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Estimating and Projecting Potential Output Using CBO's Forecasting Growth Model

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Abstract

As part of its responsibility for producing baseline projections of the economy and the federal budget, the Congressional Budget Office regularly produces estimates and projections of potential output, a measure of the economy's fundamental ability to supply goods and services. The projection of potential output serves as a key input to CBO's macroeconomic forecasts and budget projections, helping the agency maintain consistency between its projections of labor supply and capital accumulation and its projections of taxes on income from labor and capital, of federal expenditures, and of the accumulation of public debt. This paper updates the agency's description of the data sources, analytic methods, and modeling framework that it uses both to estimate historical values of the components of potential output and to project those values into the future. It describes the major changes that CBO has introduced in its approach since it last published a methodological description in 2001, outlines the linkages between its analysis of potential output and other elements of its economic and policy analysis, and discusses some of the major challenges associated with understanding and projecting recent trends in fundamental components of the economy.

Keywords: Economic growth, macroeconomic forecasting

JEL Classification: E17, E27

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Introduction

As part of its mission to provide information to the Congress, the Congressional Budget Office regularly prepares economic projections that include variables such as the components of real (inflation-adjusted) gross domestic product (GDP), employment, prices, and interest rates. Those economic projections underlie the agency's projections of the federal budget—which are reported on a yearly basis in *The Budget and Economic Outlook*, *An Update to the Budget and Economic Outlook*, and *The Long-Term Budget Outlook*—as well as its estimates of the budgetary costs and macroeconomic impacts of legislative and other proposals.[1]

This paper discusses the methods that CBO uses to estimate and project one of the key economic variables underlying its projections—potential GDP, or potential output.[2] A measure of the economy's fundamental ability to supply goods and services, potential output is an estimate of the amount of real GDP that is attainable if domestic inputs of labor and capital are employed at maximum sustainable rates. It is an estimate of the trend around which economic activity fluctuates over business cycles and the primary measure of overall economic activity that CBO projects over the long term.[3]

To construct its estimates of potential output, CBO relies on a standard modeling framework for analyzing longer-term trends in economic growth and draws from a variety of sources of historical data to estimate components of supply in different sectors of the economy. That approach helps the agency maintain consistency between its projections of labor supply and capital accumulation and its projections of taxes on income from labor and capital, federal expenditures, and the accumulation of public debt. The forecasting growth model described in this paper not only serves as the basis for CBO's macroeconomic forecasts and budget projections, but also underpins a second model, referred to as the policy growth model, that is used both to project output beyond the 10-year budget window and to analyze the economic effects of changes in fiscal policy over the 10-year window and beyond.

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[1] See Congressional Budget Office, *The 2017 Long-Term Budget Outlook* (March 2017), www.cbo.gov/publication/52480; and *The Budget and Economic Outlook: 2017 to 2027* (January 2017), www.cbo.gov/publication/52370. CBO's cost estimates are available at www.cbo.gov/cost-estimates.

[2] The paper updates reports that CBO published in 1995 and 2001. See Congressional Budget Office, *CBO's Method for Estimating Potential Output* (October 1995), www.cbo.gov/publication/10603; and *CBO's Method for Estimating Potential Output: An Update* (August 2001), www.cbo.gov/publication/13250. For a brief, more recent description, see Robert W. Arnold, "The Challenges of Estimating Potential Output in Real Time," *Federal Reserve Bank of St. Louis Review*, vol. 91, no. 4 (Federal Reserve Bank of St. Louis, July/August 2009), pp. 271–290, https://tinyurl.com/y9499oze (PDF, 265 KB).

[3] Over a business cycle, real activity rises to a peak (its highest level during the cycle) and then falls until it reaches a trough (its lowest level following the peak), whereupon it starts to rise again, defining a new cycle. Business cycles are irregular, varying in frequency, magnitude, and duration.

The agency regularly updates its estimates and projections of potential output to account for newly released data, revisions to existing data, and new legislation. Moreover, the agency routinely reviews and revises its methods of estimating and projecting the determinants of potential output, as necessary, by recalculating trends in inputs, reassessing the persistence of economic developments, and refining the equations in its models.[4] Among the most significant improvements in recent years, CBO has developed more detailed estimates and projections of the potential labor force and of capital services in the nonfarm business sector. Reflecting changes in historical patterns over the past 15 years, the agency has also significantly adjusted its estimates and projections of productivity growth, especially the growth of total factor productivity (TFP).[5] Those revisions have helped the agency to better explain recent events and project future developments and enabled it to better analyze federal government policies that might boost or constrain economic growth. (See Appendix A for a more detailed discussion of changes in the forecasting growth model since 2001.)

CBO's Framework for Potential Output

For the most part, CBO's estimate of potential output relies on a standard economic framework called the Solow growth model and on techniques based on Okun's law, named after the economist who first introduced the concept.[6] The basis of most studies of long-term economic growth, the Solow model focuses mainly on the inputs that drive growth in the supply side of the economy—specifically, the amount of labor and the productive services provided by capital. Okun's law ties changes in output to changes in unemployment.

CBO builds its estimate of aggregate potential output from estimates of the potential output in several different sectors of the overall economy.[7] Those estimates, in turn, depend on estimates of the potential inputs to sectoral production processes as well as their potential productivity.

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[4] For a detailed discussion of revisions to CBO's projection of potential output in the aftermath of the 2007–2009 recession, see Congressional Budget Office, *Revisions to CBO's Projection of Potential Output Since 2007* (February 2014), www.cbo.gov/publication/45150.

[5] The growth of TFP is one component of real growth in the nation's economic output—the residual growth that reflects all economic development that is not attributable to the growth of capital services or labor.

[6] See Arthur Okun, "Potential GNP: Its Measurement and Significance," in *Proceedings of the Business and Economics Statistics Section* (American Statistical Association, 1962), pp. 98–103.

[7] In the following sections, figures and tables present historical estimates and projections that were produced in January 2018 using the forecasting growth model. That process was undertaken while developing estimates and projections that will be published in Congressional Budget Office, *The Budget and Economic Outlook: 2018 to 2028* (forthcoming). The historical estimates presented here are the same as those that will be published in that document, but these projections do not reflect the effects of recent major legislation.

Characterizing Potential Output

CBO's approach to identifying underlying productive capacity is to focus on fundamental determinants of supply rather than on fluctuations in aggregate demand. That approach is based on the notion that the economy has an underlying but unobserved trend path along which output, employment, and investment could develop without triggering inflationary instability or recession. Estimates of that path measure the capacity of the economy to supply a steadily growing stream of output. Potential output thus does not represent a limit 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 steady growth and a stable rate of inflation.

The underlying productive capacity of the economy is obscured by business cycles that are characterized by alternating periods of expansion and contraction: According to estimates published by the National Bureau of Economic Research (NBER), the American economy has experienced 11 complete business cycles since the end of World War II.[8] During economic expansions, aggregate demand rises, triggering increases in production, employment, and investment. At some point, however, an expansion may outpace the economy's fundamental capacity to supply more inputs of labor and capital, leading to shortages in supply and accelerating price inflation. Financial markets may play a role by supplying excessive amounts of credit. Ultimately, the growth of demand stalls, investment and employment decline, and the economy falls into recession, leaving productive resources idle and slowing price inflation until the economy finally begins to recover. Government activities, such as changes in taxes and spending or in monetary policy, may moderate or exacerbate such cycles.

The distinction between trend growth in underlying supply and demand-driven fluctuations in actual output is not entirely clear-cut. Changes in supply may trigger fluctuations in demand: For example, unexpected increases in the supply price of fuel may trigger a decline in aggregate demand. Conversely, demand fluctuations can influence supply, as when changes in demand for investment goods affect the supply of capital. The concept of potential output is therefore more of a useful abstraction than a reality.[9] Nevertheless, CBO has found the concept to be a useful benchmark for determining the position of the economy in the business cycle.

In addition, the agency has concluded that for periods beyond a few years, it is more appropriate to project future economic activity on the basis of fundamental supply considerations rather than trying to forecast fluctuations in demand. Thus, the agency's economic projections over the longer term are formed on the basis of its projection of potential output.

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[8] See NBER's web page on business cycles at www.nber.org/cycles.html. Those cycles, measured from peak to peak, averaged nearly 6 years in length, with the shortest lasting less than 2 years and the longest nearly 11.

[9] For a detailed overview and critique of the concept of potential output and its estimation, see Sebastian Hauptmeier and others, *Projecting Potential Output: Methods and Problems* (Physica Verlag Heidelberg, 2009).

Modeling the supply side of the economy also provides CBO with a particularly suitable framework to relate economic activity over the long term to changes in public policies that influence it. If changes in policies affect whether and how much people choose to work, pursue education, save, and retire, or affect how much investment businesses decide to undertake, estimates of those effects flow through the model and influence the level of potential output. The framework thus helps the agency maintain consistency between its projections of labor supply and capital accumulation and its projections of taxes on income from labor and capital, federal expenditures, and the accumulation of public debt. For example, changes in federal income tax rates or money available for private investment influence the projected supply of labor and growth of potential output. Similarly, projected changes in public debt influence projected private saving and capital accumulation.

Modeling the Economy on a Sectoral Basis

CBO bases its estimates of potential output on the sectoral framework published in the national income and product accounts (NIPAs) by the Bureau of Economic Analysis (BEA).[10] In that framework, GDP comprises the output (or value added) of six productive sectors: nonfarm business, farm, the federal government, state and local governments, households, and nonprofit institutions. Potential output in each sector is estimated from data on real output, and the real values $QGDP$ are converted to nominal values GDP using the chain-weighted price indexes $PGDP$ for their actual counterparts:

$$(1)\ GDP_x = QGDP_x \times PGDP_x$$

(A similar calculation underlies the relation of all the other real and nominal series in the model, with real values denoted by Q and price indexes denoted by P.) In nominal terms, the sectoral values sum to nominal GDP for both the actual and potential series:

$$(2)\ GDP = GDP_{nfb} + GDP_{farm} + GDP_{house} + GDP_{nonprofits} + GDP_{federal} + GDP_{s\&l}$$

where

GDP = gross domestic product;
GDP_{nfb} = gross domestic product in the nonfarm business sector;
GDP_{farm} = gross domestic product in the farm sector;

[10] The national income and product accounts are available at www.bea.gov/iTable/index_nipa.cfm. The sectoral accounts that form the basis of CBO's framework are in Tables 1.3.3, 1.3.4, and 1.3.5. Aggregate economic activity can be measured in terms of expenditures on goods and services or in terms of the income earned from the production of those goods and services. In principle, the two measures should be equal. In practice, however, BEA reports a difference between its expenditure-based and income-based measures of GDP, which is referred to as the statistical discrepancy. Although some researchers prefer to use an average of the two measures, CBO focuses on the expenditure-based measure.

GDP_{house} = gross domestic product in the household sector;
$GDP_{nonprofits}$ = gross domestic product in the nonprofit sector;
$GDP_{federal}$ = gross domestic product in the federal government sector; and
$GDP_{s\&l}$ = gross domestic product in the state and local government sector.

The real sectoral values are aggregated to real GDP using chained Fisher indexes, as has been standard practice for the NIPAs since the mid-1990s.[11]

CBO uses a sectoral approach to compute potential output for two reasons. First, data for some sectors is more comprehensive than it is for others. Second, different sectors have different characteristics of production: Some sectors rely more heavily on their capital stocks, others more on their workforces.

For the bulk of the economy—the nonfarm business sector, which historically accounts for about three-quarters of total GDP—CBO uses a framework that is based on the Solow growth model.[12] The Solow model focuses primarily on two factors that determine growth in the supply side of the economy: the amount of labor (measured in terms of the number of hours worked) and the productive services provided by capital (including physical capital, such as plant and equipment, as well as more abstract types of capital, such as intellectual property). In CBO's model, the growth of output in the nonfarm business sector is tied to the growth of the supply of those two inputs through a relationship referred to as a production function. However, the growth of those inputs accounts for only about 60 percent of the growth in real nonfarm business GDP since 1950; the residual growth, or total factor productivity, must also be accounted for in estimating

[11] Fisher indexes are computed as the geometric mean of the growth rates of two-fixed-weighted indexes. The first, known as a Laspeyres index, 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, known as a Paasche index, computes the change in the value of output using the second year's prices. For further discussion of Fisher indexes, see Congressional Budget Office, *CBO's Method for Estimating Potential Output: An Update* (August 2001), www.cbo.gov/publication/13250, pp. 6–7; and J. Steven Landefeld, Brent R. Moulton, and Cindy M. Vojtech, "Chained-Dollar Indexes: Issues, Tips on Their Use, and Upcoming Changes," *Survey of Current Business,* vol. 83, no. 11 (Bureau of Economic Analysis, November 2003), pp. 8–16, https://bea.gov/scb/date-guide.htm.

[12] See Robert M. Solow, "A Contribution to the Theory of Economic Growth," *Quarterly Journal of Economics*, vol. 70, no. 1. (February 1956), pp. 65–94. CBO's forecasting growth model is based on one that researchers at the Brookings Institution developed to analyze the Social Security trust funds. For a description of the original model, see Henry J. Aaron, Barry P. Bosworth, and Gary T. Burtless, *Can America Afford to Grow Old?* (Brookings Institution Press, 1989). CBO's method for estimating potential output is similar to the methods that have been used by the International Monetary Fund, the Organisation for Economic Co-operation and Development, and the consulting firm Macroeconomic Advisers. See Macroeconomic Advisers, *Productivity and Potential GDP in the New U.S. Economy* (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 (International Monetary Fund, June 1990), pp. 232–293, www.jstor.org/stable/3867290; and Raymond Torres and John P. Martin, "Potential Output in the Seven Major OECD Countries," *OECD Economic Studies*, no. 14 (Organisation for Economic Co-operation and Development, Spring 1990), pp. 127–149.

and projecting potential GDP.[13] CBO's version of the Solow model takes the form of a Cobb-Douglas production function:

$$(3)\ QGDP_{nfb} = A_{nfb} \times ILAB_{nfb}^{(1-\alpha)} \times ICAP_{nfb}^{\alpha}$$

where

$QGDP_{nfb}$ = real GDP in the nonfarm business sector;
A_{nfb} = an index of total factor productivity in the sector;
$ILAB_{nfb}$ = an index of hours worked in the sector;
$ICAP_{nfb}$ = an index of capital services in the sector; and
α = a parameter that characterizes the relative contributions of labor and capital in the sectoral production process.

Other sectors are modeled using simpler production functions. For farms and nonprofits, production is represented in terms of the number of hours worked and labor productivity (that is, output per hour worked). For the government sectors, production is related to the number of employees, labor productivity, and the depreciation of government-owned capital. Output of the household sector is represented by its main component, the services provided by the owner-occupied housing stock. (Table 1 illustrates the basic sectoral structure of the model.)

[13] Some researchers use versions of the Solow model that also include an index of labor quality (sometimes referred to as labor composition) to account for the fact that hours of work vary in productivity. CBO does not separately account for labor quality, so any growth that is attributable to improvements in the education and skills of the labor force appears in its model as an improvement in TFP.

Table 1.
Structure of CBO's Forecasting Growth Model

Sector	Inputs			Percentage of GDP
	Labor	Capital	Productivity	
Nonfarm business	Labor hours	Services from multiple types of capital	Total factor productivity	75
Farm	Labor hours	--	Labor productivity	1
Household	--	Services from owner-occupied housing	--	7
Nonprofit	Labor hours	--	Labor productivity	5
Federal government	Labor hours	Aggregate depreciation	Labor productivity	4
State and local government	Labor hours	Aggregate depreciation	Labor productivity	8

Estimating Historical Values for Potential Inputs

CBO builds its estimate of potential output from estimates of the elements of supply—such as labor force participation, employment, stocks of capital, and productivity—using data for the period from 1948 to the present.[14] The basic approach is to estimate the aggregate potential labor force and aggregate potential employment, distribute that employment to the six sectors discussed in the preceding section, and build estimates of potential output in the six different sectors.[15] Potential output in a given sector is determined by the sector's production function and potential values of the inputs to production as well as their productivity.

Cyclical Adjustment of Historical Series

The potential values of inputs are cyclically adjusted trend values that exclude the estimated variation in the actual series that is attributable solely to business-cycle fluctuations. In principle, the resulting series measures not only the sustainable trend (the general direction or momentum) in the series but also measures its sustainable capacity to contribute to productive activity. (The agency does not adjust its measure of the contribution of capital to production, however, because the potential flow of services from any particular type of capital is related to the size of the actual stock of that type.)

To cyclically adjust a particular component of output, CBO typically estimates a linear regression equation that relates historical values of the component to values of other variables that are thought to influence it, including variables that measure the strength of the business cycle. The estimated parameters of the business-cycle variables provide an estimate of the influence of the business cycle on the component in question. Historical estimates of the potential value of the component are calculated as the fitted values of the estimated equation with the values of the business-cycle variables set to zero. That is, the potential values of the component are estimates of what values the component would take if business-cycle effects did not occur. (Throughout this paper, potential values are denoted with an asterisk; for example, the actual labor force is denoted LC whereas the potential labor force is denoted LC^*.)

The business-cycle variables used by CBO are based on the empirical relationship known as Okun's law, which ties changes in output to changes in unemployment. According to Okun's law, rising rates of unemployment are associated with declining growth of output; conversely, falling rates of unemployment are associated with rising growth of output. Consistent with that relationship, CBO estimates a rate of unemployment, referred to as the natural rate, that is consistent with stable equilibrium in the labor market and therefore consistent with maximum

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[14] Data from 1948 onward are used to construct estimates of levels of series that extend from 1949. Growth rates of those estimated series therefore extend from 1950.

[15] Values for many components of the model are estimated using quarterly data. However, some important series—particularly several series for capital assets in nonfarm business—are available only at an annual frequency. For that reason, the model is solved at an annual frequency; quarterly projections are interpolated from the annual series.

sustainable growth of output. The natural rate of unemployment—the rate that arises from all sources other than fluctuations in demand associated with business cycles—is influenced by the characteristics of jobs and of workers and by the efficiency with which the labor market matches jobs and workers. Those factors, in turn, influence the rate at which jobs are simultaneously created and eliminated, the rate of turnover in particular jobs, and how quickly unemployed workers are matched with vacant positions. (See Appendix B for a discussion of how the agency estimates the natural rate.)

In CBO's approach, the difference between the natural and actual rates of unemployment—referred to as the unemployment gap—is a pivotal indicator of the state of the business cycle. Thus, actual output exceeds its potential level when the rate of unemployment is below its natural rate and falls short of potential when the unemployment rate exceeds its natural rate. The agency uses the unemployment gap to develop its estimate of the potential labor force, as discussed in following sections, and then uses the natural rate of unemployment to estimate the level of potential employment. In other equations in the model, CBO uses the employment gap—the percentage difference between potential and actual employment—as the main indicator of the state of the business cycle.

CBO applies Okun's law in different ways in different parts of the model. Many of the equations for components of potential output in CBO's model take the form of piecewise linear regressions, also referred to as jointed stick regressions.[16] Equations of this type include a set of linear time trends that are used to estimate growth rates over different periods (in addition to the business-cycle variables as described previously). Each trend or "stick" is constructed to correspond to a specific business cycle or occasionally to more than one cycle.[17] When the values of the variable are expressed in logs, the estimated parameter for each trend or stick is a measure of the trend growth of the variable during that cycle.[18] (Reflecting that fact, many of the

[16] CBO's procedure is similar to one developed by Peter Clark, who used it to compute potential GNP from historical data. See Peter K. Clark, "Potential GNP in the United States, 1948–80," *Review of Income and Wealth*, vol. 25, no. 2 (June 1979), pp. 141–165, www.roiw.org/1979/141.pdf (329 KB).

[17] For more discussion of piecewise linear regressions, see Robert Pindyck and Daniel Rubenfeld, *Econometric Models and Economic Forecasts*, 4th ed. (McGraw-Hill/Irwin, 1978).

[18] CBO's uses NBER's determinations of business-cycle dates (available at www.nber.org/cycles.html). For example, NBER determines that the business cycle that covered most of the 1980s peaked in July 1990 and that the following cycle, which covered most of the 1990s, peaked in March 2001. Reflecting those dates, CBO's equations include trend variables specifically constructed for every business cycle. For example, one trend variable takes a value of 0 through the second quarter of 1990, 0.25 in the third quarter, 0.50 in the fourth quarter, and so on, until it takes a value of 10.5 in the fourth quarter of 2000 and in every quarter thereafter (the first quarter of 2001 being the peak of the cycle and the starting point for another trend). CBO constructs a similar trend for each business cycle from 1948 onward: Each trend takes a value of 0 until a particular business-cycle peak and then takes incrementally larger values until the next business-cycle peak, after which it takes the same value that it did at that last peak.

figures in this paper show values in logs, so that series with constant growth rates appear as straight lines.)

Allowing for breaks in the trend implies that, for the variable in question, the rate of growth of potential is constant within each business cycle but can differ from one cycle to the next. Defining the intervals of the time trends using complete business cycles helps ensure that the trends are estimated consistently throughout the historical sample. Many economic variables have distinct cyclical patterns—meaning they behave differently at different points in the business cycle. Specifying break points to coincide with cycle peaks helps ensure that such behavior is treated consistently from cycle to cycle (even though the underlying trend may vary from cycle to cycle).[19]

At any given moment, the economy is in a business cycle whose unique trend cannot be estimated because its peak has not yet occurred (or is not yet apparent). Therefore, the most recent trend that CBO estimates for any given variable covers both the latest complete business cycle as well as the current one. Particularly significant changes in CBO's estimates of potential output can occur after the economy is determined by NBER to have reached a new business-cycle peak, an event that usually leads the agency to change the period over which it estimates various trends. For example, according to the data available in early 2007, the United States was in the midst of a business cycle that had begun in the first quarter of 2001 but had not yet peaked; the last full peak-to-peak business cycle had begun in the third quarter of 1990 and ended in early 2001. As a result, the historical trends used to project future potential series in 2007 began in the third quarter of 1990. After NBER determined (in 2010) that a peak had occurred in the final quarter of 2007, CBO introduced new trends that began at the peak in the first quarter of 2001 and that were distinct from the trends estimated for the 1990–2001 business cycle. Consequently, the projected growth rates of potential series were no longer strongly influenced by actual growth rates during the 1990–2001 cycle and were more strongly influenced by growth rates that occurred after the 2001 peak.

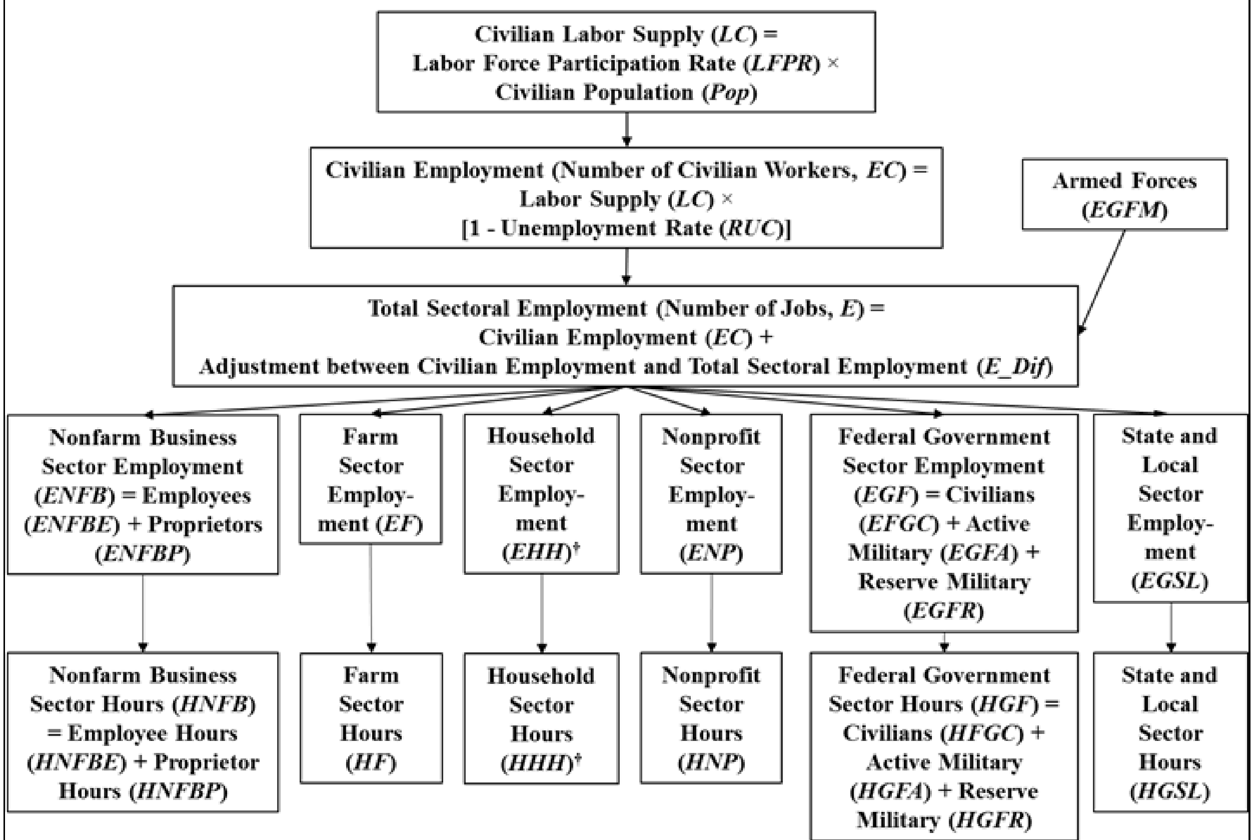
Labor Force Participation, Employment, and Hours Worked

CBO develops a historical estimate of the aggregate potential labor supply on the basis of trends in participation among different population groups. The agency combines that potential labor supply with its estimate of the natural rate of unemployment to yield an estimate of potential employment and then estimates the distribution of potential employment among sectors. Finally, the agency estimates potential average weekly hours by sector and combines those estimates with its estimates of potential sectoral employment to calculate potential total hours worked in

[19] In contrast, specifying break points that occur at different stages of different business cycles (say, from a business-cycle trough to a business-cycle peak) would be more likely to give more weight to cyclic phenomena and, therefore, more likely to yield a misleading view of the underlying trend.

each sector. All of the components of labor and employment are estimated at a quarterly frequency. Figure 1 illustrates the treatment of labor in CBO's forecasting growth model.

Figure 1.
The Treatment of Labor in CBO's Forecasting Growth Model



† = Household sector employment and hours are estimated but not used as an input to production in the model.

Data Sources. CBO draws on several different sources of data to estimate the potential supply of labor and potential employment. The agency uses data from the Current Population Survey (CPS), developed jointly by the Bureau of Labor Statistics (BLS) and the Census Bureau, for the civilian noninstitutional population, the civilian labor force, employment, and unemployment to estimate potential values of the latter three series.[20] That choice reflects the fact that household data are most appropriate for measuring how many people actually participate in the labor force and are working. That employment measure is therefore often referred to as household employment.[21]

[20] For more information on the CPS, see www.census.gov/programs-surveys/cps.html.

[21] Note that household employment is not the same as employment in the household sector, which represents a very small portion of total employment.

To estimate potential employment and potential hours worked in the various sectors of the economy, however, the agency turns to other series (mainly from BLS) that are constructed from data collected from producing establishments rather than from civilian households. The establishment data measure employment and hours in terms of the number of distinct jobs and hours worked, and are more appropriate for measuring how much labor is used in different sectors of the economy.[22] A major difference between the two measures of employment is that the total number of civilian jobs in the establishment data is larger than the number of civilian jobholders because some people hold multiple jobs. In addition, the CPS measures employment only within the civilian population and so excludes military personnel, whereas military personnel are counted as employees in the government sector and their activities are counted as part of government GDP. The BLS measure of total employment was about 12 percent larger than civilian employment in the 1950s, with the military accounting for more than 5 percentage points; however, since 2000, total employment has been only about 6 percent larger, on average, with the military representing only about 1.5 percentage points.

Labor Force Participation. CBO estimates historical values for the potential civilian labor force by estimating potential rates of labor force participation $LFPR^*$—that is, the proportions of people in particular demographic groups who, if the economy was at full employment, would choose to work or, if they were not employed, would actively seek work. People's decisions to seek employment depend on many factors, including their age, sex, level of education, marital status, and whether or not they have children. The strength of the economy also affects participation: A booming economy will tend to encourage people to seek work, whereas recessions tend to discourage them.

CBO uses quarterly labor force and population data from the CPS to estimate labor force participation rates for 516 different groups of people.[23] Those groups are distinguished by age, sex, race or ethnicity, and education. There are 15 age classes, with the youngest consisting of people ages 16 to 17 and the oldest consisting of people age 80 and over; five classes of education, ranging from less than high school to postcollege advanced degrees; and four classes for race or ethnicity (white, black, Hispanic, and other).[24]

Rather than incorporating time trends as described in the previous section, the estimated equations—one for each group—include a number of structural variables that measure influences of participation that are not related to the business cycle, such as birth-cohort effects (because the

[22] Data for employment and hours worked for the total U.S. economy and subsectors are produced by the Office of Productivity and Technology at the Bureau of Labor Statistics. Regular updates and revisions are available at www.bls.gov/lpc/special_requests/us_total_hrs_emp.xlsx.

[23] CBO's model for labor force participation is described in detail in Joshua Montes, *CBO's Projection of Labor Force Participation Rates* (Congressional Budget Office working paper, forthcoming).

[24] The agency does not distinguish every possible combination of those classes; for example, the number of white women ages 16 to 17 with advanced degrees is too small to be economically meaningful.

behavior of cohorts tends to be persistently affected by their early experiences in the labor force); family status (because marriage and children influence whether or not people choose to work); and so forth. The parameters estimated on those structural variables provide measures of their influence on labor force participation.

Models with a detailed structure of that sort have proved relatively successful in capturing historical trends in participation that occur over periods much longer than individual business cycles. That success stems mainly from the fact that such models allow the gradual development of the age-sex distribution to strongly influence overall trends in participation, as occurred with the gradually increasing participation of women from the mid-20th century through the 1990s, or with the gradual aging of the baby-boom generation out of their prime working years. Such models also allow educational trends to influence participation, as when young people forgo work to acquire more education, and when more-educated workers delay retirement and stay in the labor force longer than less-educated workers.

To estimate the effects of the business cycle on labor force participation rates, the agency introduces the aggregate unemployment gap as a variable in the equations. For each group, the potential rate of labor force participation is determined by recalculating the estimated equation with the unemployment gap set to zero (that is, as if the unemployment rate had never deviated from its natural rate over history). The resulting estimate for each group is then multiplied by the group's population to provide an estimate of the size of the potential labor force in that group. The aggregate potential civilian labor force LC_t^* is simply the sum of the group-specific potential labor forces. That is, in period *t*, summing over sexes *s*, ages *a*, and education levels *e*:

$$(4)\ LC_t^* = \sum_{s,a,e}(LFPR_{saet}^* \times Pop_{saet}).$$

The resulting historical estimates of the potential labor force follow the actual labor force (see Figure 2). Both grew particularly rapidly during the 1960s and 1970s as the baby-boom cohorts entered the labor force, gradually slowed in the 1980s and 1990s, and then slowed further as baby boomers began to retire in the mid-2000s. (Note that the figure, as well as several other figures in this paper, shows series on a log scale, so that a series with a constant growth rate is represented by a straight line.)

Aggregate Employment and Unemployment. Once the agency establishes an estimate of the potential labor force on the basis of BLS data, it uses data from the same source to estimate potential civilian employment—that is, the potential number of people with jobs. Actual employment EC_t is equal to the labor force multiplied by one minus the unemployment rate; potential employment EC_t^* is equal to the potential labor force multiplied by one minus the natural unemployment rate:

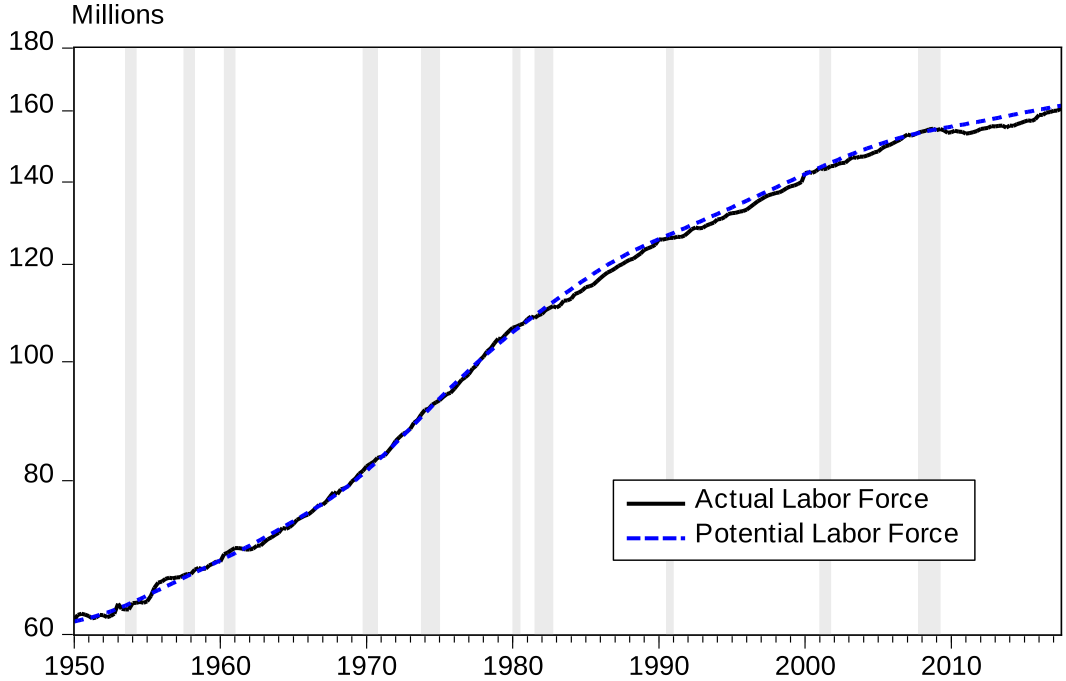
$$(5)\ EC_t = \left[1 - \left({u_t}/{100}\right)\right] \times LC_t$$

$$(6)\ EC_t^* = \left[1 - \left({u_t^*}/{100}\right)\right] \times LC_t^*$$

The employment gap $EGap_t$ is the percentage difference between the actual and potential levels of employment, and tends to be positive when the unemployment gap is negative.

$$(7)\ EGap_t = \left[\left({EC_t}/{EC_t^*}\right) - 1\right] \times 100$$

Figure 2.
The Actual and Potential Labor Force

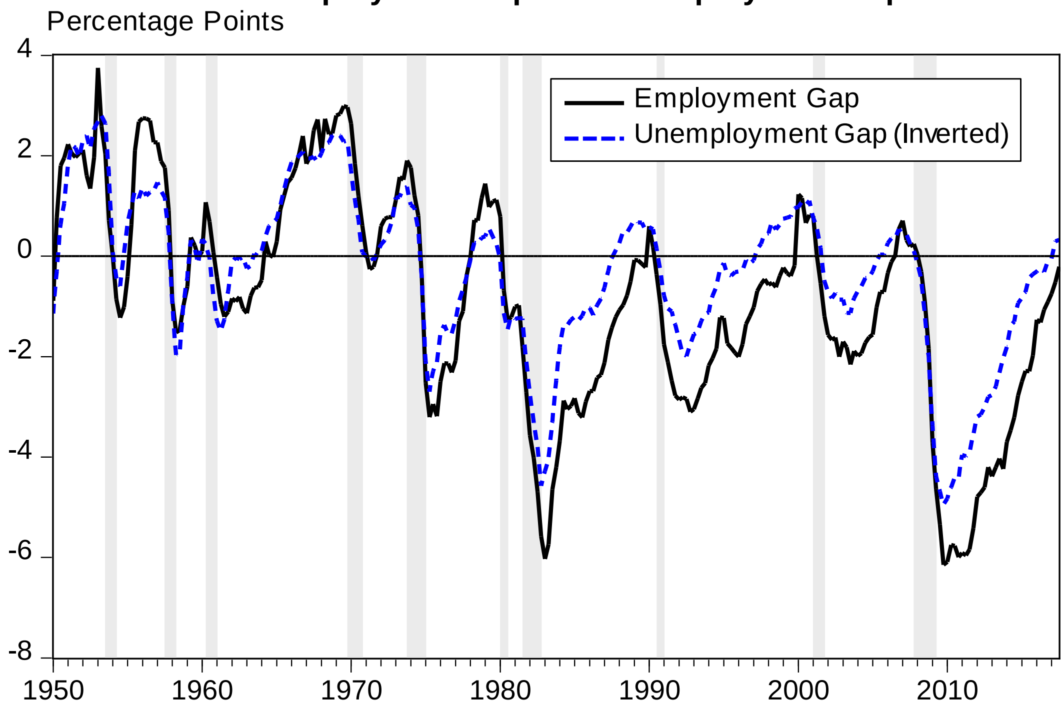


As shown in Figure 3, the employment gap tends to be larger than the unemployment gap, reflecting the fact that it is a more comprehensive measure of business-cycle effects that captures the extent to which both unemployment and participation vary from their natural rates. The agency therefore uses the employment gap as the primary measure of the business cycle in all the equations that it uses to estimate potential output other than those for labor force participation and household employment.

Because aggregate employment measured in terms of the number of jobs E is conceptually different from the "household" measure of employment in terms of the number of civilians holding jobs EC, CBO calculates the percentage difference between the two and estimates a potential value for the percentage difference:

$$(8)\ RE\_Dif_t = \left(\frac{E_t}{EC_t}\right) - 1$$

Figure 3.
The Employment Gap and Unemployment Gap



CBO's cyclical-adjustment equation for RE_Dif illustrates its general approach to estimating the potential value of a variable using a piecewise log-linear regression with time trends. The equation relates the log of RE_Dif to the following: current and lagged values of the employment gap; a series of time trends, where each T_t is a time trend or stick constructed to correspond to a specific business cycle, taking a value of zero until a particular business-cycle peak that occurs in year *t* and incrementing by one per year until the following peak; and an error term:[25]

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[25] Including the lagged value of the employment gap yields an equation that estimates not only the influence of the current gap but also the influence of the gap's recent rate of change. The agency estimates separate trends for the 2001–2007 business cycle and the post–2007 period in equation (9) because the growth of the difference changed markedly in the years following the recession and financial crisis.

$$(9)\ \ln(RE\_Dif_t) = \alpha + \beta_1(EGap_t) + \beta_2(EGap_{t-1}) + \beta_3(T_{1948}) + \beta_4(T_{1953}) + \beta_5(T_{1957}) + \beta_6(T_{1960}) + \beta_7(T_{1969}) + \beta_8(T_{1973}) + \beta_9(T_{1980}) + \beta_{10}(T_{1990}) + \beta_{11}(T_{2001}) + \beta_{12}(T_{2007}) + \varepsilon_t.$$

Once estimated, the equation is recalculated with the employment gaps and error term set to zero, thus yielding an estimate of the log percentage difference in potential terms:

$$(10)\ \ln(RE\_Dif_t^*) = \hat{\alpha} + \hat{\beta}_3(T_{1948}) + \hat{\beta}_4(T_{1953}) + \hat{\beta}_5(T_{1957}) + \hat{\beta}_6(T_{1960}) + \hat{\beta}_7(T_{1969}) + \hat{\beta}_8(T_{1973}) + \hat{\beta}_9(T_{1980}) + \hat{\beta}_{10}(T_{1990}) + \hat{\beta}_{11}(T_{2001}) + \hat{\beta}_{12}(T_{2007}).$$

Taking the exponent of equation (10) yields an estimate of the potential percentage difference $RE\_Dif_t^*$. Total potential employment is calculated as $(1 + RE\_Dif_t^*)$ times the potential number of civilians holding jobs:

$$(11)\ E_t^* = EC_t^* \times (1 + RE\_Dif_t^*).$$

The same type of cyclical adjustment applied to RE_Dif in equation (9) could also be applied directly to total employment *E*, and the resulting estimate of E^* would be very similar in magnitude to the estimate from equation (11). However, by estimating E^* as the product of EC^* and $(1 + RE\_Dif_t^*)$, the agency ensures that its estimate fully reflects the demographic influences on labor force participation that are embodied in EC_t^*.

Sectoral Employment and Hours. The business cycle affects employment in different sectors through different channels: Not only do businesses hire and lay off employees as the economy strengthens and weakens, but they also increase and reduce the number of hours that employees work. To take those differences into account, CBO estimates two different sets of equations, one for potential employment and the other for potential hours, measured as average weekly hours. The agency then combines its estimates of potential employment and potential average hours to yield estimates of potential total hours worked in each sector, which it uses as the key labor input in estimating potential output in most sectors.

Just as total employment is cyclical, the sectoral shares of employment are cyclical as well. CBO therefore estimates sectoral employment by calculating historical shares of total employment, cyclically adjusting the shares, and multiplying the cyclically adjusted potential shares by potential total employment to calculated potential employment by sector. Potential shares are estimated for four sectors: farms *REF*, the household sector *REHH*, the nonprofit sector *RENP*, and state and local governments *REGSL*. For the nonfarm business sector, separate shares are estimated for employees *RENFBE* and proprietors and unpaid family members *RENFBP*; federal government employment is split between civilians *REGFC*, active armed forces *REGFA*, and reserve armed forces *REGFR*. Taken together, the shares sum to 1.0:

$$(12) \sum_{x} REx_t = 1.0$$

The cyclical-adjustment equations for the nine sectoral employment shares take essentially the same form as equation (9) above.[26] Once the equations are estimated, the equivalents to equation (10) yield estimates of the potential shares. Because all of the share equations include exactly the same variables, the estimated potential values also sum to 1.0 in every period:

$$(13) \sum_{x} REx_t^* = 1.0$$

Potential employment by sector is calculated by multiplying potential shares by total potential employment:

$$(14)\ Ex_t^* = REx_t^* \times E_t^*$$

Employment in nonfarm business results from the sum of two of the potential shares (one for employees, the other for proprietors and family members), and employment in the federal government results from the sum of three (for civilians as well as active and reserve members of the armed forces).

CBO uses a similar set of equations to estimate potential average weekly hours for eight of the nine groups for which it estimates employment shares.[27] Average hours by group are calculated from total employment and total hours (expressed as an annual rate) by group:

$$(15)\ HEx_t = (Hx_t / Ex_t)/52$$

Once potential average hours are estimated, total annualized potential hours by sector can be calculated as:

$$(16)\ Hx_t^* = HEx_t^* \times E_t^* \times 52$$

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[26] Like equation (9), the equations include a trend for the post–2007 period because employment shares were affected by the very slow growth of employment in state and local governments following the recession and financial crisis. In the case of these equations, however, the agency takes the average of the potential shares estimated using a single post–2001 trend and the potential shares estimated using a 2001–2007 trend as well as a post–2007 trend because that approach yields estimated potential shares for employment in the state and local government sector that the agency judges to be most realistic, given general trends in that sector in the wake of the recession and weak recovery. The equations also include a dummy variable that takes a value of 1.0 in the second quarter of every census year, when the federal government hires a large number of people to assist in conducting the census and thus noticeably affects all the employment shares.

[27] Average hours for members of the reserve component of the armed forces are estimated on the basis of the standard requirements for annual service.

The approach results in a set of estimates of potential sectoral employment that sum to potential aggregate employment, along with a set of estimates of potential sectoral hours that sum to potential aggregate hours. Those estimates of employment and hours are then used as inputs in estimates of sectoral potential output, as discussed below.

Capital Stocks and Capital Services

CBO uses historical measures of investment, depreciation, and the existing stock of several distinct types of capital to estimate contributions (referred to as flows of capital services) of those different stocks to the production process.[28] Although capital is used in all sectors of the economy, the agency ignores the contribution of capital in its estimates of potential output for the farm and nonprofit sectors. In nearly all cases, the agency's estimate of the potential flow of services from any particular type of capital is directly related to the size of the actual stock; no adjustment is made for business-cycle effects. Consequently, changes in output that result from changes in the intensity of use of capital over the business cycle appear mainly as changes in nonfarm business TFP, as discussed in a following section.

CBO's estimates of historical stocks of capital in each sector are taken from BEA's fixed assets accounts, most of which are available only at an annual frequency.[29] BEA builds those estimates using a cumulation of past real investment, minus depreciation at historical real rates using a perpetual inventory method with geometric depreciation:

$$(17)\ QK_{i,t} = \left(1 - \delta_{i,t}\right) \times QK_{i,t-1} + QI_{i,t}$$

where

$QK_{i,t} =$ the real stock of capital in sector *i* in period *t*;
$QI_{i,t} =$ real investment in capital of sector *i* in period *t*; and
$\delta_{i,t} =$ the depreciation rate for capital of sector *i* in period *t*.

Total real depreciation (also referred to as the capital consumption allowance) in sector *i* in period *t*, $QCCA_{i,t}$, is:

$$(18)\ QCCA_{i,t} = \delta_{i,t} \times QK_{i,t-1}$$

For sectors other than nonfarm business, CBO generally tracks a single stock comprising all of the cumulated capital in the sector and estimates a single average depreciation rate for the entire

[28] According to standard theory, the capital input in the production function should measure the flow of productive services from the available stock of capital rather than the capital stock itself. For example, an automobile valued at $20,000 doesn't yield $20,000 worth of services per year; instead, it yields a stream of services over its lifetime that a practical investor would be willing to pay $20,000 today to receive.

[29] BEA's fixed assets accounts are available at www.bea.gov/national/index.htm#fixed.

sectoral stock. It then estimates a flow of capital services that is consistent with that depreciation rate and that is therefore proportional to the stock. For nonfarm business, however, the agency develops a more complex estimate of the input of nonfarm business capital to production that takes into account the fact that different types of capital can have very different service lives and, therefore, very different rates of use and depreciation. That more complex treatment is discussed in detail in the section titled “The Nonfarm Business Sector.”

Estimating Historical Values for Potential Inputs and Output, by Sector

As shown in Table 1, CBO estimates potential output separately for six sectors of the economy. For the nonfarm business sector, which accounts for about three-quarters of the economy, the agency uses a Cobb-Douglas production function with hours worked, capital services, and TFP as inputs. For farms and nonprofits, production is represented in terms of the number of hours and hourly labor productivity. For the government sectors, it is related to the number of hours, labor productivity, and the depreciation of government-owned capital. For the household sector, it is tied to the services provided by the owner-occupied housing stock.

The Nonfarm Business Sector

The central element of CBO’s forecasting growth model is a Cobb-Douglas production function that calculates GDP in the nonfarm business sector as a function of indexes of hours worked in the sector, the flow of services from its stock of capital, and TFP.

The potential values of those variables are substituted into the production function, yielding values of potential output in the sector. As employed by CBO, the general form of the production function is shown in equation (3) above. Another way of writing the equation (referred to as the total differential) yields the fundamental growth accounting relationship used for nonfarm business output:

$$(19)\ d\log QGDP_{nfb} = d\log A_{nfb} + (1-\alpha_t) \times d\log\left(ILAB_{nfb}\right) + \alpha_t \times d\log\left(ICAP_{nfb}\right)$$

Equation (19) states that the log growth rate (d log) of real GDP in the nonfarm business sector equals a weighted average of the log growth rates of hours worked and capital services plus the growth of TFP. Note that historical values for TFP growth are computed as a residual from equation (19), so that any historical growth in real GDP that is not accounted for by growth in labor or capital is attributed to TFP. The equation defining the growth of TFP is:

$$(20)\ d\log A_{nfb} \equiv d\log QGDP_{nfb} - (1-\alpha_t) \times d\log\left(ILAB_{nfb}\right) - \alpha_t \times d\log\left(ICAP_{nfb}\right)$$

The parameters of the production function (that is, the coefficients on labor and capital, referred to as $(1-\alpha)$ and α by convention) determine the relative contributions 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.[30] The agency calculates the capital share by subtracting wages and salaries from total NFB output, adjusted for the statistical discrepancy, indirect business taxes, and nonfarm proprietors' income:

$$(21)\ \alpha_t = 1 - \frac{WSS_t}{\left(GDP_{nfb(t)} - STAT_t - IBT_{nfb(t)} - YPAdj_t\right)}$$

where

WSS_t = NFB wages and salaries;
$STAT_t$ = the statistical discrepancy;
$IBT_{nfb(t)}$ = NFB indirect business taxes; and
$YPAdj_t$ = NFB proprietors' income, adjusted for inventory valuation and depreciation.[31]

The capital share has not been stable over history. It has tended to rise over time and also displays a cyclical pattern, generally rising during the early years of each business cycle and falling in later years. It averaged about 0.31 during the 1950–1979 period (with a low of 0.29 in 1970), about 0.34 during the 1980–1999 period, and about 0.36 since 2000 (with a high of 0.38 in 2014). Taking those variations into consideration, CBO concludes that the variations in shares related to business-cycle conditions probably do not reflect underlying characteristics of aggregate production but that the long-term variations likely manifest genuine changes in technology that have made the U.S. nonfarm business sector more capital-intensive. The agency therefore uses a Hodrick-Prescott filter to derive a smoothed long-term trend in the capital share that rises from an average of less than 0.31 during the 1950s to an average of more than 0.37 since 2010 and that smooths out the variations related to the business cycle.[32] (See Figure 4.)

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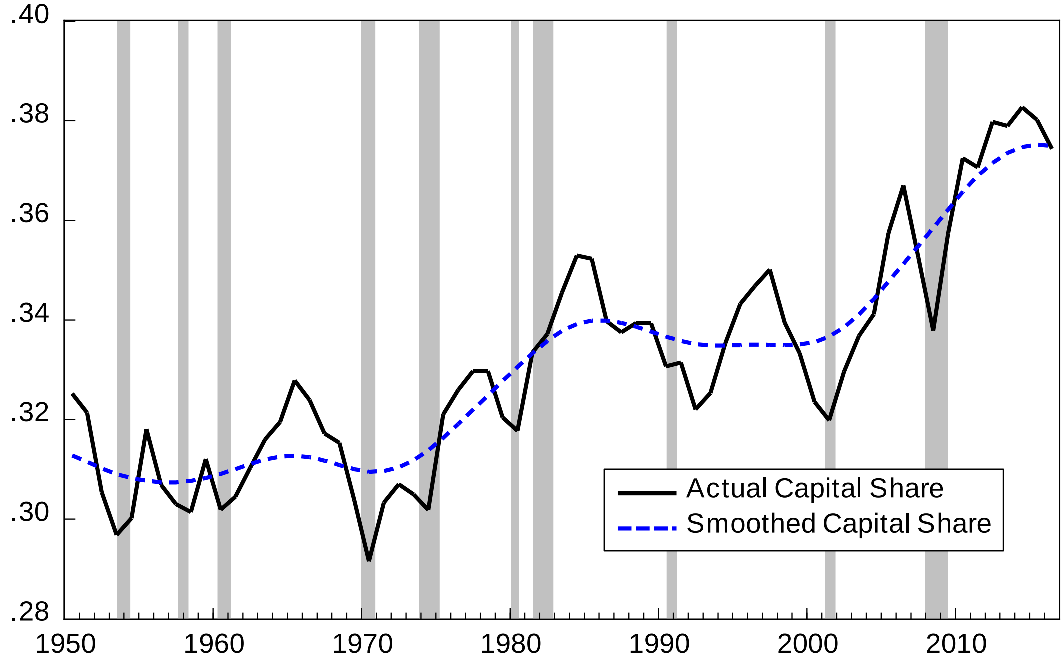
[30] That approximation follows from two common assumptions about the nonfarm business sector: that the production function displays constant returns to scale (which means that a given percentage increase in all of the factor inputs yields the same percentage increase in output) and that firms minimize 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, no. 2 (June 1987), pp. 649–698; Edward F. Denison, *Trends in American Economic Growth, 1929–1982* (Brookings Institution Press, 1985); and Dale W. Jorgenson, Frank M. Gollop, and Barbara M. Fraumeni, *Productivity and U.S. Economic Growth* (Harvard University Press, 1987).

[31] Proprietors' income is known to be a mixture of labor income and capital income, but the proportions are not well characterized. CBO's approach is equivalent to assuming that the factor shares in proprietors' income are equal to factor shares in the rest of nonfarm business income.

[32] Although business-cycle effects might be estimated using piecewise linear regressions, as are many other trends in the model, in practice, the variations in capital and labor shares over the business cycle do not appear to be closely correlated with the cyclical effects for which unemployment gaps or employment gaps serve as proxies. The Hodrick-Prescott approach appears to yield a more intuitively sensible smoothing of the series than an estimate based on gap variables.

Figure 4.
The Capital Share in the Nonfarm Business Sector



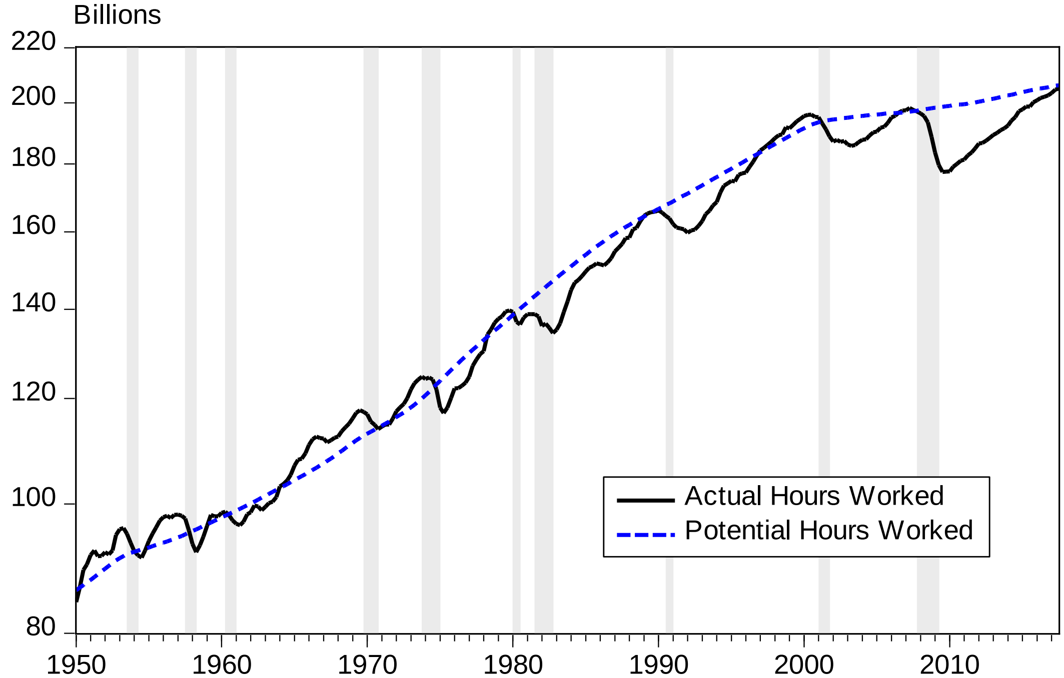
Labor Input. The labor input used in the production function for the nonfarm business sector is a measure of total hours worked in nonfarm business $HNFB$ that is decomposed into the number of employees $ENFBE$ times the average weekly hours worked per employee $HENFBE$ as well as the number of proprietors and unpaid working family members $ENFBP$ and their average hours $HENFBP$. CBO estimates equations for all four series and combines them as in equation (16) to create a series for potential total hours worked in nonfarm business (see Figure 5):

$$(22)\ HNFB^{*} = (ENFBE^{*} \times\ HENFBE^{*}\ \times 52) + (ENFBP^{*} \times\ HENFBP^{*}\ \times 52)$$

Because the production function is specified in terms of indexes, the series is converted to an index by dividing each observation by the total number of hours actually worked in 2009.

In reality, the input of labor into production is composed of hours of work that differ markedly, requiring varying types of knowledge and skill and yielding varying amounts of value in exchange. For example, the output from an hour of providing medical services is not the same as that from an hour of writing computer code. Some researchers have produced extensive analyses of such differences, weighting hours of different types of work (or different levels of educational attainment and work experience) to yield estimates of the aggregate amount of skill in the labor force—referred to as labor composition or labor quality.[33] CBO has examined how it might include such differences in labor composition in its estimates and projections of the potential labor input in nonfarm business but has concluded that including labor composition does not materially improve its estimates. Consequently, differences in labor composition are, in effect, included in the residual, TFP.

Figure 5.
Actual and Potential Hours Worked in the Nonfarm Business Sector



Capital Input. To measure the capital input in the nonfarm business sector, CBO constructs an index of the aggregate flow of real services from a number of different types of capital assets: three types of equipment (computers, communications, and other); three types of intellectual

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33 For examples of such research, see Dale W. Jorgenson, Mun S. Ho, and Jon D. Samuels, *Education, Participation, and the Revival of U.S. Economic Growth*, NBER Working Paper No. 22453 (National Bureau of Economic Research, July 2016), www.nber.org/papers/w22453.pdf (133 MB); Daniel Aaronson and Daniel Sullivan, "Growth in Worker Quality," *Economic Perspectives* (Federal Reserve Bank of Chicago, 4Q 2001), pp. 53–74, www.chicagofed.org/digital_assets/publications/economic_perspectives/2001/4qepart5.pdf (732 KB); and Canyon Bosler and others, *The Outlook for U.S. Labor-Quality Growth*, Working Paper 2016-14 (Federal Reserve Bank of San Francisco, July 2016), www.frbsf.org/economic-research/publications/working-papers/wp2016-14.pdf (765 KB).

property (software, research and development, and entertainment, artistic, and literary originals); nonresidential structures, rental residential structures, inventories, and land.[34] The index takes a form referred to as a Tornquist index and is denoted $ICAP$. Its growth rate is built from the weighted growth rates of the different types of capital in the stock:

$$(23)\ \log(ICAP_t/ICAP_{t-1}) = \sum_i \left[\omega_{i,t} \times \log\left(QK_{i,t}/QK_{i,t-1}\right)\right]$$

The weights $\omega_{i,t}$ in the equation are two-year averages of the estimated shares of total nominal capital income $s_{i,t}$ that are earned by each type of capital *i*—referred to as rental shares or cost shares:

$$(24)\ \omega_{i,t} = \left(s_{i,t} + s_{i,t-1}\right)/2$$

If every capital asset were leased in a rental market every year, estimating cost shares would be relatively simple: Rental payments would provide a basis for gauging the value of the services provided by each asset, in the same way that wages paid to workers measure the economic value of their labor. In practice, however, most assets are owned rather than leased, and the data for capital income in nonfarm business available in the NIPAs provide little information about the shares of income that are generated by different types of assets.

The approach taken by CBO to estimate and aggregate flows of capital services—standard in the economics literature—is based on two important assumptions.[35] The first (as shown in equation (23)) is that a given percentage increase in every type of capital yields an equivalent percentage increase in the index of capital services (in technical terms, capital services are homogenous of degree zero). The second assumption is that businesses invest in different types of capital in such a way that the expected return from each type—that is, the income they expect to earn from each asset's contribution to production—is equal, after accounting for depreciation, taxes, and other costs. (In technical terms, inputs are used in such a way that their marginal products should be consistent with the marginal costs of their use.) For example, a business structure such as a factory building has a long service life, has a low rate of depreciation, and yields a relatively low

[34] BEA does not estimate a stock of land, but BLS does so (as part of its estimate of multifactor productivity) 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* (September 1983), pp. 47–48, www.bls.gov/mfp/trends_in_multifactor_productivity.pdf (7.41 MB).

[35] For more details, see Michael Harper, Ernst Berndt, and David Wood, "Rates of Return and Capital Aggregation Using Alternative Rental Prices," in Dale W. Jorgenson and Ralph Landau, eds., *Technology and Capital Formation* (MIT Press, 1989), pp. 331–372; and W. Erwin Diewert, "Aggregation Problems in the Measurement of Capital," in Dan Usher, ed., *The Measurement of Capital* (University of Chicago Press, 1980).

share of its value as a flow of services in any given year. In contrast, a computer lasts only a few years and yields a large share of its value as a flow of services each year. Compared with factories, computers must be productive enough to pay for their high rate of depreciation and thus must provide a large flow of services relative to their cost in each year of their service life. Factory buildings and computers are also treated differently in the tax code: Buildings face a higher effective tax rate and therefore must generate more services, all else being equal, to yield the same after-tax return.[36] In addition, well-located buildings may appreciate in value over time, whereas computers rapidly lose value as newer models are introduced. In such cases, owners need not earn as high a rate of return from renting buildings as they would from renting computers to break even because some of the implicit return from owning a building comes in the form of appreciation.

Given those assumptions, CBO uses the various components of user costs—the price of capital goods, the cost of financial capital (including both debt and equity), depreciation rates, expected capital gains, and tax rules—to estimate the rental prices $r_{i,t}$ that owners would have to charge for each type of capital to earn the market rate of return. The agency then multiplies the values of the stocks of each type of capital by their respective rental prices to estimate the shares of total capital income that are earned by (or "paid" to) each type:

$$(25)\ s_{i,t} = \left(r_{i,t} \times QK_{i,t}\right) / \left[\sum\nolimits_{i} \left(r_{i,t} \times QK_{i,t}\right)\right]$$

It then uses two-year averages of those rental shares in equation (24) to weight the growth of different types of capital in equation (23) to construct an aggregate index of real flows of capital services into nonfarm production.[37]

Under CBO's approach, the rental price of asset type *i* in year *t* is given by:

$$(26)\ r_{i,t} = \left[R_t + \delta_{i,t} + E\left[\Delta\left(p_{i,t}/p_{GDP,t}\right)\right]\right] \times \frac{\left[1 - ITC_{i,t} - \left(T_{i,t} \times z_{i,t}\right)\right]}{\left(1 - T_{i,t}\right)} \times p_{i,t}$$

[36] CBO's estimates of tax rates on different types of capital for the period from 1948 to 1994 are taken from Jane G. Gravelle, *The Economic Effects of Taxing Capital Income* (MIT Press, 1994) and are developed from a variety of sources thereafter.

[37] The original derivation is from Robert E. Hall and Dale W. Jorgenson, "Tax Policy and Investment Behavior," *American Economic Review*, vol. 57, no. 3 (June 1967), pp.391–414, www.jstor.org/stable/1812110, and Laurits R. Christensen and Dale W. Jorgenson, "The Measurement of U.S. Real Capital Input, 1929–1967," *The Review of Income and Wealth*, vol. 15 (1969) pp. 293–320, www.roiw.org/1969/293.pdf (452 KB). Before the 2013 NIPA revisions, CBO adopted rental shares reported by BLS. After the revisions, CBO began calculating shares internally using essentially the same methodology. For more detail on BLS's method, see Bureau of Labor Statistics, *Trends in Multifactor Productivity 1948–81*, Bulletin 2178 (September 1983), www.bls.gov/mfp/trends_in_multifactor_productivity.pdf (7.41 MB).

where

> R_t = the real implicit net internal rate of return to all capital, net of depreciation and taxes;
> $\delta_{i,t}$ = the rate of depreciation for that type of capital;
> $E\left[\Delta\left(p_{i,t}/p_{GDP,t}\right)\right]$ = the expected real rate of appreciation for that type of capital (approximated by a five-year moving average of the historical rate);
> $ITC_{i,t}$ = the rate of investment tax credit that applies to that type of capital;
> $T_{i,t}$ = the corporate tax rate;
> $z_{i,t}$ = the present discounted value of a dollar of tax depreciation for that type of capital; and
> $p_{i,t}$ = the price deflator for that type of capital asset.[38]

In equation (26), only the nominal share of the flow from tenant-occupied housing is allocated to the nonfarm business sector; the flow from owner-occupied housing appears as imputed rental income in the household sector. The tax term for nonresidential structures is applied to rental residential housing even though there is actually a small difference in the rates. (Moreover, the term for nonresidential structures excludes the tax calculations for mining equipment, even though mining equipment is included in nonresidential structures, but the difference between them is quite small.)

The real implicit net internal rate of return to all capital R_t is calculated by assuming that all nominal capital income reported in the NIPAs is attributable to the services of the capital stocks (that is, that the sum of the rental prices times the capital stocks equals nominal capital income):[39]

$$(27)\ YK = \sum_i \left(r_{i,t} \times QK_{i,t}\right)$$

Substituting equation (26) for each of the rental prices in equation (27) and solving for R_t yields:[40]

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[38] Most researchers estimate a version of equation (27) with a nominal implicit rate of return and nominal expected capital appreciation. (The nominal and real depreciation rates are equal.) For simplicity, CBO assumes that past real appreciation rates are a reasonable approximation of future expected real appreciation; using such values in equation (27) yields an approximation of the real implicit rate of return that is conditional on those expectations.

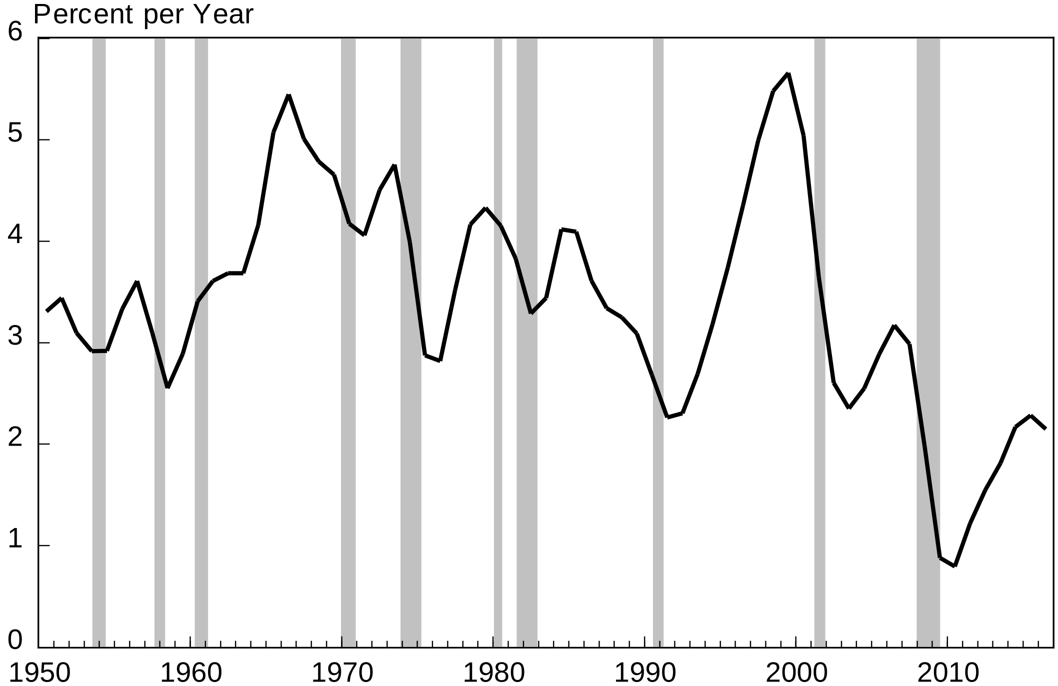
[39] In other work, CBO has explored the extent to which other factors, such as intangible capital and market power, may also contribute to determining capital income. See Mark Lasky, *CBO's Model for Forecasting Business Investment* (forthcoming). The agency is continuing to study how such elements might be included in its estimation of potential output.

[40] Note that all components of the calculation of rental prices are largely independent of the business cycle except for the overall rate of return, which is affected by fluctuations in capital income YK. However, the rate of return has only minor effects on the calculation of rental shares because it enters into each rental price equation. Consequently, the rental shares are largely unaffected by business-cycle fluctuations.

$$(28)\ R_t = \frac{YK_t - \sum_i \left[p_{i,t}QK_{i,t} \times \frac{\left[1 - ITC_{i,t} - \left(T_{i,t} \times z_{i,t}\right)\right]}{\left(1 - T_{i,t}\right)} \times \left[\delta_{i,t} - E\left[\Delta\left(p_{i,t}/p_{GDP,t}\right)\right]\right] \right]}{\sum_i \left[p_{i,t}QK_{i,t} \times \frac{\left[1 - ITC_{i,t} - \left(T_{i,t} \times z_{i,t}\right)\right]}{\left(1 - T_{i,t}\right)} \right]}$$

Using the income shares in equations (23), (24), and (25), CBO's estimate of capital services shows a pattern of moderate growth in the 1950s followed by accelerated growth in the 1960s, slowing growth in the 1970s and 1980s, strong acceleration in the late 1990s, and historically slow growth over the past decade (see Figure 6).

Figure 6.
Growth of Capital Services in the Nonfarm Business Sector



Total Factor Productivity. Output results from the use of labor and capital, and in the NIPAs, the net revenues earned from selling output can be allocated as income to labor and to capital. However, using the Cobb-Douglas production function, the growth of hours worked and of real capital services generally accounts for only about 60 percent of real GDP growth since 1950. The residual growth is attributed to increases in TFP, which is calculated by subtracting the weighted growth of the capital and labor inputs from the growth of nonfarm business output using equation (3) and converting the growth rates into an index. 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.

Although TFP is often characterized as a measure of technological progress, the index is actually a measure of residual, unexplained growth that reflects all manner of economic developments other than the growth of measured inputs. Those developments include technological progress, but they also include the following: changes in the rate at which capital is utilized (which are not captured in CBO's measure of the capital input); changes in both the quality of labor (for example, the overall level of educational attainment and work experience) and the intensity of labor effort; institutional changes (such as reorganizations that improve the functioning of existing businesses); and spillovers from investments in capital (both private and public). Moreover, because the index is a residual, any errors in the measurement of either inputs or outputs carry through to the measure of TFP, including errors arising from the pervasive difficulty of accurately measuring real improvements in the quality of the goods and services counted in GDP. Changes in TFP growth are therefore much less well understood than other elements of economic growth.

A further complication is that TFP growth in the post–World War II period shows a pattern of several periods of relatively steady growth, with each period marked by a rather abrupt break to a substantially different growth rate. By all measures, TFP growth in the United States was relatively strong in the 1950s and 1960s, slowed considerably from the early 1970s to the mid-1990s, resurged in the late 1990s and early 2000s, and slowed dramatically thereafter. As a result of such complications, TFP growth is far more difficult to project accurately than other elements of economic growth.[41]

CBO estimates trends in potential TFP by applying a piecewise log-linear regression with employment gaps and time trends to the historical series, but the irregular character of historical TFP growth occasionally calls for additional adjustments.[42]A particularly important instance is the acceleration in TFP growth in the late 1990s and early 2000s, especially the strong positive

[41] For an informative review of the history of TFP and its use in economic analysis, see Charles R. Hulten, "Total Factor Productivity: A Short Biography," in Charles R. Hulten, Edwin R. Dean, and Michael J. Harper, eds., *New Developments in Productivity Analysis* (Chicago University Press, January 2001), pp. 1–54, www.nber.org/chapters/c10122.pdf (372 KB).

[42] Because the capital input can be calculated only on an annual basis, the calculated TFP series is annual as well. Before estimating potential, CBO interpolates the annual series to quarterly values using the information contained in a related series, the index of labor productivity in the nonfarm business sector, which is published by the Bureau of Labor Statistics and available on a quarterly basis.

shock to TFP growth that occurred in 2003, and the subsequent slowdown.[43] In the years following that shock, as new data and data revisions increasingly pointed to slowing growth in TFP, CBO's standard approach resulted in estimates of the current trend that were increasingly inconsistent with more recent weak growth. It gradually became apparent that the rapid growth through 2003 was anomalous and that the underlying trend was unlikely to be as strong as the agency's standard approach implied. After experimenting with several alternatives, CBO concluded that the most appropriate adjustment was to add an additional time trend that extends from 1997 to 2005 and that overlaps both the 1990–2001 business-cycle trend and the post–2001 trend:

$$
\begin{aligned}
(29)\ \log A_t = {} & \alpha + \beta_1(EGap_t) + \beta_2(EGap_{t-1}) + \beta_3(T_{1948}) + \beta_4(T_{1953}) + \beta_5(T_{1957}) \\
& + \beta_6(T_{1960}) + \beta_7(T_{1969}) + \beta_8(T_{1973}) + \beta_9(T_{1980}) + \beta_{10}(T_{1990}) \\
& + \beta_{11}(T_{1997-2005}) + \beta_{12}(T_{2001}) + \varepsilon_t
\end{aligned}
$$

The revised equation provides a reasonable fit to the historical data, capturing the acceleration, the slowdown, and the ongoing slow growth of the past decade (see Figure 7).

To compute historical values for potential output in nonfarm business, CBO substitutes the adjusted series for the potential labor input and potential TFP back into the production function:

$$(30)\ \log\left(QGDP^*_{nfb}\right) = \log A^*_{nfb} + (1-\alpha_t) \times \log\left(ILAB^*_{nfb}\right) + \alpha_t \times \log\left(ICAP_{nfb}\right) + c$$

where the constant c (taken from the equation for actual output) is required because A^*_{nfb}, $ILAB^*_{nfb}$, and $ICAP_{nfb}$ are indexes whereas $QGDP^*_{nfb}$ is not. As mentioned above, CBO's estimate of the capital input does not need to be adjusted because its potential value is assumed to equal its actual value.

Other Sectors

Historical values for potential output in other sectors of the economy are computed using procedures similar to those used for nonfarm business, but with simpler equations. The general strategy is to model output as a function of the primary factor input (which usually accounts for the overwhelming bulk of production) and the productivity of that input. In most cases, the primary input and its productivity are cyclically adjusted using piecewise log-linear regressions with employment gaps and time trends and then combined to estimate potential output in that sector.

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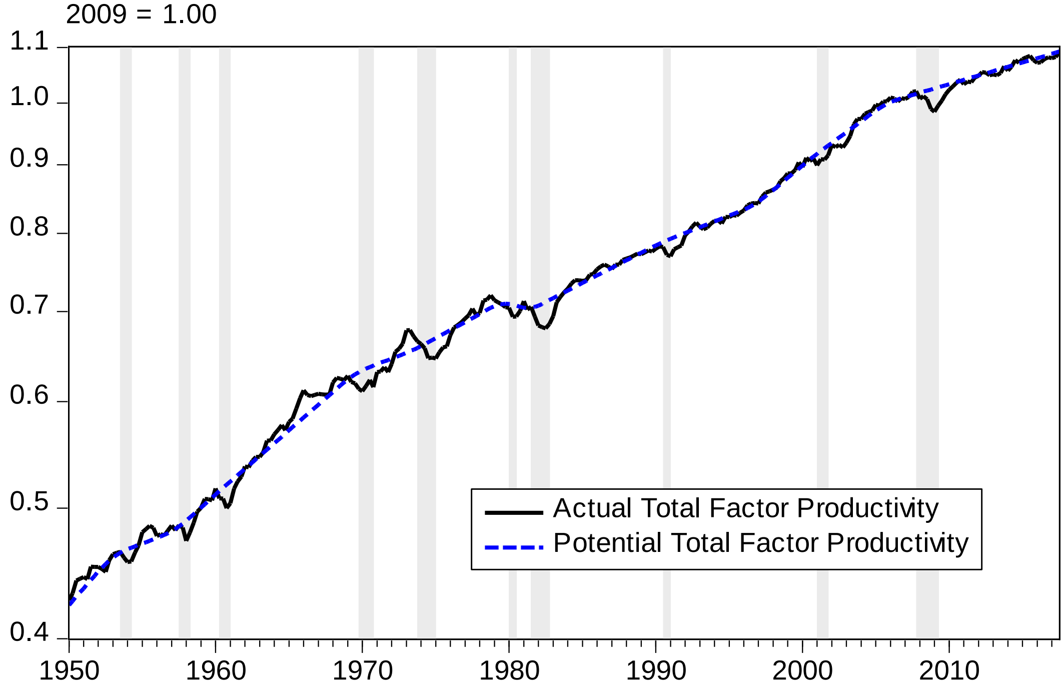
[43] For a brief discussion of the acceleration in TFP and the ensuing slowdown, see John Fernald and Bing Wang, "The Recent Rise and Fall of Rapid Productivity Growth," FRBSF Economic Letter 2015-04 (Federal Reserve Board of San Francisco, February 9, 2015), http://tinyurl.com/m467rmu. For a more detailed discussion see John Fernald, "Productivity and Potential Output Before, During, and After the Great Recession," in Jonathan A. Parker and Michael Woodford, eds., *NBER Macroeconomics Annual 2014*, vol. 29 (University of Chicago Press, 2015), pp.1–51, http://www.nber.org/chapters/c13407 (862 KB).

Figure 7.
Actual and Potential Total Factor Productivity in the Nonfarm Business Sector



The Farm Sector. The production methods used in the farm sector are similar in principle to those used in the nonfarm business sector, and the data for labor and capital inputs are available to model it using a Cobb-Douglas production function. Nevertheless, CBO models farm output separately and more simply. One reason for that approach is that trend growth in labor productivity has been fairly smooth since World War II—even though the farm sector has experienced more dramatic technological progress than nonfarm business and is even more capital-intensive. A second rationale is that farm output varies for reasons, such as weather fluctuations, that have little to do with the size of the sector's labor or capital input. CBO therefore represents farm production as a function of hours worked in the sector and measures productivity in terms of output per hour. The agency estimates trend productivity using piecewise log-linear regression but does not include variables to estimate business-cycle effects because farm productivity does not appear to be very sensitive to business conditions. It then multiplies potential productivity by potential sectoral hours (calculated using equation (16) to obtain an estimate of potential real output.

$$(31)\ QGDP^{*}_{farm} = HFARM^{*} \times PROD^{*}_{farm}$$

Nonprofits Serving Households. As with the farm sector, the data are available to model nonprofit institutions with a Cobb-Douglas production function. However, in the case of nonprofits, real output per hour has been nearly constant for most of the past two decades. With the dynamics of the sector so easily represented by output and hours alone, CBO models it the same way it models the farm sector, estimating trend productivity using piecewise log-linear regression without business-cycle variables and then multiplying potential productivity by potential sectoral hours to obtain an estimate of potential real output.

$$(32)\ QGDP^{*}_{nonprofits} = HSNP^{*} \times PROD^{*}_{nonprofits}$$

The Household Sector. CBO's representation of potential output of the household sector ignores employment in the sector, reflecting the fact that the vast bulk of the sector's output is the flow of services from owner-occupied housing; that is, the rents that homeowners implicitly pay themselves to live in their homes. Because the estimated flow of real services has been a nearly constant share of the estimated real stock of owner-occupied housing capital, ranging between 8.8 percent and 9.4 percent over the past 50 years, the agency uses a Hodrick-Prescott filter to smooth the trend in that value and calculates the value of potential output of the sector as the product of the trended value times the value of the stock.

$$(33)\ QGDP^{*}_{house} = K_{owner-occupied\ housing} \times PROD^{*}_{owner-occupied\ housing}$$

The resulting series closely approximates the value of the sector's actual historical output in the NIPAs, largely reflecting the fact that labor constitutes only a minor input to the sector and also that the implicit income from owner-occupied housing is largely unaffected by the U.S. business cycle.

Government Sectors. 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, BEA measures the value of output as the cost of inputs: The NIPAs measure nominal GDP in the federal government and state and local government sectors as the sum of total compensation of employees in those sectors plus depreciation of government fixed assets:

$$(34)\ GDP_{fed} = COMP_{fed} + CCA_{fed}$$

$$(35)\ GDP_{s\&l} = COMP_{s\&l} + CCA_{s\&l}$$

The real components in each sector are aggregated using the Fisher formula to compute real sectoral GDP. (Note that government sector GDP is not the same as government spending, which includes investment, transfer payments, interest payments, and other types of spending that are not included in sectoral GDP. In nominal terms, federal government GDP averaged about 4 percent of nominal GDP from 2000 to 2016, whereas federal spending averaged about 22 percent of GDP.)

CBO follows BEA's lead in estimating nominal potential GDP in each of the government sectors as the sum of potential compensation and depreciation. To estimate potential GDP in each sector, the agency uses compensation price deflators to calculate total real compensation $QCOMP_x$ and calculates real output per hour $PROD_x$ by dividing by total hours worked HG_x. (For the federal government, it breaks down hours and productivity separately for civilians and members of the armed forces.) As with farms and nonprofits, it then estimates trend productivity for each group using piecewise log-linear regression without using cyclical adjustments and multiplies the resulting series for potential productivity with potential hours to estimate potential total real compensation:

$$(36)\ QCOMP^*_{fed} = \left(HGFC^* \times PROD^*_{fedciv}\right) + \left((HGFA^* + HGFR^*) \times PROD^*_{fedmil}\right)$$

$$(37)\ QCOMP^*_{s\&l} = \ HGSL^* \times PROD^*_{s\&l}$$

Depreciation of government capital $QCCA_{fed}$ and $QCCA_{s\&l}$ is calculated in real terms by the same method described previously, using BEA's estimates of real capital consumption; the agency assumes that actual depreciation reflects the full potential flow of capital services to production. Potential nominal GDP in each sector is the sum of potential real compensation, multiplied by the sectoral compensation price deflator, plus real depreciation, multiplied by the sectoral capital price deflator:

$$(38)\ GDP^*_{fed} = COMP^*_{fed} + \ CCA_{fed}$$

$$(39)\ GDP^*_{s\&l} = COMP^*_{s\&l} + \ CCA_{s\&l}$$

As with actual values, potential real GDP in each sector is calculated by aggregating potential real compensation and real depreciation using the Fisher formula.

Projecting Potential Inputs and Output

CBO's forecasting growth model provides a convenient framework for projecting estimates of potential output over the next decade. Given projections of a limited number of variables exogenous to (that is, outside of) the model—including the population, the potential labor force and the natural rate of unemployment, investment and depreciation, government employment and investment, and prices—its equations automatically compute potential employment and capital stocks, calculate projections of potential output in each sector of the economy, and combine those projections into a projection of overall potential output.

To implement those projections, the agency links the forecasting growth model's estimates of potential output both to its model of potential labor supply and to its large-scale macroeconometric model (also referred to as a business-cycle model), which projects components of actual output.[44] The potential labor supply is projected using the same framework that is used for historical estimates, drawing on the agency's projections of population growth. Coupled with the model of labor supply, the forecasting growth model provides projections of all of the basic components of aggregate supply, except for capital investment, that fundamentally determine and constrain potential economic growth. The macroeconometric model projects elements of aggregate demand, including demand for various types of investment goods; those projections of investment feed into the forecasting model to determine the growth of the various stocks of capital. The projection also incorporates the assumption—required by statute for the agency's budget projections—that current laws generally remain in place and that any changes in federal fiscal policies are made pursuant to those laws.[45]

For potential variables that are estimated as growing smoothly over one or more business cycles, the most recent trend can easily be extrapolated into the future. Nevertheless, CBO exercises considerable judgment when projecting trend growth in potential variables, taking a number of other considerations into account; and those judgments evolve with changing circumstances. For example, estimated growth in potential TFP since the mid-2000s has been so slow by historical standards that CBO judges it unlikely that it will persist over a full decade. In all cases, the agency allows for elements of fiscal policy, such as taxes, transfers, and other public expenditures, that may influence the growth of potential output.

In addition, the projections of the forecasting growth model serve as an input to a second, simplified growth model—referred to as the policy growth model—that is used both to project output beyond the 10-year budget window and to analyze the economic effects of changes in fiscal policy over the 10-year window and beyond.[46] The separation of the models simplifies the agency's twin tasks of forecasting and policy analysis while maintaining consistency between the complementary activities.

Like CBO's forecasting growth model, the policy growth model is based on the Solow framework, but it differs from the forecasting model in several important ways. First, it uses a more compact representation of production that unites all of the sectors in the forecasting model into a single Cobb-Douglas production function. That function includes total potential hours of work, a flow of services from the entire stock of private capital, and a measure of aggregate

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[44] The models differ in that the forecasting growth model projects variables at an annual frequency while the labor supply and macroeconometric models project at a quarterly frequency. Output from the forecasting growth model that serves as an input to the macroeconometric model is interpolated to quarterly values.

[45] For further discussion, see Congressional Budget Office, *What Is a Current-Law Economic Baseline?* (June 2005), www.cbo.gov/publication/16558.

[46] For additional information about the policy growth model, see Congressional Budget Office, *How CBO Analyzes the Effects of Changes in Federal Fiscal Policies on the Economy* (November 2014), www.cbo.gov/publication/49494, and *How the Supply of Labor Responds to Changes in Fiscal Policy* (October 2012), www.cbo.gov/publication/43674. In those documents, the policy growth model is referred to as a Solow-type growth model.

potential TFP. The policy model is calibrated to match historical data and the Congressional Budget Office's forecast over the 10-year window. It is also used to forecast long-term economic trends beyond the 10-year window for the agency's 30-year projections of budgetary and economic conditions, under the assumption that current laws generally remain in place over that period. Second, the policy model includes explicit links through which changes in fiscal and monetary policy directly influence the supply of labor, capital investment, and TFP. (In contrast, in the forecasting model, those links are dispersed through the model of potential labor supply and the macroeconometric model that feed into it.) Those modifications allow the policy growth model to faithfully duplicate and extend the projections of the forecasting growth model but also allow it to quickly analyze policy changes over longer periods in a way that yields results consistent with those of its forecasting counterpart.

Labor Supply and Employment
As with its historical estimates, CBO develops projections of the potential aggregate labor supply and potential aggregate household and establishment employment, and then projects the distribution of potential establishment employment among sectors. To project the potential labor supply LC_t^*, the agency combines its projections of potential rates of labor force participation by age, sex, ethnicity, and education with its projections of the same groups in the civilian noninstitutional population.[47] Participation rates also reflect the agency's estimates of the impacts of public policies. The natural rate of unemployment u_t^* is projected in the same manner that it is estimated for recent years: each age-sex-education subgroup's rate of unemployment in 2005 is assumed to approximate its natural rate, and each group's projected share of the potential labor force is used to calculate a weighted average natural rate for the entire labor force. Potential civilian employment EC_t^* is then calculated using equation (8).

To project potential employment in the various sectors of the economy, CBO first projects a path for RE_Dif^*, the trend percentage difference between its historical estimates of potential household employment and the potential number of jobs, and uses the projected percentage difference to calculate the latter:

$$(40)\ E_t^* = EC_t^* \times (1 + RE\_Dif_t^*)$$

The agency then calculates and projects recent trends in employment shares REx^* and average weekly hours HEx^* for all sectors and subgroups within sectors and multiplies them together to project potential total hours Hx^* by sector and subgroup. For all of its projections of sectoral employment shares and average weekly hours, the agency projects that values will gradually stabilize over time and exercises judgment about how rapidly that stabilization will occur.

[47] Those population projections are based on the agency's own projections of rates of fertility, immigration, and mortality. For more detail on CBO's population projections, see Congressional Budget Office, *The 2017 Long-Term Budget Outlook* (March 2017), Appendix A, www.cbo.gov/publication/52480.

Capital Stocks and Capital Services

As with its historical estimates, CBO projects stocks of capital in each sector using a cumulation of projected investment minus projected depreciation. Projections of investment for the various types of capital that are included in the model are exogenous, coming from the agency's macroeconometric model. The investment projections are based on the expected growth of the labor force and on projected productivity growth (described below), both of which influence returns on capital. For each sector other than nonfarm business, CBO projects a single stock comprising all of the cumulated capital in the sector and a single average depreciation rate for the entire sectoral stock. For nonfarm business, however, the agency projects estimates of investment, depreciation, and the existing stock of several distinct types of capital, and estimates flows of services from those different types into the production process. In all sectors and for all types of capital, real depreciation rates are projected from recent trends.

CBO's approach ensures that the projection of investment (and thus of capital stocks) is consistent with the agency's projections of national income and national saving, which, in turn, are equal to the sum of projected private saving, government saving, and net foreign borrowing. As a result, projected capital accumulation is directly affected by projected changes in federal fiscal policy. For example, a change in the federal budget deficit that results in changes in revenues or spending will affect the amount of savings available for investment. Similarly, changes in marginal tax rates on capital income will influence after-tax returns, net foreign investment, and overall investment levels, while changes in the tax treatment of different types of capital will influence the composition of investment.[48]

Potential Output by Sector

CBO projects potential output separately for each of six sectors of the economy and then aggregates them to yield total potential output. As with its historical estimates, the nominal values of sectoral output sum to total nominal output; real sectoral potential values are aggregated using the Fisher formula to compute potential real GDP.

The Nonfarm Business Sector. Potential output in nonfarm business is calculated using equation (41), the log version of equation (3)—that is, the same production function that is used for estimating historical output. The coefficients $(1 - \alpha)$ and α are projected by calculating smoothed values of the income shares for labor and capital from the agency's macroeconometric model:

$$(41)\quad \log\left(QGDP_{nfb}^{*}\right) = \log A_{nfb}^{*} + (1 - \alpha_t) \times \log\left(ILAB_{nfb}^{*}\right) + \alpha_t \times \log\left(ICAP_{nfb}\right) + c$$

[48] The marginal tax rate is the percentage of an additional dollar of income from labor or capital that is paid in taxes.

where the constant is required because A^*_{nfb}, $ILAB^*_{nfb}$, and $ICAP_{nfb}$ are indexes, whereas $QGDP^*_{nfb}$ is not.

Labor Input. To project the index of potential labor input to nonfarm business $ILAB^*$, CBO combines its projections of total potential hours of employees $HNFBE^*$ and of proprietors and unpaid family members $HNFBP^*$ and then divides by actual total nonfarm business hours in 2009 to derive an index.

Capital Input. The agency projects its index of capital services in nonfarm business using several elements taken from its macroeconometric model, including asset-specific projections of investment in nonfarm business, residential investment, and the relative prices for different types of investment goods. Depreciation rates for different types of investment goods are projected by extrapolation from recent historical experience. For the first few years of the projection, investment in different types of capital assets is determined primarily by aggregate demand as projected in the macroeconometric model, but in later years of the 10-year projection period, it is influenced mainly by the growth of potential employment and potential TFP in nonfarm business. CBO projects that the real rental prices $r_{i,t}$ of different types of capital assets will remain constant over time at current rates, as has been roughly true over recent history, and that nominal rental prices will rise with prices of investment goods. The index is then calculated in the same way as the historical index, using equations (23), (24), and (25).

Total Factor Productivity. As with other components of potential output in the forecasting growth model, CBO projects potential TFP on the basis of historical trends in TFP growth. However, projecting trends in TFP is particularly challenging because it is, by definition, a measure of unexplained growth. In addition, it has been marked, historically, by lengthy periods of relatively steady growth followed by rather abrupt transitions to substantially different growth rates. The agency therefore applies a substantial degree of judgment to its projections of potential TFP rather than simply projecting the most recent estimated trend.

After exploring a variety of methods in recent years, CBO has concluded that over the past several decades, projections would have been most accurate if they had consistently assumed that the growth of potential TFP would gradually converge over several years from the most recent estimated trend to a longer-term average rate. In keeping with that conclusion, the agency currently projects trend growth in TFP to gradually increase from its recent low rate to a more rapid rate that is more consistent with such long-term trends. Specifically, growth in potential TFP is projected to converge to its weighted average trend over the preceding 25 years, with twice as much weight placed on recent trend rates as on trend rates 25 years in the past. Nevertheless, the agency will revise that judgment as necessary as new data dictate.

As discussed in detail in Appendix C, the challenge of projecting growth in potential TFP has been particularly acute in recent years because the abrupt and unexpected slowdown in TFP growth in the mid-2000s was unusually large (more than a percentage point) and the ensuing historically slow rate has persisted for well over a decade. Moreover, extensive research into the causes of the slowdown has failed to uncover a strong, compelling explanation either for the slowdown or for its persistence. Such considerations yield little guidance on the relative efficacy of different approaches to projecting trend growth in TFP, although they suggest that simply extending recent trends, as CBO does for many variables and has often done for TFP growth in the past, may not yield particularly accurate projections. Consequently, the agency has explored a variety of approaches, not only including using different methods of extending recent trends but also projecting low-frequency cycles that can be extracted from the data using other statistical methods.[49] As a general rule, all of the methods examined produce large errors when trend growth rates suddenly shift; and they would have produced comparatively poor projections over the past decade because of the slowdown in TFP growth. Nevertheless, CBO's current approach appears to minimize projection errors when applied to historical data reaching back to the 1970s.

Other Sectors. For each sector, potential output is projected largely by extrapolating cyclically adjusted trends in the primary input and average productivity of that input, and then combining the trends. The trends are generally estimated over the last full business cycle and the current cycle.

The Farm Sector. Consistent with its approach to estimating historical potential output in the sector, CBO projects potential real farm output as the product of potential farm hours and potential productivity (measured as output per hour) using equation (31). Both series are projected on the basis of trends that are estimated over the last full business cycle and the current cycle.

Nonprofits Serving Households. The agency projects potential output in the nonprofit sector as the product of extrapolated sectoral potential hours and potential productivity using equation (32).

The Household Sector. CBO's projection of potential output of the household sector, like its estimate of historical potential output in the sector, reflects the fact that nearly all of the sector's output represents the estimated flow of services from owner-occupied housing. The agency extends the smoothed trend it estimates in the historical ratio of real household sector GDP to the estimated real stock of owner-occupied housing, which it calculates by applying a Hodrick-Prescott filter to the historical data; but the agency uses judgment to taper the trend so that it gradually reaches a constant value. The residential housing stock is projected using forecasts of real residential investment from the macroeconometric model and the rate of depreciation of the

[49] For an example of cycle-extracting methods, see Ulrich K. Müller and Mark W. Watson, *Low-Frequency Econometrics*, NBER Working Paper 21564 (National Bureau of Economic Research, September 2015), www.nber.org/papers/w21564.

residential capital stock, which, like capital productivity in this sector, is extrapolated from recent trends. The projected value of potential output of the sector is calculated using equation (33), as the product of the trended ratio times the value of the stock.

The Government Sectors. The forecasting growth model projects potential output in the federal government and state and local government sectors separately. As with historical estimates, projections for potential real GDP in each sector are built on projections of employees' potential real compensation and real depreciation of the sector's capital stock. The agency also projects price deflators for those values and uses them to calculate nominal values. Nominal potential GDP in each sector is then calculated as the sum of nominal potential compensation and nominal depreciation, using equations (34) and (35).

The projection of real compensation in each government sector is calculated by combining projections of potential hours and potential productivity, using the same equations that are used for calculations of historical values. Potential employment and hours for both civilians and the military in the federal government are projected on the basis of recent trend growth; however, the agency uses judgment in adjusting the trend to ensure that projected federal employment is consistent with CBO's baseline forecast of federal spending under current law. Potential employment in the state and local government sector is projected to be a share of total potential employment that is consistent with recent historical trends. Potential productivity and compensation in both government sectors are also projected by continuing their trend growth rates of the recent past, using equations (36) and (37).

Real investment by the federal government is projected to be a constant share of discretionary federal spending under CBO's baseline forecast. State and local investment is projected as a share of potential nominal GDP, on the basis of recent historical trends. Depreciation rates for both sectors are projected from recent historical trends in those rates. Projected government capital stocks are cumulated from past stocks, projected depreciation rates, and projected investment.

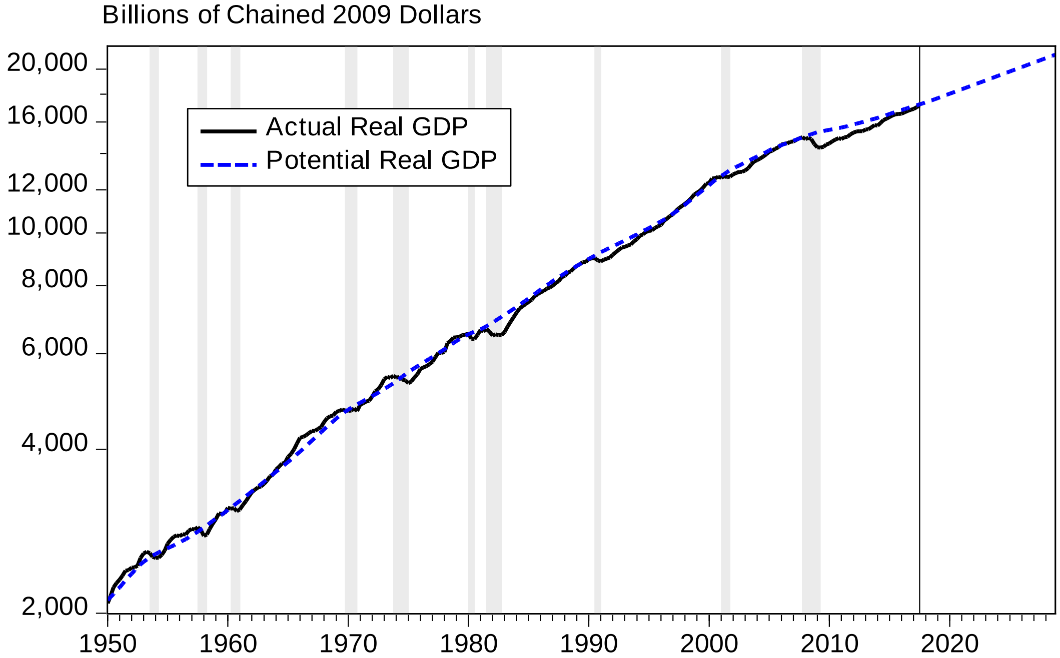
CBO's Estimates and Projections of Potential Output for 1950 Through 2028

An example of CBO's estimates of the growth of potential output and its components since 1950 is shown in Table 2, along with projections of those variables through 2028 (produced in January 2018). Historical levels of actual and potential real GDP are illustrated in Figure 8, along with projections of potential GDP through 2028. The table and figure illustrate many of the stylized facts about overall growth in the U.S. economy during the post–World War II period. The economy grew particularly rapidly during the 1950s and 1960s, buoyed by accelerating growth of the potential labor force, strong investment that resulted in rapid growth of capital services, and unusually rapid growth in potential TFP. The 1970s were marked by a substantial slowdown in the growth of potential TFP, followed by a modest resurgence in the 1980s, along with gradual slowing of the growth of the potential labor force and investment. The 1990s and early 2000s witnessed a resurgence in potential TFP growth and accompanying investment but also foreshadowed the impending slowdown in growth of the potential labor force. The period following the 2008 financial crisis and accompanying deep recession has seen unusually slow growth in all of the major components of potential output, from which CBO currently projects only a rather modest pickup over the coming decade, almost entirely as a result of the projected return of potential growth in TFP to a long-term average.

Table 2.
Key Components of CBO's Historical Estimate and Projection of Real Potential Gross Domestic Product, 1950 to 2028
By Calendar Year, in Percent

	Average Annual Growth							Projected Average Annual Growth		
	1950-1973	1974-1981	1982-1990	1991-2001	2002-2007	2008-2017	Total, 1950-2017	2018-2022	2023-2028	Total, 2018-2028
					Overall Economy					
Potential Output	4.0	3.2	3.4	3.3	2.4	1.5	3.2	1.8	1.9	1.9
Potential Labor Force	1.6	2.5	1.7	1.2	1.0	0.5	1.4	0.5	0.5	0.5
Potential Labor Force Productivity	2.4	0.7	1.7	2.0	1.4	0.9	1.7	1.3	1.4	1.4
					Nonfarm Business Sector					
Potential Output	4.1	3.5	3.6	3.7	2.7	1.7	3.4	2.1	2.2	2.2
Potential hours worked	1.4	2.3	1.8	1.3	0.3	0.4	1.3	0.4	0.4	0.4
Capital services	3.7	3.8	3.6	3.8	2.9	1.8	3.4	2.3	2.1	2.2
Potential total factor productivity	1.9	0.9	1.2	1.5	1.6	0.7	1.4	1.0	1.2	1.1
Contributions to Growth in Potential GDP in the Nonfarm Business Sector (Percentage Points)										
Potential hours worked	1.0	1.6	1.2	0.9	0.2	0.3	0.9	0.3	0.3	0.3
Capital services	1.1	1.2	1.2	1.3	1.0	0.7	1.1	0.8	0.7	0.8
Potential total factor productivity	1.9	0.9	1.2	1.5	1.6	0.7	1.4	1.0	1.2	1.1
Total of contributions	4.0	3.7	3.6	3.6	2.7	1.7	3.4	2.1	2.2	2.2
Memorandum:										
Potential labor productivity	2.7	1.2	1.8	2.3	2.4	1.2	2.1	1.7	1.8	1.7
Capital-labor ratio	2.3	1.5	1.8	2.5	2.6	1.3	2.0	1.9	1.7	1.8
					Other Sectors					
Potential Output	3.7	2.2	2.7	2.0	1.7	0.9	2.5	1.0	1.0	1.0

Figure 8.
Actual and Potential Real Gross Domestic Product

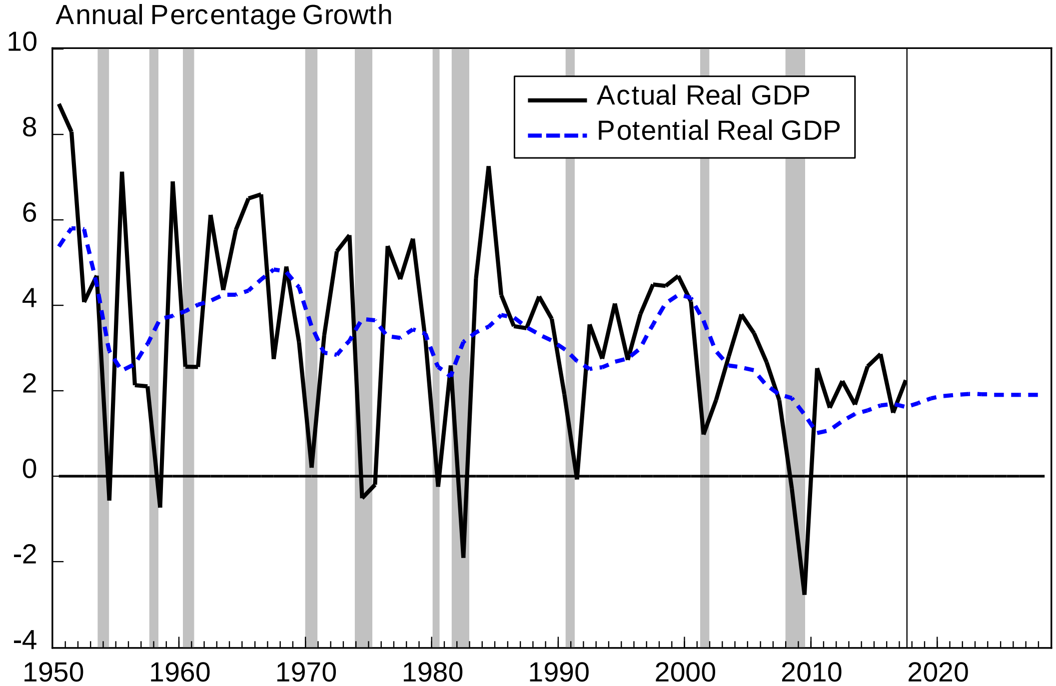


Because it measures underlying trends in components of supply rather than fluctuations in aggregate demand, the growth rate of potential output is less volatile than that of actual output (as shown in Figure 9).

Business-cycle dynamics lead output to deviate from potential: Output generally falls below potential during recessions, remains below potential during recoveries and early expansions, and rises above potential during late expansions. The GDP gap (the percentage difference between actual and potential output) is therefore a summary indicator used by CBO and other forecasters to estimate the state of the business cycle (see Figure 10). A positive gap indicates that actual GDP exceeds potential and that the economy is overheated; a negative gap, with actual GDP falling below potential, suggests underutilization of resources, or slack. The output gap closely mirrors the employment gap, partly because labor is the most important component of supply and partly because CBO uses the employment gap as the primary measure of slack in many of the equations in its forecasting growth model.

CBO's estimate of the GDP gap follows roughly the same pattern over time as estimates calculated by some other organizations, including Global Insight, the Federal Reserve Board, the International Monetary Fund, and the Organisation for Economic Co-operation and Development (see Figure 11). CBO's currently estimated historical gap tends to indicate substantially less overheating and more slack over most of the past 35 years than other organizations' measures of the gap.[50]

Figure 9.
Acutal and Potential Real Gross Domestic Product



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[50] Reflecting that pattern, for the latter half of its 10-year projection period, CBO projects that actual output will grow at the same rate as potential output but fall short of potential output by about half a percent, on average—matching its long-term average gap. See Congressional Budget Office, *Why CBO Projects That Actual Output Will Be Below Potential Output on Average* (February 2015), www.cbo.gov/publication/49890.

Figure 10.
GDP Gap and Employment Gap

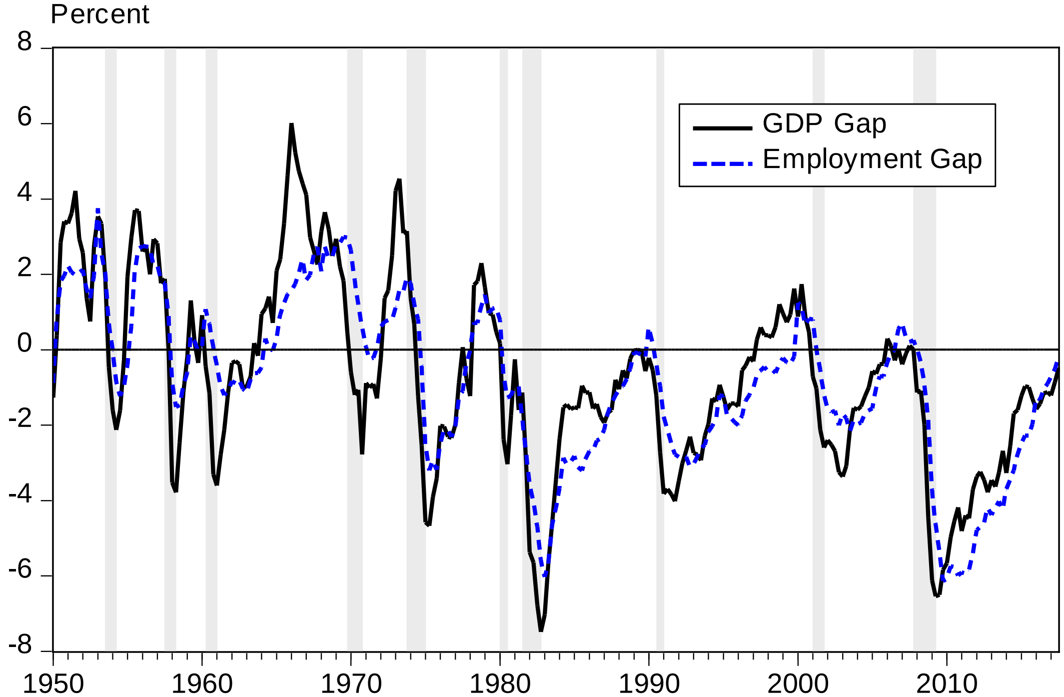
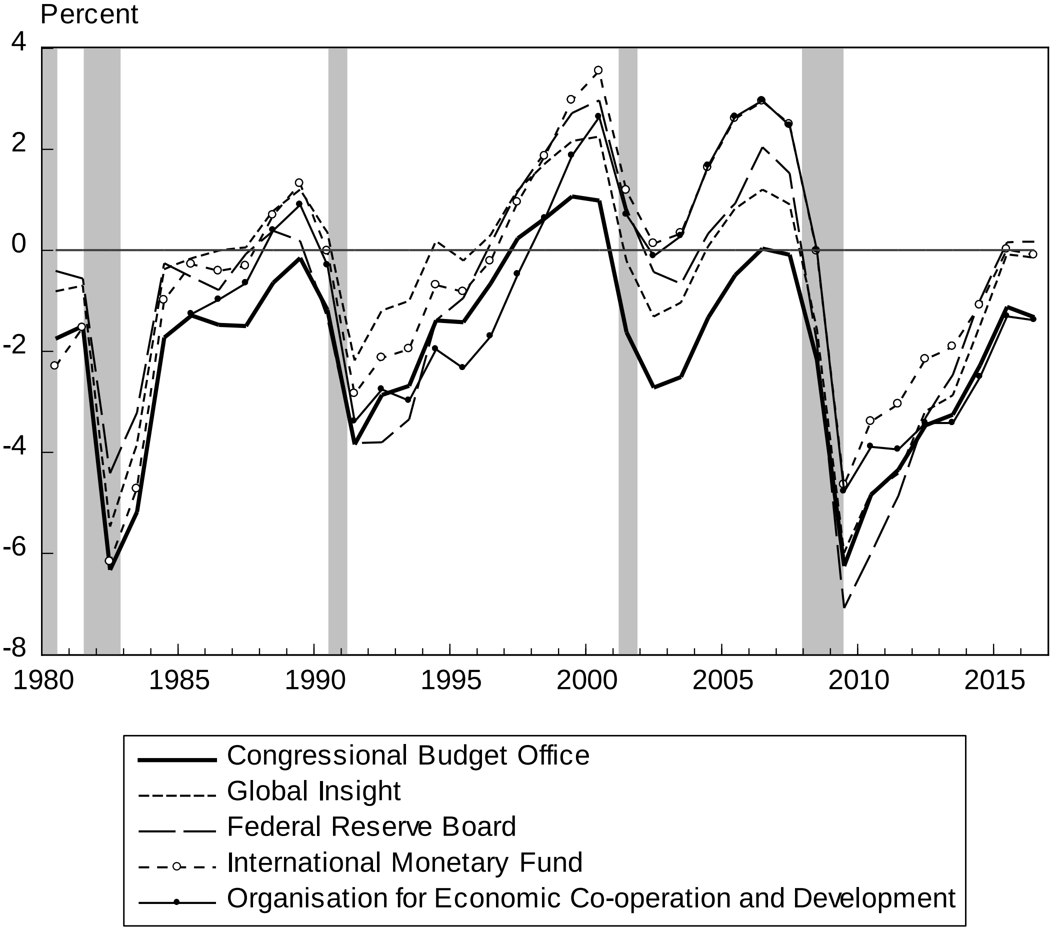


Figure 11.
Estimates of the Output Gap



Appendix A: Major Changes to CBO's Forecasting Growth Model Since 2001

The Congressional Budget Office has introduced a number of significant improvements to its forecasting growth model since it last published a detailed description of the model.[51] Among the most important improvements are more detailed estimates and projections of the potential labor force and of capital services in the nonfarm business sector. The agency has also significantly adjusted its estimates and projections of productivity growth, reflecting changes in historical patterns over the past 15 years.

In recent years, CBO has adopted a detailed approach to estimating the historical labor force that involves estimating potential participation by a large number of population groups, consistent with the approach it uses for projections. At the same time, it has extended its method of projecting potential participation to include a larger number of population subgroups as well as a larger number of explanatory variables in its equations. (In the past, the agency estimated the historical aggregate labor force using a piecewise linear regression with linear time trends over each business cycle.)[52] In addition, the agency now develops its own population projections rather than relying solely on those produced by the Social Security Administration.

In the process of developing more detailed estimates the labor force, CBO has adjusted its approach to estimating the natural rate of unemployment for years since 2005, as discussed in Appendix B. Moreover, the agency has concluded that the employment gap—the percentage difference between the actual level of employment and the estimated natural level—is a more comprehensive measure of business-cycle effects than the natural rate because it captures cyclical effects on both labor force participation and unemployment. (In contrast, the natural rate captures only the latter.) Accordingly, the agency incorporates the natural rate only in the equations that it uses to estimate potential labor force participation and household employment; in all of the other equations that estimate components of potential output, the agency incorporates the employment gap.

CBO has also revised its method of estimating potential total employment and hours (measured in terms of the number of jobs in the economy) and of distributing the totals among the various sectors of the economy. Using data from the Bureau of Labor Statistics, the agency estimates potential total employment, potential sectoral shares of total employment, and sectoral potential

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[51] See Congressional Budget Office, *CBO's Method for Estimating Potential Output: An Update* (August 2001), www.cbo.gov/publication/13250.

[52] For a more detailed discussion of the agency's previous approach, see Congressional Budget Office, *CBO's Labor Force Projections Through 2021* (March 2011), www.cbo.gov/publication/22011.

average weekly hours per worker. It multiplies potential shares by potential total employment to calculate potential employment by sector. It then multiplies those values by potential average weekly hours by sector to calculate potential total hours by sector and sums the sectoral values to calculate total potential economywide hours. In addition, the agency now uses sectoral output and hours to estimate and project potential output per hour for the farm, nonprofit, and government sectors, rather than potential annualized output per employee as it did previously.

CBO's classification of capital assets in nonfarm business differs from the one it presented in the last publication on the forecasting growth model in two important ways. First, the Bureau of Economic Analysis (BEA) has introduced two new groups of intellectual property assets—research and development; and entertainment, artistic, and literary originals—that were not included in the national income and product accounts in the early 2000s.[53] Their inclusion yields an increase in the amount of economic activity that is counted as investment and therefore as part of gross domestic product (GDP). (Such expenditures were previously counted as intermediate transactions that were excluded from the final expenditures counted in GDP.) Second, CBO now counts rental housing as part of the nonfarm business (NFB) stock, even though it is excluded from BEA's NFB stock, because rental income is part of NFB income. (Consistent with that adjustment, the agency now calculates output in the household sector as flowing only from owner-occupied housing rather than from the entire housing stock.)

CBO has also shifted from relying on measures of rental shares produced by BLS to producing its own measures.[54] That shift includes the introduction of CBO's estimates of historical and projected investment tax credits, as well as tax rates on income from different types of capital assets. The agency's estimates are somewhat different from those of BLS but show similar patterns of change over time and yield similar measures of overall capital input.

A further significant change involves the introduction of variable coefficients $(1-\alpha)$ and α on labor and capital in the production function for nonfarm business, replacing the constant coefficients (0.7 and 0.3) used previously. That change brings the coefficients more closely in line with the factors' actual shares of earnings, which, in theory, better reflects the actual relative contributions of the factors to production as they change over time. Along with the changes to the calculation of the capital input discussed above, that adjustment has had the further effect of changing the values of total factor productivity, which results as a residual from the production function.

[53] For information on the updates that included those revisions to the asset accounts, see Stephanie H. McCulla, Alyssa E. Holdren, and Shelly Smith, "Improved Estimates of the National Income and Product Accounts: Results of the 2013 Comprehensive Revision," *Survey of Current Business*, vol. 93, no. 9 (September 2013), pp. 14–45, https://bea.gov/scb/toc/0913cont.htm.

[54] BLS produces estimates of the capital input as part of its program to estimate multifactor productivity. Further information is available at BLS's website, https://www.bls.gov/mfp/.

Appendix B:
Estimating the Natural Rate of Unemployment

The Congressional Budget Office's approach to estimating the natural rate of unemployment—the rate that arises from all sources other than fluctuations in demand associated with business cycles—is based on the assumption that rates of unemployment for different demographic groups (by age, sex, education, and race) were approximately at their natural rates in 2005, a year in which employment in U.S. labor markets is thought to have been roughly at its maximum sustainable level.[55] The agency uses estimates of the size of those groups as well as their time-varying rates of potential labor force participation as weights to calculate a weighted average of those 2005 natural rates over time, yielding an estimate of the natural rate over recent history. An implication of this approach is that all of the variation in the natural rate over time arises because of changes in the relative size and participation rates of different demographic groups rather than changes in the natural rates of those groups.

For the period from 1948 to 2004, CBO uses a different approach to build up an overall natural rate of unemployment from different demographic groups. For that period, the agency's measure of the natural rate is an estimate of the nonaccelerating inflation rate of unemployment (NAIRU), the rate that is consistent with a stable rate of inflation.[56] That estimate derives from an econometric estimate of a Phillips curve, an equation that relates the change in inflation to the unemployment rate and other variables such as changes in productivity trends, oil price shocks, and wage and price controls. Through most of the 20th century, the relationship between the unemployment gap and the change in inflation was strong and fairly stable: Inflation tended to rise when the unemployment rate was below the NAIRU and fall when it was above the NAIRU. The natural rate for the period before 2005 can therefore be estimated by solving the equation for the unemployment rate that obtains when inflation is stable.

To incorporate demographic considerations into its measure for the 1948–2004 period, CBO estimates a Phillips curve for married males and uses it to estimate a NAIRU for that group. It then regresses the unemployment rates of other demographic groups (broken down by age and

[55] Economists generally consider 2005 to have been a year during which the economy was operating at a maximum sustainable level, after having been in recovery from the preceding recession for more than three years and before showing signs of overheating.

[56] For a description of the procedure used to estimate the NAIRU in the past, see Congressional Budget Office, *The Economic and Budget Outlook: An Update* (August 1994), Appendix B, www.cbo.gov/publication/15041, and David Brauer, *The Natural Rate of Unemployment*, Working Paper 2007-06 (Congressional Budget Office, April 2007), www.cbo.gov/publication/18566.

sex) against the unemployment rates of married males and uses the resulting parameter estimates to calculate NAIRUs for those groups.[57] The overall NAIRU is computed as a weighted average of the NAIRUs estimated for the different demographic groups, with the weights set equal to each group's share of the labor force. The resulting overall NAIRU varies over time largely because the shares of the different demographic groups vary. Note that until the early 2000s, CBO used this method to estimate the natural rate for all years.

CBO uses a different approach to estimate the natural rate for more recent years because the relation described by the Phillips curve became much less clear in the aggregate data during the 1990s and early 2000s. To create one time series for the estimated natural rate, CBO merges its estimates together using the two different approaches for the different periods. Nevertheless, the agency's two approaches yield estimates for the natural rate in the 1990s that are very similar. As a result, the estimated time series of the natural rate shows no notable discontinuities.

[57] Married males as a group tend to be strongly attached to the labor force, and their unemployment rate tends to be less affected by shifts in demographic factors than the overall unemployment rate.

Appendix C:
The Slowdown of Growth in Total Factor Productivity

The Congressional Budget Office estimates that, after growing at a relatively slow average annual rate of about 1.2 percent from 1981 to 1996, total factor productivity (TFP) surged at an annual average rate of nearly 2.0 percent from 1997 to 2005. However, it then slowed dramatically to about 0.7 percent, on average, from 2006 to 2016. By CBO's estimate, that slow growth in TFP accounts for more than one-third of the slowdown in the growth of real (inflation-adjusted) potential output in the nonfarm business (NFB) sector since 2006, compared with the 1950–2006 average.[58]

The acceleration of growth from the late 1990s to the early 2000s was international in scope and was heavily concentrated in industries producing or investing in information technology (IT). The reasons for the ensuing slowdown are more mysterious: It, too, has been international in scope, but it has been more widespread among industries than the acceleration that preceded it and has not been strongly correlated with the intensity of IT use in different countries.[59] In seeking explanations for the slowdown, researchers have focused on five areas of concern—measurement issues, growth feedback, demographics, structural problems, and long-term innovation—and have identified several broad themes.

Measurement Issues

Analysts have identified three distinct problems related to measuring output that might have contributed to the slowdown; but even taken together, they appear to explain at most a small portion of it. One concern is mismeasurement of real inputs and real output, a perennial and substantial problem in growth accounting that stems mainly from the difficulty of estimating improvements in product quality: If the accuracy of such estimates worsened in the mid-2000s, they could have resulted in an underestimate of quality improvements, an underestimate of actual

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[58] For detailed discussions of the growth slowdown, see John G. Fernald and others, *The Disappointing Recovery of Output after 2009*, NBER Working Paper 23543 (National Bureau of Economic Research, June 2017), www.nber.org/papers/w23543; James H. Stock and Mark W. Watson, *Why Has GDP Growth Been So Slow to Recover?* (Federal Reserve Bank of Boston, October 2016), www.bostonfed.org/-/media/Documents/economic/conf/great-recovery-2016/james-h-stock.pdf (144 MB); and Congressional Budget Office, *Revisions to CBO's Projection of Potential Output Since 2007* (February 2014), www.cbo.gov/publication/45150. For a discussion of the timing of the slowdown, see Gilbert Cette, John G. Fernald, and Benoit Mojon, *The Pre-Great Recession Slowdown in Productivity*, FRBSF Working Paper 2016-08 (Federal Reserve Bank of San Francisco, April 2016), www.frbsf.org/economic-research/publications/working-papers/wp2016-08.pdf (616 KB).

[59] For a discussion of the international scope of the productivity slowdown, see Charles I. Jones, "The Productivity Growth Slowdown in Advanced Economies," in European Central Bank, *Investment and Growth in Advanced Economies: Conference Proceedings* (European Central Bank, June 26-28, 2017), www.ecb.europa.eu/pub/pdf/other/ecb.ecbforumcentralbanking2017.en.pdf (7.95 MB).

output growth, and an illusory slowdown of TFP growth. Researchers conclude that the difficulties inherent in estimating quality generally lead them to underestimate the true rate of improvement in TFP. Nevertheless, they also conclude that problems related to measuring quality were, if anything, worse in the past, and that they are therefore unlikely to account either for the international scope of the slowdown or for its breadth across industries.[60]

A separate measurement problem arises from the fact that in some cases, innovations have made once-costly products essentially free, and therefore those products are no longer counted as output because no transactions take place that can be measured in the national income and product accounts. For example, 20 years ago, most photographs were developed by commercial processors and those services were counted as output; today people save electronic images on their phones or digital cameras, and no market transaction takes place. As a result, the number of images people take has exploded while measured output of photographic services has fallen. Nevertheless, researchers estimate that the value to consumers of such products is much smaller than the additional output that the economy would be producing if TFP had continued to grow at the rates witnessed in the late 1990s and early 2000s.[61] Thus, the problem of valuing free goods does not appear to be significant enough to explain the bulk of the slowdown in TFP growth or its broad range across industries.

A third measurement issue stems from the increasing importance of global supply chains, in which the parts of a given product are produced by firms that are active in more than one country.[62] When a multinational company uses engineering plans developed in the United States to produce a phone in another country, for example, the Bureau of Economic Analysis may fail to include the full value of the engineering plans as a U.S. export, even though the cross-border flow of such data represents the sale of a domestic product to a foreign entity. A recent study suggests that such trade-related measurement errors have slowed the growth of measured labor

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[60] See David M. Byrne, Stephen D. Oliner, and Daniel E. Sichel, "How Fast Are Semiconductor Prices Falling?" *The Review of Income and Wealth* (Wiley Online Library, April 12, 2017), http://onlinelibrary.wiley.com/doi/10.1111/roiw.12308/abstract; and David M. Byrne, John G. Fernald, and Marshall B. Reinsdorf, *Does the United States Have a Productivity Slowdown or a Measurement Problem?* Brookings Papers on Economic Activity (Brookings Institution Press, Spring 2016), pp. 109–182, www.brookings.edu/wp-content/uploads/2016/03/byrnetextspring16bpea.pdf (1.23 MB).

[61] See Chad Syverson, "Challenges to Mismeasurement Explanations for the U.S. Productivity Slowdown" (presentation to the Brookings Conference on Slow Growth in Productivity: Causes, Consequences, and Policies, Washington, D.C., September 8, 2016), www.brookings.edu/wp-content/uploads/2016/08/syverson.pdf (718 KB).

[62] Hal Varian, "A Microeconomist Looks at Productivity" (presentation to the Brookings Conference on Slow Growth in Productivity: Causes, Consequences, and Policies, Washington, D.C., September 8, 2016), www.brookings.edu/wp-content/uploads/2016/08/varian.pdf (565 KB).

productivity in the United States by about one-tenth of one percent per year over the past 20 years (and presumably slowed the growth of TFP by even less).[63]

In sum, a variety of measurement issues result in lower estimates both of real output and of TFP. However, those issues do not appear to be the primary cause of the slowdown in measured TFP growth since the mid-2000s.

Growth Feedback

Growth in TFP may be influenced by fluctuations in aggregate demand or shifts in aggregate supply that affect the rate of adoption of new technologies. Many technological innovations enter into and benefit the economy only gradually, as older capital is retired and replaced by new capital that embodies the innovations. As a result, changes in overall growth that affect the rate of investment may also affect the rate of adoption and thus influence the rate of TFP growth. For example, some research indicates that the rapid growth of aggregate demand during the late 1990s helped fuel rapid productivity growth by boosting investment and thus increasing the pace at which firms adopt new technologies; conversely, slowing demand growth after 2000 played a significant role in slowing the pace of investment and adoption, even before the 2007–2009 recession.[64] In that way, the growth of TFP may have been temporarily dampened by slower growth of aggregate demand both before and after the recession and financial crisis. Slowing growth of the labor force could be further dampening TFP growth because less investment is required to furnish workers with needed equipment.

Demographics

Research comparing the experiences of different countries finds that TFP growth is strongly associated with the share of a country's workforce that is composed of people in the middle years of their careers.[65] More rapid TFP growth presumably results from a large middle-aged workforce's accumulation of education and experience, suggesting that the retirement of members of the highly experienced baby-boom generation could be contributing to the slowdown in TFP growth. Indeed, researchers have long predicted a slowdown in the growth of labor quality (a measure of the overall educational attainment and work experience of the labor force) resulting not only from the baby-boom generation's retirement but also from the increasing difficulty of raising the level of educational attainment of succeeding generations,

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[63] See Fatih Guvenen and others, *Offshore Profit Shifting and Domestic Productivity Measurement*, NBER Working Paper 23324 (National Bureau of Economic Research, April 2017), www.nber.org/papers/w23324.

[64] See Diego Anzoategui and others, *Endogenous Technology Adoption and R&D as Sources of Business Cycle Persistence*, NBER Working Paper 22005 (National Bureau of Economic Research, February 2016; revised March 2017), www.nber.org/papers/w22005.

[65] See James Feyrer, "Demographics and Productivity," *Review of Economics and Statistics*, vol. 89, no. 1 (MIT Press Journals, February 2007), pp. 100–109, http://www.mitpressjournals.org/doi/abs/10.1162/rest.89.1.100.

given the relatively high levels already achieved by preceding ones.[66] However, recent estimates indicate that labor quality continued to grow during the 2000s at about the same average rate that it grew from 1950 to 2000. (That trend partly reflects ongoing improvements in educational attainment among younger cohorts, relative to their elders, but it also reflects the fact that within older cohorts, more-experienced, highly skilled workers tend to stay in the labor force longer than less highly skilled ones, tending to push up the average skill level.) Those developments suggest that the slowdown in TFP growth is not directly connected either to the retirement of older cohorts or to the slowing educational attainment of younger ones.

Structural Issues

Several strands of research suggest that the economy's productivity growth may have diminished as a result of a decline in economic dynamism. For example, one study finds that the most productive firms in any given industry continue to have strong productivity growth, so that the technological frontier is continuing to expand relatively rapidly. At the same time, firms whose productivity is not keeping pace are less likely than they were in the past to exit in favor of firms with productivity closer to the frontier. Consequently, the continued operation of those lagging firms—which is strongly suggestive of a slowdown in the diffusion of productivity-enhancing innovations—brings down the growth of industry productivity overall. Potential explanations for the widening gap in productivity among firms in the same industry include increased barriers to entry and product markets that have become less contestable by new firms.[67]

Another area of research has documented a long-term decline in a closely related aspect of dynamism in the U.S. economy—a decline in the rates of firm entry and, to a lesser extent, firm exit, as well as a falloff in the share of employment and output accounted for by young firms (those that are fewer than five years in age). A falloff in the presence of new and young firms could contribute to a slowdown in trend growth of TFP because an important source of productivity growth is the reallocation of economic resources from firms with relatively low productivity—which, as a result, are eventually forced out of business—to newer firms with higher productivity. Especially in the high-tech sector since 2000, highly productive young firms do not appear to be expanding as quickly as they did in the past, whereas older, less productive

[66] For a pessimistic projection from the early 2000s, see Daniel Aaronson and Daniel Sullivan, "Growth in Worker Quality," *Economic Perspectives* (Federal Reserve Bank of Chicago, 4Q 2001), pp. 53–74, www.chicagofed.org/digital_assets/publications/economic_perspectives/2001/4qepart5.pdf (732 KB). For a more optimistic recent assessment, see Canyon Bosler and others, *The Outlook for U.S. Labor-Quality Growth*, FRBSF Working Paper 2016-14 (Federal Reserve Bank of San Francisco, July 2016), www.frbsf.org/economic-research/publications/working-papers/2016/14/.

[67] See Dan Andrews, Chiara Criscuolo, and Peter N. Gal, "The Global Productivity Slowdown, Technology Divergence and Public Policy: A Firm Level Perspective" (presentation to the Brookings Conference on Slow Growth in Productivity: Causes, Consequences, and Policies, Washington, D.C., September 8, 2016), www.brookings.edu/research/the-global-productivity-slowdown-technology-divergence/.

firms are not releasing workers as quickly.[68] No clear consensus exists on the fundamental causes of the long-term decline in the presence of innovative new and young firms in the economy.[69]

Another structural determinant of productivity growth is the ability of firms to attract skilled workers and capable managers. Some researchers have noted that because productivity growth occurs overwhelmingly in cities, restrictive land-use regulations have contributed indirectly to slower productivity growth by raising housing costs and discouraging workers from migrating to the denser urban areas.[70]

Innovation

Finally, research on long-term trends in technological, economic, and organizational innovation yields a wide range of conclusions, underscoring the challenge of projecting trends that are inherently unpredictable. Pessimistic scholars argue that the economy has simply returned to a normal pattern of slow progress that reflects the difficulty of achieving rapid technological progress that, in turn, leads to improvements in well-being. According to that view, the unusually rapid and widespread innovation and improvement in living standards from the late 19th century through the early 1970s was a unique and unsustainable event, and the IT-related burst of growth in the late 1990s and early 2000s was simply a temporary deviation from an inevitable slowing of trend growth in TFP.[71] Supporting evidence points to declining productivity of research,

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[68] See Ryan A. Decker and others, *Changing Business Dynamism and Productivity: Shocks vs. Responsiveness*, NBER Working Paper 24236 (National Bureau of Economic Research, January 2018), www.nber.org/papers/w24236; Ryan A. Decker and others, "Declining Business Dynamism: Implications for Productivity?" (presentation to the Brookings Conference on Slow Growth in Productivity: Causes, Consequences, and Policies, Washington, D.C., September 8, 2016), www.brookings.edu/wp-content/uploads/2016/08/haltiwanger_conference_draft.pdf (971 KB); and Jorge Guzman and Scott Stern, *The State of American Entrepreneurship: New Estimates of the Quantity and Quality of Entrepreneurship for 15 US States, 1988–2014*, NBER Working Paper 22095 (National Bureau of Economic Research, March 2016), www.nber.org/papers/w22095.

[69] For a discussion of potential federal policy responses to factors that may stymie the growth of innovative firms, see Congressional Budget Office, *Federal Policies and Innovation* (November 2014), www.cbo.gov/publication/49487.

[70] See Chang-Tai Hsieh and Enrico Moretti, *Housing Constraints and Spatial Allocation*, NBER Working Paper 21154 (National Bureau of Economic Research, May 2015), www.nber.org/papers/w21154.

[71] For a detailed discussion of long-term growth in the United States by a noted economic historian, see Robert Gordon, *The Rise and Fall of American Growth* (Princeton University Press, 2016). Other researchers note that over the past half-century, social developments such as the civil rights and women's rights movements yielded a onetime expansion of productivity by allowing talented people who were previously excluded from many occupations to pursue their comparative advantage. See Chang-Tai Hsieh and others, *The Allocation of Talent and U.S. Economic Growth* (draft, August 26, 2016—Version 4.0), http://web.stanford.edu/~chadj/HHJK.pdf (136 MB).

suggesting that truly new and innovative ideas are becoming increasingly scarce.[72] Further support may come from the fact that the recent TFP slowdown has been global, and, within the United States, widespread across states and industries.[73]

On a more optimistic note, other researchers argue that technological advances have greatly improved the tools needed for further advances, that innovation now benefits both from a much larger, global pool of potential innovators and a much wider market for innovations, and that communication allows innovations to be shared much more rapidly.[74] They also point to a variety of recent major innovations with potentially wide-ranging applications that can be expected to diffuse slowly throughout the economy.[75]

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[72] See Nicholas Bloom and others, *Are Ideas Getting Harder to Find?* NBER Working Paper 23782 (September 2017), www.nber.org/papers/w23782.

[73] See Roberto Cardarelli and Lusine Lusinyan, *U.S. Total Factor Productivity Slowdown: Evidence From the U.S. States*, IMF Working Paper 15/116 (International Monetary Fund, May 2015), www.imf.org/external/pubs/ft/wp/2015/wp15116.pdf (1.22 MB).

[74] See, for example, Joel Mokyr, Chris Vickers, and Nicolas L. Ziebarth, "The History of Technological Anxiety and the Future of Economic Growth: Is This Time Different?" *Journal of Economic Perspectives*, vol. 29, no. 3 (Summer 2015), pp. 31–50, www.aeaweb.org/articles?id=10.1257/jep.29.3.31; and Nouriel Roubini, "Populists and Productivity" (Project Syndicate, June 3, 2016), http://tinyurl.com/ydeusyxh.

[75] See Lee Branstetter and Daniel Sichel, *The Case for an American Productivity Revival*, Policy Brief 17-26 (Peterson Institute for International Economics, June 2017), https://piie.com/system/files/documents/pb17-26.pdf (248 KB); and Erik Brynjolfsson, Daniel Rock, and Chad Syverson, *Artificial Intelligence and the Modern Productivity Paradox: A Clash of Expectations and Statistics*, NBER Working Paper 24001 (National Bureau of Economic Research, November 2017), www.nber.org/papers/w24001.