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Models and Judgement in the Estimation of U.S. Potential Output

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I. Overview

The concepts of potential output and the natural rate of unemployment are embedded in many theoretical models of the macroeconomy. Likewise, most structural macroeconomic models rely on, or yield as a byproduct, estimates of potential output and the natural rate – or its close equivalent, the non-increasing inflation rate of unemployment or NAIRU. The NAIRU is defined as the rate of unemployment consistent with stable inflation in the medium to long run and in the absence of aggregate supply shocks. For our purposes, the most useful concept of potential GDP is analogous to the NAIRU, and is defined as the level of real GDP that can be produced if factors of production are operating at rates consistent with stable inflation.

In this paper, we discuss some issues related to the definition and estimation of these quantities, highlighting the advantages and disadvantages of different approaches. Considerable uncertainty surrounds any estimate of potential GDP or the NAIRU. The sources of this uncertainty include the modeler's incomplete understanding of the structure of the economy, structural changes in product and labor markets, and the imperfect measurement of key data. As we will make clear, the best method of estimating these quantities is not a settled issue. On the contrary, methods have changed importantly in the past, and considerable work is under way even now to improve estimation of these concepts.

Certainly at present, no single model or set of models can provide a fully accurate assessment of the current state of the U.S. economy, and we believe that no such model will emerge any time in the future. Accordingly, the staff at the Federal Reserve Board apply a judgmental approach to economic forecasting. While we make heavy use of econometric models and formal estimation techniques, we take into account a wide variety of information not captured by these models in forming our forecasts of potential output and the NAIRU.

The concepts of potential output and the NAIRU find immediate and important application in the analysis of the outlook for inflation. Although economists may disagree over the most useful framework for forecasting inflation, the dominant view is that current inflation depends on inflation expectations and the degree of resource utilization, as well as supply-side indicators often including, but not limited to, food and energy prices, labor costs, and labor productivity growth. This relationship between inflation and its driving forces is usefully summarized by an expectations-augmented Phillips curve, where the degree of resource

utilization has generally been measured either as the unemployment rate gap (the difference between the actual unemployment rate and the NAIRU), the GDP gap (the difference between actual GDP and potential GDP), or the capacity utilization gap (the difference between actual capacity utilization and the NAICU—or non-accelerating inflation capacity utilization).

In the United States, the most common specifications of the Phillips curve use the unemployment rate gap as the measure of resource utilization. The unemployment rate gap has several advantages over the GDP gap or the capacity utilization gap as a measure of slack. First, unlike the published measures real GDP or capacity utilization, the source data underlying estimates of the unemployment rate are virtually complete within a month. Second, the unemployment rate is a frequently discussed indicator of overall state of the economy as well as an indicator of inflationary pressures, and the NAIRU is a convenient summary statistic by which to evaluate the unemployment rate. Nevertheless, potential GDP growth incorporates the influence of variations in the nation's capital stock and other factors as well as other information from the labor market. Accordingly, projections of GDP growth relative to potential GDP growth are useful for forecasting the unemployment rate gap and inflationary pressures going forward. Thus, reliable estimates of both potential output and the NAIRU are important for forecasting inflation.¹

The literature offers two general approaches to estimating potential GDP, one based on aggregate methods and one based on growth accounting methods.² The aggregate approach extracts an estimate of potential GDP from GDP itself rather than its components. The most common implementation of this is to estimate the level and growth rate of potential GDP in an equation relating the unemployment rate gap to the GDP gap (Okun's Law), given an estimate of the NAIRU typically derived from a Phillips curve. Implicit in this approach is the assumption that both capital and labor are operating at their natural rates when the unemployment rate is equal to the NAIRU. Several researchers have also used the Phillips curve directly as the basis

¹Orphanides and van Norden (2002) argue that “the reliability of output gap estimates in real time tends to be quite low,” and revisions to the estimates of the gaps are of the same order of magnitude as the estimates themselves.

²For summaries and comparisons of these approaches, see also *ECB Monthly Bulletin* (2000).

for estimating potential GDP, by specifying the GDP gap as the measure of resource utilization, while others have used univariate time-series methods, structural vector auto regressions (SVAR), or other multivariate time-series methods to estimate potential GDP from the aggregate GDP data.

The second general approach to estimating potential GDP is based on a growth accounting framework.³ One specifies a “production function” for potential GDP, and then builds up estimates of potential GDP growth from estimated trends in hours worked, capital services, labor quality, and multifactor productivity; in turn, estimates of trend hours can be built up from the trends in population, the labor force participation rate, and average weekly hours, and estimates of the NAIRU.

Relative to the direct estimation of potential GDP, the growth accounting approach facilitates discussion and explication of the factors driving potential GDP growth.⁴ For example, recently much attention has focused on the role of capital growth in driving up the sustainable or trend rate of labor productivity growth and potential GDP growth in the United States. Indeed, macroeconomic developments in the late 1990s – a sharp pickup in both labor productivity and GDP growth, the decline of the unemployment rate to 30-year lows, and subdued core price inflation – suggested an acceleration in potential GDP and, consequently, a GDP gap smaller (in absolute value) than most observers had previously understood. Implementations of the Okun’s Law methodology that constrained potential output growth to evolve slowly or change infrequently were slow to recognize an acceleration in potential, while the growth accounting framework indicated that the contribution of capital services growth to labor productivity and GDP growth had picked up substantially, suggesting a possible acceleration in trend productivity

³For a detailed exposition of one implementation of this approach in the U.S. context, see Congress of the United States, Congressional Budget Office, “CBO’s Method for Estimating Potential Output: An Update”, August 2001.

⁴In fact, Okun’s Law can be viewed as a reduced form of the full growth-accounting framework. Okun (1962) wrote that “[T]he entire discussion of potential output in this paper has, in effect, assumed that idle labor is a satisfactory measure of all idle resources.... Still, I shall feel much more satisfied with the estimation of potential output when our data and our analysis have advanced to the point where the estimation can proceed step-by-step and where the capital factor can be explicitly taken into account. (p. 104).”

and potential GDP.

In addition, because the growth accounting approach builds up estimates of potential GDP growth from its components, this method may also be more useful for projecting potential GDP growth in the near term.

However, the growth accounting framework also has its downsides. The full implementation of the growth accounting method for estimating potential GDP imposes heavy requirements for data, some of which cannot be satisfied. Indeed, the main argument in favor of relying on the aggregate approach is that the labor and capital inputs used in producing GDP are measured less precisely than is GDP itself. Moreover, in the United States, official data on capital services, labor input, and multifactor productivity do not exist for the economy as a whole; such data are limited to the private business sector. In contrast, because labor is relatively free to move across sectors, three of the important building blocks for trend hours – the population, the trend labor force participation rate, and the equilibrium employment rate (1 minus the NAIRU) are only well defined for the aggregate economy. Thus, estimates of some components in the growth accounting that refer to only a part (albeit the majority) of the economy must be combined with estimates for other components that refer to the entire economy.

Another issue is that for the growth accounting framework to be helpful, one must have reliable methods for extracting trends from the data on the various determinants of aggregate economic growth. Researchers have generally used the unemployment rate gap to control for the state of the business cycle and modeled trends with the same types of specifications as used in the direct estimation of potential GDP. Thus, an estimate of the NAIRU is also key to estimating potential GDP within the growth accounting framework.

We find both the direct approach – particularly Okun's Law – and the growth accounting approach useful for informing estimates of potential GDP. We view the two approaches as complementary. Although not entirely independent, each provides a check for the plausibility of the estimates implied by the other. Indeed, one procedure for estimating potential GDP is to use Okun's Law and the growth accounting framework iteratively, asking how well estimates of potential GDP growth derived from the growth accounting framework can explain the behavior of the unemployment rate and then amending the estimates until a reasonable balance is struck

between the two methods.

The rest of this paper is organized as follows. In section II, we discuss a common econometric approach to estimating the NAIRU. In section III, we briefly describe the Okun's Law approach to estimating potential GDP. In section IV, we introduce the growth accounting framework, and describe different methods for extracting trends in the labor force participation rate, the employment rate, the average workweek, capital services, labor quality, and multifactor productivity. In section V, we illustrate the role of judgement in implementing the growth-accounting method using two recent examples.

II. Estimating the NAIRU

Both the Okun's Law and the growth-accounting approaches require an estimate of the NAIRU. While the importance of the NAIRU in the Okun's Law approach is obvious, it also plays important roles in the growth-accounting approach as well. First, the NAIRU, along with the population and the trend labor force participation rate, defines trend employment. Second, the unemployment rate gap is a useful cyclical indicator that can be used to extract trends in the components of potential GDP.

The Phillips curve is the central framework for estimating the NAIRU. Phillips' initial work was on the relationship between wage inflation and unemployment, and even as the emerging Phillips curve literature focused more on price inflation, the use of the unemployment rate or unemployment rate gap continued. In the U.S., the standard Phillips curve is a well-specified reduced-form relationship between changes in inflation, the unemployment rate gap, and supply-side factors. Price-price Phillips curves of the following form, such as those discussed by Gordon (1998) or Brayton, Roberts, and Williams (1999), serve as a common starting point for estimating the NAIRU:

$$\dot{p}_t = A(L)\dot{p}_{t-1} + \beta(U_t - U_t^*) + Z_t'\Gamma + \epsilon_t \quad (1)$$

where \dot{p}_t is price inflation, $A(L)\dot{p}_{t-1}$ is a weighted distributed lag of past values of price inflation, U is the unemployment rate, U^* is the NAIRU, and Z_t is a vector of variables meant to reflect supply-side influences. Supply-side influences may include the relative prices of food, energy, and imports, labor productivity, labor costs, and variables for government policies that may

affect inflation directly. The price-price Phillips curve (1) is also referred to as an accelerationist Phillips curve, because it is typical to impose the restriction that the sum of the coefficients on lagged inflation equals 1, a restriction that does not tend to be rejected by the data for the U.S.. With this restriction in place, the NAIRU is defined as the unemployment rate consistent with stable inflation in the medium term and in the absence of supply shocks.

In the United States, unemployment rates differ substantially by age, and to a lesser degree by gender. As a result, changes in the demographic composition of the labor force – which have been dominated over the relevant time frame by the aging of the “baby-boom” generation and the increased participation of women – explain some of the variation in the aggregate U.S. unemployment rate. Since George Perry’s early work on weighted unemployment rates, the common practice has been to use a demographically adjusted unemployment rate in (1) to purge the estimates of the unemployment rate gap ($U_t - U_t^*$) from the direct influence of changes in the demographic composition of the labor force.

In the most basic specifications of (1), economists typically assume that the demographically adjusted NAIRU is constant over time. For many years, this approach has seemed reasonable for the U.S., where the unemployment rate appeared to be roughly mean reverting, but not for many Western European countries, which experienced a secular rise in unemployment from the 1970s to the 1990s.⁵ Brayton, Roberts, and Williams (1999) tested the hypothesis of a constant NAIRU for the U.S., and found evidence in support of a break in the early to mid-1990s, although the results were sensitive to the choice of price measure. As an alternative, Brayton, Roberts, and Williams (1999), Gordon (1998), and Staiger, Stock and Watson (2001) modeled the NAIRU as an unobserved component and estimated a time-varying NAIRU using the Kalman filter. They found evidence that the demographically adjusted NAIRU had declined since the late 1980s, consistent with several structural changes in the U.S. labor market during this period, including increased incarceration (Katz and Krueger 1999), increased use of temporary help agencies (Otoo 1999), and increased generosity and availability of government disability payments (Autor and Duggan 2003).

⁵Turner, et. al. (2001) discuss the issues involved in estimating the NAIRU in the OECD countries, the particularly for the countries of Western Europe, and estimate NAIRUs for all of the OECD countries individually using the Kalman filter.

Any Phillips-curve based estimate of the NAIRU has wide confidence bands. Much of this lack of precision reflects our incomplete understanding of the inflation process: Even well specified price-price Phillips curves are usually able to explain only about 60 percent of the variance in the rate of inflation, with much of the explanatory power owing to the inclusion of lags of inflation. Moreover, the estimates of the NAIRU are sensitive to the choice of price (or wage) measure, the time period covered, and the set of included supply-side variables.

Given the uncertainties surrounding estimates of the NAIRU, several observers have questioned its usefulness as an input into the policy discussion. This debate was sharpened by the coincident declines in core PCE inflation and the unemployment rate during the late 1990s. Staiger, Stock and Watson (2001) have described the theories put forward to explain this felicitous inflation performance as falling into two groups. The “Phillips curve is alive and well, but” group suggest an inward shift in the Phillips curve, which can be described as a decline in the NAIRU or, if a temporary phenomenon, a decline in the short-run or effective NAIRU. Candidates included an acceleration in labor productivity, changes in price-setting institutions, more credible monetary policy, developments in the labor market, and good luck. The “Phillips curve is dead” group (e.g., Atkeson and Ohanian 2001) suggest that the slope of the Phillips curve has changed radically, making the NAIRU an irrelevant concept from a forecasting perspective. As this debate makes clear, one needs to be continually re-evaluating estimates of the NAIRU in light of current developments; any model goes only so far.

III. Direct aggregate approaches to estimating potential GDP

Researchers have used both univariate and multivariate methods for estimating potential GDP using aggregate data. Univariate methods – which do not bring in any other information to help extract cycle from trend – have included regressions of (the log of) real GDP on linear time trends, Beveridge-Nelson decompositions (get cites), Hodrick-Prescott (HP) filters (get cites), and the Kalman Filter (see Peter K. Clark 1987). Multivariate methods improve upon the univariate techniques by adding data for unemployment, inflation, capacity utilization, or other macroeconomic indicators to aid in the identification of potential GDP; in the multivariate setting, potential GDP has been modeled as a deterministic trend (with or without breaks) or as a stochastic trend – and then estimated using the multivariate HP filter, a structural VAR, or the

Kalman filter. In this section, we will focus only on multivariate methods, highlighting the workhorse of this genre: Okun’s “Law.”

Since Okun’s (1962) seminal work, macroeconomists have been estimating potential output using what became known as Okun’s Law, which links the GDP gap to the unemployment rate gap. As a result, the estimates of potential GDP based on Okun’s Law are consistent with our working definition of potential GDP – the level of real GDP that is consistent with stable inflation. Combining Okun’s Law and the Phillips curve described above provides links between forecasts of GDP growth, the unemployment rate, and inflation.

Okun (1962) described a contemporaneous relationship between the rate of GNP growth in excess of potential GNP growth and the change in the unemployment rate and between the level of the GNP gap and the level of the unemployment rate (relative to the 4 percent full-employment benchmark of the time). Over time, Okun’s law has been generalized as a dynamic relationship between the unemployment rate gap and the GDP gap, either with the unemployment rate gap as a function of contemporaneous and lagged GDP gaps (such as in Braun 1990) or, more parsimoniously, as an autoregression, where the unemployment rate gap is a function of lags of the unemployment rate gap and the contemporaneous GDP gap (e.g. Moosa 1999, Cuaresma 2003):

$$U_t - U_t^* = \beta_1(U_{t-1} - U_{t-1}^*) + \beta_2(U_{t-2} - U_{t-2}^*) + \gamma(Y_t - Y_t^*) \quad (2)$$

where Y_t is real GDP, Y_t^* is potential GDP, and β_1 , β_2 and γ are estimable parameters that capture the timing and magnitude of the relationship between the unemployment rate gap and the GDP gap. A dynamic specification like (2) takes account of the slow adjustment of the unemployment rate to changes in the GDP gap that results in large part from firms’ labor hoarding behavior during recessions and the substitution of longer work weeks for greater hiring early in recoveries. Implicit in Okun’s Law is the assumption that all productive factors are operating at their natural rates when the unemployment rate is equal to the NAIRU. While there are no theoretical reasons to expect all of these implied relationships to hold, in practice the estimated coefficients linking the output gap to the unemployment rate gap in the U.S. have been fairly stable over time.

The simplest specification for potential output is a deterministic trend with a constant

growth rate. However, in his initial explication of the relationship between the output gap and the unemployment rate, Okun (1962) recognized that the growth rate of potential output varies over time; Okun divided his 1947-1962 sample into pre- and post-1953 periods—with the break corresponding to the end of the Korean War. Braun (1990), following Clark (1983) set the break points at cyclical peaks. In contrast, Gordon (1984, check also 1979 paper) suggested the use of “benchmark” quarters as break points for potential output growth, where he defined the benchmark quarters as those where the unemployment rate was equal to its natural rate.⁶ Gordon argued that this choice of break points was superior to using NBER business cycle peaks because the unemployment rates at the historical peaks differed from the natural rate by varying amounts and because across different business cycles, the peaks followed the benchmark periods by different numbers of quarters. Given an estimate of the NAIRU and a set of break points, potential GDP can be estimated with (2) using either OLS or NLLS (e.g. Braun 1990).

The advantage of representing potential output as a piece-wise linear trend with infrequent break points in an Okun’s Law framework is that wiggles in the relationship between GDP gaps and unemployment rate gaps are not translated into wiggly estimates of potential GDP growth. The most important disadvantage is that any rule-based method for choosing breakpoints may breakdown in the face of structural changes in the economy.⁷ Indeed, the assumption that potential output growth changed infrequently was challenged in the late 1990s with the mounting evidence that potential GDP growth had picked up, at least in part because of the emergence of the “New Economy.” For example, Rudebusch (2000) estimated Okun’s Law with an additional break in 1995 and found evidence that potential GDP had accelerated. Rudebusch’s exercise notwithstanding, real-time detection of trend breaks is difficult – and the costs of missing a break in potential GDP include the possibility of making persistent errors in forecasts of unemployment and inflation.

⁶The natural rate series is described in Gordon (1982)—Robert J. Gordon. 1982. “Inflation, Flexible Exchange Rates, and the Natural Rate of Unemployment.” in Martin Neil Baily, ed., *Workers, Jobs, and Inflation*. Brookings Institution. Pp. 89-158.

⁷Hansen (2001) reviews the literature concerned with testing for structural breaks in economic time series. Hansen levels the important criticism that most choices of break points used in empirical work are ad hoc, and not necessarily supported by statistical tests.

The Okun's Law framework for estimating potential output has been implemented using more sophisticated time-series techniques. Clark (1989) used a bivariate system of real GNP and the unemployment rate in conjunction with the Kalman filter to extract cyclical and trend components in both series consistent with Okun's Law. Apel and Jansson (1999) used the Kalman filter to jointly extract potential GDP and the NAIRU from a system of supply-side equations including both Okun's Law and the Phillips curve. Claus (2003) reports that the Reserve Bank of New Zealand's FPS model uses a multivariate Hodrick-Prescott filter to estimate potential output that improves upon an univariate HP filter by using auxiliary information from a Phillips curve, Okun's Law, and capacity utilization to help identify the output gap.⁸

Other applications of structural time series methods to extract potential GDP have not been based on Okun's Law. In some cases, the assumption that the NAIRU is constant or even well-specified has been problematic. For example, de Brouwer (1998) found that the estimates of Australian potential GDP from a multivariate HP filter are sensitive to the inclusion of the unemployment rate as an indicator variable. In this case, structural changes in the Australian labor market had resulted in the unemployment rate remaining persistently above the conventional estimates of the NAIRU, so including the unemployment rate gap as an indicator variable boosted the estimated level of potential output. Indeed, Okun's Law is only useful for analysis in countries where a well-defined NAIRU exists. In addition to Australia, it is difficult to estimate a NAIRU for many countries – including several in western Europe – because of possible hysteresis in unemployment or because structural changes in the labor market have introduced apparent breaks in the unemployment rate series.

As an alternative, potential GDP can be estimated directly from a Phillips curve. For the U.S., Kuttner (1994) modeled potential GDP as a stochastic trend, embedded the GDP gap as the measure of resource utilization in a Phillips curve, and estimated the model using maximum likelihood and the Kalman Filter. Laubach and Williams (2001) add an equation relating the dynamics of the GDP gap to the deviation of the real federal funds rate from the equilibrium

⁸This method (excluding the measure of capacity utilization) was proposed by Laxton and Tetlow (1992).

federal funds rate, and estimate potential output and the real funds rate jointly using the Kalman Filter.

IV. The growth-accounting approach to estimating potential GDP

The growth accounting approach to estimating potential output predates Okun's Law. For example, in its 1954 report, "Potential Economic Growth of the United States During the Next Decade," the Joint Committee on the Economic Report (1954) decomposed potential GNP growth into growth in population, labor force participation, unemployment, weekly hours, and output per hour. Indeed, U.S. government estimates of potential output published in the *Economic Report of the President and Business Current Conditions* have, at times, been based on the growth accounting approach.⁹ However, through most of the 1960s, estimates of potential output based on Okun's Law dominated academic discussions, reflecting the prevailing view at the time that the full-employment unemployment rate (the predecessor to the NAIRU) was constant at 4 percent and that potential output could be modeled as a piece-wise linear trend. Perry (1971) noted that estimates based on the two methods were largely in agreement through 1969, despite a pick-up in labor force growth and a slowing in both average weekly hours and labor productivity in the late 1960s, because these changes to the components of potential growth were offsetting.

With the apparent breakdown in Okun's Law in the early 1970s, there was renewed academic interest in estimates of potential output growth derived from a neoclassical growth accounting framework. Perry (1971) and Perloff and Wachter (1979) described alternative growth accounting approaches to estimating potential output growth that differed in their scope (Perloff and Wachter included energy as an input into value-added production) and in their methods of extracting trends in the components of output growth.

The description of the growth accounting approach below generally follows that in Clark (1983). Using a simple Cobb-Douglas production function, output growth can be expressed as a weighted average of the growth rates of factor inputs – capital services and labor input (which is

⁹Academic work in this area was generally limited in the 1960s, with the notable exceptions of Thurow and Taylor (1966), Kuh (1966), and Black and Russell (1969).

divided into hours worked and labor quality) – and a residual, which is labeled multifactor or total factor productivity growth:

$$\dot{y}_t = \alpha_t \dot{k}_t + (1 - \alpha_t)(\dot{h}_t + \dot{q}_t) + \dot{a}_t \quad (3)$$

Lower case letters with dots above indicate rates of change expressed as log differences, where:

Y	=	output
K	=	capital services
L	=	hours
Q	=	labor quality
A	=	multifactor (or total factor) productivity
α_t	=	income share of capital

Output growth is frequently discussed in terms of the growth rate of raw labor hours and the growth rate of output per hour (labor productivity). In these terms, the growth accounting identity can be rewritten as:

$$\dot{y}_t = \dot{h}_t + \dot{\pi}_t \quad (4)$$

where π is the log of labor productivity. Labor productivity growth can be further decomposed into:

$$\dot{\pi}_t = \alpha_t(\dot{k}_t - \dot{h}_t) + (1 - \alpha_t)\dot{q}_t + \dot{a}_t \quad (5)$$

where $\alpha_t(\dot{k}_t - \dot{h}_t)$ is the contribution of capital deepening (capital income share times the growth rate of capital services per labor hour) and $(1 - \alpha_t)\dot{q}_t$ is the contribution of labor quality.

Hours growth can, in turn, be decomposed into

$$\dot{h}_t = \dot{p}_t + \dot{r}_t + \dot{e}_t + \dot{w}_t \quad (6)$$

where \dot{p}_t is the growth rate of the civilian noninstitutional population aged 16 and older, \dot{r}_t is rate of change in the labor force participation rate, \dot{e}_t is the rate of change in the employment rate (one minus the unemployment rate), and \dot{w}_t is the rate of change in the average workweek.

An advantage of the growth accounting approach is that it focuses attention on the

various factors that drive output growth, rather than simply on observations of the historical behavior of output growth or on the relationship between output and labor input. This is particularly important during periods of structural change in the U.S. economy – such as the productivity slowdown of the late 1960s/early 1970s, the surge and subsequent slowdown in population growth owing to the entrance of the baby-boom generation in the 1960s and 1970s, the rapid increase in the female labor force participation in the 1970s and 1980s, or the pickup in labor productivity growth in the second half of the 1990s. Another advantage of the growth accounting approach is its intuitive simplicity: This framework is easily described to a wide range of audiences, in part because it can be related to the economic theory of the firm.

This approach has a few disadvantages as well. First, the growth accounting approach requires several strong assumptions about the how the economy functions. For example, the approach assumes that markets are competitive and always in equilibrium. In addition, as typically implemented, the growth accounting approach assumes that capital becomes fully productive as soon as it is installed. In steady state these assumptions may not matter much, but supply shocks that induce significant changes in production technologies or relative prices – such as large energy price shocks – may cause the accounting to go off track. Finally, a full implementation of this framework imposes heavy data requirements, raising the possibility of measurement error. Despite these limitations, this framework has been a mainstay of growth analysis for many years, reflecting the widespread view that it generates numbers that are sensible.

Unfortunately, official series for output and factor inputs for the aggregate U.S. economy do not exist. Because of these data limitations, analysis of economic growth using the production function framework in the U.S. has focused on the private nonfarm business (NFB) sector, which accounts for more than three-quarters of the nominal output produced in the U.S., and for which the U.S. Bureau of Labor Statistics (BLS) publishes consistent data.¹⁰ In general, analysts get around this limitation by aggregating estimates of potential output in the NFB sector

¹⁰Although the BLS also publishes data for the slightly larger private business sector, we, like most analysts, think that difficulties in measuring hours worked in the farm sector and differences in production technologies between the farm and nonfarm sectors favor limiting the scope of our analysis to the private nonfarm business sector.

and less sophisticated estimates of potential output in the balance of the economy (the farm sector, the housing sector, the government sector, and the household and institutions sector).

Decomposition of output growth in the NFB sector

Table 1 presents a decomposition of actual NFB output growth (line 1) over the 1960 to 2001 period. Line 2 shows the growth rate of labor productivity, and lines 3 through 5 show the components of labor productivity growth: the contribution of capital deepening, the contribution of labor quality (or composition), and MFP growth. The data for the components of labor productivity are taken from the BLS's multifactor productivity program. Line 6 shows the growth rate of NFB sector hours, and lines 7 through 11 show a decomposition of hours growth. Because labor can flow reasonably freely across sectors, it is not possible to specify what part of the population "belongs" to the nonfarm business sector; hence there are no sectoral equivalents for the population (line 7), the participation rate (line 8), or the employment rate (line 9). Accordingly, these figures refer to the aggregate economy.¹¹ Line 10 presents the average difference between the growth rates of employment in the NFB sector and employment in the economy as a whole, which reconciles the different scopes of the data. Line 11 shows the growth rate of the average weekly hours in the NFB sector.

The subperiods shown in the first four columns table 1 correspond approximately to the periods between business cycle peaks (with the exception of the peak in 1981). The average growth rates from peak to peak shed light on the factors driving economic growth, and are themselves, in effect, crude estimates of trend growth rates during each of the subperiods. We now turn to brief discussions of estimation of each component for estimating potential GDP.

Trend hours growth

In order to construct the contribution of trend capital deepening to trend labor productivity, as well as to build from trend labor productivity to potential output, we must have an estimate of the growth rate of trend hours in the NFB sector. As just mentioned, because the

¹¹The data are adjusted for discontinuities in the published estimates, due mostly to updates to estimates of the population.

population is only well-defined for the total economy, we express trend NFB hours growth in terms of the growth in the population, changes in the labor force participation rate, changes in the equilibrium employment rate, changes in the average workweek, and a “wedge” between aggregate and NFB employment growth:

$$\dot{h}_t^* = \dot{p}_t^* + \dot{r}_t^* + \dot{e}_t^* + \dot{w}_t^* + \dot{n}_t^* \quad (7)$$

where \dot{p}_t^* is the growth rate of the civilian noninstitutional population aged 16 and older, \dot{r}_t^* is rate of change in the trend in the labor force participation rate, \dot{e}_t^* is the rate of change in the equilibrium employment rate, \dot{w}_t^* is the rate of change in the average workweek, and \dot{n}_t^* is defined (tautologically) as the difference between the trend growth rates of aggregate employment and NFB sector employment.

In order to estimate NFB sector trend hours, it is necessary to decompose the labor force participation rate, the employment rate, the average workweek, and the wedge between aggregate employment and NFB sector employment into cyclical, trend, and idiosyncratic components:

$$x_t = x_t^c + x_t^* + x_t^i \quad (8)$$

where x_t represents any of the series, x_t^c is the cyclical component, x_t^* is the trend component, and x_t^i is the idiosyncratic component; the decomposition of trend hours growth assumes that trend population is equivalent to actual population.

Several methods are available for extracting the trend components. The CBO models each trend component as a linear spline with break points at business cycle peaks and uses the unemployment rate gap to control for the cycle. The FRB/US model specifies the trend components as stochastic trends (to be estimated with the Kalman filter) and also uses the unemployment rate gap as the cyclical control. However, no single method seems entirely appropriate to all series. While the methods we discuss below may not be directly applicable to other countries because of cross-country differences in labor market structure, they are demonstrative of the type of analysis we see as necessary to construct trend hours and, subsequently, potential output using the growth accounting framework.

Population

As shown in the table, the actual U.S. noninstitutional civilian population rose at an average annual rate of nearly 2 percent from the mid-1960s through the 1970s, then slowed fairly dramatically to between 1 and 1-1/4 percent thereafter.¹² The slowing of population growth reflects the passing of the “baby boom” that followed World War II. More recently trends in population growth have been increasingly driven by trends in immigration. Because illegal immigration is naturally difficult to measure, this has increased the uncertainty surrounding real-time estimates of population growth. It also raises the possibility of cyclicity in population growth, which would violate the typical assumption that trend population equals actual population.

Labor force participation

The labor force participation rate in the U.S. moved up sharply through the 1970s and 1980s, driven by rising female labor force attachment that was only partially offset by declining male participation rates. Beginning in the late 1980s, the rise in female participation slowed, and the aggregate participation rate flattened out. Figure 1 shows the aggregate labor force participation rate, with recessions shaded in grey. It is clear from the figure that the changes in the slope of the participation rate did not correspond to business cycle peaks. In this case, then, modeling the trend as a linear spline with breaks at the business cycle peaks is inadequate. We have found that specifying the trend as a spline with simultaneously chosen break points or modeling the trend as an unobserved component and using the Kalman filter to estimate it yield superior results.

In principle, it also makes sense to estimate the trend separately for different demographic groups. Not only have the trends for men and women obviously been different, but institutional and other influences ought to differ by age. (For example, the evolution of pension systems is more relevant to older than to younger age groups.) In addition, the cyclical sensitivity of labor force participation seems to differ across demographic groups; this could

¹²The noninstitutional civilian population which excludes active duty military personnel, prisoners, and those confined to psychiatric institutions

imply that the coefficient on the unemployment rate gap in a regression using the aggregate participation rate may be unstable over time. However, in practice, we have found it difficult to estimate stable and easily interpretable trends for individual demographic groups. This is puzzling, but estimating a trend for the aggregate participation rate appears to meet with more success.

Equilibrium employment rate

The equilibrium employment rate is 1 minus the NAIRU, and varies over time with changes in the demographic composition of the labor force and with structural changes in the labor market. The baby boom's entrance into the labor market drove up the labor force share of young people and, because younger workers tend to have higher unemployment rates, depressed the equilibrium employment rate through the 1970s into the early 1980s; then, as the baby boomers aged, their cohort-average unemployment rate declined, which boosted the equilibrium employment rate.

In addition, structural changes in the labor market may have lowered the NAIRU (raised the equilibrium employment rate) since the mid-1980s. Autor and Duggins have pointed out that more generous government disability benefits have induced a greater number of disabled workers to remain out of the labor force, and that because these individuals were more likely to be unemployed than average this has pushed down the NAIRU. Maria Otoo has suggested that increased internet job search has raised search efficiency and lowered the NAIRU. Others have suggested that an increased rate of incarceration has also lowered the NAIRU over the past 20 years.

The trend workweek

The average workweek in the U.S. (as measured by the survey of establishments) declined in the 1960s, 1970s, and 1980s, reflecting changes in the demographic and industrial composition of U.S. employment. The workweek appeared to have leveled off in the 1990s, although the failure of the workweek to recover since the end of the 2001 recession suggests that the trend may have turned down again.

The workweek is shown in figure 2. As with the participation rate (figure 1), the changes

in slope of the workweek do not correspond to business cycle peaks, which suggests that modeling the trend in the workweek as a linear spline with breaks at business cycle peaks could produce misleading estimates of both the cyclicalities of the workweek and the trend growth rates. We have explored two different specifications for the trend in the average workweek. The first specifies the trend in the workweek as a function of the demographic composition of the labor force. Because adult men aged 20-54 have higher workweeks, on average, than adult women, teenagers, and older workers aged 55 and above, increases in the labor force shares of these latter groups have tended to push down the average workweek. The second specifies the trend as a function of the industrial composition of employment. Whereas there has been no discernible trend in the manufacturing workweek, which has remained at around 40 hours, workweeks outside of manufacturing have fallen over time. Moreover, as the employment shares of retail trade and services have increased, the average aggregate workweek has tended to decrease. Both specifications yield similar estimates of the trend workweek.

Trend Labor Productivity Growth

In addition to their importance for the growth accounting of potential GDP, estimates of trend labor productivity growth are of interest because of the possible link between the sustained acceleration of labor productivity beginning in the mid-1990s and the quiescent inflation performance over this same period. Ball and Moffitt (2001) attribute nearly all of the favorable inflation performance to the acceleration in productivity, while Gordon (1998) is more muted in his conclusions. In this section we will discuss methods for extracting trends in labor productivity and separately for its components – the contribution of capital deepening, the contribution of labor quality, and multifactor productivity.

Direct estimates of trends in labor productivity

A wide range of econometric techniques have been applied to reduced-form specifications to estimate the trend component of labor productivity, including a simple regression of labor productivity on a linear spline, univariate Beveridge-Nelson decompositions, multivariate Beveridge-Nelson decompositions (e.g. George Evans and Lucrezia Reichlin 1992 and Giuseppe Nicoletti and Lucrezia Reichlin, 1993), and structural VARS. Among these, both

the multivariate Beveridge-Nelson approach and the structural VAR approach exploit the comovements among cyclical variables to decompose labor productivity into trend and cyclical components, and as a result produce smoother estimates of the trend component. These methods do not, however, exploit the economic relationships between the labor productivity and other macroeconomic variables..

Oi (1962) characterized labor as a quasi-fixed factor of production, and the cyclical nature of labor productivity has often been explained as the result of firms' labor hoarding behavior – that is that firms hold on to valuable workers during periods of low production in order to economize on hiring costs when the economy picks up. Braun (1990) wrote down a simple hours-adjustment model that is consistent with labor hoarding behavior

$$\Delta h_t = \beta(\hat{h}_t - h_{t-1}) \quad (9)$$

in which hours adjust to close part of the gap each period between desired hours (\hat{h}_t) and last period's actual hours. Under the assumption that production reacts so that output equals aggregate demand, desired hours can be defined as the hours that would be required to meet aggregate demand (y_t) if productivity was at its trend level (π_t^*) and (9) can be rewritten as:

$$\Delta h_t = \beta \left[(y_t - \pi_t^*) - (y_{t-1} - \pi_{t-1}^*) \right] \quad (10)$$

or

$$\Delta h_t = \beta \left[\Delta y_t + (\pi_{t-1}^* - \pi_t^*) \right] \quad (11)$$

In this model, β is between 0 and 1, so that hours grow faster when output grows more rapidly and in order to close the gap between lagged productivity and current-period trend productivity. Braun specified trend labor productivity as a linear spline with growth rates constrained to be equal from business cycle peak to business cycle peak, and estimated the model using NLLS.

While simulations of Braun's model can generate procyclical productivity consistent with labor hoarding behavior, this specification effectively rules out the presence of the labor adjustment costs that lead to labor hoarding by assuming that firms' desired level of hours depends only on current production. In unpublished work, Charles Fleischman wrote down a

simple model of cost minimization that includes quadratic adjustment costs for hours and a quadratic loss function for allowing hours to deviate from desired hours (as defined above). Embedded within the model was a specification for trend labor productivity as a linear spline with growth rates constrained to be constant from peak to peak. The Euler equation (intertemporal first-order condition) could be estimated by GMM using an approach described by Fleischman (1997). Estimates of trend labor productivity growth were similar to those obtained from the Braun model, and simulations of hours and productivity were surprisingly similar as well.

Roberts (2001) relaxed another constraint implied by Braun's model—that the response of hours growth to output growth is the same as the response to the gap between trend and actual productivity. Roberts' alternative posits that hours growth depends on trend hours growth, the change in the output gap, and the lagged gap between actual and trend labor productivity:

$$\dot{h}_t = \dot{h}_t^* + \beta_1(\dot{y}_t - \dot{y}_t^*) + \beta_2(\pi_{t-1} - \pi_{t-1}^*) + e_t \quad (12)$$

where y_t^* is potential output in the NFB sector, defined as $h_t^* + \pi_t^*$. Roberts specified trend labor productivity as a random walk with a stochastic drift:

$$\pi_t^* = \pi_{t-1}^* + d_t + e_t^1 \quad (13)$$

where

$$d_t = d_{t-1} + e_t^2 \quad (14)$$

and d_t is the stochastic drift and e_t^1 and e_t^2 are iid innovations.

By specifying trend labor productivity as a random walk with stochastic drift, Roberts allows for the possibility of both permanent jumps in the level of trend productivity and permanent changes in the growth rate of trend labor productivity. Especially during periods of structural change, like the late 1990s, the use of a stochastic trend has several advantages over the deterministic trends used by Braun (1990) and Fleischman (unpublished). Most importantly, it allows the level and growth rate of trend labor productivity to adjust in a timely fashion to structural changes—like the increased importance of the growth in high-tech capital in driving

economic growth.¹³ Indeed, Roberts found that trend labor productivity accelerated from a growth rate of an average annual rate of around 1-1/2 percent from the early 1970s to the mid 1990s to about 2-1/2 percent in early 2001,¹⁴ which was consistent with the view that rapid capital services growth had led to a late-1990s sustainable acceleration in labor productivity.

Estimates of the components of trend labor productivity

As described above, trend labor productivity growth can be decomposed into the contribution of trend capital deepening, the contribution of trend labor quality, and the growth rate of trend MFP:

$$\dot{\pi}_t^* = \alpha(\dot{k}_t^* - \dot{h}_t^*) + (1 - \alpha)\dot{q}_t^* + \dot{a}_t^* \quad (15)$$

The advantage of estimating trend labor productivity growth as above, is that the labor productivity data are better measured than the data for capital services, labor quality, and multifactor productivity. Nevertheless, a decomposition like (15) can be extremely useful for developing a richer understanding of the factors driving labor productivity growth.

The Contribution of Trend Capital Deepening

Calculation of the contribution of capital deepening to trend labor productivity growth has typically used data on capital services growth and capital's income share from the BLS and an estimate of the trend growth rate of NFB hours. There is a question of how to distinguish between actual capital services and trend capital services. One approach, which is used by the CBO in their growth accounting framework, is to treat actual and trend capital services as equivalent. Indeed, while business investment and capital stock growth clearly fluctuate over the

¹³This approach has important limitations for policy analysis, however. First, the forecasts of the trend labor productivity growth are sensitive to the choice of allowing both I(1) and I(2) shocks or allowing only I(2) shocks. Second, at the endpoints of the sample, the estimates of the trend are subject to being “head-faked” by the recent data; for example, one-sided estimates of trend productivity growth in the early 1990s—another period of “jobless recovery” suggested an acceleration in the trend, while two-sided (smoothed) estimates of trend productivity growth during this period now show no signs of an early 1990s acceleration.

¹⁴Subsequent and pending data revisions would likely change these estimates.

business cycle, the actual path of investment – and hence the actual growth rates of firms’ capital stocks and services – may best capture the growth in available resources (that is, the potential) to produce goods and services at any point in time; this is analogous to the treatment of the population.

The BLS constructs aggregate capital services as a weighted sum of the capital stocks of individual detailed assets, where the weights represent the relative marginal products of the different assets. The BLS estimates capital stocks (KS_{it}) for the detailed assets using a perpetual inventory method, in which the stock of a particular asset is a weighted sum of previous investments in this asset (I_{it-j}):

$$KS_{it} = s_{i0}I_{it} + s_{i1}I_{it-1} + s_{i2}I_{it-2} + \dots \quad (16)$$

where the s_{ij} are the asset’s relative economic efficiency j years after purchase. The efficiency function, s_{it} , captures the normal economic depreciation of an asset, and depends on the asset’s normal service life and the pattern of depreciation.

The marginal product of each asset is related to the (after tax) rental rate:

$$\text{after-tax rental rate}_{it} = (1 - \text{tax rate}_{it})(\text{interest rate}_i + \text{depreciation}_i - \text{capital gain}_{it}) \quad (17)$$

and reflects the relative efficiency of each particular asset. The after-tax rental rates differ across assets primarily because of differences in their useful lives. For example, a unit of computer capital has a short useful life and likely will be scrapped after only a few years. Because the cost of the computer is amortized over a very short period of time, it implicitly must (in equilibrium) have a high marginal product and gets a high weight. In effect, the service flow from a unit of this capital must be large enough to cover the costs of rapid obsolescence. In contrast, a unit of office building capital—which has quite a long useful life—generates a smaller service flow in each year and gets a smaller weight because there are many years over which the costs of the asset can be amortized.

Several potentially problematic assumptions go into constructing capital services. First, the efficiency function depends only on the asset’s age, and not on economic conditions, relative input prices, interest rates, or technological development. Thus, the BLS measure of capital

services will not capture cyclical changes in depreciation, such as the lengthening of replacement cycles for high-tech equipment that likely occurred in the current recession. Second, the efficiency function for most assets assumes that investment is most efficient initially, and that efficiency declines as the asset ages. For some assets, there can be a considerable interval between when the capital good is purchased (investment) and when it comes on line. In addition, there may be a further interval between when a project comes on line and when it contributes fully to production. The costs associated with the lags between investment and productivity are often referred to as adjustment costs, and may include physical installation costs, training costs, and learning how best to fit the capital into the company's production processes. Third, while the BLS accounts for the fact that some assets are discarded (scrapped) more quickly than average, while others remain employed considerably longer than their normal service lives, this variation in actual asset lives is assumed to be constant over the business cycle; as a result, the BLS will not capture accelerated scrapping of plants that also occurs during recessions. Finally, the prices of most capital goods are poorly measured; most likely, published capital goods prices overstate true capital goods prices, which will lead to a downward bias in the measure of capital services.

Contribution of Trend Labor Quality

In estimating the contribution of labor input to production, the BLS attempts to adjust hours worked for changes in the experience, education, and gender composition of the work force. Hours for worker classified by educational attainment, age and gender, are aggregated with weights determined by their shares of labor compensation. The difference between the growth in this weighted aggregation of hours and the growth in unweighted hours is an estimate of the contribution of changes in labor quality to productivity growth.

The contribution of changes in labor composition to actual output growth was negligible in the 1960s and especially the 1970s as increases in educational attainment were offset by increases in the share of relatively inexperienced younger persons (from the baby boom) and women in the workforce. In the 1980s, as the Baby boomers aged and educational attainment continued to increase, the contribution turned positive. The rise in educational attainment had slowed considerably by the 1990s, but remained positive as female labor force participation rates

flattened out, and both the Baby boomers and women continued gain experience.

Some of the changes in the contribution of labor composition to productivity growth are cyclical or idiosyncratic in nature, so in writing down the contributions of trends in labor quality to trend productivity one wants to smooth out the fluctuations in the contributions to actual productivity. Moreover, the rates of change in labor composition likely evolve slowly, so it is not unreasonable to extrapolate recent rates forward for purposes of forecasting. On the other hand, Aaronson and Sullivan (2001) produce a forecast of changes in labor quality based on Census Bureau projections of the working-age population by age, sex, race, and Hispanic ethnicity. Using this information and extrapolating trends in the educational attainment and labor force participation rates of these demographic groups, Aaronson and Sullivan expect the contribution of changes in labor composition to productivity growth to fall steadily, reaching less than 0.1 percentage point per year by 2010. The primary reason for this decline is the aging of many Baby boomers past their peak earning years.

Trend MFP growth

MFP growth is defined as the residual—the portion of NFB labor productivity growth that cannot be accounted for by the contributions of capital deepening and labor quality, and, importantly, should not be misidentified as technology growth. Notably, any errors in measuring capital deepening or labor quality will skew estimates of MFP growth. For example, because the BLS measures of capital services only partially account for the procyclicality of capital utilization, there is a procyclical bias in MFP. In addition, because years of education, years of experience (typically proxied by age), and sex are only crude and incomplete indicators of labor quality, any changes in labor quality that are not captured or proxied for by these measures – such as changes in the quality of schooling, changes in the quantity and importance of on-the-job training or changes in the share of immigrants in the workforce – that have implications for productivity will affect estimates of MFP growth.

Even (especially) with these caveats in mind, estimation of trend MFP growth is a critical part of the estimation of trend labor productivity growth in the growth accounting framework. The correlation of MFP growth and labor productivity growth is greater than 0.9 over the 1960 to 2001 period, and cyclical fluctuations in MFP account for nearly all of the cyclicity of labor

productivity. Moreover, as indicated on table 1, there have been important low frequency changes in MFP growth since 1960.

To extract the trend in MFP, the CBO models trend MFP growth as a deterministic trend with break points at cyclical peaks and controls for the cyclical nature of MFP using the unemployment rate gap. However, the arbitrary choice of break points may be particularly problematic for estimating the trend in MFP. The peak-to-peak method generates an abrupt slowdown in trend MFP growth in 1973, whereas others generally using a Hodrick-Prescott filter have dated the beginning of the slowdown sometime in the mid-to-late 1960s, and found that the slowing in MFP growth was somewhat gradual.

Roberts (2001) respecified his hours adjustment model so that trend MFP, rather than trend labor productivity was the unobserved component:

$$\dot{h}_t = \dot{h}_t^* + \beta_1(\dot{y}_t - \dot{y}_t^*) + \beta_2(\pi_{t-1} - \alpha(k_{t-1} - h_{t-1})^* - (1 - \alpha)q_{t-1}^* - a_{t-1}^*) + e_t \quad (18)$$

and

$$a_t^* = a_{t-1}^* + d_t + e_t^1 \quad (19)$$

and

$$d_t = d_{t-1} + e_t^2 \quad (20)$$

Estimates of trend MFP based on (18) - (20) suggest a modest acceleration in the second half of the 1990s that, when combined with an estimate of the contributions of capital deepening and labor quality to trend labor productivity growth, was consistent with his estimates of trend labor productivity growth.

V. Current issues: The role of judgment

Analysts are faced with the ongoing challenge of updating their estimates of potential GDP, trend productivity, and the NAIRU in reaction to new and often uncertain or incomplete data on the recent performance of the economy. The techniques and approaches we have described constitute a useful set of tools for doing so, but even the best techniques often leave much to judgment.

For example, relying on model-based estimates of trend MFP growth alone could yield estimates of trend labor productivity growth and potential GDP growth that might be too smooth—as would be the case if trend MFP is modeled as a piece-wise linear trend—or that might fluctuate widely from year to year—as could be the case if trend MFP is modeled as an unobserved component. Thus, in order for the model-based estimates of trend MFP to be useful for estimating and forecasting trend labor productivity growth and potential output growth, they must be refined using other information about technological developments and supply shocks (such as changes in energy prices) that influence the choice of production technologies, and assessments about the sources and sustainability of changes in the estimated growth rate of MFP over recent quarters and over longer history.

One still-unresolved question is what to make of the surprisingly high rates of labor productivity growth over the past two years. It had been widely anticipated that productivity growth would slow if business investment spending slowed because the acceleration in NFB sector labor productivity—from a annual average growth rate of about 1-1/2 percent in the 1974-1995 to annual average growth rate of about 2-1/2 percent between 1996:Q1 and 2000:Q4—had been attributed largely to strong growth in capital services in the late 1990s. In the event, business investment spending fell during the 2001 recession and then remained weak through the middle of 2003. However, rather than slowing, labor productivity accelerated further, to an average annual growth rate of 4-1/4 percent from 2001:Q1 to 2003:Q3 (and more than 5 percent since the end of the recession). A key question is, naturally, how much of the recent pick-up in productivity growth is a temporary phenomenon, and how much is likely to persist. That is, has trend productivity, and thus potential output, accelerated? The answer to this question, in turn, depends upon identifying the sources of the pickup and its recent continuation.

An acceleration in productivity is not unusual early in a recovery. Similar accelerations occurred following every post-WWII recession. However, in the recoveries from the 1974-75 and early 1980s recessions, a surge in hours growth soon followed the jump in productivity. In the recovery from the 1990-91 recession, however, this pattern broke down. In the two years following the 1991:Q1 cyclical trough, productivity growth was strong, while hours growth was weak. The current recovery has deviated further from the earlier pattern, as the surge in productivity was accompanied by a decline in NFB hours.

One possibility, of course, is that the nature of technological advances has raised the growth rate of trend productivity growth. For example, the Roberts (2001) Kalman filter model would interpret the recent experience this way. However, the fact that the early 1990s experience was somewhat similar to the recent episode raises the possibility that we may instead be seeing a different cyclical pattern rather than, or in addition to, a change in trend productivity growth.¹⁵ If so, of course, one wants an explanation for the change, and particularly for the more surprising recent episode.

One argument for why the recent acceleration may in part reflect unusual (or changed) cyclical behavior is that uncertainty about the strength and durability of the recovery has caused employers to continue to substitute worker effort for hours because of the sunk costs involved in adjusting hours. For this argument to be correct, the level of uncertainty following the end of the recession would have to have been unusually high by historical standards. This is, of course, plausible, given the concerns that the September 11, 2001 terrorist attacks would lead to a deep recession, the financial market scandals of late 2001 and 2002, and the uncertainty surrounding the timing and ramifications of the war in Iraq. If uncertainty has been unusually elevated, then trend productivity growth has not accelerated as much as would be indicated by the Kalman filter estimates, and one would expect to see the recent above-trend growth in productivity to reverse as the economy and hiring picks up steam.

Another possibility is that sustainable level of trend productivity has increased in recent years, but there has not necessarily been any increase in the sustainable growth rate of trend productivity. Perhaps, relatively low profit margins have led firms to concentrate on improving the efficiency of existing operations rather than expanding them. In this argument, firms are more fully integrating their IT capital purchased in the late 1990s or taking better advantage of improvements in communications, software, and computing technology than was possible during the late 1990s boom. Moreover, the shake-out of less efficient or profitable firms, such as many speculative internet start-ups, may increase productivity by reallocating resources within

¹⁵Indeed, Kalman-filter based estimates of trend productivity had a tendency to initially attribute the strong productivity growth coming out of the 1990-91 recession as an increase in trend growth; subsequently, actual productivity growth slowed dramatically and the models recognized that there had been no permanent acceleration in trend productivity.

industries. This might be interpreted as a permanent increase in the level of trend productivity that has few implications for the growth rate of trend productivity going forward.

In contrast, Basu, Fernald, and Shapiro (2001) suggest that the growth rate of MFP was understated in the late 1990s, because the strong growth in investment caused firms to incur large capital adjustment costs. They have argued that output growth, and hence MFP growth, was understated because firms devoted resources to installing new capital that would otherwise have been used to produce measurable output. Thus, when investment slowed, this drag on output and MFP growth subsided. One interpretation of their argument is that in the late 1990s the contribution of capital growth to productivity growth was overstated because adjustment costs were not taken into account; as a result, the role of MFP growth was understated. Depending on the size of the adjustment costs, this story could be consistent with either a further pickup in trend productivity growth or a permanent increase in the level of trend productivity with no implications for growth rates looking forward.

None of the models described earlier can discriminate convincingly in real time among the three possibilities: An increase in the rate of trend productivity growth; a temporary surge in productivity; and a one-off increase in the level of trend productivity. Other data must be brought to bear. For example, one bit of evidence against the effort-substituting-for-hours hypothesis is the behavior of the workweek, which has declined fairly steadily over the past two years. A priori one might expect the workweek to be positively correlated with employee effort because it, too, likely requires very small sunk costs to adjust. However, a significant share of private sector employees are salaried and have non-varying weekly hours paid. Thus, if increases in effort were achieved through additional weekly hours worked by salaried employees, this hypothesis would still be tenable.

Another unresolved question is how to interpret substantial revisions to the data on hours introduced to the productivity calculations this past summer. The sources of these revisions were several, involving both new source data and changes to methods. Most notable among them were the conversion of the U.S. survey of establishments to a new probability sample/birth-death model system, which one would expect to lead to more accurate measurement, and the conversion of the survey of establishments to the North American Industrial Classification System, which changed the classification of many workers from production or nonsupervisory to

non-production or supervisory.

Revisions to hours growth for years prior to 2001 were small and offsetting. However, NFB sector hours growth over the four quarters of 2001 was revised down 1-1/4 percentage points, the majority of which implicitly reflected a downward revision to the workweek. Hours growth over 2002 and the first quarter of 2003 was revised down as well.

As a result, the official estimates of productivity growth since the recession began were revised up substantially, raising a question similar to that raised above: How much of this revision to take as a signal that the rate of trend productivity growth was greater than we had thought, how much to take as a signal that the level of trend productivity was higher, without any necessary implications for the rate of growth going forward, and how much reflected a new or unique cyclical response of productivity with no implications for trend productivity?

Naturally, the upward revisions to historical productivity growth implied by the revisions to hours lead models such as the Kalman filter models to revise up their estimates of trend productivity growth. According to such models (e.g. Roberts 2001), the coincidence of strong productivity growth and sustained hours declines does not conform to the usual cyclical pattern. Consequently, the models believe that the recent large increases in the level of productivity are not due to transitory cyclical phenomena, but are instead permanent. Kalman filter models attribute the permanent increase in the level of productivity to both permanent changes in only the level (i.e. shocks to the I(1) component of trend productivity) and permanent changes in the growth rate of trend productivity (i.e. shocks to the I(2) component) in fixed proportions depending on the estimated variances of these two components.

However, as above, it is also possible to interpret the data as indicating only a one-time permanent shift in the *level* of trend productivity. That is, one could interpret the greater post-revision drop in hours and associated jump in productivity, particularly in 2001, as reflecting primarily a one-off shift in the level of trend hours and trend productivity, owing to changes in methodology, as well as one-time gains in trend productivity owing to firms learning to better use their existing productive resources. Under this view, the greater productivity shown in the revised data reflects a permanent gain in trend productivity, but not one that necessarily implies a greater rate of trend productivity growth in the future.

On the other hand, because the revised hours data were not accompanied by revisions to

data on GDP, the unemployment rate, or prices, the revisions to the hours data do not affect the fit of Okun's Law or Phillips curve equations. Thus, they need not imply any revision to estimates of potential GDP. In terms of the growth accounting, this dichotomy could be accommodated by revising the estimates of trend hours to offset revisions to the estimates of trend productivity.

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Supply-Side Components of Actual GDP
(Average annual log difference)

	1964-1973	1973-1980	1980-1990	1990-2000	2000-2001
1. NFB Output	4.8	3.0	2.8	3.4	0.9
2. Labor Productivity (NFB)	2.6	1.2	1.4	2.0	2.6
3. Private capital deepening	0.9	0.9	0.8	0.8	1.9
4. Labor composition	0.0	0.1	0.4	0.4	0.4
5. Multifactor productivity	1.7	0.3	0.2	0.8	0.3
6. NFB hours	2.1	1.7	1.4	1.4	-1.8
7. Working-age population	1.9	1.9	1.2	1.2	1.8
8. Labor-force participation	0.4	0.7	0.4	0.1	-0.2
9. Employment rate	0.1	-0.3	0.0	0.1	-0.8
10. NFB employment minus aggregate employment	0.2	0.1	0.1	0.2	-1.4
11. Average weekly hours	-0.5	-0.7	-0.2	-0.1	-1.2
12. GDP – NFB output	-0.6	-0.3	-0.1	-0.4	0.3
13. GDP	4.2	2.7	2.7	3.0	1.1

Note. Detail may not sum to totals due to rounding.

Figure 1

Labor Force Participation Rate

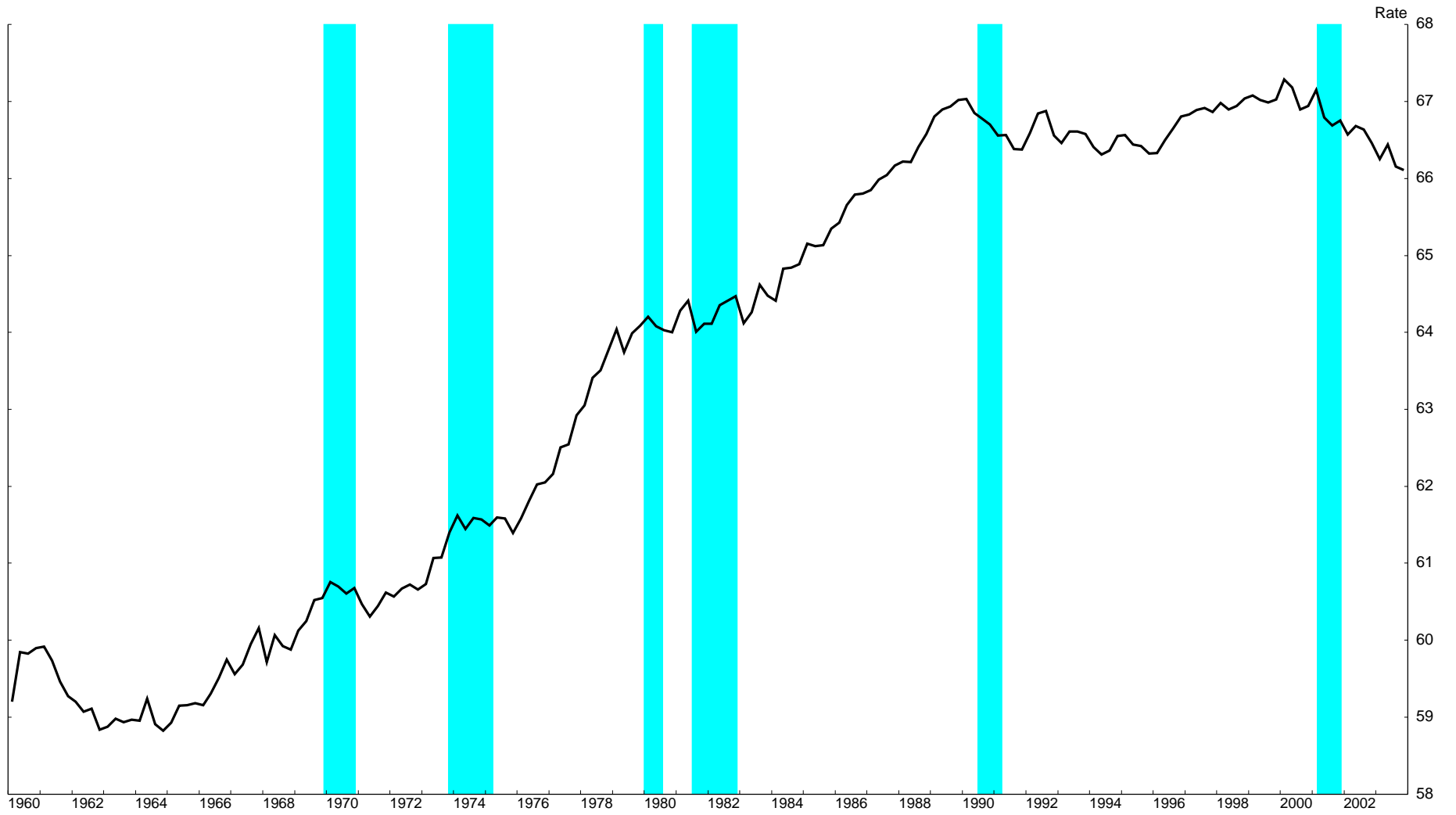
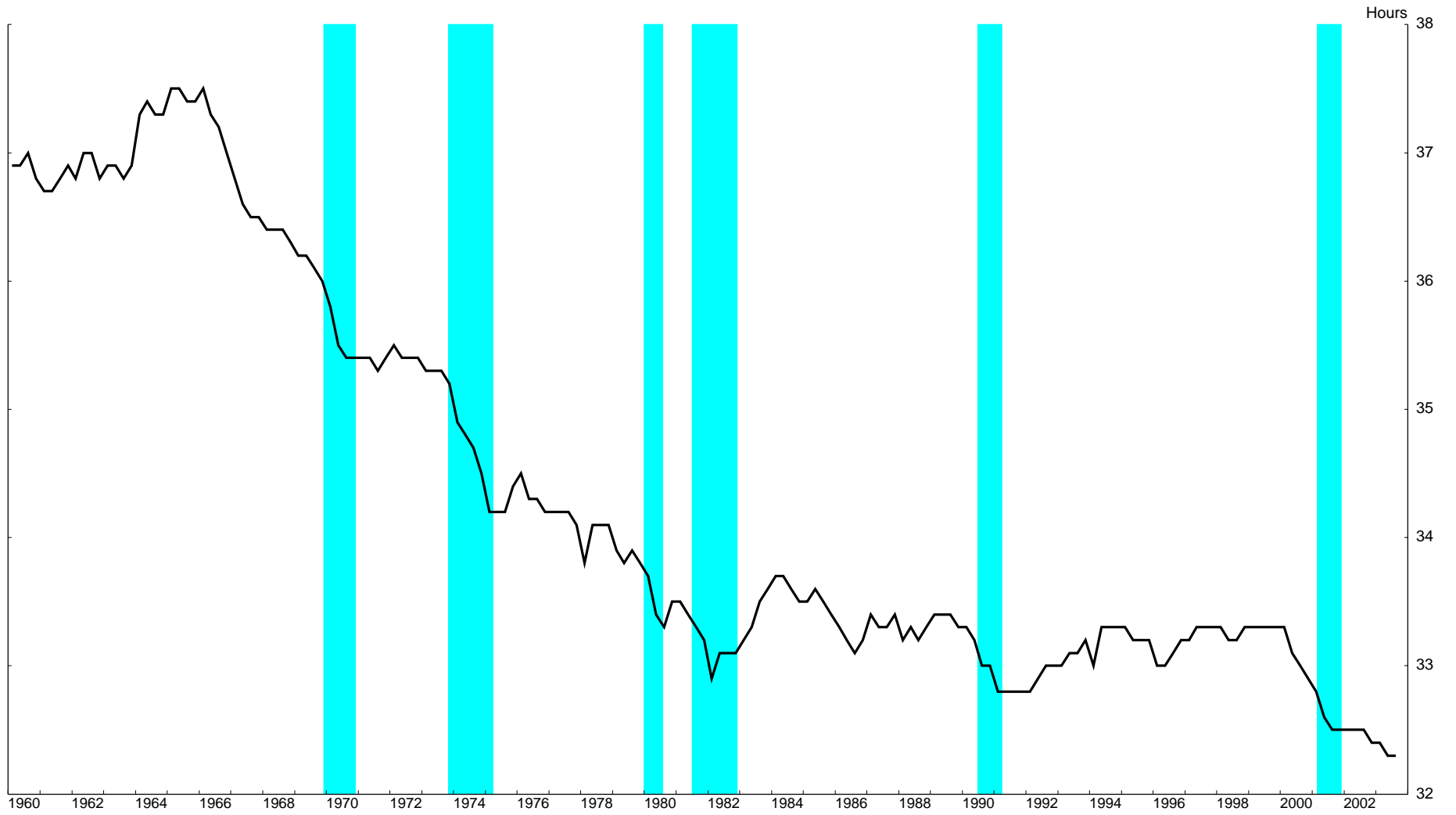


Figure 2

NFB Workweek



Models and Judgment in the Estimation of Potential Output for the U.S.A.

Bruce Fallick
Federal Reserve Board

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Federal Reserve Board

Disclaimer

The views expressed in this paper are those of the authors and do not necessarily represent the views or policies of the Board of Governors of the Federal Reserve System or their staff.

Potential GDP and the NAIRU

- NAIRU: the rate of unemployment consistent with stable inflation in the absence of supply shocks.
- Potential GDP: the level of GDP if factors of production are operating at rates consistent with stable inflation.

Judgmental Approach

- Econometric models and formal estimation techniques
- A wide variety of information not captured in formal models

Estimating the NAIRU

$$\dot{p}_t = A(L)\dot{p}_{t-1} + \beta(U_t - U_t^*) + Z_t'\Gamma + \varepsilon_t$$

- Wide confidence bands
- Time varying?
- Outside information
 - Disability payments; efficient job search
 - Credibility of monetary policy
 - Acceleration in labor productivity
 - Pricing power
 - Good luck
- “Short-run” or “effective” NAIRU

Estimating Potential GDP: Okun's Law

$$U_t - U_t^* = \beta_1(U_{t-1} - U_{t-1}^*) + \beta_2(U_{t-2} - U_{t-2}^*) + \gamma(Y_t - Y_t^*)$$

- Potential GDP is often specified as a linear spline, with knots at business cycle peaks.

Other Aggregate Approaches

- Phillips curve
- Systems of supply-side equations
- Univariate or multivariate filters

Growth Accounting

- Rate of output growth is the weighted sum of rates of growth of inputs.

$$\dot{y}_t = \alpha_t \dot{k}_t + (1 - \alpha_t)(\dot{h}_t + \dot{q}_t) + \dot{a}_t$$

Rewrite and expand the growth accounting equation:

$$\dot{y}_t = \dot{h}_t + \dot{\pi}_t$$

$$\dot{\pi}_t = \alpha_t (\dot{k}_t - \dot{h}_t) + (1 - \alpha_t) \dot{q}_t + \dot{a}_t$$

$$\dot{h}_t = \dot{p}_t + \dot{r}_t + \dot{e}_t + \dot{w}_t$$

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Advantages

- Facilitates discussion and explication of individual factors driving output growth
 - E.g., capital growth in the late 1990s
 - Baby boom and rise in female participation
- Intuitive simplicity
 - Related to theory of the firm
 - Easily described to a wide audience

Disadvantages

- Strong assumptions
 - Competitive equilibrium
 - Capital is fully productive when installed
- Heavy data requirements
 - Non-business sector
 - Measurement error
- Only as good as methods for extracting trends for components

Extracting Trends

- General methods
 - Linear splines
 - Stochastic trends; Kalman filter
 - Unemployment rate gap as cyclical control
- Must be modified case by case

Figure 1

Labor Force Participation Rate

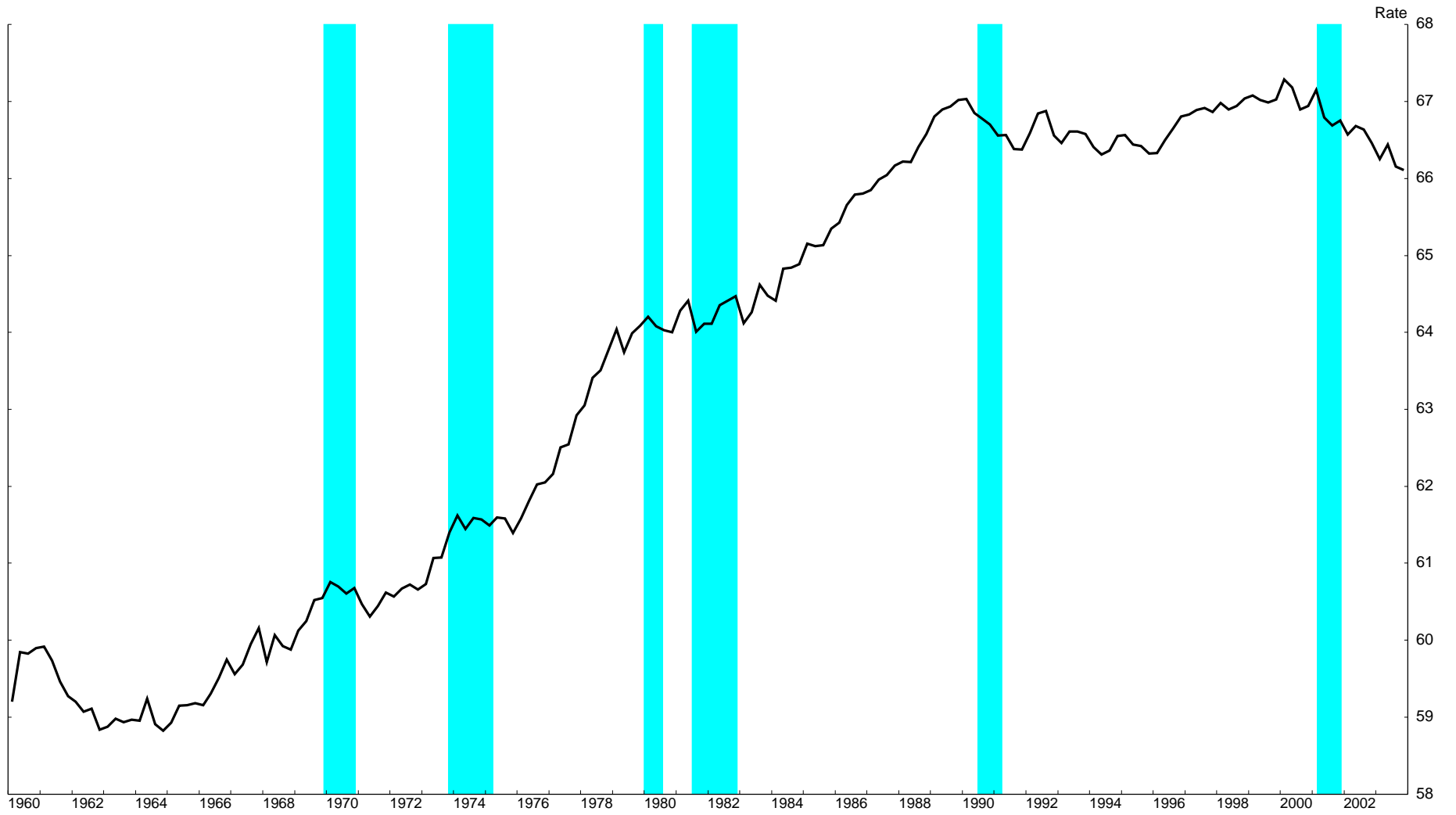
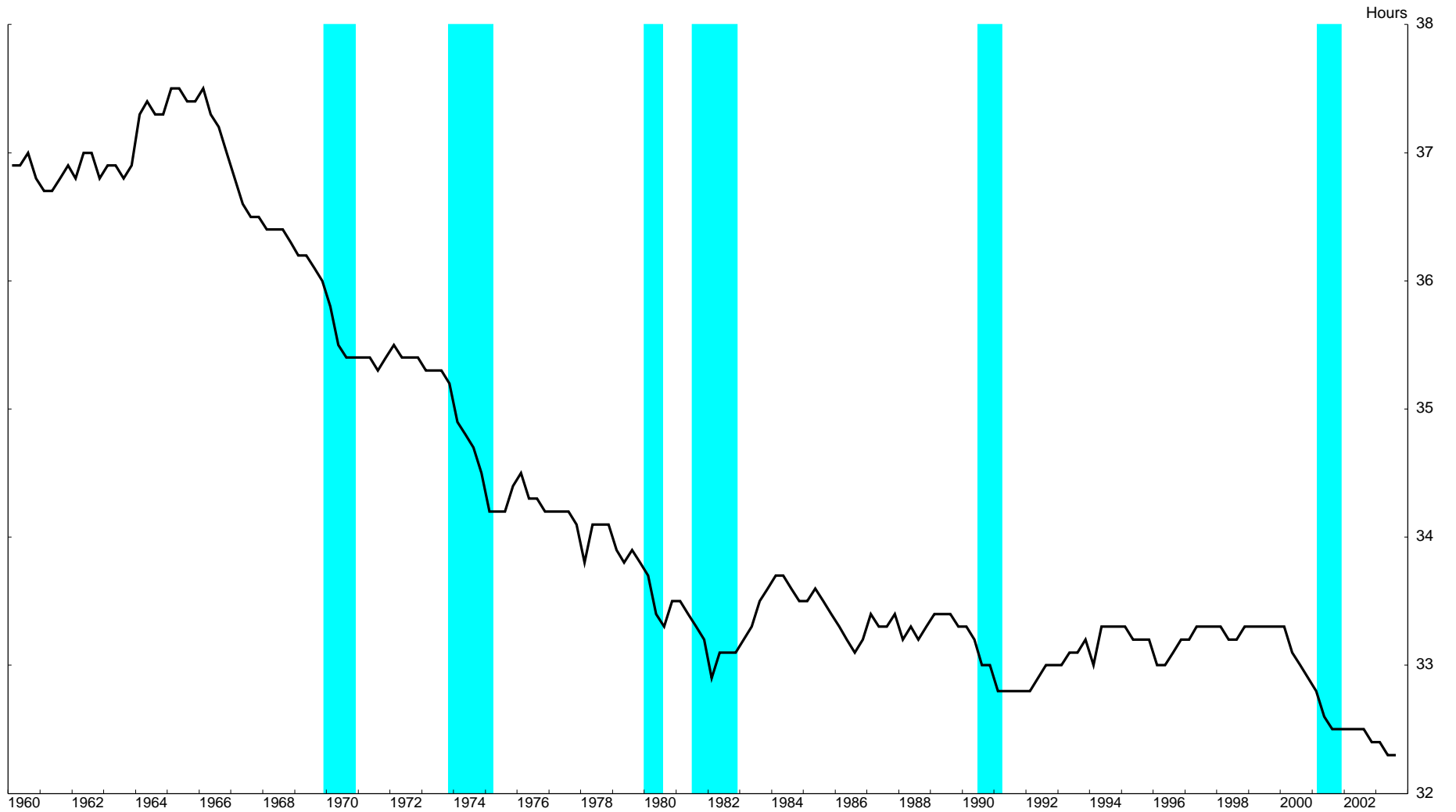


Figure 2

NFB Workweek



Trend Capital Deepening

- Data on actual capital services growth and capital's share of income from BLS
 - Depreciation a function of age only
 - Prices often poorly measured
- How to extract trend in capital services?
 - Assume that actual represents productive capacity, that is, potential.

Trend MFP

- Linear spline with unemployment gap
- Hours adjustment models
 - Deterministic linear spline
 - Stochastic growth rate and level; Kalman filter
 - Markov switching with Kalman filter

Cautions

- MFP is a residual
 - Deficiencies in measurement of other components appear in estimates of MFP
- Comprehensive revision next month

Judgment: Recent Acceleration

- Productivity has accelerated since the recession began in 2001:Q1.
- Three possibilities w.r.t. trend productivity
 - Trend has accelerated.
 - Trend has jumped (one-time shift in level).
 - Trend unaltered; Temporary deviation.

Acceleration in MFP?

- Usual cyclical pattern would have hours accelerating as productivity accelerated.
- In this episode, hours growth was weak.
- Kalman filter models interpret this as an acceleration in trend MFP.
- Followed a smaller apparent acceleration in MFP in the late 1990s.

Temporary Deviation?

- Early 1990s similar, although less severe; Productivity slowed once the expansion was well underway
- Numerous anecdotes of uncertainty about recovery currently restraining hiring
- Productivity could again stall once business confidence returns

One-time level shift?

- Most of the acceleration in productivity in late 1990s attributable to capital deepening.
- In the past few years, capital deepening decelerated, and MFP accelerated.
- Companies may be better utilizing the large amounts of IT capital they bought during the expansion
- Shake-out of unprofitable “boom” firms.