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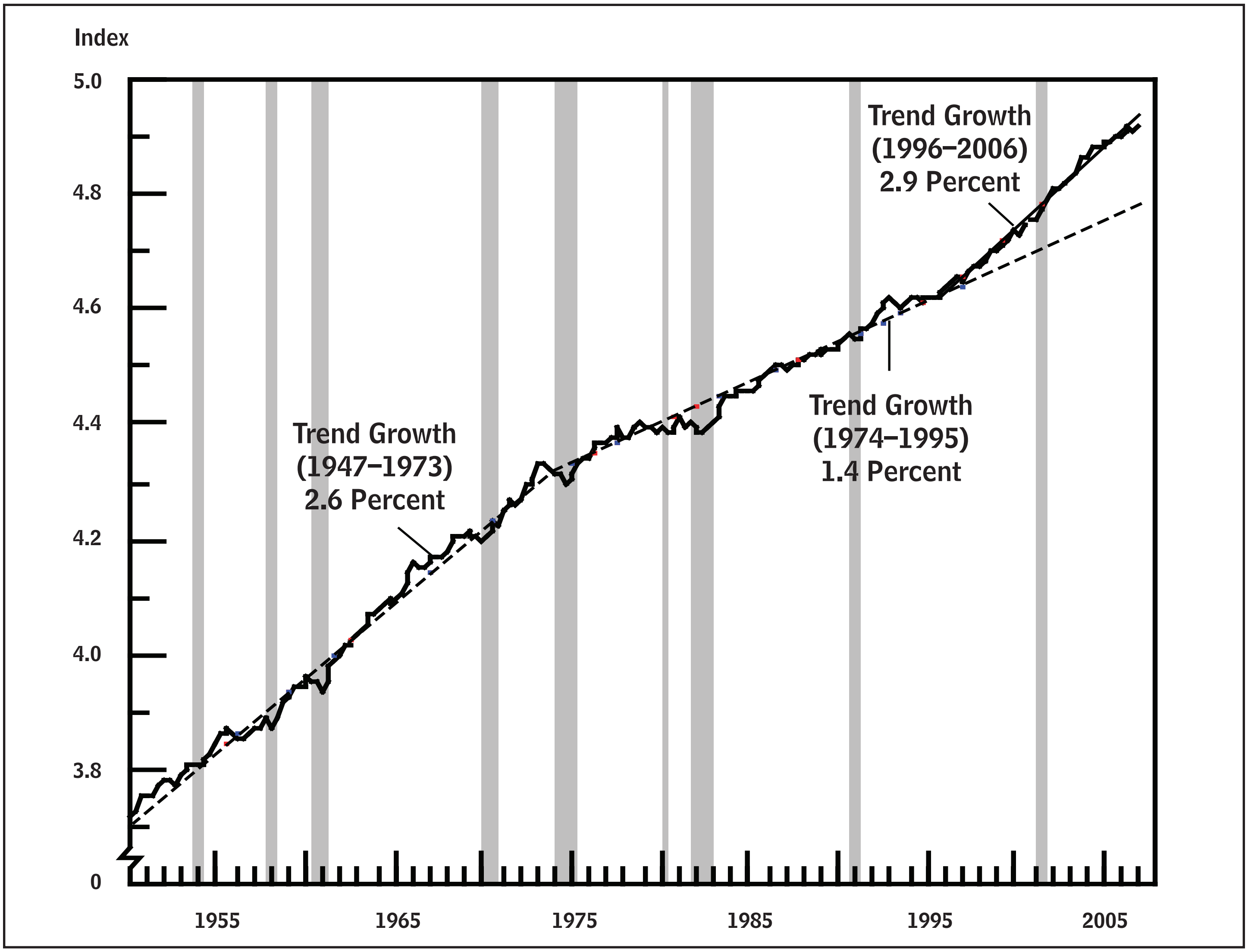
Labor Productivity: Developments Since 1995



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Labor Productivity: Developments Since 1995

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Notes

All years are calendar years.

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

The shaded vertical bars in the figures indicate business-cycle recessions, as determined by the National Bureau of Economic Research.

Preface

The Congressional Budget Office (CBO) regularly reviews the methods it uses to develop its economic and budget projections. Among the more important assumptions that underlie CBO's economic forecast is the projection for the growth of labor productivity. It is widely recognized that labor productivity accelerated during the mid-1990s and that the increase in growth has largely continued until the present. This paper, prepared at the request of the Chairman and the Ranking Member of the Senate Budget Committee, documents that productivity acceleration, highlighting some less-well-known aspects of the upswing in growth, including the effect that data revisions have had on CBO's view of the trend in productivity growth and the shift in the source of the growth in labor productivity from increases in capital per worker toward total factor productivity.

The paper also explores the reasons for the productivity acceleration and concludes that it likely stemmed from developments in the information technology (IT) sector, including faster technological change in the production of IT goods and the boom in business investment in those goods. Although widely accepted, that explanation raises two questions: Why did productivity growth accelerate further during a period—the years since the 2001 business-cycle peak—when IT investment fell substantially? And why did European economies fail to experience a similar productivity surge even though they had access to the same IT goods that were available in the United States? The paper outlines several possible answers to those questions but concludes that further research will be necessary before economists can provide a consensus answer.

Robert Arnold of CBO's Macroeconomic Analysis Division wrote this paper under the supervision of Robert Dennis and John Peterson. Donald Marron, Arlene Holen, and Kim Kowalewski provided valuable comments. Kate Kelly edited the manuscript, and Christian Howlett proofread it. Andrew Gisselquist assisted with formatting, and Maureen Costantino prepared the paper for publication. Lenny Skutnik produced the printed copies, Linda Schimmel coordinated the print distribution, and Annette Kalicki and Simone Thomas prepared the electronic version for CBO's Web site (www.cbo.gov).

Peter R. Orszag
Director

March 2007

Contents

Labor Productivity: Developments Since 1995

One striking aspect of recent U.S. economic history has been the vigorous growth in labor productivity. Between 1995 and 2006, the nation's labor productivity, or output per hour worked, grew at an average annual rate of 2.7 percent, well above its 1947–1995 average of 2.1 percent. The acceleration occurred despite several shocks that buffeted the economy during the period—a recession, two wars, terrorists' attacks, corporate governance scandals, and a sharp increase in the price of oil.[1]

More recently, productivity growth slowed, which has raised concerns that the trend rate of growth has shifted again. Since 2003, labor productivity growth has averaged 1.8 percent annually, and in the final two quarters of 2006 it averaged 0.5 percent at an annual rate. This recent slowdown underscores the variability in productivity growth and highlights the need for a long-term perspective when estimating trends in productivity. It also highlights the need to identify the sources of changes in productivity growth to determine whether they are likely to persist.

Productivity growth is the fundamental source of long-term improvement in standards of living. When workers are able to produce more output per hour of work, economic theory predicts that they will receive more pay, on average; and indeed, this is what the data show. Growth in aggregate real (inflation-adjusted) labor compensation generally has matched changes in overall productivity growth in the United States since World War II. The relationship, however, is not tight—the two measures can diverge for spans of several years—and the gains from productivity growth do not appear to be shared equally: Gains for the typical worker (and for lower-compensated workers) have trailed behind the average increase since the late 1990s while gains for highly compensated workers have exceeded the average.[2]

The trend in productivity growth also plays an important role in the budget outlook published by the Congressional Budget Office (CBO), because productivity growth is a key determinant of potential gross domestic product (GDP). The estimate and projection of potential GDP—the level of gross domestic product that corresponds to a high rate of resource use—drives CBO's projections of actual GDP and of tax bases for the 10 years ahead. For example, CBO estimates that each increase of 0.1 percentage point in the average growth rate of labor productivity would, if sustained for 10 years, raise the level of GDP in 2017 by roughly 1 percent, or by about $200 billion. A higher level of GDP, in turn, would mean that the government could collect more in taxes and spend less on interest on the debt. All told, each increase of 0.1 percentage point would be expected to cut the deficit by an amount that also would rise each year, climbing to an annual reduction of roughly $60 billion by 2017.

This paper describes the behavior of labor productivity since 1995, highlighting several aspects of productivity growth that perhaps have not been widely recognized and examining some possible explanations for the acceleration. Analysts have concluded that the productivity

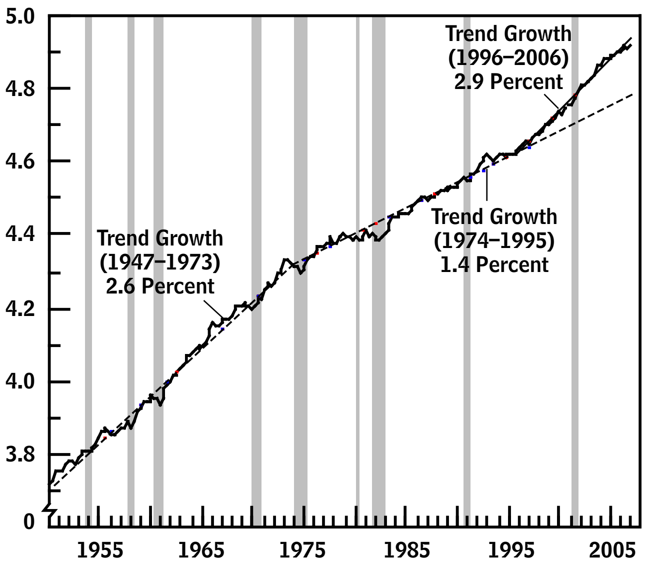
1. Labor productivity is average real (inflation-adjusted) output per hour of labor; it is defined for the nonfarm business sector (the overall economy, excluding government, farms, residential housing, nonprofit institutions, and private households). Labor productivity differs from total factor productivity (TFP), a concept discussed later in this paper, in that increases in capital per worker increase labor productivity but not TFP.

2. See Ian Dew-Becker and Robert Gordon, *Where Did the Productivity Growth Go? Inflation Dynamics and the Distribution of Income,* Working Paper 11842 (Cambridge, Mass.: Bureau of Economic Research, December 2005).

Figure 1.

Labor Productivity and Trend Growth, 1950 to 2006

(Index)



Sources: Congressional Budget Office; Department of Labor, Bureau of Labor Statistics.

Note: Index (1996 = 1.0); data expressed in logarithmic form.

acceleration likely stemmed from developments in the information technology (IT) sector, including rapid technological change in the industries that produce IT goods.

Labor Productivity Growth Since 1995

After more than 20 years of slow growth, labor productivity accelerated sharply during the second half of the 1990s. It then sped up again after 2001, although it has slowed somewhat during the past three years. Nonetheless, the post-1995 acceleration was substantial: The growth trend in labor productivity stepped up to nearly 3 percent, on average, between 1995 and 2006, a rate considerably faster than the 1.4 percent pace from 1974 to 1995 (see Figure 1).[3] Had it followed that pre-1996 trend of 1.4 percent instead of the actual 2.9 percent, labor productivity would be 16 percent lower than it is today. Furthermore, if the 3 percent trend is sustained over the next decade, the level of real GDP will be nearly 40 percent higher in 2017 than the level that would have resulted from the pre-1996 rate of growth.

In the mid-1990s, few forecasters projected a dramatic increase in the trend rate of productivity growth; most anticipated a continuation of the modest growth of the two decades before. For example, in January 1995, CBO projected an average annual labor productivity growth rate of 1.3 percent for 1995 to 2000.[4] Similarly, in its five-year projection published in February 1995, the Clinton Administration projected a rate of 1.25 percent.[5] And both projections for real GDP were similar to the GDP estimated by the consensus of private forecasters surveyed for the March 1995 edition of *Blue Chip Economic Indicators.* That concordance suggests that the CBO and Administration projections for labor productivity also were consistent with the *Blue Chip* consensus.[6]

The upswing in productivity growth in the second half of the 1990s went unrecognized until very late in the decade, in part because of the volatile nature of the data series. Labor productivity growth can swing widely from quarter to quarter, and two or three years is a short period within which to discern a new trend. Moreover, the acceleration followed on the heels of a period of subpar growth (productivity growth averaged only 0.22 percent annually between the end of 1992 and the third quarter of 1995)

3. The increase in the productivity growth trend since 1995 illustrated in Figure 1 consists of several changes in productivity growth over shorter periods. Between late 1995 and the business-cycle peak in the first quarter of 2001, for example, labor productivity growth averaged 2.5 percent annually. Between the first quarter of 2001 and the third quarter of 2003, labor productivity surged at an average annual rate of 4.5 percent before falling back to a 1.6 percent rate of growth between the end of 2003 and the end of 2006. Productivity growth averaged 2.8 percent annually between the peak in 2001 and the end of 2006.

4. See Congressional Budget Office, *The Economic and Budget Outlook: Fiscal Years 1996–2000* (January 1995).

5. See *Economic Report of the President* (February 1995), p. 125.

6. One notable exception was Federal Reserve Board Chairman Alan Greenspan, who, as early as 1992, raised the possibility of faster trend growth in labor productivity, based in part on anecdotal evidence from industry sources. Nevertheless, Federal Reserve staff forecasts of trend productivity growth during that period were similar to the consensus of private-sector and government forecasts. For more details, see Richard G. Anderson and Kevin L. Kliesen, *Productivity Measurement and Monetary Policymaking During the 1990s,* Working Paper 2005-067A (Federal Reserve Bank of St. Louis, October 2005).

Table 1.

Changes in Estimates of the Average Annual Growth Rate for Labor Productivity

(Percent)

CBO Forecast[a]	Period, Beginning Last Quarter 1995	Average Annual Rate of Growth: Initial Estimate Using Original Data	Average Annual Rate of Growth: Current Estimate Using Current Data	Revision (Percentage points)
January 1997	To 3rd Quarter 1996	0.3	3.1	2.8
January 1998	To 3rd Quarter 1997	1.8	2.5	0.7
January 1999	To 3rd Quarter 1998	2.0	2.6	0.6
January 2000	To 3rd Quarter 1999	2.7	2.5	-0.2

Source: Congressional Budget Office based on data from the Bureau of Labor Statistics and the Bureau of Economic Analysis.

a. CBO's annual January forecast is based on a Bureau of Labor Statistics data set that extends through the third quarter of the previous year.

so, initially, the faster growth looked as if it were just making up lost ground rather than establishing a new, higher trend growth rate. The history of the series includes several episodes of faster- or slower-than-trend growth that were later reversed.[7]

Inaccuracies in early vintages of the underlying data are the other reason the productivity acceleration went unrecognized during its early stages. Data that were available to analysts in 1996, 1997, and 1998 showed only a small rise in the rate of labor productivity growth. After several revisions, however, and with data from a longer period, a stronger pattern emerged. Data published by the Bureau of Labor Statistics (BLS) during the late1990s (see Table 1) illustrate the pattern. At first, there was no apparent acceleration. Data available in early 1997 showed labor productivity growing by a mere 0.3 percent from the fourth quarter of 1995 through the third quarter of 1996. Currently available data tell a different story: Labor productivity growth for the period was actually a robust 3.1 percent.

A similar case holds for 1998 and 1999. Data that were available in January 1998 showed labor productivity growth averaging 1.8 percent between the fourth quarter of 1995 and the third quarter of 1997. That rate has since been revised to 2.5 percent. The growth rate for the three-year period ending in the third quarter of 1998 also has been revised from 2.0 percent (using data from early 1999) to 2.6 percent (using currently available data).

7. Slower productivity growth during the past three years has raised concerns about the possibility of another shift in the trend, but it is too soon to conclude that such a shift has taken place.

The information in Table 1 highlights an important point: Productivity data are revised frequently, and the revisions can be large enough to alter analyses of trends in productivity growth.[8] Indeed, after being revised upward several times during the late 1990s, productivity data have been revised downward somewhat during recent years. In January 2000, labor productivity growth for 1996 to 1999 was estimated at 2.7 percent; that estimate has since been revised to 2.5 percent. The estimate of growth in total factor productivity (TFP), or output per unit of labor and capital combined, was revised downward by a slightly larger amount. Using current data, CBO estimates that TFP grew at an average annual rate of 1.3 percent between 1995 and 1999. In contrast, data available in late 1999 showed a 1.7 percent average annual rate of TFP growth for the period.[9]

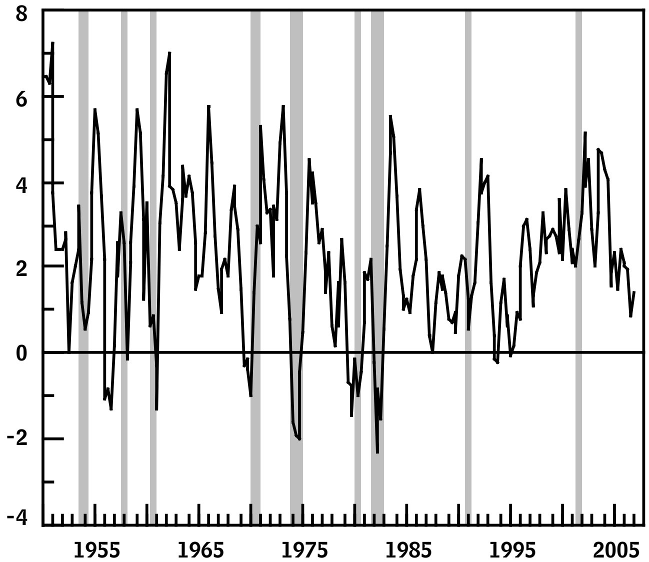
8. Productivity is computed using GDP data (from the national income and product accounts tabulated by the Bureau of Economic Analysis) and employment data (largely from the Bureau of Labor Statistics payroll survey) so estimates will be affected by revisions to either data source. For more on those revisions, see Richard Anderson and Kevin Kliesen, "The 1990s Acceleration in Labor Productivity: Causes and Measurement," *Federal Reserve Bank of St. Louis Review,* vol. 88, no. 3 (2006), pp. 181–202. Anderson and Kliesen note that early data supported only a limited role for service-producing industries in the late-1990s productivity acceleration and that improved source data have since revealed that growth in productivity in the service sector increased by more than had been estimated originally.

9. For more details on the revisions to the data underlying TFP, see Congressional Budget Office, *The Budget and Economic Outlook: Fiscal Years 2006 to 2015* (January 2005), Box 2-1, p. 29.

Figure 2.

Growth in Labor Productivity, 1950 to 2006

(Percentage change from previous year)



Sources: Congressional Budget Office; Department of Labor, Bureau of Labor Statistics.

More recently, revisions have changed the view of productivity growth in 2005 and 2006. In early 2007, BLS released revised productivity data that showed labor productivity growth averaged 1.5 percent annually between the beginning of 2005 and the third quarter of 2006. That rate was about 0.5 percentage points lower than BLS's previous estimate of 2.0 percent. The revisions to the productivity data highlight the difficulty in recognizing a change in the underlying trend growth rate, warranting additional caution in reaching conclusions about changes in that trend based on only a few quarters' worth of information.

New Cyclical Pattern

Current data show that the productivity acceleration has been durable, proceeding without pause through the 2001 recession, although it has moderated somewhat since 2003. Quarterly growth in labor productivity is volatile, but a pattern is discernible from past business cycles. Typically, labor productivity declines during a recession but grows robustly during recovery and in the early stages of an expansion (see Figure 2). Although harder to detect, there may also be an "end-of-expansion" effect in operation, when productivity growth is relatively low near the end of a business-cycle expansion.[10]

Since 1995, however, labor productivity has departed from that pattern. Growth in labor productivity surged during the early phase of the recovery from the 1990 recession and then briefly fell back toward its previous trend before steadily accelerating in the late 1990s, just when past patterns would have suggested a period of below-trend growth. Although it was not evident at the time, that acceleration during the second half of the 1990s coincided with the latter stages of a business-cycle expansion. Productivity growth has remained relatively strong since 2000, averaging 2.7 percent despite the 2001 recession, the attacks of September 11, 2001, the wars in Iraq and Afghanistan, a series of corporate governance scandals, and a spike in oil prices—each of which had the potential to restrain the growth of output and productivity. Although productivity growth has slowed somewhat since 2003, the volatile nature of the growth rate and the possibility of further revisions mean that it is too soon to conclude that the growth trend has slowed or that the economy is approaching the end of the current business-cycle expansion.

Shifting Sources of Growth

The sources of growth in productivity also have changed over the past decade. Analysts divide labor productivity growth into two components: capital deepening (increases in the amount of capital available per worker) and total factor productivity.[11] Capital per worker rises not only because investment provides more factories, equipment, and software but because the quality of

10. See Robert Gordon, *Five Puzzles in the Behavior of Productivity, Investment, and Innovation,* Working Paper 10660 (Cambridge, Mass.: National Bureau of Economic Research, August 2004).

11. Tracing the sources of economic growth in this manner is termed growth accounting. An explanation is beyond the scope of this paper, but there is an excellent discussion of growth accounting in Bureau of Labor Statistics, *Trends in Multifactor Productivity, 1948–81,* Bulletin 2178 (September 1983). CBO's estimate of total factor productivity is similar to the bureau's estimate of multifactor productivity (MFP). The two data series are calculated by the same method, but CBO uses slightly different source data, which allow it to estimate TFP for years too recent for MFP data to have become available.

Table 2.

Contributions of Capital Deepening and Total Factor Productivity to Labor Productivity Growth, 1990 to 2005

	Average Annual Growth Rate			Change	
	1991–1995	1996–2001	2002–2005	1991–1995 to 1996–2001	1996–2001 to 2002–2005
Contribution of Capital Deepening (Percentage points)	0.50	1.33	0.76	0.83	-0.57
Contribution of Total Factor Productivity (Percentage points)	1.04	1.22	2.45	0.18	1.23
Labor Productivity (Percent)	1.54	2.54	3.21	1.01	0.66

Source: Congressional Budget Office based on data from the Bureau of Labor Statistics and the Bureau of Economic Analysis.

capital goods improves over time. For example, the computer sitting on a typical office worker's desk today has a vastly faster processor and far more disk storage than did an equivalent machine a decade ago.

Although growth in TFP often is interpreted as a measure of technological change, it is an imperfect measure. TFP is computed by subtracting the growth contributions of labor and capital from the growth in output, so it reflects anything that causes output to grow faster than the combined inputs. Analysts have attributed growth in TFP to such factors as economies of scale, measurement error, the educational attainment of the labor force, the regulatory environment, managerial ability, and innovation. The calculation is imprecise, but an examination of the trends in TFP and capital deepening reveals that the primary source of growth in labor productivity has shifted during the past 10 years.

CBO estimates that capital deepening was the primary source of the surge in labor productivity growth in the late 1990s and that faster TFP growth was the primary source during the period after the business-cycle peak in 2001. Between the first and second halves of the 1990s, labor productivity growth stepped up from about 1.5 percent, on average, to 2.5 percent per year. Growth in capital per worker accounted for 80 percent (0.8 percentage points) of that 1-percentage-point increase, CBO estimates (see Table 2). Faster TFP growth was responsible for the rest of the step-up in productivity growth. Those conclusions are based on the data as currently published, so it is possible that future revisions will change the assessment of the period.

Since 2001, the sources of growth in labor productivity have reversed. Business investment fell substantially in 2001 and 2002 and remained weak in 2003, thus slowing the growth in capital deepening relative to that in the late 1990s. The contribution of capital per worker to labor productivity growth fell by 0.6 percentage points between 2001 and 2005 relative to the 1996–2001 period. At the same time, however, TFP growth was accelerating sharply, especially in 2003 (see Figure 3). CBO estimates that TFP was responsible for all of the acceleration in labor productivity in the 2001–2005 period.[12]

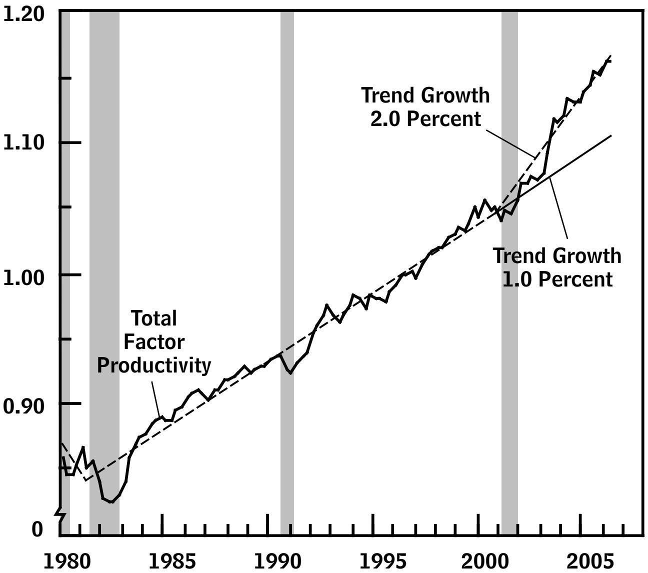
It is important to ask whether labor productivity will continue to grow as rapidly over the next 10 years as it has during the past decade. But experience since 1995 illustrates why that question is so hard to answer. Labor productivity growth is volatile, its measurement is subject to large revisions, and the reasons for changes in its rate of growth are not well understood. Consequently, it is a

12. Estimates of TFP (calculated at an annual frequency) are available through 2005. Estimates by CBO indicate that TFP growth, like labor productivity growth, slowed in 2006. The conclusions about the shifting sources of growth in labor productivity are based on the growth model used to calculate CBO's medium-term projections. However, they are consistent with results published by other researchers. See, for example, Dale Jorgenson, Mun Ho, and Kevin Stiroh, "The Sources of the Second Surge of U.S. Productivity and Implications for the Future" (working paper, Harvard University, March 2006); Carol Corrado and others, "Modeling Aggregate Productivity at a Disaggregate Level: New Results for U.S. Sectors and Industries" (working paper, Federal Reserve Board, July 2006); and Mark Lasky, *Putty-Clay Capital and an Index of Capital per Hour,* CBO Working Paper 2005-08 (June 2005).

Figure 3.

Total Factor Productivity and Trend Growth, 1980 to 2006

(Index)



Sources: Congressional Budget Office; Department of Labor, Bureau of Labor Statistics.

Note: Index (1996 = 1.0); data expressed in logarithmic form.

difficult variable to forecast; past patterns and recent data provide only a rough guide to where labor productivity will go in the future. Explanations for the recent acceleration help to determine whether any of the changes to growth since 1995 will reverse or recur in the next 10 years.

Explaining the Post-1995 Productivity Acceleration

Although it is hard to say conclusively that one factor is the sole cause of the acceleration in productivity growth that began in 1995, there is a consensus among economists that investment in information technology is a primary source. Evidence comes from studies that have analyzed aggregate (economywide), industry-level, and firm-level data.

Early evidence came from studies that used a growth-accounting framework and aggregate data to calculate the contributions to economic growth made by the inputs to production—labor, capital, and TFP. Using that framework, several analysts determined that developments in IT have influenced productivity growth both through capital deepening and through TFP growth.[13] Increased investment in IT capital goods, spurred perhaps by falling prices, contributed to growth in labor productivity by increasing the amount of capital available to each worker (capital deepening). During the late 1990s, not only did business investment boom, but it was heavily tilted toward IT goods (see Figure 4). CBO's estimates indicate that faster capital deepening accounted for about 80 percent of the 1-percentage-point acceleration in labor productivity during the late 1990s and that IT capital accounted for 75 percent of the contribution from capital deepening.

Rapid technological change in the IT industries (which include computers, software, and telecommunications) can speed TFP growth in those industries. And if those industries are large enough or the pace of technological change is fast enough, then faster TFP growth in that sector of the economy can accelerate TFP growth overall. Indeed, this is what appears to have happened in the late 1990s. According to estimates by Steven Oliner and Daniel Sichel, for example, the computer and semiconductor industries accounted for about half of TFP growth from 1996 to 1999, even though the output of those industries contributed only about 2.5 percent of GDP in the nonfarm business sector during that period.[14]

The research illustrates that both the production and the use of IT goods in the United States contributed substantially to the productivity acceleration in the late 1990s. The studies, however, have inherent limitations. In particular, growth-accounting exercises assume the values of key parameters rather than estimating them by statistical techniques. For example, the elasticity of output with respect to IT capital—which measures the effect on output of an increase in the stock of IT capital—is an assumption that is based on the predictions of economic theory rather than on the results of an econometric regression equation. Setting the value of the elasticity

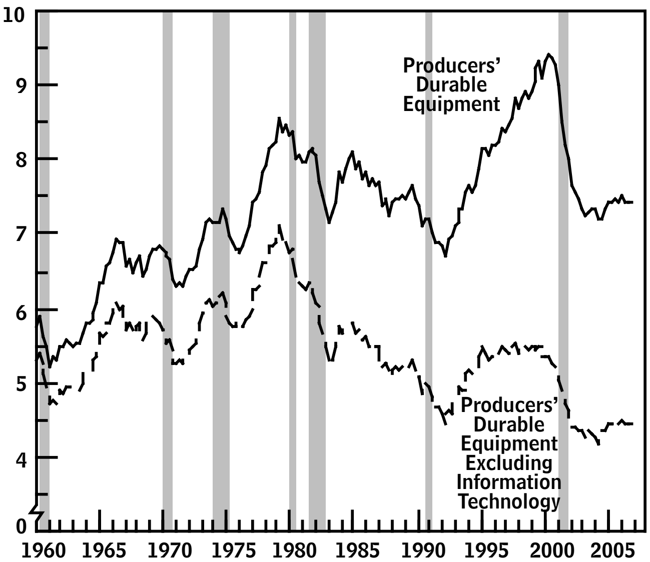
13. See Steven Oliner and Daniel Sichel, "The Resurgence of Growth in the Late 1990s: Is Information Technology the Story?" *Journal of Economic Perspectives,* vol. 14, no. 4 (2000), pp. 3–22; and Dale Jorgenson and Kevin Stiroh, "Raising the Speed Limit: U.S. Economic Growth in the Information Age," *Brookings Papers on Economic Activity,* vol. 1 (2000), pp. 125–211.

14. See Oliner and Sichel, "The Resurgence of Growth in the Late 1990s" (2000).

Figure 4.

Investment in Producers' Durable Equipment, 1960 to 2006

(Percentage of gross domestic product)



Sources: Congressional Budget Office; Department of Commerce, Bureau of Economic Analysis.

implies that investment spending is not wasted (on average) and that the productivity impact of, say, a newly acquired computer is immediate.[15] That assumption could be an important source of error; there is evidence that the full effect of IT spending on productivity occurs after a considerable delay. Consequently, productivity growth in the late 1990s could have been the result of IT spending in the early 1990s or even in the late 1980s.

To be sure, economists would prefer to estimate the effect of IT spending on productivity growth rather than impose it by assumption, but there are considerable statistical problems associated with estimating the relevant parameters, at least using economywide data. The application of growth-accounting methods, however, is a reasonable approach that sidesteps those statistical challenges. Nevertheless, growth-accounting studies identify only the proximate sources of growth and not the factors that drive investment or technological progress.

15. See Robert Gordon, "Exploding Productivity Growth: Context, Causes, and Implications," *Brookings Papers on Economic Activity,* vol. 2 (2003), pp. 207–279.

Despite the important limitations, the fundamental conclusion of growth-accounting studies—that IT was the primary source of the acceleration—is still valid. Other studies that used industry- and firm-level data support the growth-accounting results and provide further information about the effects of IT spending. In a 2002 paper, for example, Kevin Stiroh reported that the post-1995 revival in labor productivity was widespread, that it reflected gains in a majority of industries, and that it was linked to IT spending.[16] Moreover, IT-intensive industries realized larger productivity accelerations than other industries did. Other researchers have reported that the productivity acceleration was concentrated in service-producing industries.[17]

Perhaps the strongest evidence of a link between IT and productivity comes from studies that use firm- or plant-level data. That research typically uses regression equations to estimate the elasticity of output with respect to IT capital, and it generally reports a positive and significant relationship between IT spending and productivity.[18] Indeed, some estimates from studies that use microeconomic data suggest that the productivity payoff from IT investment could be quite large, perhaps twice what would be predicted by economic theory. That is a tentative conclusion, however, and there is considerable variation among studies in the estimates of the elasticity associated with IT spending.[19]

16. See Kevin Stiroh, "Information Technology and the U.S. Productivity Revival: What Do the Industry Data Say?" *American Economic Review,* vol. 92, no. 5 (2002), pp. 1559–1576. In another paper, Stiroh presents evidence that the primary effect of IT spending is capital deepening and that such spending does not speed TFP growth. See Kevin Stiroh, "Are ICT Spillovers Driving the New Economy?" *Review of Income and Wealth,* vol. 48, no. 1 (2002), pp. 33–57. Similar findings were presented by Martin Baily and Robert Lawrence, "Do We Have a New E-conomy?" *American Economic Review,* vol. 91, no. 2 (2001), pp. 308–312.

17. See Anderson and Kliesen, "The 1990s Acceleration in Labor Productivity." Among service industries, it appears that TFP was the primary source of the acceleration in labor productivity during the late 1990s. See Jack Triplett and Barry Bosworth, "Productivity Measurement Issues in Services Industries: 'Baumol's Disease' Has Been Cured," *Economic Policy Review,* Federal Reserve Bank of New York (September 2003), pp. 23–33; and Barry Bosworth and Jack Triplett, "Is the 21st Century Productivity Expansion Still in Services? And What Should Be Done About It?" (paper prepared for the National Bureau of Economic Research Conference on Research in Income and Wealth, Cambridge, Mass., July 16, 2006).

Analysts generally agree that IT investment is the primary source of the revival in labor productivity, but research on the causes of the acceleration has revealed two conundrums about the connection between IT investment and productivity. First, although spending on IT capital collapsed after 2000, a second surge in productivity began about the same time. And second, although IT technology is accessible to businesses anywhere in the world, the productivity acceleration was limited largely to the United States. Although European economies in particular invested heavily in IT, they have not shared in the productivity gains.

Explaining the Post-2001 Productivity Acceleration

The sources of the surge in productivity growth after 2001 are murkier. Less time has elapsed, so analysts have a smaller data set for evaluation, and thus it is more difficult to identify a new trend. Moreover, the data for the period already have been revised substantially and undoubtedly will be revised again in the coming years, to further cloud the picture.

The second productivity acceleration occurred during a period when business investment collapsed, which strongly suggests that capital deepening was not the primary source of the surge. Indeed, the post-2001 acceleration can be explained entirely by faster TFP growth, with no contribution from capital deepening. Moreover, analysts have reported a shift in the set of industries responsible for the second surge in productivity. Whereas the post-1995 surge can be traced to the industries that were the most intensive users of IT capital (along with those that produced IT capital), the post-2001 acceleration has been more broadly based, and strong gains have been registered by industries that use IT less intensively.[20]

Despite that, the second surge could still be the result of IT spending if there is a lag between the time when the IT capital is installed and the time when businesses achieve productivity gains. If so, the surge could be a delayed response to the late-1990s investment boom. Studies that use firm-level data have identified a strong relationship between IT spending and productivity growth, and there is evidence of long delays—five to seven years, in some cases—between IT spending and productivity payoff.

Several theories, not necessarily mutually exclusive, have been proposed to explain the delay. One focuses on the adjustment costs associated with large changes in the size of the capital stock.[21] According to that theory, businesses had difficulty absorbing all of the IT goods acquired during the investment boom of the late 1990s and were forced to divert resources from production in order to integrate new equipment and technology into their productive processes. If that is the case, then adjustment costs suppressed productivity growth in the late 1990s but boosted it after 2001. The pause in capital spending since 2001 has allowed companies to catch up, and the recent hike in productivity is a delayed payoff for the investments of the 1990s.

Another hypothesis holds that computers (and IT goods in general) are examples of general-purpose technology that allows businesses to fundamentally change the way they operate. Like dynamos and electric motors, which freed early-20th-century factory owners from the requirement to build next to a river, computers gave businesses a faster way to manage information and, therefore, a way to produce more efficiently. But it takes time for new technology to produce results: Business owners must learn to adjust processes to make the best use of the new technology, and that transition can take years, or even decades.[22]

Still another idea, closely related to the first two, focuses on the link between IT spending and investment in "intangible capital"—investment spending that is

18. See Erik Brynjolfsson and Lorin Hitt, "Computing Productivity: Firm-Level Evidence," *Review of Economics and Statistics,* vol. 85, no. 4 (2003), pp. 793–808; Brynjolfsson and Hitt, "Paradox Lost? Firm-Level Evidence on the Returns to Information Systems Spending," *Management Science,* vol. 42, no. 4 (1996), pp. 541–558; and Brynjolfsson and Hitt, "Information Technology as a Factor of Production: The Role of Differences Among Firms," *Economics of Innovation and New Technology,* vol. 3, no. 4 (1995), pp. 183–200.

19. See Kevin Stiroh, "Reassessing the Impact of IT in the Production Function: A Meta-Analysis and Sensitivity Tests," (working paper, Federal Reserve Bank of New York, November 2004).

20. See Kevin Stiroh, "The Industry Origins of the Second Surge of U.S. Productivity Growth" (working paper, Federal Reserve Bank of New York, February 2006); and Corrado and others, "Modeling Aggregate Productivity at a Disaggregate Level" (2006).

21. See Susanto Basu, John Fernald, and Matthew Shapiro, "Productivity Growth in the 1990s: Technology, Utilization, or Adjustment?" *Carnegie-Rochester Conference Series on Public Policy,* vol. 55 (2001), pp. 117–165.

intended to increase future output more than current production and that does not result in ownership of a physical asset. When new technology is introduced, businesses must dedicate resources—time and effort—to training workers in its best use. That process is an investment that results in an intangible asset, a body of knowledge or expertise. The introduction of personal computers provided immediate benefits to businesses as workers performed regular tasks more efficiently. But to make the best use of the new technology—to reap its full benefits—employees had to be trained, and that training is an investment in an intangible asset.

One insight of the research on intangible capital is that productivity growth can be understated in periods when IT investment is growing rapidly because businesses are likely to divert labor from current production in favor of training in the use of new IT capital. The official statistics treat most spending for intangible capital—formal training classes are an exception—as a current expense rather than as investment, so such spending is not included in GDP. An explanation for the pattern in productivity growth since 1995 is that TFP growth was suppressed in the late 1990s (although it continued to grow), when investment in IT capital was heaviest, and then was unleashed after 2001, when spending for intangibles to absorb IT capital had abated.

Another and perhaps more powerful insight from the research on intangible capital is that advances in information technology allow businesses to exploit the benefits of their investments in another form of intangible capital, often called "organizational capital." As computing power becomes cheaper and more pervasive, managers can invent new business processes, work practices, and organizational structures, which in turn allow companies to produce entirely new goods and services or to improve their existing products' convenience, variety, or quality.[23]

The gains in productivity made possible by organizational changes can dwarf the direct increases in productivity that arise from doing familiar tasks more efficiently.

Erik Brynjolfsson and Lorin Hitt provide case study examples of business transformations made possible by combining information technology with new work practices and other investments in organizational capital.[24] Some of their examples describe changes to production processes, as when factories install computer-controlled machine tools. Although the machines can duplicate the established production methods (presumably more efficiently), Brynjolfsson and Hitt demonstrate that more substantial productivity gains accrue when old work methods are replaced with new organizational practices. Other examples show how IT investments enable companies to change their relationships with suppliers, as when IT investments allow a company to order supplies electronically and share inventory data with suppliers, thus streamlining the process of restocking inventory and likely cutting costs. Still other examples involve the way companies interact with consumers, as when a computer manufacturer allows its customers to configure their systems online before purchase.

The research on intangible capital reveals three reasons that growth-accounting calculations can misstate the true contributions of computers and other IT goods: First, it is difficult to measure changes in the quality of goods and services. This is especially true if the changes are intangible, involving improvements in convenience, timeliness, or variety, for example. Next, official statistics treat most spending for intangible capital as a current expense rather than as an investment. Consequently, most of that spending is excluded from estimates of GDP and the capital stock.[25] Finally, standard calculations can miss the complementary inventions that IT makes possible. They can occur years (or even decades) after the initial expenditure. Growth-accounting calculations usually assume that the investments produce immediate results.

There is only indirect evidence that the post-2001 productivity acceleration is a delayed effect of the late-1990s IT boom. Some recent studies using industry-level data

22. For more on the diffusion of technology, see Paul David, "The Dynamo and the Computer: An Historical Perspective on the Modern Productivity Paradox, *American Economic Review,* vol. 80, no. 2 (1990), pp. 355–361; or Rodolfo Manuelli and Ananth Seshadri, *Frictionless Technology Diffusion: The Case of Tractors,* Working Paper 9604 (Cambridge, Mass.: National Bureau of Economic Research, April 2003). Another study concluded that there were substantial delays between IT investment and increased productivity in the trucking industry: See Thomas Hubbard, "Information, Decisions, and Productivity: On-Board Computers and Capacity Utilization in Trucking," *American Economic Review,* vol. 93, no. 4 (2003), pp. 1328–1353.

23. For more details, see Erik Brynjolfsson and Lorin Hitt, "Beyond Computation: Information Technology, Organizational Transformation and Business Performance," *Journal of Economic Perspectives,* vol. 14, no. 1 (2000), pp. 23–48.

24. Ibid.

indicate a positive correlation between TFP growth in the late 1990s and IT investment several years earlier. A 2003 paper by Susanto Basu and several coauthors, for example, linked TFP growth during the late 1990s with the rate of IT investment in the 1980s and early 1990s.[26] More recently, Carol Corrado and her coauthors reported a similar relationship between IT investment in the late 1990s and TFP growth after 2000.[27] Not everyone agrees, however. Kevin Stiroh finds that the link between IT spending and TFP growth was weaker during the 2000s than in the late 1990s.[28]

Studies that use firm-level data also support the idea that the post-2001 acceleration is related to IT spending during the late 1990s. Several report that the full benefits of investments in computers do not emerge for several years. For example, one study that relied on the results of a survey of more than 500 large U.S. businesses showed that the short-run rate of return on investments in computers is consistent with a normal rate of return on other investments. [29] The same paper showed that the productivity contribution of computers over longer periods—say, five to seven years—can be as much as five times greater, a result attributed to the payoff from the large investments in intangible capital, such as organizational redesign and business process reengineering, that often accompany investments in IT capital.

Analysts also have discovered that financial markets place a high value on companies that have made substantial investments in computers and other IT goods.[30] The idea is that businesses must invest in new processes and training to reap the full benefits of computerization. Presumably, the companies that do so expect to increase future productivity and profits. If their spending on organizational capital represents the accumulation of intangible assets and if financial markets recognize the value of those assets, then the companies' market value should reflect that. The high value placed on firms that have spent heavily on IT capital supports this interpretation, and there is evidence that U.S. industries with larger investments in IT undertake more substantial reorganizations, thus providing further support for the intangible-capital hypothesis.[31]

Despite that evidence, it is possible that the post-2001 productivity surge was not a delayed response to the IT boom of the late 1990s. Rather, it could have a more general, macroeconomic, explanation: It could have evolved from increased competitive pressure attributable to globalization, for example, or deregulation, or businesses' caution in hiring that stemmed from geopolitical uncertainty.

Studies that closely examine individual businesses or industries suggest that competitive pressure is an important driver of productivity growth. Jose Galdon-Sanchez and James Schmitz, for example, describe a strong relationship between an increase in competitive pressure among iron ore mines in the early 1980s and later growth in labor productivity.[32] In countries where competition was light, mines showed little increase in productivity; in countries with more competitive pressure, productivity gains were dramatic, with 50 percent to 100 percent increases by the end of the decade. Case studies, Martin Baily notes, show that productivity gains have diverse and

25. Estimates vary, but the size of the stock of intangibles could be quite large, perhaps 10 times the stock of physical IT assets. See Erik Brynjolfsson, Lorin Hitt, and Shinkyu Yang, "Intangible Assets: Computers and Organizational Capital," *Brookings Papers on Economic Activity,* vol. 1 (2002), pp. 137–181. For another estimate, see Carol Corrado, Charles Hulten, and Daniel Sichel, "Measuring Capital and Technology: An Expanded Framework," in Carol Corrado, John Haltiwanger, and Daniel Sichel, eds., *Measuring Capital in the New Economy* (Chicago: University of Chicago Press, 2005), pp. 11–41.

26. See Susanto Basu and others, "The Case of the Missing Productivity Growth, Or Does Information Technology Explain Why Productivity Accelerated in the United States but Not in the United Kingdom?" in Mark Gertler and Kenneth Rogoff, eds., *NBER Macroeconomics Annual 2003* (Cambridge, Mass.: MIT Press, 2003), pp. 9–63.

27. See Corrado, Hulten, and Sichel, "Measuring Capital and Technology" (2005).

28. See Stiroh, "The Industry Origins of the Second Surge of U.S. Productivity Growth."

29. See Brynjolfsson and Hitt, "Computing Productivity."

30. See, for example, Brynjolfsson and Hitt, "Beyond Computation," and Brynjolfsson, Hitt, and Yang, "Intangible Assets."

31. See Edward Wolff, "Productivity, Computerization, and Skill Change," *Economic Review,* Federal Reserve Bank of Atlanta, vol. 87, no. 3 (2002), pp. 63–87. There is evidence that it is more productive for businesses to combine high organizational capital with high IT capital than it is to invest in large amounts of one or the other. See Timothy Bresnahan, Erik Brynjolfsson, and Lorin Hitt, "Information Technology, Workplace Organization, and the Demand for Skilled Labor: Firm-Level Evidence," *Quarterly Journal of Economics,* vol. 117, no. 1 (2002), pp. 339–376.

idiosyncratic origins.[33] He also argues that competitive pressure, which has increased steadily since the 1970s because of deregulation and globalization, appears to have been the catalyst.

Other suggestive evidence comes from a study of individual retail establishments. Lucia Foster and her coauthors concluded that virtually all productivity growth in retail arises through entry and exit, and there is essentially no role for productivity growth among continuing establishments.[34] Specifically, they reported that almost all productivity growth in the U.S. retail trade sector between 1987 and 1997 came in the entry of establishments with higher-than-average productivity effectively displacing exiting establishments with lower-than-average productivity. Their results suggest that IT investments—at least those made by continuing plants—were not the source of productivity growth in that sector of the economy.

The argument that competition spurs productivity growth appears compelling. And it also seems clear that the degree of competitive pressure has increased since the 1970s, when the U.S. economy was subject to more regulation and exposed to less competition from abroad. One problem with the competition argument is that it does not explain the abrupt rise in TFP growth after 2001. The decrease in regulation and the increase in globalization were gradual and would suggest a gentler increase in productivity growth than actually occurred.

32. See Jose Galdon-Sanchez and James Schmitz, "Competitive Pressure and Labor Productivity: World Iron-Ore Markets in the 1980s," *American Economic Review,* vol. 92, no. 4 (2002), pp. 1222–1235. A similar effect has been shown for the concrete industry in the United States. See Chad Syverson, *Market Structure and Productivity: A Concrete Example,* Working Paper 10501 (Cambridge, Mass.: National Bureau of Economic Research, May 2004).

33. See Martin Baily, "Recent Productivity Growth: The Role of Information Technology and Other Innovations" *Economic Review,* Federal Reserve Bank of San Francisco (December 2004), pp. 35–41.

34. See Lucia Foster, John Haltiwanger, and C.J. Krizan, *The Link Between Aggregate and Micro Productivity Growth: Evidence from Retail Trade,* Working Paper 9120 (Cambridge, Mass.: National Bureau of Economic Research, August 2002).

Explaining the Lag in European Productivity Growth

Many European countries have productivity levels that are equal to or exceed that of the United States, and they have invested heavily in IT, but they have not shared in the productivity gains those investments produced in the United States. The divergence between productivity growth in the United States and in Europe since 1995 is difficult to explain—both economies had access to the same technology. Indeed, it seems that the difference in performance does not stem from the productivity performance of the IT-producing sectors. Raffaella Sadun and John Van Reenen report that the acceleration in Europe among IT-producing industries matched that in the United States.[35] Instead, the difference comes from IT-using industries—while productivity growth in those industries has surged ahead in the United States, it appears to have slowed in most of Europe.

No single explanation has emerged for the difference in European and U.S. productivity growth. Most hypotheses, however, focus on differences in economic policies and institutions. U.S. labor markets tend to be more flexible than are those in Europe, a condition that presumably allows U.S. companies to reorganize work practices, to retrain (or transfer) workers, or to expand or contract as the market dictates. Some analysts argue that labor market rigidities prevent many countries in Europe from taking full advantage of IT investments because they inhibit the changes that are necessary to build intangible capital.[36]

Because product markets also are less regulated in the United States, competition is greater and there are fewer barriers to entry for new firms. Restrictions on land use in many European nations also limit the size of U.S.-style "big-box" retail stores, thus inhibiting competition, the development of efficient supply chains, and economies of scale.[37]

35. See Raffaella Sadun and John Van Reenen, *Information Technology and Productivity: It Ain't What You Do It's the Way You Do I.T.* Discussion Paper 2 (London: London School of Economics and Political Science, EDS Innovation Research Programme, October 2005).

36. See Christopher Gust and Jaime Marquez, *International Comparisons of Productivity Growth: The Role of Information Technology and Regulatory Practices,* International Finance Discussion Paper 727 (Washington, D.C.: Board of Governors of the Federal Reserve System, May 2002).

However, competition appears to influence productivity growth in other industries as well. For example, after reviewing a sample of industrialized nations, analysts at the Organisation for Economic Co-operation and Development reported that countries with more restrictive product market regulations had slower rates of productivity growth over the 1978–2003 period than did those with more lenient rules.[38] The authors focus on two channels to explain the inverse correlation. First, countries with more restrictive regulation of product markets generally had lower investments in IT, presumably because firms in those countries had less incentive to upgrade their capital stock with the latest technology. Second, countries with greater regulation had less foreign direct investment, which generally is thought to spur productivity growth because it introduces new foreign technology into the domestic economy and because it increases the number of competitors in domestic product markets.

Management practices also have been credited with the divergence in productivity. Companies that rely on strict centralized decision making generally are less productive and less able to exploit investments in IT capital than are their more decentralized counterparts.[39] According to this view, one reason for the divergence is that U.S. companies mostly favor decentralized management structures. There also is evidence that multinational firms are more productive than are purely domestic firms and that U.S. multinationals are more productive than are those based in other countries.[40] That condition does not appear to arise from differences in the quantity or quality either of capital or of labor. Instead, it appears that U.S. multinationals have better management practices than do their counterparts in Europe.

CBO's Projections

CBO's projection for potential GDP reflects the consensus that faster productivity growth after 1995 arose from developments in information technology, including technology advances and the boom in IT investment. CBO projects total factor productivity, an important input in the GDP estimate, by extrapolating the trend in TFP estimated from recent history. A key question is whether the rapid growth in TFP that has occurred since 2001 indicates a change in the trend rate of growth. That is, should a forecast of TFP continue the 2.0 percent rate of growth since 2001? Should TFP instead be projected to grow at its pre-2001 rate? Or does the recent slowing in TFP growth suggest that the acceleration will reverse itself completely, with a period of below-trend growth that brings the series back to its pre-2001 trend line? The answers have important implications for the projection of real GDP.

In CBO's judgment, the burst of IT innovation combined with the boom in IT investment during the late 1990s and early 2000s permanently increased the level, but not the growth rate, of productivity in the nation's economy. Although the faster pace of productivity growth is unlikely to persist indefinitely, it also seems unlikely that the gains of the past decade will be undone. Consequently, CBO projects that TFP will follow a middle path—the recent surge in TFP growth will not continue at the same rate, but neither will the surge be reversed. Instead, TFP is projected to grow at a rate that is close to its pre-2001 trend rate.

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37. See Robert Gordon, *Five Puzzles in the Behavior of Productivity, Investment, and Innovation* (2004). In a more recent paper, Gordon has tempered this interpretation somewhat in recognition that the European slowdown has affected industries across the board. See Robert Gordon and Ian Dew-Becker, "Why Did Europe's Productivity Catch-Up Sputter Out? A Tale of Tigers and Tortoises" (paper prepared for the Federal Reserve Bank of San Francisco Center for the Study of Innovation and Productivity Conference, "Productivity Growth: Causes and Consequences," San Francisco, November 18, 2005).

38. See Paul Conway and others, *Regulation, Competition and Productivity Convergence,* OECD Economics Department Working Paper 509 (Paris, France: Organisation for Economic Co-operation and Development, September 2006).

39. See Bresnahan, Brynjolfsson, and Hitt, "Information Technology, Workplace Organization, and the Demand for Skilled Labor."

40. See Nick Bloom, Raffaella Sadun, and John Van Reenen, "It Ain't What You Do It's the Way That You Do I.T.—Testing Explanations of Productivity Growth Using U.S. Affiliates" (working paper, Centre for Economic Performance, London School of Economics, September 2005).