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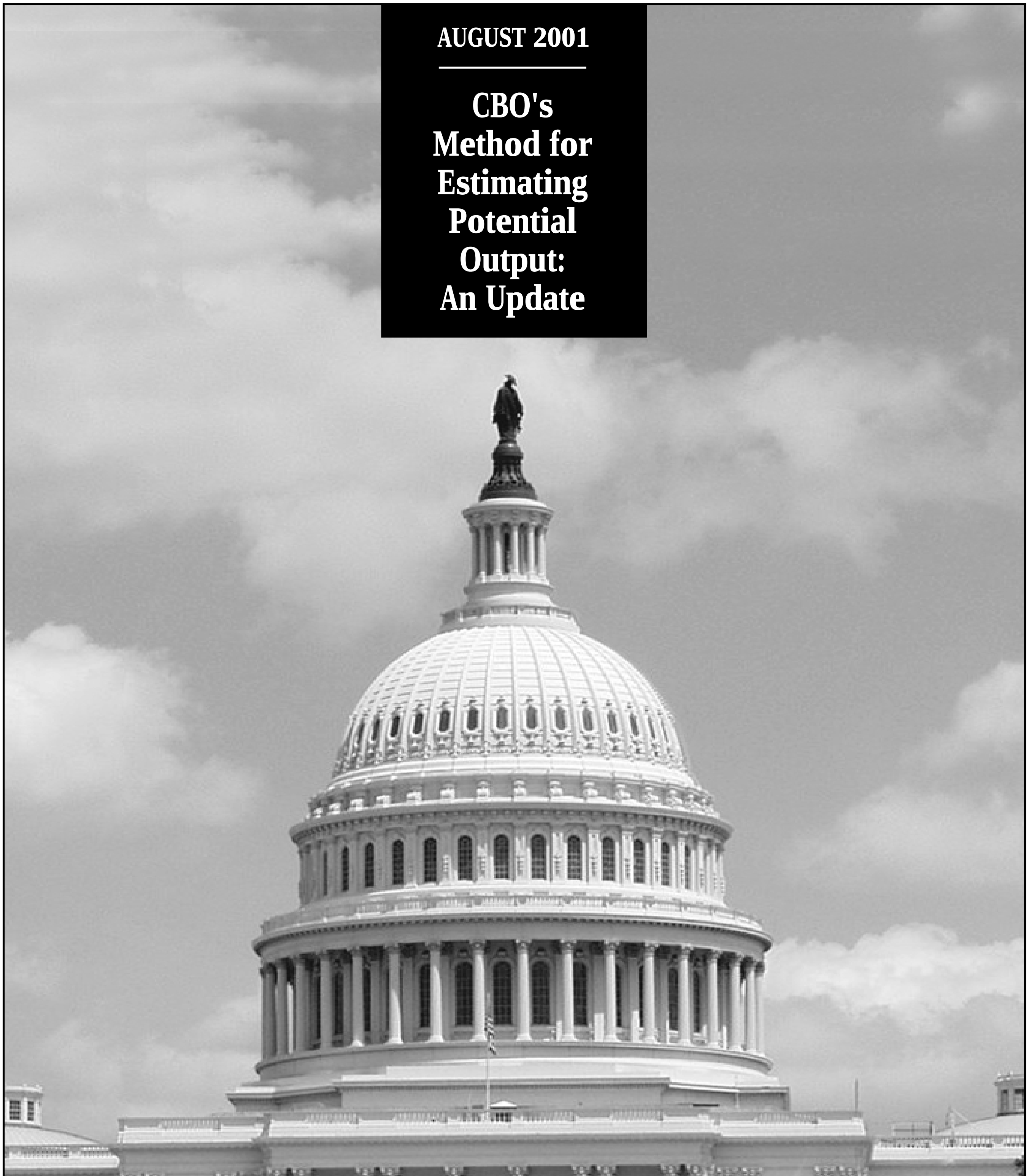
CBO's Method for Estimating Potential Output: An Update



CBO'S METHOD FOR ESTIMATING POTENTIAL OUTPUT: AN UPDATE

August 2001

The Congress of the United States
Congressional Budget Office

NOTES

Unless otherwise indicated, all of the years referred to in this paper are calendar years.

Numbers in the text and tables may not add up to totals because of rounding.

The figures in this paper use shaded vertical bars to show periods of recession. The bars extend from the peak to the trough of each recession.

PREFACE

The Congressional Budget Office's (CBO's) estimate of potential output plays an important role in its economic forecast. This paper describes the method that CBO uses to estimate past and present potential output and to make 10-year projections, as well as changes in that method over the past five years. The paper also compares CBO's estimates with those of other agencies and discusses the advantages and disadvantages of alternative estimating methods. The paper updates a report of the same title published in October 1995.

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INTRODUCTION AND SUMMARY

As part of its mission to provide information to the Congress, the Congressional Budget Office (CBO) is required to produce budget projections 10 years into the future. An important underpinning of those budget projections is projections of various economic variables, such as the real (inflation-adjusted) level of the nation's output—gross domestic product, or GDP. CBO forecasts real GDP two years ahead. For the other eight years of its 10-year projections, it assumes that actual output will gradually move to the level of potential output.

Potential output—the trend growth in the productive capacity of the economy—is an estimate of the level of GDP attainable when the economy is operating at a high rate of resource use. It is not a technical ceiling on output that cannot be exceeded. Rather, it is a measure of maximum *sustainable* output—the level of real GDP in a given year that is consistent with a stable rate of inflation. If actual output rises above its potential level, then constraints on capacity begin to bind and inflationary pressures build; if output falls below potential, then resources are lying idle and inflationary pressures abate.

This paper describes the method that CBO uses to estimate potential output. That method starts with the framework of a Solow growth model, with a neoclassical production function at its core, and estimates trends in the components of GDP using a variant of a tried-and-tested relationship known as Okun's law. According to that relationship, actual output exceeds its potential level when the rate of unemployment is below the "natural" rate of unemployment.[1] Conversely, when the unemployment rate exceeds its natural rate, output falls short of potential. In models based on Okun's law, the difference between the natural and actual rates of unemployment is the pivotal indicator of what phase of a business cycle the economy is in.

Other methods could also be used to make 10-year projections of GDP. CBO has investigated a variety of time-series methods—which rely primarily on historical patterns in real GDP itself rather than in capital or labor—as alternatives to the standard growth model. In addition, some forecasts use a more simplified growth model that relies on projections of total hours worked and overall labor productivity.

CBO will continue to examine alternative procedures for developing 10-year projections of real GDP. Some of those alternative methods, and their strengths and weaknesses relative to the method used by CBO, are discussed in this paper. However, in CBO's view, the standard growth-accounting framework, despite its drawbacks, is preferable to any of the alternatives examined to date.

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1. CBO's estimate of the natural (or equilibrium) rate of unemployment is the nonaccelerating inflation rate of unemployment (NAIRU), which is the rate of unemployment consistent with a stable rate of inflation. CBO estimates the NAIRU using the historical relationship between the unemployment rate and changes in the rate of inflation. Other researchers use different estimates of the natural rate, such as the average historical rate of unemployment.

This paper updates one that CBO released in 1995.[2] Since then, CBO has altered its method slightly to accommodate revisions in historical data and to better explain recent events. Despite those modifications, the basic procedure for computing potential output remains much the same.

CBO made several of the modifications to cope with changes in the way that underlying data are calculated. Those changes include the Bureau of Economic Analysis's (BEA's) switch from fixed-weighted quantity indexes to chain-weighted Fisher indexes, its redefinition of GDP in the government sector to include depreciation, its revision of business investment to include software, and various changes to the formulas used to compute the price indexes that underlie data from the national income and product accounts (NIPAs).

CBO also altered its method to address changing economic circumstances. In particular, labor productivity has been growing much faster since 1995 than its post-1973 trend. Because that acceleration has coincided with explosive growth in many areas of information technology (IT)—including telecommunications, personal computers, and the Internet—many observers have speculated that the U.S. economy has entered a new era, characterized by more-rapid productivity growth. Those observers argue that trends from the 1980s and early 1990s are no longer relevant benchmarks for projecting labor productivity. After analyzing the data and the relevant empirical literature, CBO has concluded that elements of the so-called IT revolution—including very strong investment in IT goods and rapid productivity growth in the manufacture of semiconductors and computers—explain much of the acceleration in the growth of labor productivity during the late 1990s. CBO has incorporated many of those elements into its economic projections.

None of the changes described above affected the fundamental structure of CBO's growth model; however, two other revisions did. Based on a review of the theoretical evidence and advice from members of its Panel of Economic Advisers, CBO modified the model by adding land as a factor of production. Also, to better gauge the impact of IT investment on the growth of potential output, CBO added two more categories—software and communications equipment—to its breakdown of business investment. Those changes alter the index of capital services that enters the model's production function.

2. Congressional Budget Office, *CBO's Method for Estimating Potential Output*, CBO Memorandum (October 1995).

CBO'S GROWTH MODEL FOR POTENTIAL OUTPUT

As noted above, CBO's model for estimating potential output is based on the framework of the Solow growth model.[3] Though simple, Solow's model has become a workhorse; it is now the basis of most studies of long-term economic growth. The Solow growth model focuses on two factors that drive growth in the supply side of the economy: labor input (hours worked) and accumulation of physical capital (additions to the nation's stock of plant and equipment). The equation that summarizes the relationship between the growth of real GDP in the core business sector and the growth of those two inputs is called a production function. (The part of real GDP growth that cannot be attributed to growth of those two inputs is called total factor productivity; it also plays an important role in estimating potential GDP.) For smaller sectors of the economy, such as government, agriculture, or housing, simpler equations are used to model output. Those equations generally relate the growth of output in a sector to the growth of the factor input—either capital or labor—that is more important for production in that sector.

To compute historical values for potential output, CBO estimates potential, or cyclically adjusted, versions of the factor inputs and then combines them using the production function. Cyclical adjustment removes the influence of the business cycle on a variable in order to estimate the variable's trend component. To project potential output in future years, CBO extrapolates those cyclically adjusted factor inputs and substitutes them back into the production function. (The cyclically adjusted variables are constructed to follow linear time trends over history, so they have constant growth rates and are easy to extrapolate.)

The crucial advantage of using a growth model to calculate potential output is that its framework includes the capital stock—a fundamental input to production. Not all methods do; some include only the labor input, and others rely solely on the historical behavior of real GDP to estimate potential output. Perhaps more important, CBO's framework explicitly models the factors that determine the accumulation of capital, so the projection for the capital stock is fully consistent with CBO's projections for private saving and the federal budget. Specifically, a higher projected rate of saving will lead to faster accumulation of capital and faster growth of potential output. Therefore, a higher projected federal surplus, which generally raises

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3. CBO's growth model is based on one that researchers at the Brookings Institution developed to analyze the Social Security trust funds. See Henry J. Aaron, Barry P. Bosworth, and Gary T. Burtless, *Can America Afford to Grow Old?* (Washington, D.C.: Brookings Institution, 1989) for a description of the original model. CBO's method for estimating potential output is similar to the methods used by the International Monetary Fund, the Organization for Economic Cooperation and Development, and the consulting firm Macroeconomic Advisers. See Macroeconomic Advisers, *Productivity and Potential GDP in the New U.S. Economy* (St. Louis: Macroeconomic Advisers, September 1999); Charles Adams and David Coe, "A Systems Approach to Estimating the Natural Rate of Unemployment and Potential Output for the United States," *IMF Staff Papers*, vol. 37 (June 1990), pp. 232-293; and Raymond Torres and John P. Martin, "Potential Output in the Seven Major OECD Countries," *OECD Economic Studies*, no. 14 (Spring 1990), pp. 127-149.

the rate of national saving, will speed up the growth of the capital stock and potential output in the model. Conversely, a recession or other event that depresses the saving rate will temporarily slow the accumulation of capital and the growth of potential output.

A range of other effects on potential output can be incorporated using the model. For example, if a change in policy, such as a cut in tax rates, is estimated to alter the incentives that affect work effort or productivity, then including those effects in a projection or policy simulation is a straightforward task.

CBO's measure of potential output is computed from real gross domestic product, which comprises the output of five sectors: nonfarm business, government, farm, households and nonprofit institutions, and residential housing, as shown in equation (1).[4] The nonfarm business sector is by far the largest of the five. In 2000, it accounted for 76 percent of total GDP, compared with 11 percent for the next largest sector (government). Combining GDP and gross foreign product (the return to U.S. residents on factors of production held abroad minus the return to foreigners on factors of production held in the United States) yields gross national product, as shown in equation (2).

$$GDP = GDP_{nfb} + GDP_{govt} + GDP_{farm} + GDP_{hhnp} + GDP_{housing} \tag{1}$$

$$GNP = GDP + \text{gross foreign product} \tag{2}$$

where

GDP	=	gross domestic product
GDP_{nfb}	=	gross domestic product in the nonfarm business sector
GDP_{govt}	=	gross domestic product in the government sector
GDP_{farm}	=	gross domestic product in the farm sector
GDP_{hhnp}	=	gross domestic product in the households and nonprofit institutions sector
$GDP_{housing}$	=	gross domestic product in the housing sector
GNP	=	gross national product

All of the variables in equations (1) and (2) are measured in billions of chained 1996 dollars.

4. Earlier versions of the model included a statistical discrepancy in equation (1) because BEA's estimates of sectoral output were based on data from the income side of the NIPAs, whereas overall GDP was based on data from the product side of the NIPAs. That statistical discrepancy is the difference between GDP measured using production-based components and GDP measured using income-based components. In principle, the two measures should be identical, but in practice, they generally are not. In 1995, however, BEA changed its calculation of sectoral output from one based on income-side definitions to one based on product-side definitions. Consequently, the statistical discrepancy no longer appears in equation (1).

CBO uses that disaggregated approach to compute potential output for two basic reasons. First, limitations on data make it difficult to estimate a single production function for GDP. A complete set of data on factor inputs (capital and labor) is available for the nonfarm business sector, but data for many of the other sectors are incomplete. Those limitations affect the way in which some sectors of the economy are modeled. Second, different sectors have different methods of production; some rely more heavily on their capital stock, others more on their workforce. Since those sectors' production methods are not well described by the neoclassical production function used for the core business sector, they are modeled separately.

In the previous version of CBO's model, equations (1) and (2) were used to compute both nominal (not adjusted for inflation) and real GDP. In late 1995, however, BEA began to compute inflation-adjusted variables using new formulas, replacing fixed-weighted indexes with Fisher indexes (see Box 1). The new indexes give a more accurate picture of real growth in the long run because they are less tainted by substitution bias (which occurs when businesses and households switch from goods and services whose prices rise fastest to those whose prices grow more slowly). Moving to Fisher indexes did not substantially change the basic relationships captured by the model, but it did introduce the complication that one cannot aggregate the components of real variables merely by adding them together. In CBO's model for computing potential output, all aggregation of real variables is done with Fisher formulas.[5]

Equations (1) and (2) form the basis for estimating potential GDP and potential GNP. The model computes potential output in current dollars for each sector and then computes potential GDP and GNP as the Fisher sum of the individual sectors.

$$(1') \quad GDP^{*} = GDP^{*}_{nfb} + GDP^{*}_{govt} + GDP^{*}_{farm} + GDP^{*}_{hhnp} + GDP_{housing}$$
$$(2') \quad GNP^{*} = GDP^{*} + \text{gross foreign product}$$

where (*) denotes the potential values for a series.

For two elements—residential housing and gross foreign product—potential output is close to actual output because those elements are largely unaffected by the U.S. business cycle. The Department of Commerce measures the output of the housing sector (the flow of housing services) as the sum of all rents paid to the owners of the nation's housing stock, including rent paid to others as well as an imputed rent

5. BEA's revised formulas are described in a series of articles in the *Survey of Current Business*. See J. Steven Landefeld and Robert Parker, "BEA's Chain Indexes, Time Series, and Measures of Long-Term Economic Growth," *Survey of Current Business* (May 1997); Robert Parker and Eugene Seskin, "Preview of the Comprehensive Revision of the National Income and Product Accounts: New and Redesigned Tables," *Survey of Current Business* (October 1995); and Allan Young, "Alternative Measures of Change in Real Output and Prices, Quarterly Estimates for 1959-92," *Survey of Current Business* (March 1993).

BOX 1.
FISHER INDEXES

To compute changes in real (inflation-adjusted) gross domestic product (GDP), the Bureau of Economic Analysis (BEA) must be able to divide the change in total spending in the economy into the components that result from changes in prices and from changes in quantities produced. One way to do that is to specify a single base period, or a constant set of prices, and then compute the value of quantities produced in all periods using those prices. An advantage of that so-called fixed-weighted measure of real GDP is that it has a clear interpretation—it is the value of a given year's output if all prices had remained at their base-year level. BEA used fixed-weighted indexes to compute real GDP until 1996.

As an example of how fixed-weighted measurement works, consider a world in which only two goods exist: apples and bananas. In such a world, nominal GDP is computed as the sum of all expenditures, or

$$GDP_t = P_{apple,t} \bullet Q_{apple,t} + P_{banana,t} \bullet Q_{banana,t}$$

where $P_{apple,t}$ = price of apples in year t
$Q_{apple,t}$ = quantity of apples purchased in year t
$P_{banana,t}$ = price of bananas in year t
$Q_{banana,t}$ = quantity of bananas purchased in year t

To compute real GDP using fixed-weighted indexes, simply use the prices that prevailed in an arbitrary base year (say, 1987) in the calculation,

$$\text{Real } GDP_t = P_{apple,1987} \bullet Q_{apple,t} + P_{banana,1987} \bullet Q_{banana,t}$$

One problem with the fixed-weighted measure of real GDP is that it can give a distorted picture of real growth when relative prices are changing, which happens when some prices rise faster than others. Since buyers tend to shift their purchases toward goods and services whose prices are rising less quickly, holding the price weights fixed at their base-year values gives an increasingly distorted picture of growth as more time passes. Until 1996, BEA addressed that problem—known as substitution bias—by updating the base year every five or 10 years. Although that updating improves current growth rates, it distorts past growth rates by a greater amount. Moreover, each update of the base year forced BEA to rewrite economic history. Furthermore, the increasing importance of computer purchases, with their rapidly declining prices, meant that the base-year pricing procedure could not keep pace and resulted in distorted estimates.

To solve the problem of substitution bias, BEA switched from using fixed-weighted indexes of real GDP to chain-type annual-weighted indexes, known as Fisher indexes. Those indexes do not use any specific base year; instead, they calculate each year's real growth using the prices of that year and the preceding year as weights. Thus, they reflect any changes in relative prices or shifts in the composition of output that occur over time. Under the new procedure, BEA does not need to rewrite economic history every few years, as it did under the previous method.

BOX 1.
CONTINUED

Fisher indexes are computed as the geometric average of the growth rates of two fixed-weighted indexes. The first, known as a Laspeyres index (IL), computes the growth in the value of the quantities produced from one year to the next using the first year's prices as weights. The second index, known as a Paasche index (IP), computes the change in the value of output using the second year's prices. The formulas are somewhat involved, but they simplify into expressions that calculate overall real growth for each component of GDP by its share of nominal output. Continuing the previous example,

$$IL_t = (s_{apple,t-1} \bullet (Q_{apple,t} / Q_{apple,t-1})) + (s_{banana,t-1} \bullet (Q_{banana,t} / Q_{banana,t-1}))$$
$$IP_t = [(s_{apple,t} \bullet (Q_{apple,t} / Q_{apple,t-1})^{-1}) + (s_{banana,t} \bullet (Q_{banana,t} / Q_{banana,t-1})^{-1})]^{-1}$$

where
$$s_{apple,t} = (P_{apple,t} \bullet Q_{apple,t}) / (P_{apple,t} \bullet Q_{apple,t} + P_{banana,t} \bullet Q_{banana,t})$$
$$s_{banana,t} = (P_{banana,t} \bullet Q_{banana,t}) / (P_{apple,t} \bullet Q_{apple,t} + P_{banana,t} \bullet Q_{banana,t})$$

Both indexes are computed as weighted averages of the growth rates of output of the components, where the weights are each component's nominal share of GDP. An important difference between the two indexes is that the first one, IL_t, uses a lagged share whereas the second, IP_t, uses the contemporaneous share. The Fisher index (IF) is the geometric mean of those two indexes:

$$IF_t = (IL_t \bullet IP_t)^{1/2}$$

The Fisher formula yields a time series of growth rates for real GDP. BEA computes the level of GDP by "chaining," or cumulatively multiplying, those growth rates. To do that, BEA sets real GDP equal to nominal GDP in an arbitrary base year, currently 1996. Then it sequentially applies the growth rates from the Fisher formula forward and backward to compute a time series for real GDP. BEA refers to the units of that series as chained 1996 dollars.

Although the chain-type indexes give a more accurate view of real growth over long periods of time, they have a significant disadvantage, aside from their added complexity. The components of real GDP (such as real consumption, real investment, and so on) no longer sum to overall real GDP, as they did when fixed-weighted indexes were used. Therefore, it is impossible to calculate real shares of GDP. For example, dividing real investment expenditures by real GDP will not produce an estimate of real investment as a share of real GDP.

on owner-occupied housing.[6] Although investment in residential housing displays a marked cyclical pattern, the services that flow from the existing stock of housing do not. CBO smooths the Commerce Department's values for GDP in the housing sector to eliminate short-run fluctuations and assumes that potential output in the housing sector equals smoothed output in all time periods.

Like housing GDP, gross foreign product also lacks a strong cyclical component. In the NIPAs, it is measured as U.S. receipts of factor income from foreigners minus U.S. payments of factor income to foreigners. Although factor income includes employee compensation, the bulk of it comes from income flows that are only loosely related to the U.S. business cycle, such as undistributed corporate profits, interest, and dividend payments based on corporations' overseas activities. CBO adds historical values for gross foreign product to potential GDP to estimate historical values for potential GNP.

ESTIMATING HISTORICAL VALUES FOR POTENTIAL OUTPUT

Estimates of past values for potential output depend heavily on estimates of potential output in the nonfarm business sector, which accounts for about three-quarters of GDP. For that sector, CBO uses the growth model's production function, which explains the growth of output in terms of three explanatory variables: labor, capital, and total factor productivity (TFP). Those variables are cyclically adjusted and then substituted back into the production function, yielding values of potential output. Historical values for potential output in other sectors of the economy are computed separately, using the same procedure but with simpler equations that generally include a single factor input.

The Nonfarm Business Sector

The heart of CBO's growth model is a neoclassical production function that calculates GDP in the nonfarm business sector as a function of hours worked (labor), the capital stock, and TFP. The general form of the production function, known as Cobb-Douglas, is

(3) $$Q_{nfb} = A_{nfb}L^{(1-\alpha)}{}_{nfb}K^{\alpha}{}_{nfb}$$

where Q_{nfb} = real GDP in the nonfarm business sector (in chained 1996 dollars)
A_{nfb} = total factor productivity (index, 1992 = 1.0)

6. The sum is adjusted to avoid double-counting payments for intermediate goods and services, such as property insurance, maintenance, and durable goods (appliances). Those adjustments are a small proportion of the total.

L_{nfb} = hours worked in the nonfarm business sector (in billions)
K_{nfb} = capital input in the nonfarm business sector, lagged one year (index, 1992 = 1.0)

The production function also includes a scaling constant that is suppressed from equation (3) to simplify the exposition.[7]

Taking logs of equation (3) yields equation (3a):

(3a) $\log(Q_{nfb}) = \log(A_{nfb})\ (1\text{-}\alpha)\bullet\log(L_{nfb}) + \alpha\bullet\log(K_{nfb})$

Taking the total differential of equation (3a) yields equation (3b), which is the fundamental growth-accounting relationship used in the model:

(3b) $\%\Delta Q_{nfb} = \%\Delta(A_{nfb}) + (1\text{-}\alpha)\bullet\%\Delta(L_{nfb}) + \alpha\bullet\%\Delta(K_{nfb})$

which states that the growth rate of real GDP in the nonfarm business sector equals a weighted average of the growth rates of labor and capital plus the growth of TFP. Note that the equation must hold over time because the historical values for TFP growth are computed as a residual from equation (3b). Thus, any historical growth in real GDP that is not accounted for by growth in labor or capital is attributed to TFP. Although growth in TFP is often ascribed to technological progress, in practice it can also result from anything else, such as model error or measurement error, that causes output to grow faster than the measured inputs.

The parameters of the production function (that is, the coefficients 1-α and α on labor and capital) represent the contribution that the growth of labor and capital make to the growth of output. CBO follows the economics literature on growth accounting in assuming that those coefficients can be approximated by the shares of labor compensation and capital income in the value of output.[8] For example, payments to owners of capital in the United States have averaged roughly 30 percent of total U.S. income since 1947. In that case, the growth-accounting framework suggests that 1 percent growth in the capital stock leads to 0.3 percent growth in

7. The constant is required because TFP is rebased from its native units—output per unit of combined factor input—to equal 1.0 in 1992.

8. That approximation follows from two common assumptions about the nonfarm business sector: that the production function displays constant returns to scale (which means that a given percentage increase in the factor inputs yields the same percentage increase in output) and that firms minimize costs. Taken together, those assumptions imply that each factor's contribution to output will equal its share of total factor compensation. For a more complete discussion of economic growth and growth accounting, see Angus Maddison, "Growth and Slowdown in Advanced Capitalist Economies: Techniques of Quantitative Assessment," *Journal of Economic Literature*, vol. 25 (June 1987), pp. 649-698; Edward F. Denison, *Trends in American Economic Growth, 1929-1982* (Washington, D.C.: Brookings Institution, 1985); and Dale W. Jorgenson, Frank Gollop, and Barbara Fraumeni, *Productivity and U.S. Economic Growth* (Cambridge: Harvard University Press, 1987).

nonfarm business output.[9] Similarly, an increase of 1 percent in the growth of hours worked leads to an increase of 0.7 percent in the growth of nonfarm business output. Therefore, CBO assumes that α equals 0.3 in equations (3), (3a), and (3b).

An alternative method for determining the appropriate values of the coefficients is to use an econometric approach, which allows the data to determine the coefficients through statistical methods. CBO chose not to follow that approach, in part because of several estimation problems. For instance, in econometric estimates of production functions, a correlation is likely between the explanatory variables (particularly capital) and the error term in the regression. Estimating a regression in the presence of such a correlation would result in biased coefficients.[10]

Another problem is that in order to estimate the coefficients statistically, the capital input must be adjusted (over time) to reflect how intensively the capital stock is used. That adjustment introduces a source of measurement error because of the difficulty in accurately measuring the rate at which the capital stock is used. Since most analysts who employ the econometric approach check to see whether their estimates are reasonable by comparing them with income shares, the payoff to using the econometric approach is small.[11]

To compute historical values for potential output in the nonfarm business sector, CBO removes the influence of the business cycle from the labor input and TFP before using them in equation (3). Without that adjustment, the equation would compute historical values of actual rather than potential output. (The capital input does not need to be adjusted because its potential value is assumed to equal its actual value.) The final form of the production function is:

$$\text{(3a}'\text{)} \qquad \log(Q^*_{nfb}) = \log(A^*_{nfb}) + 0.7\bullet\log(L^*_{nfb}) + 0.3\bullet\log(K_{nfb})$$

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9. Other approaches suggest that capital's contribution to the growth of output is understated—perhaps greatly—by its share of total income. Adherents of "new growth" theories of long-run growth argue for a larger coefficient on capital, reasoning, for example, that benefits spill over from firms that add new capital to firms that do not. However, those theories are not well supported by empirical evidence and therefore have not been adopted by CBO in estimating potential GDP. See Congressional Budget Office, *Recent Developments in the Theory of Long-Run Growth: A Critical Evaluation,* CBO Paper (October 1994), for a survey of "new growth" theories and evidence.

10. For a survey of the problems associated with econometric estimates of aggregate production functions, see Zvi Griliches and Jacques Mairesse, *Production Functions: The Search For Identification*, Working Paper No. 5067 (Cambridge, Mass.: National Bureau of Economic Research, March 1995).

11. For examples of the econometric approach, see Claude Giorno and others, *Estimating Potential Output, Output Gaps and Structural Budget Balances,* Economics Department Working Paper No. 152 (Paris: Organisation for Economic Co-operation and Development, 1995); J.M. Perloff and M.L. Wachter, "A Production Function-Nonaccelerating Inflation Approach to Potential Output: Is Measured Potential Output Too High?" in Karl W. Brunner and Allan H. Meltzer, eds., *Three Aspects of Policy and Policymaking: Knowledge, Data, and Institutions,* Carnegie-Rochester Conference Series on Public Policy (Amsterdam: North-Holland Publishing Co., 1979), pp. 113-163; R.A. Raasche and J.A. Tatom, "Energy Resources and Potential GNP," *Review,* Federal Reserve Bank of St. Louis, vol. 59, no. 6 (June 1977), pp. 10-24; and Adams and Coe, "A Systems Approach to Estimating the Natural Rate of Unemployment."

where the variables are defined as they were in equation (3) and (*) denotes potential values.

What does it mean to calculate the potential values of a data series such as labor hours or TFP? To adjust a series to potential, one must remove the variation that is attributable solely to fluctuations in the business cycle. Ideally, the resulting series will not only reflect the trend (the general direction or momentum) in the series but also be benchmarked to some measure of capacity in the economy. There is no single correct way to accomplish that task—several methods appear in the literature. Each has advantages and disadvantages, which will be discussed later in this paper.

CBO uses a regression equation that incorporates linear time trends to cyclically adjust the labor and productivity inputs.[12] Several components of CBO's model are cyclically adjusted using that equation, but it will be described below only as it is used for the labor input.

Labor Input. The labor input (L) in the production function—hours worked in the nonfarm business sector—displays marked cyclical fluctuation. Labor input can be separated into three components: the labor force, employment, and average weekly hours. The business cycle affects each component differently. Thus, each is cyclically adjusted separately, using the same equation.[13]

CBO's cyclical-adjustment equation relies on a version of a well-known empirical relationship called Okun’s law.[14] Specifically, CBO’s equation rests on two assumptions: that an observable, exogenous benchmark exists that indicates when the labor force equals its potential level, and that the potential labor force follows smooth trends over time.

CBO's benchmark is an estimate of the natural rate of unemployment, called the nonaccelerating inflation rate of unemployment (NAIRU). It corresponds to a particular notion of full employment—it is the rate of unemployment that is con-

12. CBO's procedure is similar to one developed by Peter Clark, who used it with real GNP to compute potential GNP directly. See P.K. Clark, "Potential GNP in the United States, 1948-80," *Review of Income and Wealth*, vol. 25, no. 2 (June 1979), pp. 141-165. For a survey of related methods, see Charles Adams, Paul R. Fenton, and Flemming Larsen, "Potential Output in Major Industrial Countries," *Staff Studies for the World Economic Outlook*, International Monetary Fund (August 1987), pp. 1-38.

13. In an earlier version of the model, hours worked was cyclically adjusted directly.

14. In its original form, Okun’s law related the size of the gap between GDP and potential GDP to the gap between the unemployment rate and the natural rate of unemployment. See Arthur Okun, “Potential GNP: Its Measurement and Significance,” appendix in Okun, *The Political Economy of Prosperity* (Washington, D.C.: Brookings Institution, 1970).

sistent with a stable rate of inflation.[15] The historical estimate of the NAIRU derives from an econometric estimate of a Phillips curve, which is an equation that relates the change in inflation to the unemployment rate and other variables, including changes in productivity trends, oil price shocks, and wage and price controls.[16] The relationship between the unemployment gap (the difference between the unemployment rate and the NAIRU) and the change in inflation is strong and fairly stable. When the unemployment rate is below the NAIRU, inflation tends to rise, and when the unemployment rate is above the NAIRU, inflation tends to fall (see Figure 1).

During the second half of the 1990s, the combination of low rates of unemployment and falling inflation led many forecasters to reduce their estimates of the NAIRU and led others to question the usefulness of the concept.[17] In CBO's view, the evidence does not warrant jettisoning the NAIRU as a benchmark for estimating potential output, for two basic reasons.

First, although inflation was easing during the 1995-1999 period, indicators from the labor market were consistent with the story told by the unemployment gap. Most important, wages, and to a lesser degree compensation, increased according to the predictions of the Phillips curve. If something fundamental had changed in the workings of the labor market, that would not have happened.

Second, the NAIRU—standing in for the balance of demand and supply in the economy—is only one of many influences on inflation. It turns out that during the late 1990s, several other factors were offsetting the inflationary pressure reflected in the unemployment gap. The most important of those factors was acceleration in productivity growth, but others include declines in prices for computers and imports and a dramatic slowing of medical care inflation.[18]

The second assumption in CBO's cyclical-adjustment equation—smooth time trends—implies that the potential labor force grows at a constant rate over one or more specified historical periods. CBO does not constrain the potential variables in the model to follow a single time trend throughout the entire sample. Instead, the model allows for several time trends, each beginning at the peak of a business cycle. Allowing for breaks in the trend implies that the rate of growth of the potential labor

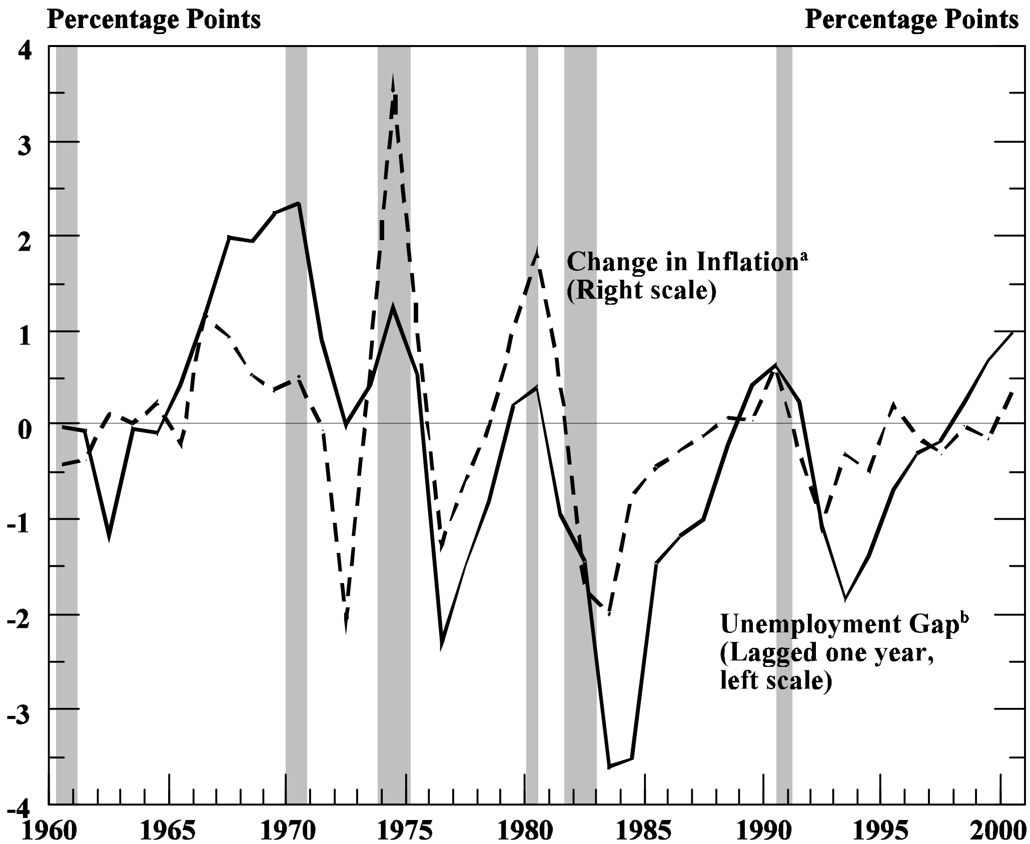
15. For a description of the procedure used to estimate the NAIRU, see Congressional Budget Office, *The Economic and Budget Outlook: An Update* (August 1994), Appendix B.

16. CBO uses the married-male unemployment rate in its Phillips curve equation. Married males are a group with strong labor force attachment, and their unemployment rate will be less affected by shifts in demographic factors than the overall unemployment rate.

17. For a summary of the arguments, see the symposium in the Winter 1997 *Journal of Economic Perspectives*.

18. For further discussion, see Congressional Budget Office, *The Budget and Economic Outlook: Fiscal Years 2001-2010* (January 2000), pp. 29-33.

FIGURE 1. THE UNEMPLOYMENT GAP AND THE CHANGE IN INFLATION



SOURCE: Congressional Budget Office using data from the Department of Labor, Bureau of Labor Statistics.

a. Inflation is measured as the consumer price index for all urban consumers (CPI-U) excluding food and energy.

b. The difference between the actual unemployment rate and the nonaccelerating inflation rate of unemployment (NAIRU), which is the unemployment rate consistent with a stable rate of inflation.

force is constant within each cycle but can differ from one business cycle to the next. Defining the intervals of the time trends using full business cycles helps to ensure that the trends are estimated consistently throughout the historical sample. Most economic variables have distinct cyclical patterns—meaning they behave differently at different points in the business cycle. Specifying break points for the trends that occur at different stages of different business cycles (say, from a business-cycle trough to a business-cycle peak) would probably give a misleading view of the underlying trend in the data.

The following equations provide the foundation for the cyclical-adjustment equation:

$$\log(LF/LF^*) = \alpha(U - U^*) + \varepsilon \tag{4}$$

(5) $\log(LF^*) = f(T_{1953}, T_{1957}, T_{1960}, T_{1969}, T_{1973}, T_{1980}, T_{1981}, T_{1990})$

where
- LF = civilian labor force
- LF^* = potential labor force
- U = unemployment rate
- U^* = NAIRU
- T_i = zero until the business-cycle peak occurring in year i, after which it equals the number of quarters elapsed since that peak

Equation (4) relates the percentage difference between the actual and potential labor force to the difference between the actual unemployment rate and the NAIRU. That equation implies a statistical relationship between the labor force gap and the unemployment gap, which will be true if the labor force has a cyclical component (meaning that it varies systematically with the overall business cycle). In particular, if the unemployment rate is above the NAIRU, the labor force is likely to be below its potential level, because higher rates of unemployment are associated with greater numbers of discouraged workers, and so forth. The reverse is true when the unemployment rate falls below the NAIRU.

Equation (5) restates the assumption that the potential labor force follows smooth trends over time, with breaks at business-cycle peaks. Nothing in the equation forces the trend to change at each peak. If the data do not call for a change, the trend will remain constant. However, the equation does not constrain the trend growth rate to be equal across business cycles.

The cyclical-adjustment equation, equation (6), results from combining equations (4) and (5):

(6) $\log(LF) = \alpha(U - U^*) + f(T_{1953}, T_{1957}, T_{1960}, T_{1969}, T_{1973}, T_{1980}, T_{1981}, T_{1990}) + \varepsilon$

That equation, of a type often called a piecewise linear regression, is estimated using quarterly data and ordinary least squares (a standard method of statistical estimation).[19] Historical values for the potential labor force are calculated as the fitted values from the regression, with U constrained to equal U^*. Fitted values from the regression are estimated values of the dependent variable that are computed using historical values of the explanatory variables and the estimated coefficients of the regression. Setting the unemployment rate to equal the NAIRU removes the estimated effects of fluctuations in the business cycle; the resulting estimate gives the equation's prediction of what the size of the labor force would be if the unemployment rate never deviated from the NAIRU.

19. For more discussion of piecewise linear regressions, see Robert Pindyck and Daniel Rubenfeld, *Econometric Models and Economic Forecasts*, 4th ed. (Boston: Irwin McGraw Hill, 1998).

Once the potential labor force has been computed, estimating potential employment with the following equation is a straightforward process.

(7) $Empl^* = [1 - (U^*/100)] \bullet LF^*$

where $Empl^*$ = potential employment

That equation yields potential employment for the civilian noninstitutional population (the population included in the Census Bureau's Current Population Survey).

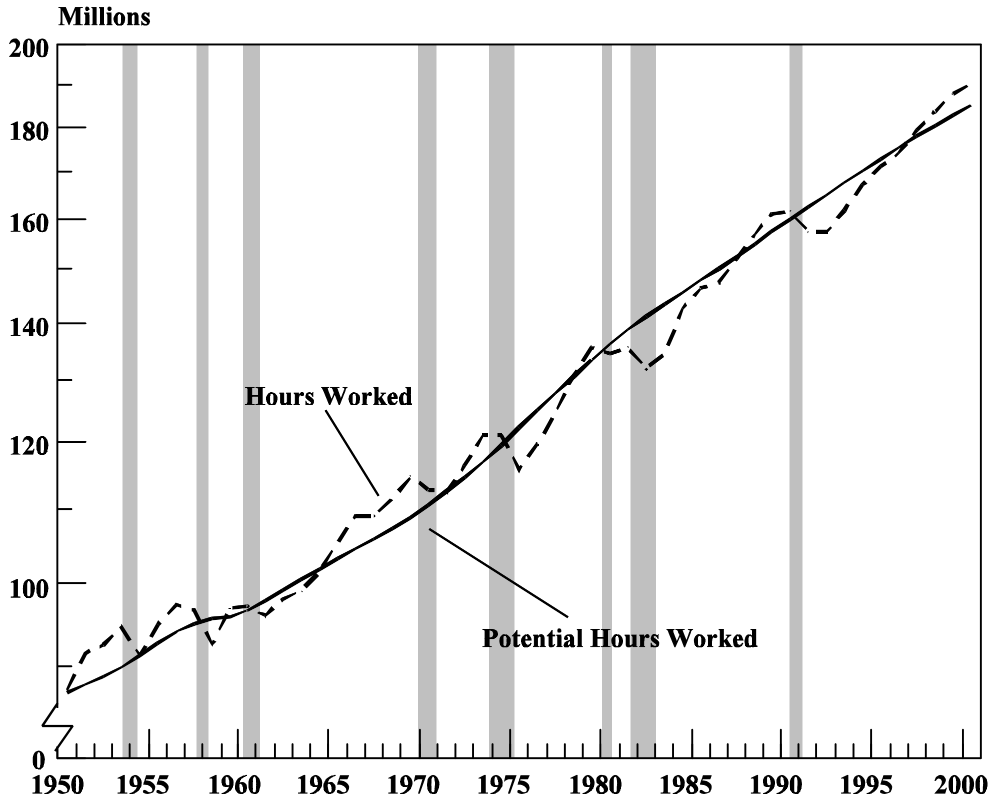
Several adjustments are necessary to compute employment in the nonfarm business sector. First, the discrepancy between employment measured using the Current Population Survey and the Bureau of Labor Statistics's (BLS's) Current Employment Statistics survey is smoothed and subtracted from total employment.[20] Then, potential employment in government, farms, private households, and nonprofit institutions is computed using an equation like equation (6) and subtracted from total employment. Next, employment of unpaid family workers and proprietors is cyclically adjusted and added to determine potential employment in the nonfarm business sector. Finally, average weekly hours are adjusted to potential using a regression such as equation (6) and multiplied by potential employment to compute potential hours worked in the nonfarm business sector (see Figures 2 and 3).

Capital Input. Production theory dictates that the capital input in the production function should measure the flow of capital services available for production. If every capital asset were leased in a rental market every year, estimating the capital input would be relatively simple: rental payments would provide a basis for gauging the value of the capital services provided (analogous to the wages paid to workers per period for their labor). However, most assets are owned, not leased, so the transfer of capital services from owner to user cannot be observed by data-collection agencies.

Similarly, the task of estimating the capital input would be more difficult, but still relatively straightforward, if every type of capital asset were identical. Economists could use the total stock of capital and assume that the flow of productive services was proportional to that stock. The Bureau of Economic Analysis publishes the relevant data. It estimates capital stocks at a relatively fine level of detail and then aggregates those stocks using the Fisher formula discussed in Box 1. In reality, however, capital assets are not identical; they differ in many ways. Most important,

20. Labor force data come from the Current Population Survey whereas the labor input (hours worked) comes from the Current Employment Statistics survey. The two surveys cover different samples, use different methods, and often give different views of employment growth. For a discussion of the differences between estimates of employment from the two surveys, see Congressional Budget Office, *The Budget and Economic Outlook: An Update* (July 2000), Appendix A.

FIGURE 2. HOURS WORKED AND POTENTIAL HOURS WORKED IN THE NONFARM BUSINESS SECTOR



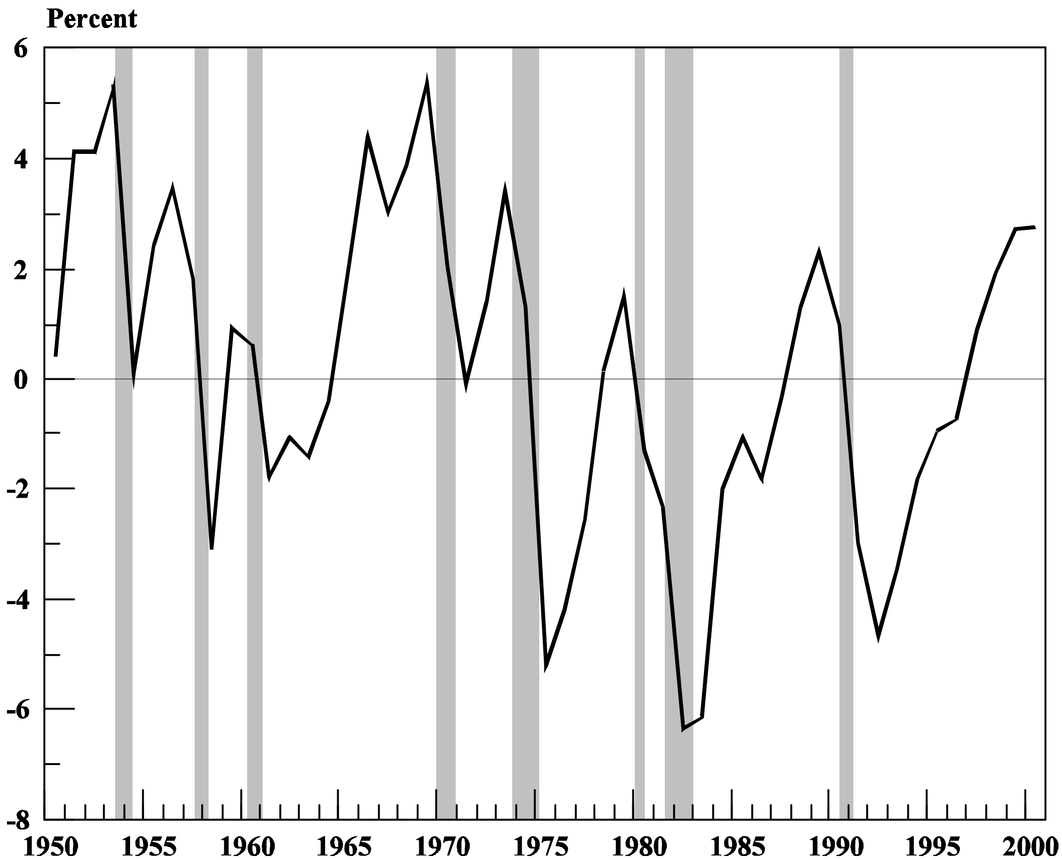
SOURCE: Congressional Budget Office using data from the Department of Commerce, Bureau of Economic Analysis.

NOTE: The y-axis is plotted using a logarithmic scale.

different types of capital have different levels of productivity in any given year, meaning that they have different service flows.

To see why that is the case, consider a factory, which is classified as a business structure. A factory building has a long service life, which implies that it has a low rate of depreciation. Therefore, the part of its value that it contributes to production each year—its capital input—is also low. In contrast, a computer has a very short service life and, consequently, a high depreciation rate. Economic theory predicts that businesses will buy plant and equipment in such a way that the returns (or contributions to output) from different types of assets are equal after subtracting depreciation and other costs. Computers must be productive enough to pay for their high rate of depreciation and thus must provide a large capital input relative to their cost in each year of their service life. If they did not, buying computers would ultimately undermine businesses' profitability.

FIGURE 3. THE GAP BETWEEN HOURS WORKED AND POTENTIAL HOURS WORKED IN THE NONFARM BUSINESS SECTOR



SOURCE: Congressional Budget Office using data from the Department of Commerce, Bureau of Economic Analysis.

To construct a single capital input from several dissimilar types of capital assets, CBO adopts the approach that BLS uses to construct the capital input that underlies its multifactor productivity series.[21] Based on the pioneering work of Robert Hall and Dale Jorgenson during the 1960s, CBO's estimate of the capital input is an annual index that accounts for the fact that different types of capital assets have disparate levels of productivity, rates of depreciation, and tax treatment.[22] The index is based on the following equation:

$$\log(K_t/K_{t-1}) = \textstyle\sum_i \omega_{i,t} \bullet \log(K_{i,t}/K_{i,t-1}) \tag{8}$$

21. See Bureau of Labor Statistics, *Trends in Multifactor Productivity, 1948-81*, Bulletin 2178 (September 1983).

22. See Robert Hall and Dale Jorgenson, "Tax Policy and Investment Behavior," *American Economic Review* (June 1967), pp. 391-414.

where $K_{i,t}$ = stock of capital asset i in year t
$K_{i,t-1}$ = stock of capital asset i, lagged one year
$\omega_{i,t}$ = $(s_{i,t} + s_{i,t-1})/2$
s_i = $(r_{i,t} \bullet K_{i,t})/(\sum_i r_{i,t} \bullet K_{i,t})$
$r_{i,t}$ = rental price for asset i in year t

The capital assets in equation (8) are the stocks of computers, software, communications equipment, other equipment (excluding computers, software, and communications equipment), nonresidential structures, inventories, and land in the nonfarm business sector. The growth of the capital input is a weighted average of the growth rates of the different types of capital assets, where the weights (ω_i) are functions of the relative cost shares (s_i) of each type of capital. The relative cost shares—estimates of the share of total capital income that is "paid" to each kind of capital—are directly analogous to the coefficients on labor and capital in the production function in equation (3), above. As such, they represent the contribution that the growth of each type of capital makes to the growth of capital services. The marginal productivity of each kind of capital will be proportional to its relative cost share if two conditions apply: businesses minimize their costs, and the "true" capital-aggregator function displays constant returns to scale.[23] Thus, the overall index reflects the marginal productivities of the different types of capital being aggregated.

Unlike total capital income, the relative cost shares of different kinds of assets cannot be observed directly, largely because rental prices for capital assets owned by businesses are invisible. For most types of capital, those prices must be inferred from the price of capital goods, the cost of capital (including both debt and equity), depreciation rates, expected capital gains, and tax rules. However, once rental prices are estimated, the cost shares can be approximated: the compensation "paid" to each type of capital will equal the stock of that type of capital multiplied by the corresponding rental price. That compensation as a percentage of total capital income represents the cost share for that type of capital.

Unlike the labor input, the capital input does not need to be cyclically adjusted to create a "potential" level—the unadjusted capital input already represents its potential contribution to output. Although use of the capital stock varies greatly during the business cycle, the potential flow of capital services will always be related to the total size of the capital stock, not to the amount currently being used.

23. Constant returns to scale is a property of some mathematical functions; it holds when a given percentage increase in the function's inputs (the different capital assets in this case) yields the same percentage increase in the function's dependent variable (the capital index). For more details, see M.J. Harper, E.R. Berndt, and D.O. Wood, "Rates of Return and Capital Aggregation Using Alternative Rental Prices," in D.W. Jorgenson and R. Landau, eds., *Technology and Capital Formation* (Cambridge: MIT Press, 1989); or W.E. Diewert, "Aggregation Problems in the Measurement of Capital," in Dan Usher, ed., *The Measurement of Capital* (Chicago: University of Chicago Press, 1980).

Since CBO published the previous version of this paper in 1995, it has revised the capital input to include land as a factor of production. In the context of production theory, land is measured not by total geographical area but rather by the area devoted to production in the nonfarm business sector (generally, the land needed to support a structure such as an office building, store, or oil well). As such, growth in the stock of land is closely correlated with growth in the stock of nonresidential structures, a component that was already included in the capital input. Early versions of CBO's model excluded land because of that correlation and because the quality of the data on land is poor.[24]

However, the growing importance of computers highlighted a key drawback of excluding land. As noted earlier, the capital input is calculated as a weighted average of the growth rates of different types of capital assets, with the weights set equal to each type's cost share. The cost shares must add up to 100 percent, so excluding land raises the weights on the other types of capital in the index. Moreover, because the stock of land grows relatively slowly, its exclusion increases the weight on the relatively fast-growing stock of producers' durable equipment (PDE), thus raising the growth of the capital services index.

Adding land aligns CBO's method with that of BLS, academic economists, and private forecasters. The addition lowers the estimated growth rate of potential output very slightly for the 1990s and leaves it largely unchanged for the whole period from 1960 to 2000.

The second change that CBO made to the capital input in recent years was to further break down producers' durable equipment by adding categories for software and communications equipment. During the late 1990s, the IT sector was increasingly viewed as the driving force behind the rapid advance in overall labor productivity. Dramatic increases in investment in such IT goods as computers, software, and network routers suggested that capital deepening (an increase in the amount of capital available per worker) was contributing to the acceleration of productivity growth. In order to analyze the contribution of IT goods other than computers to potential growth, CBO modified the breakdown of PDE investment in the growth model to include four components (computers, software, communications equipment, and other PDE) instead of two components (computers and noncomputer PDE), as in the previous version of the model. That change raised the estimated growth of the capital services index by about 0.2 percentage points for the 1990s and by about 0.1 percentage point for the 1960-2000 period. However, the revision had

24. BEA does not estimate a stock of land. However, BLS does as part of the multifactor productivity estimate. BLS estimates the stock of land by applying a land-to-structure ratio, based on a 1966 Census survey, to the value of the stock of nonresidential structures in 1966. That benchmark is extrapolated forward and backward in time using the gross stock of nonresidential structures, ensuring that the stock of land is highly correlated with the net stock of structures. For more details, see Bureau of Labor Statistics, *Trends in Multifactor Productivity, 1948-81*, pp. 47-48.

almost no impact on the estimate of potential output because it caused an offsetting change in the estimate of TFP.

Total Factor Productivity. TFP is computed as a residual—the growth in output that remains after removing the contributions from the growth in labor and capital. TFP is analogous to the more commonly used concept of labor productivity; but whereas labor productivity is defined as the growth in output beyond growth in labor, TFP is defined as the growth in output that exceeds growth in both labor and capital.

Because TFP growth is defined as the growth in output not explained by other factors, it is inherently difficult for economists to model or predict. Although TFP growth is typically attributed to technological change, anything that causes output to increase more quickly or more slowly than the measured levels of its inputs will cause TFP to increase more quickly or more slowly. Analysts have attributed TFP growth to many causes besides technological progress: changes in the rate at which capital is used, changes in the quality of labor or the amount of human capital, changes in businesses' organization or culture, spillovers from investments in capital, or shocks to productivity.[25] Note that the first two causes involve some kind of measurement error—a change in the actual flow of labor or capital services that the traditional measures of labor and capital do not pick up.

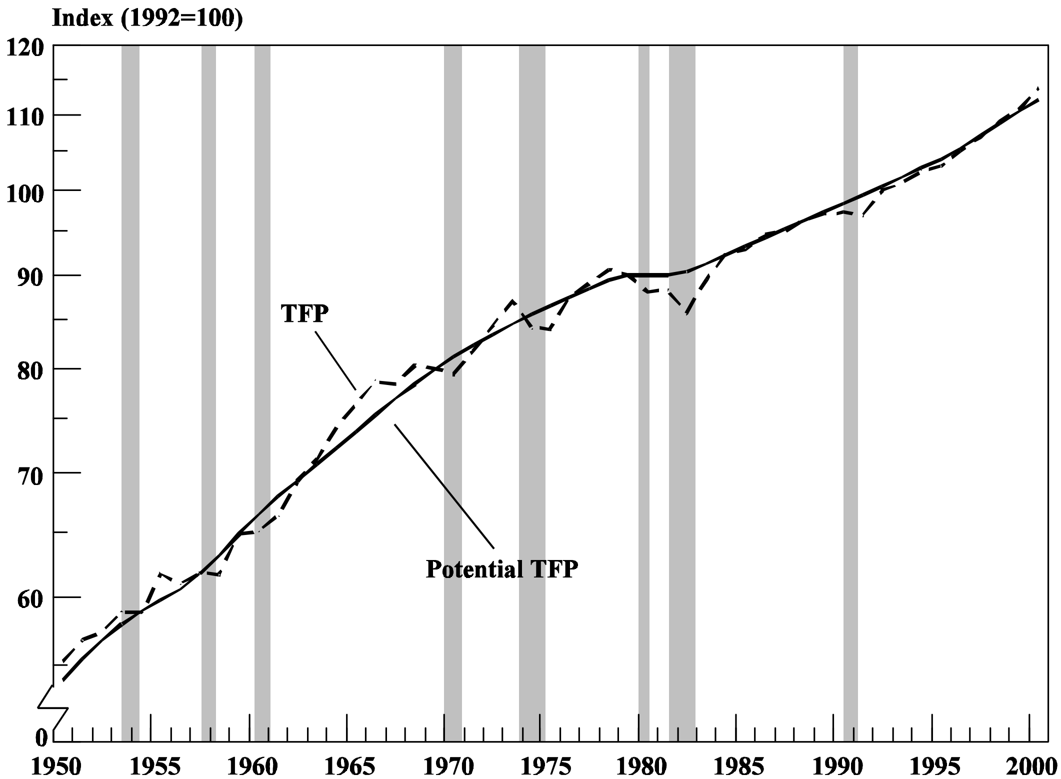
CBO calculates historical values for TFP by substituting actual historical values for output and the capital and labor inputs into equation (3). Essentially, TFP is computed as an index whose growth rate equals the growth in output minus the growth in a weighted average of the factor inputs, where the weights are the cost shares (0.7 and 0.3) in equation (3). Like the labor force, TFP must be adjusted to its potential level before being used to compute potential output. An equation like equation (6) is used to make that adjustment (see Figure 4).[26]

Occasionally, the estimate of potential TFP must be adjusted, using non-statistical methods, to account for identifiable shocks to TFP. A growth model is a simple representation of the economy that is meant to capture the essence of the long-term growth process. Periodically, events occur that are not covered by the model's equations. In particular, any event that shocks real growth but not the factor inputs will induce a shock to TFP. Of course, small shocks of that sort occur continually and are incorporated into the trend that is used to compute potential TFP. Some-

25. See the symposium on the slowdown in productivity growth in *Journal of Economic Perspectives*, vol. 2, no. 4 (Fall 1988).

26. Before the adjustment can be made, TFP must be recomputed on a quarterly basis. Limitations on data make direct recomputation difficult, so CBO interpolates the annual values to quarterly values by using the information contained in a related series that is available on a quarterly basis. That related series is the index of labor productivity in the nonfarm business sector that is published by the Bureau of Labor Statistics.

FIGURE 4. TOTAL FACTOR PRODUCTIVITY AND POTENTIAL TFP



SOURCE: Congressional Budget Office using data from the Department of Commerce, Bureau of Economic Analysis.

NOTE: The y-axis is plotted using a logarithmic scale.

times, however, the effects of an event are identifiable and quantifiable, so they can be modeled explicitly using an exogenous adjustment to potential TFP. The two examples below illustrate the kinds of adjustments that can be made.

Change in Methods Used to Calculate Inflation. In July 1998, BEA, using data from the Bureau of Labor Statistics, revised some of the price indexes in the NIPAs, but only for data starting in 1995. Earlier data were not affected. That switch abruptly reduced measured inflation, but it had no impact on total expenditures in the economy and, therefore, no effect on nominal GDP. Because nominal GDP remained the same, the measurement change that lowered inflation raised real GDP one for one. Furthermore, since the labor and capital inputs were unaffected, the increase in real GDP growth fed through to TFP, which also jumped abruptly in 1995.

The discontinuity in the data for TFP complicates the task of estimating the trend in that series; the data from 1949 to 1995 are not measured on the same basis as the data after 1995. Fortunately, research by BLS provided enough information to estimate the impact of the change in measurement on TFP growth. To prevent the discontinuity in TFP data from affecting its estimate of potential TFP, CBO removes the effects of the measurement change from the historical data before estimating trend TFP using equation (6). (That way, the trend in TFP is estimated using data measured on a consistent basis throughout the sample.) The effects of the measurement change are then added to the trend value to compute potential TFP.

More recent revisions to the underlying data have shrunk the size of the discontinuity caused by differences in price measurement. One component of BEA's initial revision, the use of geometric mean price indexes, no longer needs to be adjusted for. When the bureau released its comprehensive revisions to the NIPAs in late 1999, the geometric weighting formula was extended backward to calculate price indexes for years before 1995. As a result, that component no longer contributed to the jump in TFP, so CBO eliminated the portion of its adjustment to TFP attributable to geometric weighting.[27]

Technological Change in Computer Production. Another example of an adjustment to TFP comes from the sector of the economy that manufactures computers. That sector experienced a burst of productivity growth in the late 1990s that appeared to result from faster technological change. At that time, computers made up a large enough share of GDP that the sector's faster productivity growth had measurable effects on the growth of overall productivity. CBO determined that estimating and projecting TFP was best accomplished by modeling technological change in the computer sector separately from change in other sectors. Thus, CBO's model for potential output removes the effects of faster technological change in the computer sector from the historical data before estimating a partial measure of potential TFP; it then adds the effects of that change back into the final estimate of potential TFP.

To estimate the contribution of changes in computer quality to overall TFP growth, CBO first calculates an index of economywide computer prices using BEA's price indexes for personal and business spending on computers and for computer imports and exports. BEA adjusts those indexes for changes in quality using a so-called hedonic approach. Under that approach, if the list price of a computer remains constant from one year to the next but the newer computer has a faster processor or more storage capacity, the BEA price index declines. As a result of technological progress in the computer industry, computer prices, as measured in the NIPAs, have declined continuously since the 1970s. However, that decline accelerated during the late 1990s, from an average drop of roughly 15 percent a year between 1990 and 1995 to about 30 percent per year between 1995 and 2000.

27. For further discussion of the revisions to the price indexes, see Congressional Budget Office, *The Economic and Budget Outlook: Fiscal Years 1999-2008* (January 1998). For discussion of the incorporation of geometric weighting into the historical data, see Congressional Budget Office, *The Budget and Economic Outlook: Fiscal Years 2001-2010* (January 2000).

The next step in estimating the contribution of changes in computer quality to productivity growth is to assume that the rate of change in computer quality can be approximated by the rate of decline of the computer price index relative to the rate of growth of the price index for GDP in the nonfarm business sector. The final step is to weight the growth rate of computer quality by the nominal share of computers in the nonfarm business sector to calculate the contribution of computer-quality growth to the growth of overall TFP. The deviation of that contribution from its trend is used to estimate any acceleration or deceleration in the growth of potential TFP resulting from changes in the rate of technological progress in the computer sector.[28]

Other U.S. Sectors

The method for computing historical values for potential output in the other sectors of the economy (government, farms, household and nonprofit institutions, and housing) differs slightly from that used for the nonfarm business sector—either because those sectors use different methods of production or because CBO's assumption about what they use is limited by the availability of data. As explained below, each sector's production depends primarily on either its labor input or its capital input. The general strategy for estimating historical values for potential output is to express real GDP in those sectors as a function of the primary factor input and the productivity of that input. The primary input and its productivity are cyclically adjusted using an analogue to equation (6) and then combined to estimate potential output in that sector. (Values for the housing sector are not cyclically adjusted because that sector is not influenced significantly by fluctuations in the business cycle. Instead, housing output is smoothed using a centered, moving average to remove short-term variation.) The following sections detail the differences between the sectors.

Government Sector. Unlike companies in the private sector, government agencies do not sell their output in markets, so BEA cannot tally their sales to measure the value of government output. Instead, the national income and product accounts measure GDP in the government sector as the sum of total compensation of employees in that sector plus depreciation of government fixed assets (capital consumption allowance, or CCA). That is admittedly an imperfect way to measure the production of government services. Using compensation as a measure of labor output sharply

28. For further discussion of the adjustment for computer quality, see Congressional Budget Office, *The Budget and Economic Outlook: Fiscal Years 2001-2010,* Appendix A. CBO's procedure is similar to that used by the consulting firm Macroeconomic Advisers. See Macroeconomic Advisers, *Productivity and Potential GDP in the New U.S. Economy.*

limits the estimated growth of labor productivity in that sector.[29] Using depreciation to measure the return on capital underestimates the true return because it constrains the net return to equal zero, but that is better than BEA's previous method, which held the gross return to zero.[30]

Given the way in which government GDP is measured, specifying a neoclassical production function would be inappropriate. Instead, CBO estimates government GDP as the sum of government compensation and government depreciation. First, CBO separates GDP in the government sector into a federal component and a state and local component. Each component is cyclically adjusted separately, as shown in the following equation; then, they are added together to compute government GDP, using the Fisher formula.

(9) $$GDP^{*}_{govt} = GDP^{*}_{federal} + GDP^{*}_{s\&l}$$

where
GDP_{govt} = gross domestic product in the government sector
$GDP_{federal}$ = gross domestic product in the federal government sector
$GDP_{s\&l}$ = gross domestic product in the state and local government sector

For each of those sectors, potential GDP is computed by combining potential compensation of employees and CCA, which is not adjusted to a potential.

(10) $$GDP^{*}_{federal} = Comp^{*}_{federal} + CCA_{federal}$$

(11) $$GDP^{*}_{s\&l} = Comp^{*}_{s\&l} + CCA_{s\&l}$$

where
$Comp_{federal}$ = compensation of federal government employees
$CCA_{federal}$ = consumption of the federal government's fixed capital
$Comp_{s\&l}$ = compensation of state and local government employees
$CCA_{s\&l}$ = consumption of state and local governments' fixed capital

29. The Bureau of Economic Analysis computes the constant-dollar estimate of total compensation by extrapolating current-dollar output in a base year (currently 1996) using an index of hours worked that is adjusted, to the extent possible, for changes in education and experience. Therefore, productivity is constant over time for a given type of employee, but overall government productivity can rise if employment shifts toward workers with more education or experience. See Bureau of Economic Analysis, *Government Transactions*, Methodology Paper Series MP-5 (November 1988).

30. In 1995, BEA revised its method for estimating output in the government sector. Before then, the NIPAs measured government GDP simply as the total compensation of employees in that sector. With the 1995 revision, BEA reclassified government purchases of fixed assets (those used to produce government services for more than one year) as investment rather than consumption expenditures. In addition, BEA introduced an estimate of services provided by government fixed assets, measured by depreciation, which was added to government consumption expenditures. The latter change increased the level of GDP throughout the historical sample. See Robert Parker and Jack Triplett, "Preview of the Comprehensive Revision of the National Income and Product Accounts: Recognition of Government Investment and Incorporation of a New Methodology for Calculating Depreciation," *Survey of Current Business* (September 1995), pp. 33-41.

All of the variables in equations (9), (10), and (11) are measured in billions of chained 1996 dollars, and potential values are denoted with a (*). Since the calculations in those equations are made with inflation-adjusted variables, Fisher aggregation is used. Compensation is modeled as a function of employment and productivity, both of which are adjusted to potential values using equation (6).

(12) $Comp^{*}_{federal} = Empl^{*}_{federal} \bullet Prod^{*}_{federal}$

(13) $Comp^{*}_{s\&l} = Empl^{*}_{s\&l} \bullet Prod^{*}_{s\&l}$

where

$Empl_{federal}$ = full-time and part-time employees of the federal government (in thousands)

$Prod^{*}_{federal}$ = productivity in the federal sector (in chained 1996 dollars per employee)

$Empl_{s\&l}$ = full-time and part-time employees of state and local governments (in thousands)

$Prod^{*}_{s\&l}$ = productivity in the state and local sector (in chained 1996 dollars per employee)

Farm Sector. Although the technology used to produce output in the farm sector is likely to be similar to that in the nonfarm business sector, CBO models farm output separately. One reason is that farm output is quite volatile, varying for reasons (especially the weather) that have little to do with the size of its labor or capital input. In addition, the dramatic technological progress that the farm sector has experienced since World War II makes it less comparable with the nonfarm business sector. CBO models output in this sector as a function of farm employment and output per employee, both of which are adjusted to potential values using an equation like equation (6).

Households and Nonprofit Institutions Sector. The NIPAs measure output in this sector as the value of work supplied by people employed in private households (such as domestic workers) and in not-for-profit institutions. In each case, the value of the work supplied is measured as the sum of all compensation paid to employees, just as it is in the government sector. CBO calculates potential hours worked and potential productivity (output per hour) in this sector using an equation like equation (6) and combines them to estimate potential output in the sector.

Housing Sector. The NIPAs measure housing output as a stream of housing services that flows almost entirely from the capital input (the stock of residential housing), with virtually no contribution from labor. For that reason, CBO models this sector separately from the nonfarm business sector using the stock of residential housing and an estimate of the productivity of capital.

(14) $GDP^{*}_{housing} = Capital\ Stock_{housing} \bullet Productivity^{*}_{housing}$

Even though productivity in this sector is denoted with a (*), that variable is not adjusted to a potential value. Rather, to eliminate short-run variation in the productivity numbers, CBO smooths them using a five-year, centered, moving average. That, in turn, smooths the short-run variation in the figures for housing output.

PROJECTING POTENTIAL OUTPUT TEN YEARS AHEAD

A Solow growth model provides a convenient framework for estimating potential output in future years. Given projections of the exogenous variables (such as potential labor force, the rate of national saving, and potential total factor productivity), the model's equations compute capital accumulation automatically, calculate projections of potential output in each sector of the economy, and then combine those projections into a projection of overall potential output. The sections that follow describe how CBO projects the exogenous variables and combines them to project potential output. The general approach is to extrapolate the trend growth rate from recent history for each exogenous variable. Doing that is easy because all of the variables have been cyclically adjusted and therefore are quite smooth in their patterns. Moreover, some exogenous variables, most notably the saving rate, are projected as part of CBO's two-year economic forecast.

The Nonfarm Business Sector

Potential output in the nonfarm business sector is projected using equation (3a′), the same production function used to estimate historical values for that variable. To project potential output, equation (3a′) requires that its components—labor, capital, and total factor productivity—be projected forward in time.

Labor Input. To project the model's labor input—potential hours worked in the nonfarm business sector—CBO projects separately its four components: the potential labor force, the NAIRU, potential employment in the sectors other than nonfarm business, and potential average weekly hours worked in the nonfarm business sector.

CBO's projection of the potential labor force is based on projections by BLS and the Social Security Administration (SSA) of the working-age population and the labor force participation rate (the fraction of the population that is working or actively seeking work). CBO uses the SSA's projection of the working-age population (the civilian noninstitutional population), which is quite similar to the Census Bureau's middle population projection. For labor force participation rates, CBO examines historical patterns in those rates, broken down by age and sex, to determine its projections. After comparing the projections with those of other forecasters, CBO applies the projected participation rates to the corresponding population groups and then adds them up to determine the total potentional labor force.[31]

Like the labor force projection, CBO's projection of the NAIRU also reflects demographic considerations. As noted earlier, the historical estimate of the NAIRU derives from an econometric estimate of a Phillips curve that relates the change in inflation to the unemployment rate of married males, among other variables. That equation can be solved to compute the NAIRU for married males, which in turn can be used to estimate NAIRUs for 28 demographic groups (broken down by age, sex, and race). The historical estimate of the overall NAIRU is computed as a weighted average of the NAIRUs for the 28 demographic groups, with the weights set equal to each group's share of the labor force. Since each of those NAIRUs is constant throughout the data sample, the overall NAIRU varies over time largely because the shares of the different demographic groups vary. To project the NAIRU, CBO combines BLS's projection of the labor force shares of the 28 demographic groups with the historical estimate of the NAIRU for each group.

To project potential employment, the growth model combines the projections for the potential labor force and the NAIRU using equation (7):

$$\text{(7)} \qquad Empl^{*} = [1 - (U^{*}/100)] \bullet LF^{*}$$

Potential employment in the nonfarm business sector is equal to total potential employment minus potential employment in the government, farm, and household and nonprofit sectors plus potential employment of unpaid family members and proprietors.[32] Potential employment in each of those other sectors is projected to continue its recent trend as a share of total potential employment—with an adjustment, if necessary, to ensure consistency with CBO's assumptions about fiscal policy.

CBO projects the final component—potential average weekly hours worked in the nonfarm business sector—by extrapolating the estimated trend in that component from the recent past (since 1990 in the current projection).

<u>Capital Input</u>. One advantage of using a growth model for potential output is that the model projects the capital input using CBO's projection of national saving, thus ensuring that the projection of potential output is consistent with the projection of national saving. Since the capital input in the model is calculated from the capital stock in the nonfarm business sector, its growth is fundamentally determined by the

31. For further details, see Congressional Budget Office, *The Economic and Budget Outlook: An Update* (July 2000), Appendix A.

32. The discrepancy between employment measured using the Current Population Survey and the Current Employment Statistics survey, which is smoothed over history, is projected to continue its trend of the recent past.

level of capital accumulation, or net investment. The model defines the level of gross investment as being equal to the level of national saving (the sum of private and government saving plus net foreign borrowing).

The level of saving is set by the model using three prespecified rates of saving from national income—one each for private, federal government, and state and local government saving.[33] CBO develops the saving rates as part of its short-term economic forecast by analyzing patterns of income, consumption, investment spending, and fiscal policy. Those rates are applied to the growth model's projection of national income to determine the level of saving, investment, and capital accumulation. Government saving comprises surpluses in federal as well as state and local budgets and is therefore directly affected by changes in fiscal policy. The model allows the user, for example, to adjust the federal saving rate to constrain the federal surplus to equal CBO's baseline projection.

The capital input enters the production function for the nonfarm business sector, so it should be influenced only by capital accumulation in that sector, not by investment that is channeled to capital accumulation in others sectors. With gross investment set equal to national saving, the model determines fixed investment in the nonfarm business sector by removing from gross investment both fixed investment in the farm and housing sectors and changes in inventories. The remainder is then separated into investment in structures, computer PDE, software, communications equipment, and other PDE (excluding computers, software, and communications equipment) using shares that are consistent with CBO's short-term macroeconomic forecast. Those five categories constitute capital accumulation in the nonfarm business sector; equation (15) adds each category of investment to its corresponding capital stock after adjusting the stock for depreciation.

$$K_{i,t} = (1-\delta_i)K_{i,t-1} + I_{i,t} \tag{15}$$

where
$K_{i,t}$ = stock of capital asset i in year t
δ_i = depreciation rate for asset i
$K_{i,t-1}$ = stock of capital asset i, lagged one year
$I_{i,t}$ = investment in asset i in year t

The capital stocks are then combined with the change in nonfarm inventories (computed as a function of real growth) and the stock of land (projected as a fixed ratio to investment in nonresidential structures) to form the capital input, which is

33. Since those rates of saving are set exogenously, the model's user must determine whether an increase in government saving will be matched by a decrease in other components of national saving, in keeping with the doctrine of Ricardian equivalence. The model itself neither assumes nor precludes the existence of Ricardian equivalence. Although Ricardian equivalence is theoretically appealing, the empirical evidence supporting it is mixed. See Congressional Budget Office, *The Federal Deficit: Does It Measure the Government's Effect on National Saving?* (March 1990).

entered into the production function. The capital input is a weighted average of the growth rate of its seven components (structures, computers, software, communications equipment, other PDE, inventories, and land); the weights reflect the levels of productivity of each type of capital good, as shown in equation (8). Equipment, for example, has higher marginal productivity than structures, so it receives greater weight in the capital input.

Total Factor Productivity. To project potential output, the growth model requires an independent projection of potential TFP, which is produced by extrapolating the growth rate of the recent past (including any adjustments). If the trend in TFP is expected to change during the projection period for some reason, an adjustment can be added to account for it. One exception to that method for projecting TFP is the computer-quality adjustment, which is calculated from projections for computer prices and for the share of nominal GDP in the nonfarm business sector that is composed of computers.

Other U.S. Sectors

CBO's growth model uses very simple production relationships to model potential output in sectors of the U.S. economy other than nonfarm business. Recall that historical values for potential output in each of the other sectors are computed by cyclically adjusting the primary factor input and the average productivity of that input and then combining them. Potential output in each sector is projected by extrapolating trends in the cyclically adjusted factor inputs and productivity. Those trends are generally estimated for the period since the most recent business-cycle peak (since 1990 in the current projection).

Government Sector. The growth model determines potential output in the government sector by combining potential output in the federal and state and local sectors. Since BEA calculates GDP in those two sectors using the same method—adding together government compensation and government depreciation—the growth model's equations for the two are similar. Government compensation in each sector is projected by combining projections of potential employment and potential productivity, using equations (12) and (13). Potential employment in the federal government is projected to be consistent with CBO's baseline forecast of federal spending. Potential employment in the state and local government sector is projected as a share of total potential employment. That share is extrapolated from its recent historical trend. Potential productivity in both government sectors is also projected by continuing their trend growth rate of the recent past.

To project government depreciation (or capital consumption allowance), CBO combines projections for CCA in the federal and state and local sectors. Those projections are computed by applying a projection for the depreciation rate to a projection for each type of government capital:

$$CCA_{i,t} = \delta_{i,t} \bullet K_{i,t-1} \tag{16}$$

where $CCA_{i,t}$ = capital consumption allowance (depreciation) for asset i in year t

$\delta_{i,t}$ = depreciation rate for asset i in year t

$K_{i,t-1}$ = stock of capital asset i, lagged one year

i = government capital assets (federal defense, federal nondefense, and state and local)

Historical values for the government depreciation rates are calculated from the government CCAs and capital stocks, both of which are estimated and published by BEA. The depreciation rate for government capital is then projected by extrapolating its trend growth rate of recent years. Government capital stocks are projected using equations like equation (15), which cumulate those stocks on the basis of the depreciation rate and a projection for real government investment.[34]

Farm Sector. The growth model projects potential farm output as the product of potential farm employment and productivity (measured as output per worker). Since both of those variables are cyclically adjusted, they have steady growth rates during the recent past, and both are assumed to continue those growth rates during the 10-year projection period.

Households and Nonprofit Institutions Sector. The growth model's equation for potential output in this sector takes the same form as that for government compensation—the product of potential hours worked and potential labor productivity. As in the government sector, output is measured as the sum of all constant-dollar compensation paid to employees in the sector. Both potential hours worked and potential productivity are projected to continue their rate of growth since the cyclical peak in 1990.

Housing Sector. Output in the housing sector is modeled as a function of the stock of residential housing and the productivity of that stock. The residential housing stock is projected using projections of real residential investment and the rate of depreciation of the residential capital stock, which, like capital productivity in this sector, is extrapolated from recent trends.

34. The capital stocks in equation (16) are not necessary to estimate potential output in the government sector over history because capital does not appear in the equation used to estimate potential output in that sector.

The Foreign Sector

The growth model requires projections of net foreign investment and gross foreign product to project the capital stock in the nonfarm business sector and to compute GNP. Net foreign investment is the difference between gross domestic saving and gross domestic investment. If that number is negative, as it has been in recent years, then foreigners are supplying funds used for investment in the United States. Gross domestic investment is therefore larger than it could be using only domestically supplied funds, allowing productive capacity to expand more quickly than it would otherwise. Negative net foreign investment also implies that the stock of foreign-owned U.S. assets is growing more quickly than the stock of U.S.-owned foreign assets (net foreign investment is the difference between the increments in those variables). The model computes the stock of U.S.-owned foreign assets and the level of net foreign investment as shares of potential GDP and then computes the stock of foreign-owned U.S. assets implied by the projections of those two variables.

Gross foreign product is measured by U.S. receipts of factor income from foreigners minus U.S. payments of factor income to foreigners, as shown in equation (17):

(17) $$GNP_{row} = YX_{row} - YM_{row}$$

where
GNP_{row} = gross foreign product (in billions of dollars)
YX_{row} = income receipts from the rest of the world (in billions of dollars)
YM_{row} = income payments to the rest of the world (in billions of dollars)

As noted earlier, those income receipts are composed primarily of income from the stocks of foreign-owned U.S. assets and U.S.-owned foreign assets, such as undistributed corporate profits, interest, and dividend payments. Therefore, the income receipts (and thus gross foreign income) are projected by applying rates of return on those assets to the projections of stocks of U.S.- and foreign-owned assets determined by the model, as shown in equations (18a) and (18b).

(18a) $$YX_{row} = rx \bullet USOFA$$

(18b) $$YM_{row} = rm \bullet FOUSA$$

where
rx = the rate of return on U.S.-owned foreign assets (in percent)
USOFA = U.S.-owned foreign assets (in billions of dollars)
rm = the rate of return on foreign-owned U.S. assets (in percent)
FOUSA = foreign-owned U.S. assets (in billions of dollars)

The rates of return in equations (18a) and (18b) reflect real rates of return worldwide and are projected with reference to CBO's baseline forecast of interest rates on 10-year Treasury notes.

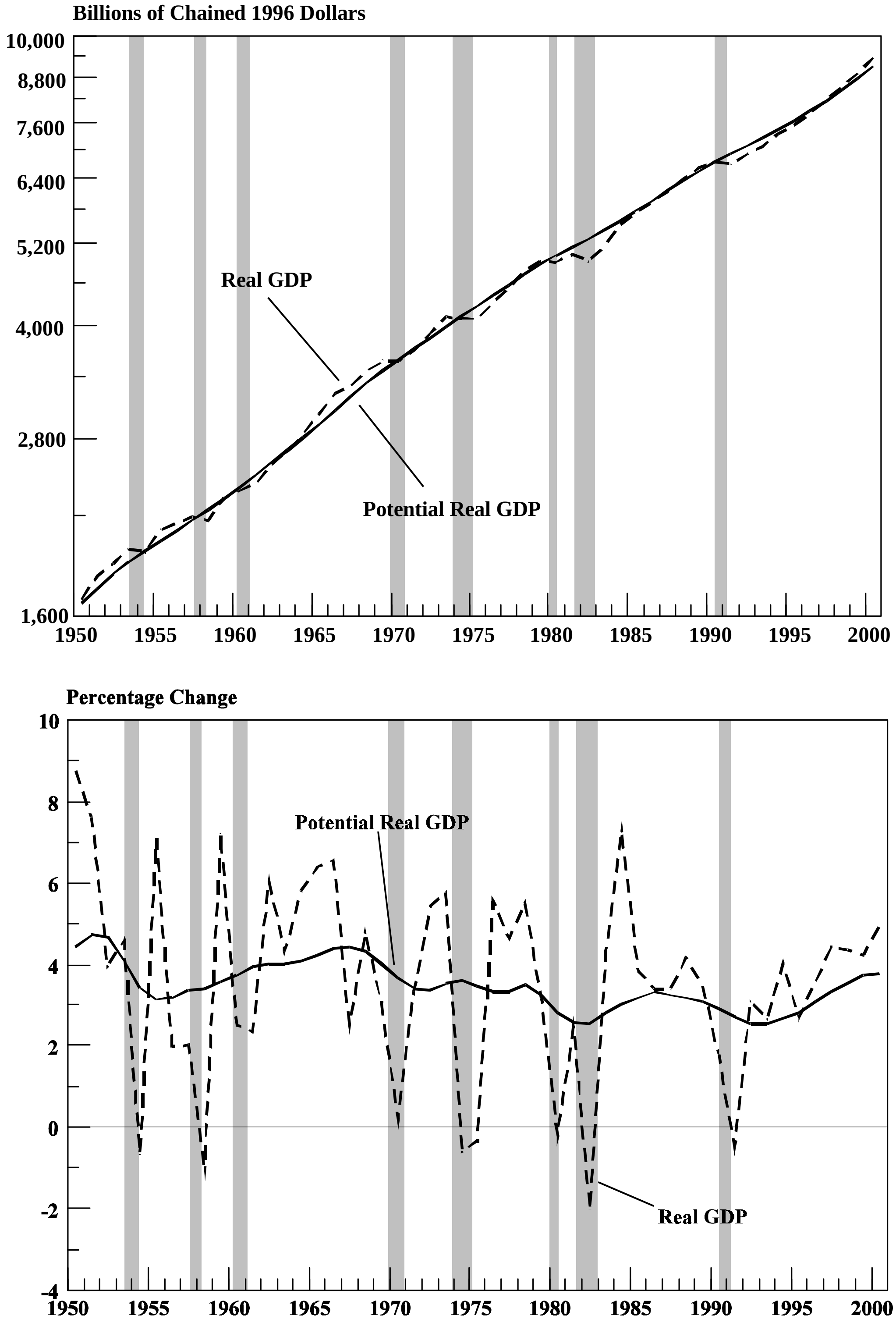
CBO'S ESTIMATES OF POTENTIAL OUTPUT FOR 1950 THROUGH 2011

Potential output provides a useful measure of capacity for the overall economy. Output generally falls below potential during recessions, remains below potential during recoveries and early expansions, and rises above potential during late expansions (as illustrated in Figure 5). Such effects of the business cycle are shown most clearly by the GDP gap (the percentage difference between actual and potential output), which is one of the indicators that CBO and other forecasters use to estimate the degree of short-run inflationary pressure in the economy. When output rises above potential—as indicated by a positive GDP gap—the rate of consumer price inflation is likely to rise in the next year or two (in the absence of any shocks). Similarly, when output falls below potential, price pressures ease and the rate of inflation tends to fall (see Figure 6).

CBO's estimates of actual and potential output and the GDP gap since 1950 are shown in Table 1 (on pages 36 and 37), along with projections of those variables through 2011. CBO's estimate of the GDP gap is roughly similar to estimates calculated by some other agencies and private forecasters: DRI (an economics consulting firm), the Organization for Economic Cooperation and Development, and the International Monetary Fund (IMF). Although the levels of those estimates differ, all follow roughly the same pattern over time (see Figure 7). The DRI estimate, in particular, is quite close to CBO's estimate for most of the period since 1960. For the past two business cycles, however, CBO's estimate shows slightly larger output gaps (implying a larger degree of inflationary pressure) than the other estimates. That difference probably reflects a slightly higher estimate of the NAIRU than the other forecasters use.

Two other features of the comparison in Figure 7 stand out. First, the IMF's estimate implies the existence of much more excess capacity during the mid-1990s than the other estimates do. Second, unlike the others, DRI's measure of potential output shows a much smaller output gap in 1999 and 2000, implying almost no inflationary pressure during that period.

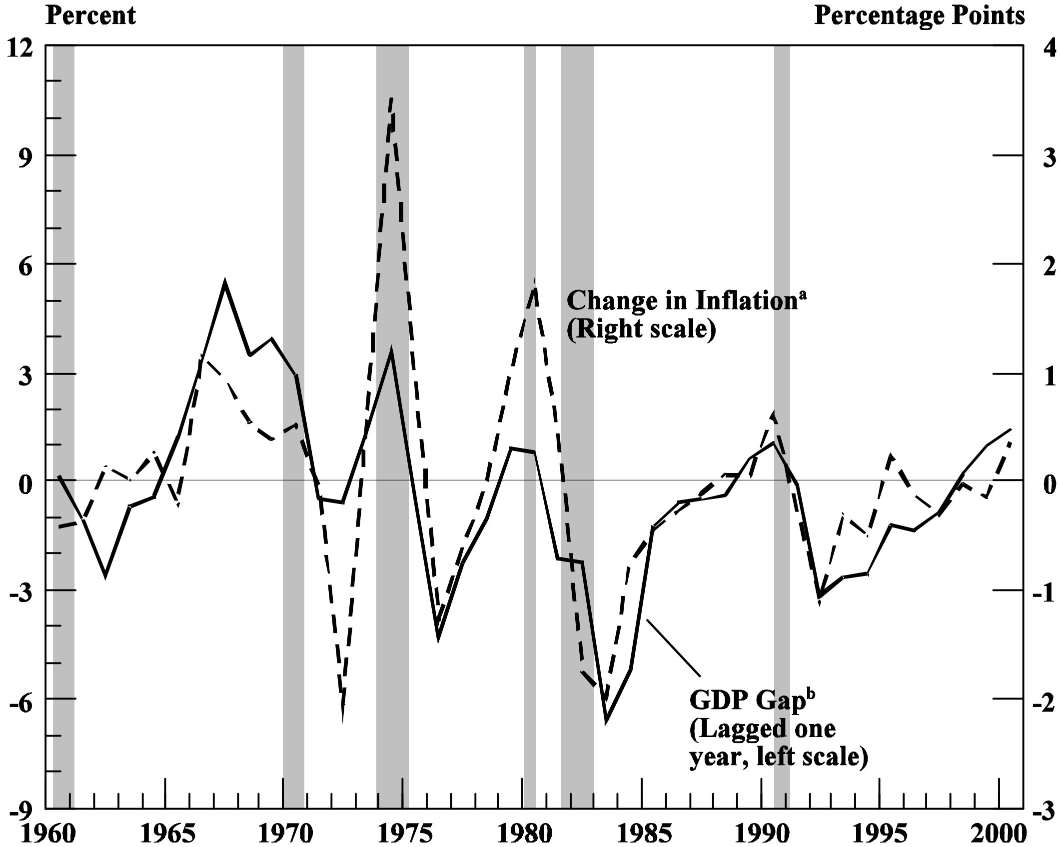
FIGURE 5. REAL GDP AND POTENTIAL REAL GDP



SOURCE: Congressional Budget Office using data from the Department of Commerce, Bureau of Economic Analysis.

NOTE: The y-axis of the top panel is plotted using a logarithmic scale.

FIGURE 6. THE GDP GAP AND THE CHANGE IN INFLATION

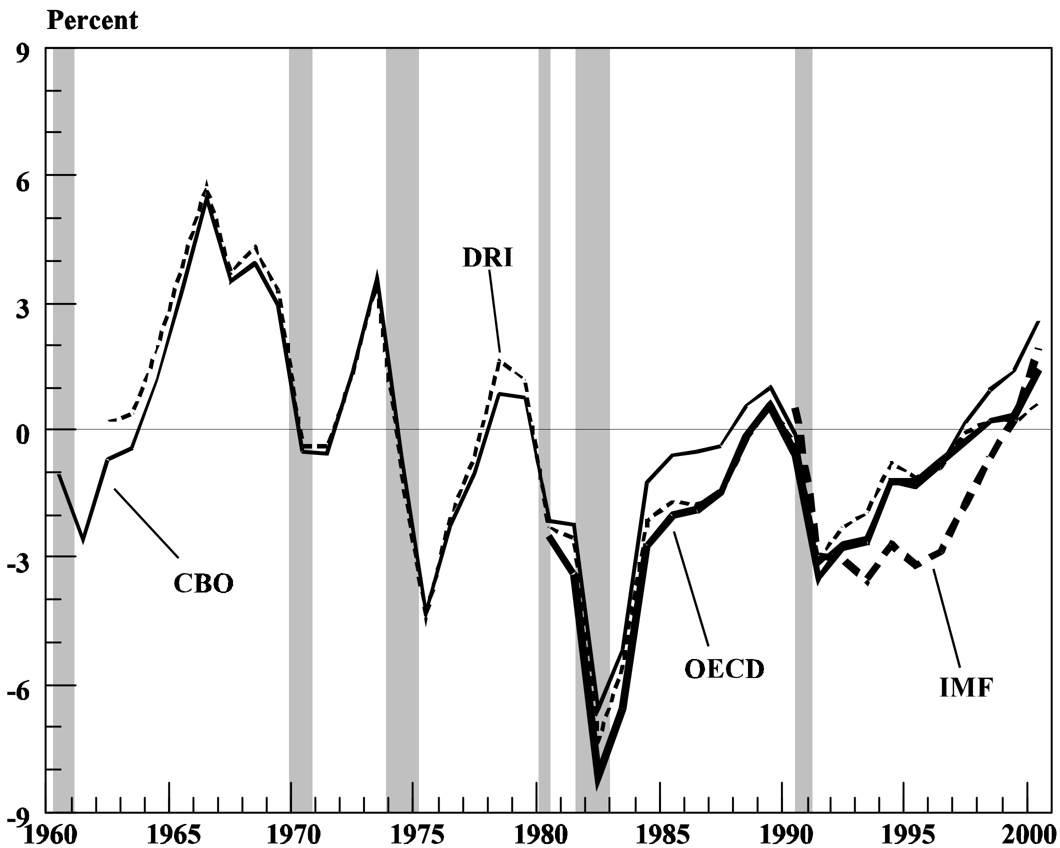


SOURCE: Congressional Budget Office using data from the Department of Commerce, Bureau of Economic Analysis, and from the Department of Labor, Bureau of Labor Statistics.

a. Inflation is measured as the consumer price index for all urban consumers (CPI-U) excluding food and energy.

b. The gap between actual and potential gross domestic product.

FIGURE 7. ESTIMATES OF THE GDP GAP BY CBO AND OTHER FORECASTERS



SOURCE: Congressional Budget Office using data from the Department of Commerce, Bureau of Economic Analysis; DRI-WEFA (an economics consulting firm); the Organization for Economic Cooperation and Development; and the International Monetary Fund.

TABLE 1. POTENTIAL OUTPUT AND RELATED SERIES, 1950-2011

	Real Gross Domestic Product (Billions of Chained 1996 Dollars)		Gap Between Actual and Potential GDP (Percent)	NAIRU[a] (Percent)
	Actual	Potential		
1950	1,687	1,665	1.3	5.3
1951	1,815	1,743	4.1	5.3
1952	1,887	1,825	3.4	5.4
1953	1,974	1,900	3.9	5.4
1954	1,961	1,965	-0.2	5.4
1955	2,100	2,026	3.6	5.4
1956	2,141	2,091	2.4	5.4
1957	2,184	2,162	1.0	5.4
1958	2,163	2,236	-3.3	5.4
1959	2,319	2,316	0.1	5.4
1960	2,377	2,402	-1.1	5.5
1961	2,432	2,497	-2.6	5.5
1962	2,579	2,597	-0.7	5.5
1963	2,690	2,702	-0.4	5.5
1964	2,846	2,813	1.2	5.6
1965	3,029	2,931	3.3	5.7
1966	3,227	3,060	5.5	5.8
1967	3,308	3,196	3.5	5.8
1968	3,466	3,335	3.9	5.8
1969	3,571	3,469	3.0	5.8
1970	3,578	3,596	-0.5	5.9
1971	3,698	3,719	-0.6	5.9
1972	3,898	3,845	1.4	6.0
1973	4,123	3,980	3.6	6.1
1974	4,099	4,124	-0.6	6.2
1975	4,084	4,268	-4.3	6.2
1976	4,312	4,411	-2.3	6.2
1977	4,512	4,559	-1.0	6.2
1978	4,761	4,719	0.9	6.3
1979	4,912	4,873	0.8	6.3
1980	4,901	5,009	-2.2	6.2
1981	5,021	5,137	-2.3	6.2
1982	4,919	5,266	-6.6	6.1
1983	5,132	5,413	-5.2	6.1
1984	5,505	5,575	-1.2	6.0

(Continued)

TABLE 1. CONTINUED

	Real Gross Domestic Product (Billions of Chained 1996 Dollars)		Gap Between Actual and Potential GDP (Percent)	NAIRU[a] (Percent)
	Actual	Potential		
1985	5,717	5,752	-0.6	6.0
1986	5,912	5,944	-0.5	6.0
1987	6,113	6,137	-0.4	6.0
1988	6,368	6,331	0.6	5.9
1989	6,592	6,525	1.0	5.9
1990	6,708	6,714	-0.1	5.9
1991	6,676	6,895	-3.2	5.8
1992	6,880	7,068	-2.7	5.7
1993	7,063	7,247	-2.5	5.5
1994	7,348	7,439	-1.2	5.4
1995	7,544	7,647	-1.4	5.3
1996	7,813	7,882	-0.9	5.2
1997	8,159	8,145	0.2	5.2
1998	8,516	8,435	1.0	5.2
1999	8,876	8,751	1.4	5.2
2000	9,318	9,083	2.6	5.2
2001	9,481	9,413	0.7	5.2
2002	9,728	9,732	0	5.2
2003	10,045	10,045	0	5.2
2004	10,366	10,366	0	5.2
2005	10,702	10,702	0	5.2
2006	11,050	11,050	0	5.2
2007	11,406	11,406	0	5.2
2008	11,772	11,772	0	5.2
2009	12,147	12,147	0	5.2
2010	12,533	12,533	0	5.2
2011	12,928	12,928	0	5.2

SOURCE: Congressional Budget Office using data from the Department of Commerce, Bureau of Economic Analysis.

NOTE: Numbers for 2001 through 2011 are CBO projections.

a. The nonaccelerating inflation rate of unemployment.

ADVANTAGES AND DISADVANTAGES OF CBO'S METHOD

Although the details of CBO's approach to calculating potential output can be complicated, the growth model on which it is based is a very simple representation of the economy. As described earlier, potential output is basically modeled as the sum of the growth rates of a few fundamental factors of supply: labor, capital, and TFP. That setup is a standard model of long-term economic growth and has formed the basis for numerous studies of long-term growth and growth-accounting exercises.

Advantages

One important advantage of using the growth-accounting framework is that it looks explicitly at the supply side of the economy. Because potential output is a measure of productive capacity, any estimate of it should benefit from explicit dependence on factors of production. For example, if growth in the available pool of labor increases, the estimate of potential output should accelerate too, all else being equal. Similarly, a boom in business investment would be expected to speed the growth in productive capacity.

Another advantage of using a growth model to calculate potential output is that it supplies a projection for potential output that is consistent with CBO's projection for the federal budget. That consistency allows CBO to incorporate the effects of changes in fiscal policy into its medium-term (10-year) economic and budget projections. Fiscal policy has obvious effects on aggregate demand in the short run, effects that CBO reflects in its short-term (two-year) forecast. However, fiscal policy will also influence the growth in potential output over the medium term through its effect on national saving and capital accumulation. Because the growth model explicitly includes capital as a factor of production, it captures that effect.

A third advantage of basing CBO's method on the Solow growth model is that it allows for a transparent accounting for the sources of growth. Such a growth-accounting exercise (familiar from the research of Angus Maddison, Edward Denison, and Dale Jorgenson) divides the growth of actual or potential GDP into the contributions from each of the factor inputs.[35] A growth-accounting exercise for CBO's estimates since 1951 is shown in Table 2. The table displays the growth rates of potential output and its components for the overall economy and for the nonfarm business sector. Note that since the growth rates of the factor inputs are not weighted in any way, they do not sum to the growth in potential output.

35. See Maddison, "Growth and Slowdown in Advanced Capitalist Economies"; Denison, *Trends in American Economic Growth*; and Jorgenson, Gollop, and Fraumeni, *Productivity and U.S. Economic Growth*.

TABLE 2. KEY ASSUMPTIONS IN CBO'S PROJECTION OF POTENTIAL GDP
(In percent)

	Average Annual Growth						Projected Average Annual Growth, 2001-2011
	1951-1973	1974-1981	1982-1990	1991-1995	1996-2000	Total, 1951-2000	
Overall Economy							
Potential GDP	3.9	3.2	3.0	2.6	3.5	3.5	3.3
Potential Labor Force	1.6	2.5	1.6	1.1	1.2	1.7	1.1
Potential Labor Force Productivity[a]	2.2	0.7	1.4	1.5	2.3	1.8	2.1
Nonfarm Business Sector							
Potential Output	4.0	3.6	3.2	3.0	4.0	3.7	3.7
Potential Hours Worked	1.3	2.2	1.6	1.6	1.4	1.5	1.2
Capital Input	3.7	4.3	3.6	2.5	5.2	3.8	4.8
Potential Total Factor Productivity	2.0	0.8	1.0	1.1	1.5	1.5	1.4
Potential TFP excluding adjustments	2.0	0.7	1.0	1.1	1.1	1.4	1.1
TFP adjustments	0	0	0	0	0.4	0	0.3
Computer quality	0	0	0	0	0.1	0	0.2
Price measurement	0	0	0	0	0.2	0	0.2
Temporary adjustment[b]	0	0	0	0	0.1	0	0
Contributions to Growth of Potential Output (Percentage points)							
Potential hours worked	0.9	1.5	1.1	1.1	1.0	1.1	0.8
Capital input	1.1	1.3	1.1	0.8	1.5	1.1	1.5
Potential TFP	2.0	0.8	1.0	1.1	1.5	1.5	1.4
Total Contributions	4.0	3.6	3.2	2.9	4.0	3.7	3.7
Memorandum:							
Potential Labor Productivity[c]	2.7	1.4	1.6	1.4	2.6	2.1	2.5

SOURCE: Congressional Budget Office.

NOTE: CBO assumes that the growth rate of potential total factor productivity (TFP) changed after the business-cycle peaks of 1973, 1981, and 1990 and again after 1995.

a. Potential GDP divided by the potential labor force.

b. The temporary adjustment raises the growth of potential TFP during the 1996-2000 period to help make the estimate of potential GDP more compatible with the observed weakness of inflation. That adjustment is considered transitory, in the sense that although it has a permanent effect on the estimated *level* of potential TFP, its effect on the growth rate of TFP is temporary.

c. Estimated trend in the ratio of output to hours worked in the nonfarm business sector.

Table 2 also shows the contribution of each factor input to the growth of potential output in the nonfarm business sector by weighting each input's growth rate by its coefficient in the production function. The sum of the contributions equals the growth of potential output. Computing the contributions to growth highlights the sources of any quickening or slowdown in growth. For example, the acceleration in potential labor productivity that occurred during the late 1990s can be attributed to accelerations in potential TFP (of 0.4 percentage points) and capital input (of 0.7 percentage points).

CBO's model has a relatively high degree of disaggregation, which reveals more insights about the economy than a more aggregated model would. For example, the model calculates the capital input to the production function as a weighted average of seven types of capital. Those data indicate a shift over the past few decades to capital goods with shorter service lives: a larger share of total fixed investment is going to producers' durable equipment relative to structures, and a larger share of PDE is going to computers and other IT capital. Since shorter-lived capital goods depreciate more rapidly, the shift toward PDE and IT capital increases the share of investment dollars used to replace worn-out capital and tends to lower net investment and the capital input. Shorter-lived capital goods are also more productive than those with longer service lives and are therefore weighted more heavily in the growth model's capital aggregate. A model that ignores the capital input or that does not disaggregate capital is likely to miss both of those effects.

Disadvantages

On the negative side, the simplicity of CBO's model could be seen as a drawback. The model uses some parameters—most notably, the coefficients on labor and capital in the production function—that are imposed rather than econometrically estimated. Although that approach is standard practice in the growth-accounting literature, it is tantamount to assuming the magnitude of the contribution that each factor input makes to growth. With such an approach, the magnitude of that contribution will not change from year to year as the economy evolves, as it would in an econometrically estimated model.[36]

Some analysts would argue against using a growth model to estimate potential output because including the capital stock introduces measurement error. Most

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36. Econometric approaches include "systems" models—which use equations similar to CBO's but with more econometrically estimated parameters—and multivariate time-series models. The latter category, which includes vector autoregressions (VARs) and structural VARs, imposes fewer restrictions on the structure of and relationships between equations in the system than CBO's method does. For a survey of alternative statistical approaches, including VARs, see Chantal Dupasquier, Alain Guay, and Pierre St. Amant, *A Comparison of Alternative Methodologies for Estimating Potential Output and the Output Gap,* Working Paper No. 97-5 (Ottawa: Bank of Canada, February 1997).

economic variables are subject to measurement error, but the problem is particularly acute for capital.[37] First, settling on an appropriate definition for economic depreciation (the decline in the value of capital associated with aging, including declines caused by wear and tear, accidental damage, obsolescence, and scrappage) and then measuring it as defined is extremely difficult. Businesses' purchases of plant and equipment can be tallied to produce a historical series for investment, but no corresponding source of data exists for depreciation. Consequently, economists disagree about a host of empirical and conceptual issues regarding depreciation.[38] CBO's estimates of capital stocks reflect depreciation data from the NIPAs, which the Bureau of Economic Analysis estimates using assumptions about service lives and efficiency patterns for different types of capital.

Measurement error can also arise in constructing the capital input, even if capital stocks and depreciation are measured without error. The problem is that capital goods come in many types, each with different fundamental characteristics, such as productivity and durability. The disparate nature of capital means that merely summing the stocks would give a misleading view of the level of capital services available for production. Economic theory provides an approach to the problem of aggregating capital—embodied in equation (8)—but the assumptions that underlie that equation may not be satisfied in practice. Compounding the aggregation problem is the vast number of capital goods used in the nonfarm business sector; including every type of capital separately in the equation would be impractical, if not impossible.

Analysts who thought that measurement error was a severe problem would model potential output as a function of labor input and labor productivity. They would estimate trends in those variables and combine them to determine potential output. In such a framework, any effects on potential output from capital deepening would show up in labor productivity. That approach is reasonable, but by not including capital, it misses the endogenous effects of fiscal policy on potential output and the explicit effects of capital deepening. Also, that approach is encompassed by CBO's method, which produces an estimate of potential labor productivity as a by-product of its calculations. In addition, failing to explicitly examine the role of capital would have hidden one of the reasons why labor productivity accelerated during the late 1990s.

37. For more details about measurement error, see Charles R. Hulten, "The Measurement of Capital," in E.R. Berndt and J.E. Triplett, eds., *Fifty Years of Economic Measurement* (Chicago: University of Chicago Press, 1990).

38. For a summary of various controversies surrounding the concept of depreciation, see Jack Triplett, "Depreciation in Production Analysis and in Income and Wealth Accounts: Resolution of an Old Debate," *Economic Inquiry*, vol. 34 (January 1996), pp. 93-115. For a description of BEA's methodology for estimating depreciation, see Barbara Fraumeni, "The Measurement of Depreciation in the U.S. National Income and Product Accounts," *Survey of Current Business*, vol. 77, no. 7 (July 1997), pp. 7-23.

Another point of contention with CBO's method is the use of deterministic time trends to cyclically adjust many variables in the model. Some analysts assert that relying on such time trends provides a misleading view of the cyclical behavior of some economic data series. Those analysts argue, based on empirical studies of the business cycle, that using variable rather than fixed time trends is more appropriate for most data series.[39] They assert that a trend should not be represented as a fixed rate of growth (say, 2 percent a year) but rather as a fixed rate of growth plus or minus some random amount, which could differ from year to year.

Several alternatives to fixed trends exist, including centered, moving averages, the Hodrick-Prescott filter, and the Kalman filter.[40] Any of those alternatives could be used to cyclically adjust the inputs in CBO's growth model instead of equation (6). All of the alternative methods are reasonable, and depending on how they were implemented, none would give results that differ significantly from CBO's. However, some of those methods are more computationally burdensome, and it is not entirely clear that they would produce a better estimate of trends than CBO's method does. One problem in particular is that those filtering methods perform poorly at the beginning or end of a sample period (by losing observations or losing the ability to identify the trend). In addition, many of the alternative methods do not benchmark their trends to any external measure of capacity. Therefore, unlike CBO's results, the results of those methods cannot be interpreted as the level of output that is consistent with stable inflation.

Finally, CBO's model does not contain explicit channels of influence for all major effects of government policy on potential output. For example, it includes no explicit link between tax rates and labor supply, productivity, or the personal saving rate, nor does it include any link between changes in regulatory policy and those variables. However, that does not mean that the model precludes a relationship between policy changes and any of those variables. If a given policy change is estimated to be large enough to affect the incentives governing work effort, productivity, or saving, then including those effects in a projection or policy simulation is a straightforward task. Moreover, the structure of CBO's model makes it easier to isolate the effects of such policy changes and to incorporate those effects in the model than would be the case with a time-series-based model.

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39. See James H. Stock and Mark W. Watson, "Variable Trends in Economic Time Series," *Journal of Economic Perspectives*, vol. 2, no. 3 (Summer 1988), pp. 147-174; and John Campbell and Pierre Perron, "Pitfalls and Opportunities: What Macroeconomists Should Know About Unit Roots," in Olivier Blanchard and Stanley Fischer, eds., *NBER Macroeconomics Annual 1991* (Cambridge, Mass., and London: MIT Press, 1991).

40. For an example of potential output calculated using the Hodrick-Prescott filter, see Jane Haltmaier, *Inflation-Adjusted Potential Output*, International Finance Discussion Paper No. 561 (Federal Reserve Board of Governors, August 1996). For an example that uses the Kalman filter, see Kenneth Kuttner, "Estimating Potential Output as a Latent Variable," *Journal of Business and Economic Statistics*," vol. 12, no. 3 (1994), pp. 361-368.

Conclusion

CBO's current method for estimating potential output offers a combination of transparency and computational ease. It also produces accurate results relative to forecasts by the Administration and the *Blue Chip* survey of private economic forecasters.[41] However, CBO staff continue to evaluate alternatives and may modify that method when evidence points to a superior approach.

41. See, for example, Congressional Budget Office, *The Budget and Economic Outlook: An Update* (July 2000), Appendix B.

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