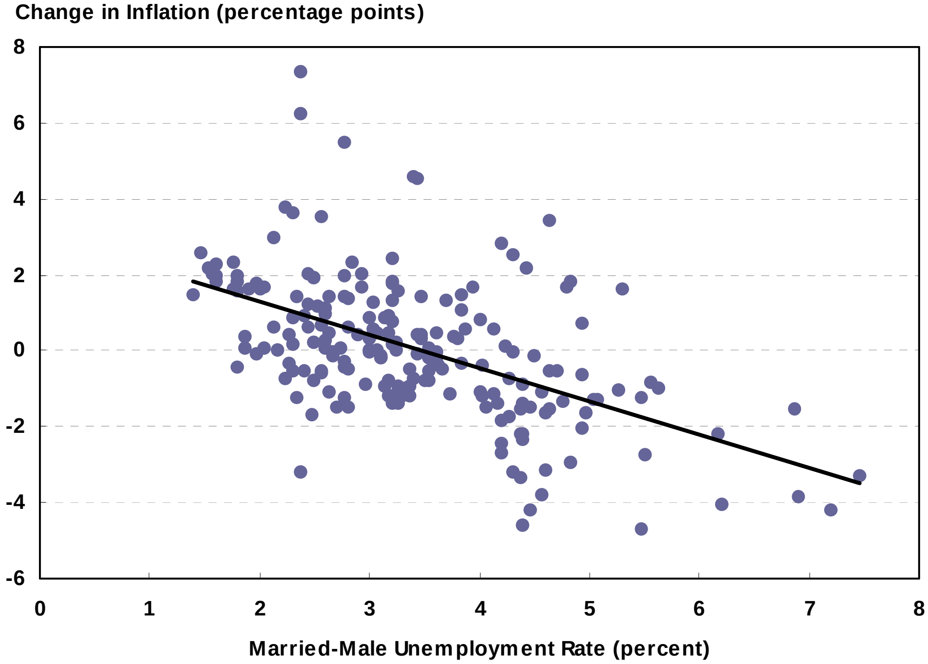
Using the estimated coefficients (α and the constant) from equation (1), it is possible to compute an estimate of the NAIRU. Since the NAIRU is defined as the rate of unemployment that is consistent with a stable rate of inflation, set $\Delta\pi = 0$ in equation (1) and solve for UN. Doing so yields

(1') $UN^* = -(\text{Constant}/\alpha)$

Where UN^* = NAIRU.

In Figure 3, for example, the estimate of the NAIRU for married males is 3.48 percent, which corresponds to the point where the regression line intersects the horizontal axis. Although equation (1) is an effective way to demonstrate the method used to calculate the NAIRU, it is too simple to use as the basis of a NAIRU estimate or to forecast inflation because it is missing many other factors that influence inflation. In particular, it ignores the role of expectations. As a result, it will not be a stable relationship, which Friedman and Phelps pointed out during the late 1960s.

Figure 3. The Married-Male Unemployment Rate and the Change in Inflation, 1953–2007



Note: The change in inflation is defined as the difference between the quarterly rate of inflation in the Personal Consumption Expenditure (PCE) price index and a 24-quarter moving average of PCE inflation.

Friedman and Phelps found that equation (1) described a short-run relationship: if, for example, government policy attempted to keep the unemployment rate below the natural rate then inflation would rise, as implied by equation (1). However, as companies and workers came to expect a higher rate of inflation, the relationship expressed in equation (1) would break down and the new higher expected rate of inflation would become associated with the natural rate. Consequently, to get to the old lower unemployment rate, further policy actions would be required, causing an even higher rate of inflation. Indeed, this is exactly what happened during the 1970s. And partly as a result, economists came to see that the tradeoff was not stable and that holding the unemployment rate below the natural rate would lead to ever increasing inflation. This insight was termed the accelerationist hypothesis because steadily increasing inflation implies accelerating growth in the price level.

An implication of this hypothesis is that the tradeoff between inflation and unemployment exists only in the short run. Workers' and employers' expectations of inflation tend to lag behind changes in actual inflation, so an unanticipated increase in aggregate demand can temporarily boost real wages and employment but will ultimately result in higher inflation as people's expectations adjust. Therefore, in the long run, the only way to keep inflation stable is to keep the unemployment rate at its natural rate.[5]

Another legacy of the 1970s was the realization that supply shocks can affect the inflation-unemployment tradeoff. Supply shocks are unexpected exogenous changes in the level of aggregate supply (at a given price level) in the economy; examples of such shocks include economywide strikes, wage and price controls, spikes in energy prices, and changes in the productivity trend.[6] A negative supply shock would increase the level of inflation at any level of aggregate demand and confound the statistical relationship estimated in equation (1). During the 1970s, the economy was buffeted by large increases in the price of energy and a decline in the trend rate of productivity growth, both of which affected equation (1).

Adding variables that reflect the influence of expectations and supply shocks on inflation to equation (1) yields

$$(2) \qquad \pi_t = \text{Constant} + E(\pi_t) - [\alpha \, UN_t] + \beta \, Z_t + \text{error}$$

where $E(\pi)$ = expected inflation, and
Z = a list of supply shocks.

This equation highlights the importance of expectations and the impact of supply shocks and of aggregate demand.[7]

A more common approach uses lagged values of inflation as a proxy for inflation expectations and includes lagged values of the unemployment rate:

$$(3) \qquad \pi_t = \text{Constant} + \Sigma\beta_i \, \pi_{t-i} + \Sigma\alpha_j \, UN_{t-j} + \beta \, Z_t + \text{error}$$

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5. For further discussion of the mechanism by which a policy-driven increase in aggregate demand can raise real GDP growth in the short run, see Jeffrey Lacker and John Weinberg, "Inflation and Unemployment: A Layperson's Guide to the Phillips Curve," Federal Reserve Bank of Richmond, *2006 Annual Report*, p. 6.

6. It might not be immediately clear why changes in energy prices, which are actually changes in relative prices, should affect inflation, which is a sustained increase in the general level of prices. But energy is (or was) a large enough component of firms' costs that an increase can have an effect on aggregate supply. During recent years, the impact of energy prices on inflation appears to have diminished. See Congressional Budget Office, *The Economic Effects of Recent Increases in Energy Prices,* July 2006.

7. This framework, known as the triangle model, has been used by Robert Gordon since the early 1980s. See Robert Gordon, "Phillips Curve Specification And the Decline in U.S. Output and Inflation Volatility," draft of paper presented at Symposium on The Phillips Curve and the Natural Rate of Unemployment, Institut für Weltwirtschaft, Kiel, Germany, June 2007, and the papers cited within. For another derivation, see Jeremy Rudd and Karl Whelan, "Modeling Inflation Dynamics: A Critical Review of Recent Research," *Journal of Money, Credit and Banking,* Vol. 39 (s1), 2007, pp. 155-170.

Two observations on equation (3) are necessary. First, in order for a unique NAIRU to exist, the sum of the coefficients on the lagged inflation terms must sum exactly to 1. That restriction is generally supported by the data and is discussed further in the section below describing the explanatory variables. Second, the supply shock variables in equation (3) are generally defined such that they equal zero when shocks are absent and so they drop out of the equation for the NAIRU:

$$(3') \qquad UN^* = -(\text{Constant}/\Sigma\alpha_j)$$

Equation (3') yields an estimate of the NAIRU that is constant through time. However, the discussion above and the data displayed in Figure 1 strongly suggest that the NAIRU has declined during the past 20 or so years. Opening up the NAIRU estimate to the possibility of structural change is discussed below.

Measures of Price and Wage Inflation

There are several choices for the dependent variable in the Phillips curve equation. First, should it be the change in prices or the change in wages (or labor compensation)? Good arguments can be made for both. Wages are a natural choice because they are most closely related to the degree of tightness in the labor market. Indeed, the original Phillips curve was specified using unemployment and nominal wages. One problem with estimating a wage-based equation is that one must also specify a markup equation that can forecast inflation based on the forecast of labor compensation. Since the relationship between compensation and prices can shift, a good forecast of the former does not necessarily imply a good forecast of the latter.

Because one of CBO’s goals is to forecast inflation, using price inflation as the dependent variable is also logical choice. Although the equation will be used to estimate the NAIRU, our concern is to forecast inflation, not to characterize the wage- and price-setting process. To that end, the unemployment rate is a convenient proxy for the state of aggregate demand. In addition, researchers have generally found more success estimating price-based Phillips curves than wage-based equations. Ultimately, though, it will be an empirical question and this paper presents estimates with both labor compensation and prices on the left-hand-side of the equation.

Second, there are several possible measures of prices and compensation to use in the equation. For prices, there is a choice between an overall price index like the GDP price index and an index of consumer prices such as the CPI-U or the PCE price index. The GDP price index gives the broadest possible measure of inflation, but it includes the prices of many goods and services that are not part of a typical consumption basket, including for example the price of government services. Alternatively, one could use a "core" measure of inflation; such measures are thought to give a better representation of the underlying inflation trend because they remove the volatile food and energy components from the calculation. In addition, they are thought to better reflect the influence of changes in domestic demand because they exclude commodities whose prices are set largely by worldwide demand. Core measures exist for the CPI-U and for the PCE and GDP price indexes.

For compensation, the main choice is between the Employment Cost Index (ECI) and the hourly compensation measure for the nonfarm business (NFB) sector. The ECI is a purer measure of wage inflation because it is insulated from the effects of changes in composition—that is, changes in the growth of overall compensation that arise from shifts of employment from industries or jobs with low pay levels to those with higher pay (or vice versa). The advantages of the hourly NFB compensation measure are that it is available for a longer time span and it is closely related to unit labor costs, a key indicator of overall inflation.

This paper presents results from equations using five measures of wage and price inflation: the GDP price index, the PCE price index (both overall and core), the ECI compensation measure, and compensation per hour in the NFB sector. Details on the sources of all data series used in this paper are presented in Appendix I.

<u>Discussion of the Explanatory Variables</u>

The generic Phillips curve in equation (3) includes variables that measure expected inflation and the state of aggregate demand, and that control for the effects of shocks to aggregate supply. As with the dependent variable, there are several approaches for measuring these concepts.

Expected Inflation. Economic theory suggests that expected inflation belongs in the Phillips curve equation, but since workers' and consumers' expectations of inflation are unobservable, empirical researchers must use a proxy. Surveys of inflation expectations are available, but they have proven unsatisfactory when used to forecast future inflation. An alternative is to use a model-based approach in which a price equation is specified in a first stage and its predictions are used as expected inflation in a second-stage estimate of equation (3). However, empirical support for such an approach is weak. Instead, researchers have found that expectations of future prices are not important in explaining the behavior of inflation but that past inflation is empirically important.[8] This importance could be due to the way agents form their expectations or to lags in the speed of price adjustment resulting from the existence of wage contracts and other frictions in the wage- and price-setting process.

Researchers typically include several lagged values of inflation in their equations to proxy for expected inflation as well as, in some cases, very long lags on past inflation (on the order of 3 to 6 years). In addition, researchers must impose a constraint implied by the Friedman-Phelps accelerationist hypothesis: that the sum of the coefficients on lagged inflation sum to 1. Failure to impose this constraint would imply that changes in the rate of inflation are not fully reflected in the estimate of expected inflation, even in the long run, and would result in a long-run tradeoff between inflation and unemployment. Since past empirical studies have soundly rejected the existence of the long-run tradeoff and have supported the assumption that the coefficients on lagged inflation sum to 1, this assumption is imposed in each of the specifications described below.

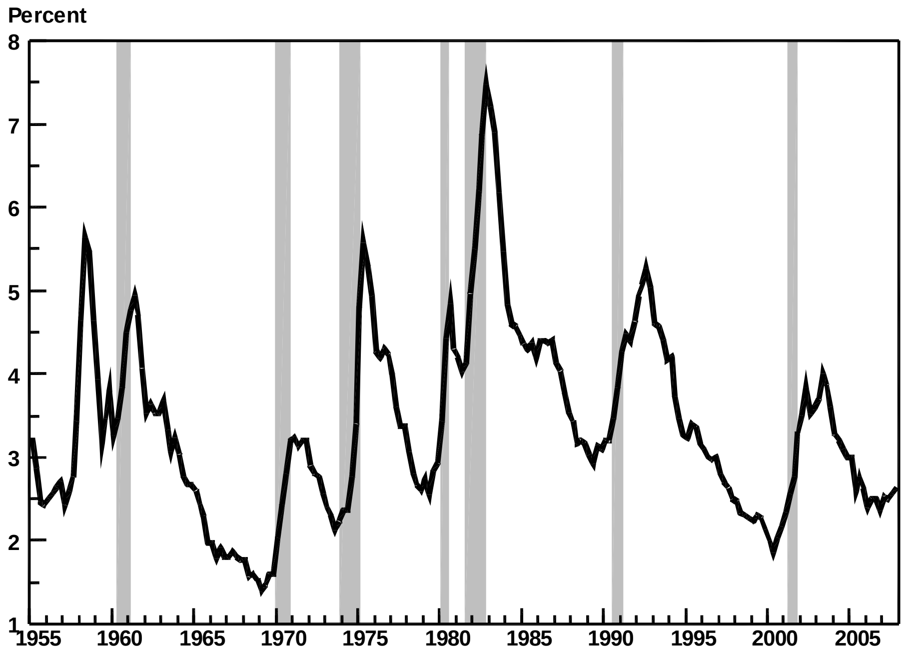
Unemployment Rate. Although it appears in equation (3), the overall unemployment rate is not the best measure of aggregate demand to use in a Phillips curve equation because of the influence of demographic and other structural changes. Shifts in the demographic composition of the labor force can change the unemployment rate even if the state of aggregate demand is held constant. For example, younger workers have higher rates of unemployment than older workers because they are less experienced and more of them are searching for the correct match between their skills and interest and the available jobs. Termed frictional unemployment, this is part of the normal working of the labor market, but it means that the unemployment rate associated with "full employment" could rise if there were an unusually large influx of youths into the labor force. That is what happened during the 1960s and 1970s: the share of workers between the ages of 16 and 24 rose from 16 percent of the labor force in 1959 to 24 percent in 1979, and then declined to about 15 percent in 2006. Consequently, it is misleading to compare unemployment rates from the late 1970s to those of the more recent past—a 6 percent rate of unemployment in 1979 implies a different level of aggregate demand than a 6 percent rate in 2006.

A solution to the problem is to use a measure of unemployment that is insulated from such demographic shifts. Such alternatives include the prime-age male unemployment rate, the married-male unemployment rate, and the so-called Perry-

8. For example, see Jeffrey Fuhrer, "The (Un)Importance of Forward-Looking Behavior in Price Specifications," *Journal of Money, Credit and Banking*, Vol. 29, No. 3 (August 1997), pp. 338-350.

weighted unemployment rate (calculated using constant labor force shares).[9] This paper uses the married-male unemployment rate because it is less affected by demographics than the overall unemployment rate and because married males are likely to have a strong attachment to the labor force. However, each of the alternative unemployment rates yields roughly the same results when estimated empirically.

Figure 4. The Married-Male Unemployment Rate, 1955–2007



Even unemployment rates that have been purged of the effects of demographics display medium-term trends. As shown in Figure 4, the average level of the married-male unemployment rate has declined steadily since the early 1980s, as have the peak and trough levels. This decline might stem from an increase in the average age of married males, which could increase that group's attachment to the labor force. Regardless of the underlying reason, the decline certainly suggests a decline in the equilibrium level of the unemployment rate, a question that will be

9. A Perry-weighted unemployment rate is calculated by holding the shares of each demographic group in the labor force constant at some base year value. In each quarter, the Perry-weighted unemployment rate equals the actual unemployment rate for each age-sex group in that quarter multiplied by the labor force share of that group in a base year.

explored in the empirical section below.

Using the married-male unemployment rate in equation (3) yields an estimate of the NAIRU for married males that is constant through time. To calculate an overall NAIRU, we first estimate regressions that relate the unemployment rate for each demographic group to the unemployment rate for married males plus a constant term.[10] A NAIRU for each demographic group is then calculated by inserting the NAIRU for married males in the equation for that group. Finally, the overall NAIRU is computed as a weighted average of the NAIRUs of the demographic groups, with each group's labor force shares used as the weights, and thus reflects the impact of shifts in the demographic composition of the labor force. Since the NAIRU for married males and for each of the demographic groups are constant throughout the sample, the overall NAIRU varies through time only because the shares of the labor force change over time.

Supply Shocks. Events during the 1970s showed that shocks to aggregate supply—the economy's ability to produce goods and services—could cause both inflation and unemployment to rise concurrently. Those factors thus can alter the presumed negative short-run relationship between inflation and unemployment described in equation (1). Energy prices were the most important supply shock during that era, but there were others, including the Nixon-era wage and price controls, changes in trend productivity growth, and the price of imported goods.

During the 1990s, the situation was reversed. Estimates of the NAIRU generally signaled the presence of considerable inflationary pressure, but the actual rate of inflation remained low and stable. In part, this was due to a series of positive shocks to aggregate supply—declines in price inflation for computers, medical care and imported goods, and a surge in the growth of labor productivity. The presence of such favorable supply shocks can obscure a decline in empirical estimates of the NAIRU.

To control for shocks to the price of food and energy, we include a relative price variable in all but one of the Phillips curve regressions (the exception is the equation for the PCE price index excluding food and energy). This variable equals zero when the price index for food and energy grows at the same rate as the overall price level; consequently, it drops out of the equation used to compute the NAIRU. A similarly calculated variable is included to control for shocks to import prices.[11]

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10. CBO breaks down the labor force by sex and age (16-19, 20-24, 25-34, 35-44, 45-54, 55-64, and 65 and over).

11. Variables to control for shocks to computer prices and the cost of medical care were found to be insignificant and are not included in the final specification.

For productivity growth, we use the difference between labor productivity growth and a 32-quarter moving average of productivity growth as a control variable. The long moving average of past growth rates, which captures the trend in productivity growth, is a proxy for expected future growth, so the variable is meant to reflect the surprise in current productivity growth. Observationally, this variable is almost identical to the one proposed by Laurence Ball and Greg Mankiw in their paper published in the *Journal of Economic Perspectives* in 2002.[12]

We used two variables to account for the imposition and subsequent termination of wage and price controls during the early 1970s. These variables, which were originally calculated by Robert Gordon and used in CBO's 1994 paper, are defined in the footnote to Table 1.[13]

Possible Sources of Structural Change

There is considerable evidence of a fundamental change since the mid-1980s in the way the economy works. In particular, there has been a substantial reduction in the volatility of economic growth and inflation since roughly 1985, a phenomenon often termed the Great Moderation.[14] For example, the standard deviation of growth in the PCE price index declined from 3.3 percentage points during the 1947–1985 period to 1.3 points during the period since 1985. For real GDP, the decline in volatility was even larger, from 4.9 percentage points before 1985 to about 2 points during the period since. In addition, the level of inflation has been lower during the past 20 or so years than it was previously.[15] Growth in the PCE price index averaged 2.6 percent annually since 1985, compared with nearly 4 percent on average during the 1947–1985 period.

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12. Laurence Ball and N. Gregory Mankiw, "The NAIRU in Theory and Practice," *Journal of Economic Perspectives*, Vol. 16, No. 4 (Fall 2002), pp. 115-136.

13. See Robert Gordon, "Inflation, Flexible Exchange Rates, and the Natural Rate of Unemployment," in Martin N. Baily, ed. *Workers, Jobs and Inflation* (Washington, D.C.: The Brookings Institution, 1982).

14. See, for example, Margaret McConnell and Gabriel Perez-Quiros, "Output Fluctuations in the United States: What Has Changed Since the Early 1980s?" *American Economic Review*, Vol. 90, No. 5 (December 2000), pp. 1464-1476; Evan Koenig and Nicole Ball, "The 'Great Moderation' in Output and Employment Volatility: An Update," *Economic Letter*, Federal Reserve Bank of Dallas, Vol. 2, No. 9, September 2007; or John Williams, "The Phillips Curve in an Era of Well-Anchored Inflation Expectations," Federal Reserve Bank of San Francisco Working Paper, September 2006.

15. In addition, some authors have speculated that there has been a flattening of the short-run tradeoff between unemployment and inflation. See John Roberts, "Monetary Policy and Inflation Dynamics," *International Journal of Central Banking*, Vol. 2, 2006, pp. 193-230.

Economists have yet to determine the sources of the Great Moderation. Some analysts argue that it has resulted from the good conduct of monetary policy, while others assert that the economy has benefitted from good luck (meaning that it has been hit by fewer exogenous shocks), and still others point to the increased flexibility of the economy that resulted from decreased regulation, increased competition, and innovations in product, financial, and other markets.[16] Of course, these explanations are not mutually exclusive—it's possible that a combination of factors is behind the reduced volatility of output and inflation.

No matter what the source, lower and more stable inflation can alter the equations used to explain and forecast inflation, including the Phillips curve. In general, a stable rate of inflation is easier to forecast than one that swings widely from year to year. However, the lack of variation in the inflation rate also means that econometric techniques will be less able to identify the factors that cause the rate to change. As a result, it will be harder to predict changes in the inflation rate if and when they do occur.[17]

Labor markets also appear to be functioning differently since the early 1980s and these changes raise the possibility that the NAIRU has declined during the past 20 or so years. As noted above, both the overall and the married-male unemployment rates have been trending downward during the past three decades, which suggests that the equilibrium rate of unemployment has declined. In addition, recent research at CBO has identified the following factors that could have caused a reduction in the natural rate of unemployment:

- **Demographics**. A declining share of younger workers, with their higher rate of frictional unemployment, has lowered the natural rate of unemployment by nearly 1 full percentage point since the late 1970s.

- **Disability Policy**. A change in the rate of disability can affect the natural rate if those who move out of the labor force and onto the disability rolls have higher-than-average unemployment rates. According to one estimate, this could have contributed a half percentage point to the decline in the unemployment rate since the mid-1980s.[18]

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16. See, for example, James Stock and Mark Watson, "Has the Business Cycle Changed and Why?" NBER Working Paper No. W9127 (August 2002); Richard Clarida, Jordi Gali, and Mark Gertler, "Monetary Policy Rules and Macroeconomic Stability: Evidence and Some Theory," *Quarterly Journal of Economics*, Vol. 115, No. 1, February 2000, pp. 147–180; or Congressional Budget Office, "The Economic Effects of Recent Increases in Energy Prices," *CBO Paper*, July 2006.

17. See James Stock and Mark Watson, "Why Has U.S. Inflation Become Harder to Forecast?" NBER Working Paper No. 12324, June 2006.

18. See David H. Autor and Mark G. Duggan, "The Rise in the Disability Rolls and the Decline in Unemployment," *Quarterly Journal of Economics*, vol. 118 (2003), pp. 57–205.

- **Educational Attainment**. A better educated workforce can perform a wider range of tasks and, presumably, learn new tasks more readily. If this improves the match between workers and jobs, then the increase in the education level of the labor force should reduce the unemployment rate.

- **Changes in the Mix of Industries**. Rapid changes in the mix of industries can result in the simultaneous creation and destruction of a large number of jobs and an increase in the rate of unemployment. There is some evidence that unemployment associated with such changes has fallen during the past two decades.

- **Labor Market Efficiency**. Some have argued that factors such as the rapid growth of employment in the temporary-help industry and the increased importance of Internet job searching have made the job-matching process more efficient during the past 20 years. Consistent with that notion, there appears to have been an inward shift in the Beveridge curve, which traces the relationship between job vacancies and the unemployment rate, since roughly 1987.[19]

A recent paper found that the factors described above—especially the influence of demographics and the efficiency of the labor market—have reduced the natural rate of unemployment by an amount that ranges from about 1 to 1.5 percentage points since the mid-1980s.[20] Of that decline, roughly two- to three-tenths of a percentage point occurred since 1998. That finding accords well with the results of researchers who have documented a decline in empirical estimates of the NAIRU.[21] Recall that CBO's procedure for calculating the NAIRU accounts for the influence of demographics, so it already declines approximately 0.9 percentage points between 1979 and 2007.

Other explanations for changes in the relationship between unemployment and inflation include the increase in competitive pressure brought about by globalization and the effects of the late-1990s surge in productivity growth. Increased openness to foreign trade can have many effects on inflation, but most observers focus on supply factors. The entry of labor-abundant countries such as China and India into the world trading system, combined with improved com-

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19. See Robert G. Valletta, "Why Has the U.S. Beveridge Curve Shifted Back? New Evidence Using Regional Data," Working Paper 2005-25 (Federal Reserve Bank of San Francisco, December 2005); Robert G. Valletta and Jaclyn Hodges, "Job Matching: Evidence from the Beveridge Curve," Economic Letter 2006-08 (Federal Reserve Bank of San Francisco, April 21, 2006).

20. See David Brauer, "The Natural Rate of Unemployment," CBO Working Paper 2007-06, April 2007.

21. See Robert Gordon, "Foundations of the Goldilocks Economy: Supply Shocks and the Time-Varying NAIRU," *Brookings Papers on Economic Activity*, 1998:2, pp. 297-333; Laurence Ball and N. Gregory Mankiw, "The NAIRU in Theory and Practice," *Journal of Economic Perspectives*, Vol. 16, No. 4 (Fall 2002), pp. 115-136.

munication and transportation networks that facilitate integration across national borders, has exposed U.S. companies to increased competition and limited their ability to raise prices. By itself, increased globalization would tend to reduce the responsiveness of inflation to changes in the domestic unemployment rate.[22]

Faster labor productivity growth also affects the unemployment-inflation relationship. Economic theory predicts that, in the long run, increases in real labor compensation will track increases in labor productivity. Over shorter periods, however, gaps can open up between the two series. During the 1970s, for example, productivity growth fell short of real compensation growth during at least two spans that lasted a year or longer. During the period since 1990, the opposite has occurred: productivity growth has exceeded real compensation growth for periods of several years on at least two occasions. These episodes can alter the simple Phillips curve relationship.

After estimating the base specification of the Phillips curve, we present evidence on structural change, determine whether it affected the inflation-unemployment tradeoff, ascertain whether it has affected the level of the NAIRU, and, most important, find out whether the Phillips curve relationship is useful for forecasting inflation.

Results of the Estimation

Empirical estimates of equation (3) appear to be satisfactory. The equations generally fit the data well (as evidenced by the adjusted R-squared statistics) and the coefficients have the correct signs and are strongly significant (see Table 1). In particular, the coefficients on the unemployment term are strongly significant in every specification, which suggests the presence of a short-run tradeoff between inflation and unemployment. In addition, shocks to food and energy prices have a positive and statistically significant impact on the GDP price index, though not on the PCE price index. Import price shocks have a positive and significant impact on all of the inflation measures except real compensation in the nonfarm business sector. In contrast, positive shocks to productivity growth (meaning increases in productivity that exceed the long-run average) are associated with smaller increases in inflation.

Estimates of the NAIRU for married males that are implied by the estimates in Table 1 vary slightly across the different specifications, from about 3.4 percent to roughly 3.6 percent. After adding in the effects of demographics, those estimates

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22. For more details about the effects of globalization, see Charles Bean, "Globalisation and Inflation," *Quarterly Bulletin*, Bank of England, 2006Q4, pp. 468-475.

are consistent with overall NAIRUs that range from 5.3 to 5.5 percent in 2007, a range that is above the level that most analysts would consider appropriate for the current natural rate. Recall that, in order to use these equations to solve for the NAIRU, the sum of the coefficients on lagged inflation must add up to 1 exactly. In Table 1, that constraint, which was tested empirically, is imposed on each of the equations.

CBO last published empirical estimates of a Phillips curve during the mid-1990s.[23] Broadly speaking, the results shown in Table 1 are similar to those estimates, which are reproduced in Appendix II. The adjusted R-squared is slightly higher, while most of the coefficients have roughly the same magnitude and statistical significance as they did in the earlier estimates. These results seem to suggest that the Phillips curve is still a useful concept for forecasting inflation.

However, there are important differences. Some of the coefficients are smaller than in the earlier estimation and some are less significant in statistical test. In particular, the coefficient on the (married-male) unemployment rate is somewhat lower than it was previously, which implies that a given change in unemployment is associated with a smaller change in inflation, all else being equal. In short, it suggests a flatter tradeoff between inflation and unemployment. In addition, the estimates of the NAIRU calculated from these estimates are about half a percentage point lower than in the previous estimation, varying in the vicinity of 5.4 percent instead of 5.9 percent. These differences between the current and previous estimates suggest that the relationship between inflation and unemployment has changed during the past two decades.

The set of variables used to estimate the Phillips curve is similar (though not identical) to the set used in the earlier estimates. In particular, the benchmark-years-weighted price indexes and the fixed-weighted price indexes used in the earlier estimation are no longer calculated by BEA. Another change is in the definition of the productivity trend, for which a 32-quarter moving average of the growth rate of productivity has replaced a segmented linear trend. In addition, several other variables were tried to see if they had explanatory power but were omitted because they did not improve the fit of the equation. These included the relative price of medical care (another type of supply shock), an estimate of the shift in the Beveridge curve (a measure of labor market efficiency), and several alternate definitions of productivity deviation variable. None of these variables was retained because they did not meet conventional levels of statistical significance.

23. See Congressional Budget Office, "Reestimating the NAIRU," Appendix B in *The Economic and Budget Outlook: An Update*, August 1994.

Evidence of Structural Change

To analyze the possibility that the inflation-unemployment relationship has changed during the past 20 years, this paper uses three approaches. First, we used a statistical test for the presence of structural change—known as a Chow test—to determine whether the equations changed since 1980 and when the change most likely occurred. Second, we used dummy variables to determine whether there was a statistically significant change in the coefficients on some (but not all) of the explanatory variables. Under this approach, the constant term and the coefficients on the unemployment rate are allowed to change at the break points suggested by the results of the Chow test, but the other coefficients were held constant. And third, we reestimated the equations using a split sample, where the timing of the split was based on the findings of the Chow test. With this approach, all of the coefficients in the regression equation are allowed to change between the two periods.

The Chow test is a commonly-used statistical test of the hypothesis that the coefficients of a regression estimated using one data set are equal to those estimated using a different data set. When testing for a structural break at a given point in time, the full data sample is divided into an earlier and a later period (i.e., before and after the break point) to test the hypothesis that all of the coefficients are equal in the two periods.

The results of the Chow test reject the hypothesis of equal coefficients and thus indicate the presence of structural change in the equations for each inflation measure except the core PCE price index (see Table 2). To determine when the structural break occurred for each equation, we computed the Chow test statistic for multiple break points between 1980 and 2000. The values of the test statistics, shown in Table 2, suggest that the break in each equation happened at different times. For the GDP price index and for the employer cost index, the results of the Chow test indicate the presence of a structural break in 1984, roughly consistent with the beginning of the Great Moderation. For the PCE price index, the largest value of the test statistic is in 1991, and for the compensation per hour measure the test results suggest a break during the late 1990s.[24] These break points will be used to compute the dummy variables used in the second approach to test for structural change and again in the third approach, when the sample is split at the break point.

Estimating the equations using the second approach also suggests the presence of structural change. In this approach, dummy variables were included in the

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24. We will use 1995 as the break point when we estimate the equation for compensation per hour using the second and third approaches so that there are enough observations available in the second subperiod.

regression to allow the coefficients on the constant and married-male unemployment rate to change while constraining the coefficients on the other explanatory variables to remain constant throughout the sample. Table 3 displays the results of reestimating the equation with the addition of the dummy variable, which equals zero during the first period and unity thereafter, and an interaction variable, which equals the product of the dummy variable and the unemployment rate (labeled “Dummy*Unemployment Rate”). In each equation, the break point between the first and second periods is set using the results of the Chow tests.

The coefficient labeled “constant” in these equations is relevant for the first period; to calculate the constant for the second period, one must add the coefficient on the dummy variable to the estimate of the constant. The t-statistic on the dummy term shows the significance of the shift in the constant term. A similar calculation can be used to estimate the shift in the coefficients on the unemployment rate: the coefficient labeled “unemployment rate” pertains to the first part of the sample, while the sum of that coefficient and the coefficient on the interaction term is relevant for the second part of the sample. The t-statistic on the interaction term indicates the statistical significance of the shift in the coefficient on the unemployment rate.

The results, summarized in Table 3, suggest the presence of significant change in the structure of the equations for the GDP and PCE price indexes, with significant coefficients on the dummy variable and the interaction term but not for the other equations. Estimates from the first two equations indicate that the unemployment coefficient is smaller (in absolute value) during the second period, which suggests a flattening of the tradeoff between unemployment and inflation. In the remaining equations, the coefficients on the dummy variable and the interaction term are insignificant and the other coefficients are little changed from their values in Table 1. In all of the equations, the estimated NAIRU is lower during the second period.

In the third approach, using a split-sample regression, all of the coefficients in each regression equation are allowed to change during the second part of the sample. This approach corroborates and amplifies the findings of the Chow tests and the dummy-variable estimates (see Table 4). In almost every case, the performance of the split-sample regression deteriorates during the second period, with lower adjusted R-squared statistics, smaller coefficients, and less statistical significance. The deterioration is particularly acute for the compensation-based measures: the adjusted R-squared statistics fall precipitously and the coefficient estimates swing sharply. One exception is the equation for the core PCE price index, which is more stable than the others; in that equation, the coefficients diminish in size but most retain their significance and the overall fit does not change much.

Of particular interest is the estimated coefficient on the unemployment rate, which falls in magnitude and in statistical significance during the second period of the sample for all but one of the equations. For example, in the equation for the GDP price index, the coefficient equals –0.87 during the first period (and is strongly significant) but just –0.14 (and insignificant) during the second period. In addition, the NAIRU estimates implied by the equations fall during the second period, sharply in some instances. Moreover, the estimates of the NAIRU span a wide range, from a low of 3.9 percent implied by the equation for the PCE price index to a high of 5.2 percent in the equation for the core PCE price index.

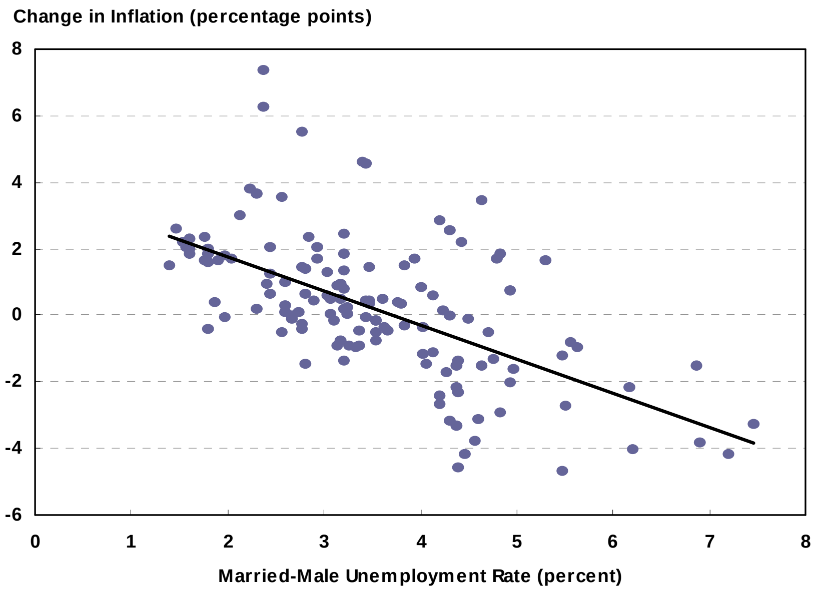
A hint at why the results came out the way they did is shown in Figure 5, which plots changes in a measure of unanticipated inflation against the married-male unemployment rate, similar to what was shown in Figure 3. The top panel shows data from the 1957–1990 period, while the bottom panel shows data from the remaining years of the sample. Comparing the two panels reveals three features of the later period. First, both graphs show a negative correlation between the two series, so there still appears to be a tradeoff between inflation and unemployment, as was the case in the full sample. Second, the slope of the trend line is lower during the second part of the sample, which suggests that the inflation-unemployment tradeoff is somewhat flatter during the second period. And, third, there is much less variation in both inflation and unemployment during the past 20 or so years than there had been previously. These features are all consistent with the results of the regression estimates.

These results indicate that the relationship between inflation and unemployment has changed during the past 30 years and as a result is now less useful for forecasting inflation. While the full-sample regressions appear to be satisfactory, in many cases they are hiding a structural shift that is strongly statistically significant. The exception is the equation for the PCE price index: results of the Chow test did not indicate the presence of structural change, and the equation showed the fewest differences in the dummy-variable and split-sample estimates.

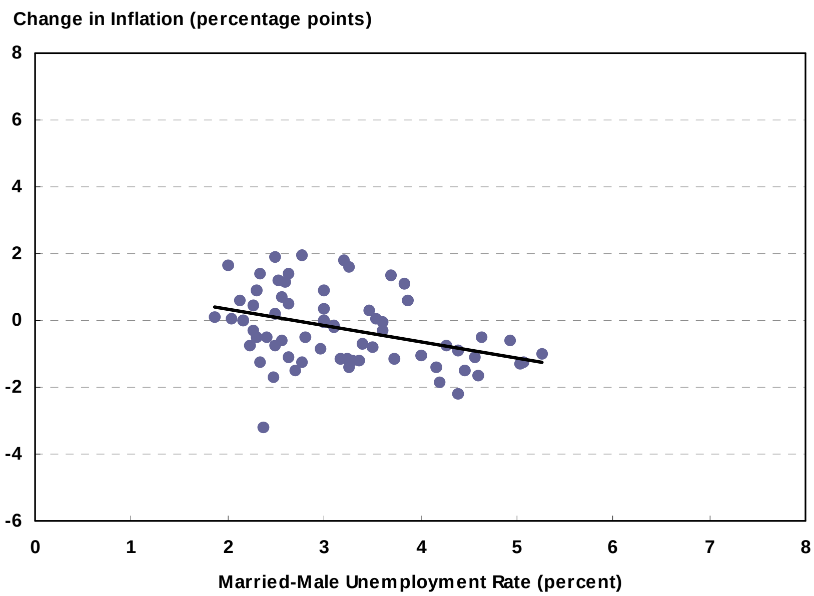
The results also suggest that the NAIRU is lower now than it was during the first part of the sample and that the tradeoff between inflation and unemployment is somewhat flatter. It's hard to pin down an estimate with any precision, but the results suggest that a value near 5 percent is appropriate.

Figure 5. Married-Male Unemployment and the Change in Inflation: Early vs. Late Sample

Early Sample (1957–1990)



Late Sample (1991–2007)



Note: The change in inflation is defined as the difference between the quarterly rate of inflation in the PCE price index and a 24-quarter moving average of PCE inflation.

Conclusion

Changes in the economic landscape since about 1985 have made inflation both easier and more difficult to analyze and forecast. Although it is unclear whether the changes came about through changes in policy, structural shifts, changes in measurement, or random chance, the rate of inflation has been lower and more stable during the past 20 or so years than it had been previously. All else being equal, a steadier inflation rate is easier to predict; a forecast of constant core inflation would have been quite successful during the 1990s and the early part of the 2000s. However, changes in the behavior of inflation and other macro-economic variables can alter the models used to forecast inflation, including the Phillips curve.

The results presented in this paper suggest that the structure of the Phillips curve has changed during the past 20 or so years. Full-sample regressions are somewhat misleading as they indicate a strong statistical relationship between inflation and several explanatory variables, including unemployment and control variables for supply shocks. In contrast, the estimation results from the equations that allow for structural change are much less satisfactory, especially those from the latter part of the sample period. The fit of the equations is lower and the coefficients are generally smaller and less significant. The inclusion of additional variables did not improve the fit of the equations or identify the source of the structural change.

These results suggest that the Phillips curve is less useful for analyzing and fore-casting inflation than it once was. It's not useless and it should remain part of the inflation forecaster's toolbox, but it should not get primary placement. In a world of stable inflation (and well-anchored inflation expectations), a fundamental approach—meaning a focus on the components of inflation—may be necessary. Of the five measures of inflation, the equation for the PCE price index excluding food and energy showed the most stability between the first and second parts of the sample. The equations for compensation were the least stable in the split-sample estimation.

These results also suggest that the NAIRU is lower now than during the period before 1985. However, they also indicate that the deterioration in the performance of the Phillips curve equations is not the result of failing to allow for variation in the NAIRU. That deterioration, combined with the wide span of NAIRUs estimated using the second part of the sample, justifies a decreased emphasis on the NAIRU as an inflation indicator.[25]

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25. These results are consistent with previous research that concluded that empirical estimates of the NAIRU have wide confidence intervals. See Douglas Staiger, James Stock, and Mark Watson, "How Precise are Estimates of the Natural Rate of Unemployment?" in Christina Romer and David Romer, eds., *Reducing Inflation: Motivation and Strategy* (Chicago: University of Chicago Press, 1997).

Table 1. Estimated Coefficients from Phillips Curve Regressions

	Dependent Variables				
	GDP Price Index	PCE Price Index	Core PCE Price Index	ECI for Compensation	Compensation per Hour
Constant	1.94 (7.04)	1.67 (6.28)	1.67 (5.20)	1.45 (4.77)	3.32 (5.74)
Lagged Inflation[a]	1.00	1.00	1.00	1.00	1.00
Unemployment Rate[b]	-0.57 (7.21)	-0.49 (6.44)	-0.47 (5.08)	-0.40 (4.63)	-0.97 (5.78)
Food and Energy Prices[c]	0.06 (4.44)	0.19 (1.30)	n.a.	n.a.	n.a.
Imports Excluding Food and Energy[d]	0.07 (4.25)	0.09 (5.25)	0.09 (4.38)	0.06 (2.92)	0.06 (1.43)
Productivity Deviation[e]	-0.11 (3.96)	-0.09 (3.17)	-0.08 (2.12)	0.08 (3.25)	0.20 (4.29)
Wage and Price Controls					
On[f]	-1.22 (2.60)	-1.43 (3.04)	-1.96 (3.06)	-0.84 (1.29)	-1.33 (1.07)
Off[g]	2.29 (5.34)	1.05 (2.39)	2.14 (3.73)	0.62 (1.12)	1.18 (1.11)
R-Bar Squared	0.89	0.90	0.79	0.72	0.48
Number of Obs.	208	208	207	211	211
NAIRU (2007)					
Married-Male	3.42	3.43	3.56	3.60	3.43
Overall	5.32	5.33	5.46	5.51	5.33

Source: Congressional Budget Office.

Notes: t-statistics are shown in parentheses below coefficients,
NAIRU = nonaccelerating inflation rate of unemployment,
n.a. = not applicable.

a. Third-degree polynomial distributed lag with the coefficients on the lags restricted to sum to 1. Twenty-four lagged values in price equations, twenty-eight lagged values in wage equations.

b. Contemporaneous and four lagged values in price equations; contemporaneous and one lagged value in wage equations.

c. The difference between the growth rate of food and energy prices and the growth rate of the PCE price index excluding food and energy prices.

d. The difference between the growth rate of import prices (less food and energy) and the growth rate of the GDP price index. Contemporaneous and two lagged values.

e. The difference between the growth rate of labor productivity in the nonfarm business sector and a 32-quarter moving average of the growth rate of labor productivity. Contemporaneous and one lagged value in price equations; no lagged values in wage equations.

f. A dummy variable designed to control for the imposition of wage and price controls in 1971. It equals 0.8 for the five quarters from 1971:3 through 1972:3.

g. A dummy variable designed to control for the termination of wage and price controls in 1974. It equals 0.4 in 1974:2 and 1975:1 and 1.6 in 1974:3 and 1974:4.

Table 2. Chow Test Statistics for Phillips Curve Regressions

	Date of Structural Break																				
	1980Q1	1981Q1	1982Q1	1983Q1	1984Q1	1985Q1	1986Q1	1987Q1	1988Q1	1989Q1	1990Q1	1991Q1	1992Q1	1993Q1	1994Q1	1995Q1	1996Q1	1997Q1	1998Q1	1999Q1	2000Q1
GDP Price Index	2.73 ***	2.49 ***	2.36 ***	2.45 ***	2.72 ***	2.41 ***	2.01 **	2.07 **	2.17 ***	1.97 **	1.93 **	1.93 **	1.92 **	1.83 **	1.80 **	1.71 *	1.83 **	1.81 **	1.64 *	1.58 *	1.66 *
PCE Price Index	2.00 **	1.94 **	2.09 **	1.98 **	2.19 ***	2.10 **	1.84 **	2.12 **	2.06 **	2.34 ***	2.31 ***	2.56 ***	2.48 ***	2.33 ***	2.38 ***	2.37 ***	2.25 ***	2.12 **	1.74 **	1.68 *	1.60 *
Core PCE Price Index	0.70	0.76	0.72	0.71	0.80	0.77	0.54	0.44	0.37	0.50	0.45	0.45	0.47	0.48	0.54	0.49	0.49	0.50	0.39	0.37	0.47
ECI for Compensation	1.29	1.79 *	1.93 **	1.87 *	2.04 **	1.57	1.32	1.01	1.25	0.82	0.91	1.06	1.28	1.29	1.20	1.19	1.03	1.03	1.22	1.43	0.94
Compensation per Hour	1.12	1.30	1.46	1.13	0.98	1.01	1.09	0.97	1.02	0.94	1.22	1.55	1.79 *	2.32 **	2.37 **	2.83 ***	3.10 ***	3.45 ***	3.43 ***	4.26 ***	4.03 ***

Source: Congressional Budget Office.

* denotes significance at the 90% level.

** denotes significance at the 95% level.

*** denotes significance at the 99% level.

Notes: A Chow test is a test of the hypothesis that the parameters of a regression are equal in two periods. A significant test statistic indicates that the hypothesis is rejected, implying that a structural shift has occurred. The dates of the structural break listed in the column headings indicate where the sample was split to perform each Chow test. They refer to the first observation in the second subperiod.

Table 3. Estimated Coefficients from Phillips Curve Regressions With Dummy Variables

	Dependent Variables				
	GDP Price Index	PCE Price Index	Core PCE Price Index	ECI for Compensation	Compensation per Hour
Constant	2.57 (7.99)	2.53 (8.47)	2.01 (4.97)	1.70 (4.66)	3.59 (5.42)
Lagged Inflation[a]	1.00	1.00	1.00	1.00	1.00
Unemployment Rate[b]	-0.73 (8.12)	-0.70 (8.49)	-0.53 (4.74)	-0.43 (4.33)	-1.02 (5.61)
Food and Energy Prices[c]	0.08 (5.12)	0.21 (1.46)	n.a.	n.a.	n.a.
Imports Excluding Food and Energy[d]	0.05 (2.87)	0.06 (3.88)	0.09 (3.69)	0.06 (2.44)	0.05 (1.16)
Productivity Deviation[e]	-0.10 (3.54)	-0.07 (2.61)	-0.08 (2.15)	0.08 (3.32)	0.20 (4.37)
Wage and Price Controls					
On[f]	-1.32 (2.86)	-1.66 (3.75)	-2.06 (3.18)	-0.93 (1.43)	-1.47 (1.17)
Off[g]	2.53 (5.93)	1.45 (3.46)	2.20 (3.76)	0.67 (1.20)	1.22 (1.14)
Dummy[h]	-1.54 (3.32)	-2.17 (4.62)	-0.60 (0.94)	-0.35 (0.59)	0.58 (0.31)
Dummy * Unemployment Rate	0.40 (3.00)	0.51 (3.74)	0.09 (0.51)	0.00 (0.00)	-0.34 (0.53)
R-Bar Squared	0.90	0.92	0.78	0.72	0.48
Number of Obs.	208	208	207	211	211
NAIRU (2007)					
Married-Male	3.07	1.97	3.21	3.13	3.06
Overall	4.94	3.68	5.09	5.01	4.93

Source: Congressional Budget Office.

Notes: t-statistics are shown in parentheses below coefficients,
NAIRU = nonaccelerating inflation rate of unemployment.

a. Third-degree polynomial distributed lag, with the far end point restricted to zero. Twenty-four lagged values in price equations, twenty-eight lagged values in wage equations.

b. Contemporaneous and four lagged values in price equations; contemporaneous and one lagged value in wage equations.

c. The difference between the growth rate of food and energy prices and the growth rate of the PCE price index excluding food and energy prices.

d. The difference between the growth rate of import prices (less food and energy) and the growth rate of the GDP price index. Contemporaneous and two lagged values.

e. The difference between the growth rate of labor productivity in the nonfarm business sector and a 32-quarter moving average of the growth rate of labor productivity. Contemporaneous with one lagged value in price equations; no lags in wage equations.

f. A dummy variable designed to control for the imposition of wage and price controls in 1971. It equals 0.8 for the five quarters from 1971:3 through 1972:3.

g. A dummy variable designed to control for the termination of wage and price controls in 1974. It equals 0.4 in 1974:2 and 1975:1 and 1.6 in 1974:3 and 1974:4.

h. Equals 0 during the first period (1955-1990 for the PCE price index equation; 1955-1994 for the Comp per Hour equation; and 1955-1983 for the other equations). Equals 1 during the second period, which runs from the end of the first period through 2007.

Table 4. Estimated Coefficients from Split-Sample Phillips Curve Regressions

	Dependent Variables									
	GDP Price Index		PCE Price Index		Core PCE Price Index		ECI for Compensation		Compensation per Hour	
	pre-84	post-84	pre-91	post-91	pre-84	post-84	pre-84	post-84	pre-95	post-95
Constant	3.08 (7.58)	0.44 (1.04)	2.47 (6.75)	0.58 (1.60)	1.90 (3.31)	1.06 (2.83)	1.73 (4.00)	1.00 (2.03)	3.16 (5.79)	6.79 (1.46)
Lagged Inflation[a]	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Unemployment Rate[b]	-0.87 (7.61)	-0.14 (1.19)	-0.68 (6.75)	-0.27 (2.56)	-0.49 (3.04)	-0.32 (2.98)	-0.42 (3.52)	-0.35 (2.45)	-0.89 (5.90)	-2.32 (1.40)
Food and Energy Prices[c]	0.09 (3.51)	0.05 (2.92)	0.22 (1.03)	0.19 (1.21)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Imports Excluding Food and Energy[d]	0.04 (1.67)	0.04 (1.35)	0.07 (3.27)	0.02 (0.44)	0.10 (2.68)	0.06 (2.28)	0.07 (2.02)	-0.01 (0.21)	0.05 (1.25)	-0.08 (0.33)
Productivity Deviation[e]	-0.09 (2.37)	-0.06 (1.34)	-0.08 (2.26)	-0.05 (1.24)	-0.10 (1.60)	-0.03 (0.67)	0.11 (3.39)	0.02 (0.51)	0.23 (5.66)	0.11 (0.60)
Wage and Price Controls										
On[f]	-1.28 (2.56)	n.a.	-1.66 (3.29)	n.a.	-2.04 (2.44)	n.a.	-1.08 (1.45)	n.a.	-1.81 (1.78)	n.a.
Off[g]	3.01 (5.81)	n.a.	1.57 (2.99)	n.a.	2.03 (2.51)	n.a.	0.47 (0.70)	n.a.	1.08 (1.25)	n.a.
R-Bar Squared	0.92	0.58	0.91	0.78	0.75	0.74	0.77	0.24	0.65	-0.01
Number of Obs.	112	96	140	68	111	96	115	96	159	52
NAIRU (2007)										
Married-Male	3.55	3.11	3.62	2.13	3.86	3.29	4.17	2.82	3.55	2.93
Overall	5.45	4.99	5.53	3.88	5.78	5.18	6.09	4.67	5.45	4.79

Source: Congressional Budget Office.

Notes: t-statistics are shown in parentheses below coefficients,
NAIRU = nonaccelerating inflation rate of unemployment,
n.a. = not applicable.

a. Third-degree polynomial distributed lag, with the far end point restricted to zero. Twenty-four lagged values in price equations, twenty-eight lagged values in wage equations.

b. Contemporaneous and four lagged values in price equations; contemporaneous and one lagged value in wage equations.

c. The difference between the growth rate of food and energy prices and the growth rate of the PCE price index excluding food and energy prices.

d. The difference between the growth rate of import prices (less food and energy) and the growth rate of the GDP price index. Contemporaneous and two lagged values.

e. The difference between the growth rate of labor productivity in the nonfarm business sector and a 32-quarter moving average of the growth rate of labor productivity. Contemporaneous with one lagged value in price equations; no lags in wage equations.

f. A dummy variable designed to control for the imposition of wage and price controls in 1971. It equals 0.8 for the five quarters from 1971:3 through 1972:3.

g. A dummy variable designed to control for the termination of wage and price controls in 1974. It equals 0.4 in 1974:2 and 1975:1 and 1.6 in 1974:3 and 1974:4.

APPENDIX I — Data and Sources

Price Measures. The three price measures used in the paper—the GDP price index, the overall PCE price index, and the core PCE price index (which excludes food and energy prices)—are published by the Bureau of Economic Analysis (BEA) as part of the national income and product accounts (NIPAs). Official data for the core PCE price index start in 1959, so this index was "backcast" for the 1950–1958 period using the growth rates from a comparable fixed-weighted price index. BEA used fixed-weighted indexes in the NIPAs until the mid-1990s, when it switched to chain-weighted indexes. However, CBO retained a set of fixed-weighted indexes in an internal database since BEA ceased publishing them.

Wage Measures. The two measures of compensation used in the paper—the ECI compensation measure for private industry workers, and compensation per hour in the nonfarm-business sector—are both published by the Bureau of Labor Statistics (BLS). Official data for ECI compensation starts in 1980, so we backcasted this measure for the 1950–1979 period using the growth rates from the compensation per hour measure.

Explanatory Variables. Data series used to construct the variables that appear on the right-hand side of the Phillips curve equations come from various sources. The married-male unemployment rate is compiled as part of the Current Population Survey, which is conducted by the Census Bureau for the Bureau of Labor Statistics. Price indexes for consumer spending for energy goods and services and for food are available in the NIPAs. An overall index for food and energy prices was calculated using the same Fisher formula that BEA uses to calculate the chain-type price indexes in the NIPAs. That index was backcasted for the 1950–1958 period using the growth rates from a comparable fixed-weighted index, similar to the procedure used for the core PCE index. Price indexes for each category of imports except food and energy are available in the NIPAs; these were aggregated using the Fisher formula and backcasted for the 1950–1958 period using the overall price index for imports, which is also available in the NIPAs. The productivity measure used in the regressions, output per hour in the nonfarm business sector, is published by BLS as part of its Major Sector Productivity and Costs program.

APPENDIX II — CBO's 1994 Estimate

Table B-1.
Estimated Coefficients from Phillips Curve Regressions to Determine the NAIRU

Independent Variables	Dependent Variable: Inflation				
	Benchmark-Years-Weighted Price Index (GDP)	Benchmark-Years-Weighted Price Index (PCE)	CPI-U	Fixed-Weighted Price Index (PCE)	Fixed-Weighted Price Index (PCE less food and energy)
Constant	2.45	2.50	2.87	2.67	1.92
	(5.2)	(4.4)	(5.0)	(5.5)	(5.3)
Lagged Inflation[a]	1.0[b]	1.0[c]	1.0[b]	1.0[b]	1.0[d]
Lagged Unemployment Rate (Married males)[e]	-0.69	-0.69	-0.77	-0.72	-0.53
	(5.4)	(4.5)	(4.9)	(5.5)	(5.4)
Food and Energy Prices[f]	0.19	0.43	0.43	0.34	n.a.
	(1.7)	(2.7)	(2.6)	(2.7)	
Productivity Deviation[g]	-0.10	-0.13	-0.06	-0.13	-0.10
	(2.9)	(2.8)	(1.3)	(3.4)	(3.0)
Wage and Price Controls On[h]	-0.75	-1.19	-1.83	-1.25	-1.37
	(1.3)	(1.5)	(2.2)	(1.8)	(2.3)
Off[i]	3.19	1.17	0.99	1.62	2.34
	(6.6)	(1.7)	(1.4)	(2.7)	(4.3)
R-Bar Squared	0.82	0.75	0.76	0.80	0.83
Number of Observations	117	119	152	152	152

SOURCE: Congressional Budget Office.

NOTES: T statistics appear in parentheses below coefficients.

NAIRU = nonaccelerating inflation rate of unemployment; GDP = gross domestic product; PCE = personal consumption expenditures; CPI-U = consumer price index for all urban consumers; n.a. = not applicable.

a. In each equation, lagged values of inflation are assumed to follow a third-degree polynomial distributed lag, with the far end point restricted to zero.

b. Lag length is 20 quarters.

c. Lag length is 18 quarters.

d. Lag length is 12 quarters.

e. Four lagged values of the unemployment rate for married males.

f. One period lag of food and energy prices; defined as the difference between the rates of growth of the fixed-weighted price index for PCE and the fixed-weighted price index for PCE less food and energy.

g. The difference between the rates of growth of labor productivity in the nonfarm business sector and trend labor productivity. The trend variable is segmented trend; its rate of growth is constant between business cycle peaks but differs between business cycles.

h. A dummy variable designed to control for the imposition of wage and price controls in 1971. (It equals 0.8 for the five quarters between 1971:3 and 1972:3.)

i. A dummy variable designed to control for the termination of wage and price controls in 1974. (It equals 0.4 in 1974:2 and 1975:1 and 1.6 in 1974:3 and 1974:4.)

Source: CBO, *The Economic and Budget Outlook: An Update*, August 1994.