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A Retrospective Look at the U.S. Productivity Growth Resurgence

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The mid-1990s was a time of uncertainty for analysts of U.S. productivity growth. The rapid growth of information technology and what some called a "new economy" led to expectations of fundamental changes in business practices and strong productivity growth. However, the U.S. economy remained mired in an era of slow productivity growth that began in the early 1970s. This apparent contradiction became known as the "computer productivity paradox," famously summarized by Robert Solow (1987) as "you can see the computer age everywhere but in the productivity statistics."

Labor productivity (hereafter productivity) in the nonfarm business sector, defined as output per hour worked, was originally reported to grow at only 1.0 percent per year from 1991 to 1996 (Bureau of Labor Statistics, 1997). Official forecasts at that time for the medium term were equally pessimistic; both the Congressional Budget Office (1997) and the Council of Economic Advisors (1997) projected nonfarm business productivity growth of only 1.2 percent over the next seven to ten years. Paul Krugman (1993, p. 174) was even more gloomy, worrying "that productivity growth may actually decline."

In fact, productivity growth surged after 1995, averaging 2.8 percent from 1996 to 2000, and the pessimism of the "computer productivity paradox" gave way to near-universal belief in a "productivity resurgence" led by information technology in the late 1990s. Official estimates of potential growth were raised repeatedly. For

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example, the Congressional Budget Office (2001) raised its medium-term projections of labor productivity growth to 2.7 percent for the next decade. This point is worth emphasizing: in just four years, from 1997 to 2001, the Congressional Budget Office more than doubled its ten-year projection of nonfarm business productivity growth from 1.2 to 2.7 percent!

The dramatic improvement in productivity growth in the late 1990s did not escape the notice of monetary and fiscal policymakers. Rapid price declines in information technology assets, defined to include computers, software, and communications equipment, acted as a "positive supply shock"—the mirror image of the negative oil price shocks in 1970s—and improved the outlook for inflation. On the real side, the growth of information technology contributed to the stunning increase in estimates of potential growth for the U.S. economy. A combination of lower inflation and rapid economic growth allowed monetary policymakers to pursue a policy of "opportunistic disinflation" (for example, Aksoy, Orphanides, Small, Wieland, and Wilcox, 2006). Similarly, strong productivity growth contributed to the more optimistic outlook for the fiscal budget (Congressional Budget Office, 2001).

Is the resurgence in U.S. productivity growth sustainable? The rise in productivity growth lasted through the middle of 2004, but more recent data have been considerably weaker. The 1.3 percent annual productivity growth rate from the middle of 2004 through the middle of 2007, for example, falls short of even the dismal performance of the 1970s and 1980s. In this paper, we examine the evolution of the historical record and review contemporaneous interpretation and analysis, particularly the shift in the perceived importance of information technology.

We will argue that the sources of productivity growth have changed twice since 1995. The productivity growth from 1995 up to about the dot-com crash of 2000 was driven by productivity growth in the information-technology–producing sectors and the massive investment in the information-technology–using sectors. While the contributions of information technology to productivity growth remain large in relation to the relative importance of information technology production in the U.S. economy, information technology appears much less important after 2000, as both the contribution from the production and use of information technology have receded from the phenomenal rates observed in the late 1990s. Since 2000, the sources of productivity growth have shifted as total factor productivity growth outside of the production of information technology increased. In Jorgenson, Ho, Samuels, and Stiroh (2007), we and our coauthor show that much of this total factor productivity originated in the industries that are the most intensive users of information technology. The remainder likely reflects some combination of increased competitive pressures on firms, cyclical factors, and efficiency gains outside of the production of information technology, but some uncertainty about the underlying forces remains.

Our outlook for potential productivity growth remains optimistic with a base-case trend estimate for the next decade of 2.4 percent per year. This rate of productivity growth would be relatively rapid for the U.S. economy from a historical perspective, although below the average for the decade after 1995. Somewhat slower productivity growth reflects a natural evolution of the U.S. economy toward a more sustainable growth path as widely anticipated demographic trends unfold. We believe, however, that there is little likelihood that the U.S. economy will revert to the low rates of productivity growth of the 1970s and 1980s.

The Evolving Productivity Picture

We begin with a retrospective look at U.S. productivity growth during the last decade. What did economists and policy makers know, or think they knew, about productivity trends at different points of time? The post-1995 productivity surge clearly took virtually all observers by surprise, as economic growth greatly surpassed their expectations.

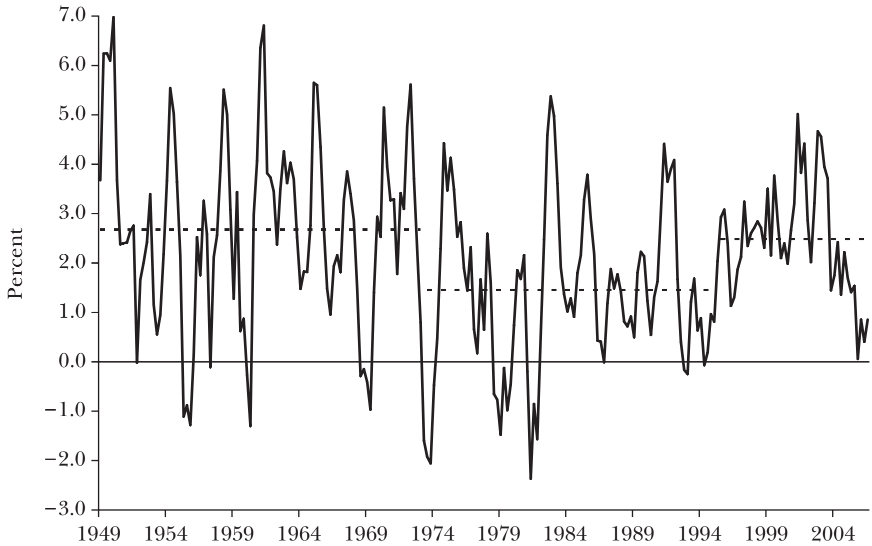
Official Productivity Data

We first report the productivity data for the nonfarm business sector ending in 2007:Q2 as estimated with hindsight in Bureau of Labor Statistics (2007c). Figure 1 plots both four-quarter moving averages (solid line) and mean annual growth rates (dotted lines) for three eras: 1948:Q4–1973:Q4, 1973:Q4–1995:Q4, and 1995:Q4–2007:Q2. Clearly, productivity growth slowed during the 1970s, 1980s, and early 1990s, and then increased substantially in the mid 1990s. More recently, since 2004:Q2, productivity growth has slowed with average growth below the rates seen in the 1970s and 1980s.

We also examine different vintages of historical data and trend projections. The solid line in Figure 2 plots estimates of nonfarm business productivity growth for a trailing 10-year period, based on Bureau of Labor Statistics data from February of each year. To be clear, this is not a rolling 10-year window from a single dataset, but rather the 10-year trailing average from data available at each point in time; the 1996 figure, for example, is the average of the growth rates from 1986 to 1995. These estimates evolve for two reasons: First, the sample period changes as the 10-year window moves through time with the earliest year dropped and a later year added. Second, data and methods are revised, which can lead to quite substantial changes. The initial estimate of nonfarm business productivity growth for 1996, released in Bureau of Labor Statistics (1997), was only 0.8 percent. Over the subsequent years, however, incorporation of new data and methodology changes led to substantial upward revisions. The Bureau of Labor Statistics (2006a) data indicate that productivity growth for 1996 was actually 2.7 percent!

We also compare in Figure 2 the actual productivity data with projections from the Congressional Budget Office, which estimates potential growth of productivity,

Figure 1
U.S. Productivity Growth, 1948:Q4–2007:Q2
(in the U.S. nonfarm business sector)



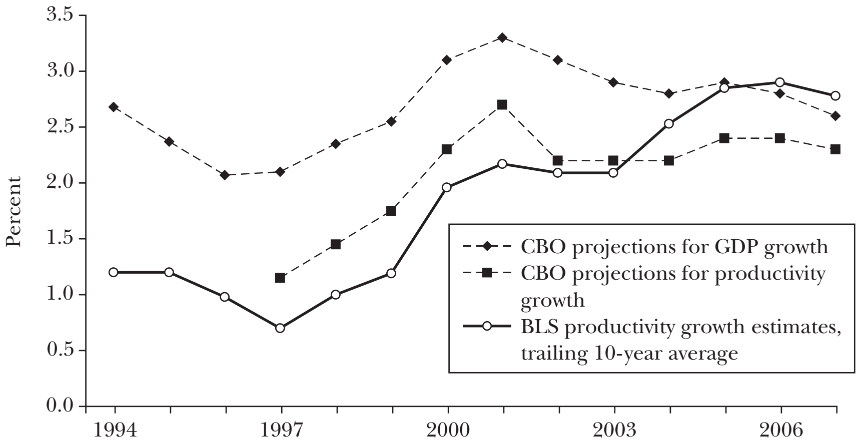
Source: Data are from Bureau of Labor Statistics (2007c).
Note: Figure 1 plots both four-quarter moving averages (solid line) and mean annual growth rates (dotted lines) of U.S. productivity growth for three eras: 1948:Q4–1973:Q4, 1973:Q4–1995:Q4, and 1995:Q4–2007:Q2. The average annual growth rates for the three eras are 2.7, 1.5, and 2.5 percent, respectively.

abstracting from cyclical fluctuations. The two dotted lines in Figure 2 show projections of potential output growth and nonfarm business productivity growth from the Congressional Budget Office's *Budget and Economic Outlook*, typically released in January of each year. The projections are for 10 years into the future, the "budget window" used in analyzing the fiscal outlook.

Figure 2 shows that the steady improvement in U.S. productivity growth was matched by increased optimism in the productivity outlook. In January 1997, for example, the Congressional Budget Office (1997) 10-year projection of nonfarm business productivity growth was only 1.15 percent. By January 2001, just four years later, this projection had more than doubled to 2.7 percent in Congressional Budget Office (2001). This change reflects the increase in the real-time estimates of the trailing ten-year period from 0.7 percent to 2.2 percent and a considerably greater rise in the trailing five-year period.

More recently, the Congressional Budget Office (2005, 2006a, 2006b, 2007b, 2007c) ten-year projections for annual productivity have moderated, remaining at 2.4 percent from January 2005 to August 2006 and falling to 2.3 percent in 2007. The CBO (2005, 2007a) has interpreted the strong productivity growth observed from 2001 to about 2004 as a one-time phenomenon that raised the level, but not

Figure 2
The Evolving Productivity Data and Outlook
(growth rates in percent)



Note: "CBO projections for GDP growth" and "CBO projections for productivity growth" are the ten-year-ahead projections from the January report of the Congressional Budget Office's *Budget and Economic Outlook* for each year for growth in GDP and in nonfarm business labor productivity, respectively. Bureau of Labor Statistics data are the average growth rates of nonfarm business productivity for the trailing ten years as reported in February of each year.

the long-run growth rate of productivity. For the next decade, the Congressional Budget Office is projecting that productivity growth will remain somewhat below the average level of productivity from 1995 to 2006. However, these most recent projections from the Congressional Budget Office do not include the July 2007 revision to the U.S. National Income and Product Accounts (NIPA), which lowered GDP growth somewhat below the average rate of productivity growth from 2004 to 2006.

Interpretation

We now turn to the interpretation of the evolving productivity data by examining the sources of productivity growth with specific attention on the role of information technology. We focus on aggregate growth accounting studies of the United States.[1] Some recent studies that offer a useful starting point in this literature are Gordon (2006), Jorgenson, Ho, and Stiroh (2006), and Oliner, Sichel, and Stiroh (2007).

Under the assumptions of constant returns to scale and competitive markets,

[1] We do not systematically review the large literature on the link between information technology and productivity growth in other economies, summarized, for example, by van Ark and Inklaar (2005), or the microeconomic literature reviewed by Brynjolfsson and Hitt (2000, 2003).

labor productivity growth reflects the contributions of three factors: capital deepening, labor quality growth, and growth in total factor productivity. Capital deepening is defined as the increase in capital services per hour worked and captures the fact that workers become more productive if they have more and better capital with which to work. Labor quality is defined as labor input per hour worked and reflects changes in the composition of the workforce.

Total factor productivity growth must be distinguished from growth in labor productivity. Labor productivity is defined as output per hour. In contrast, total factor productivity is defined as output per unit of both capital and labor inputs and primarily reflects innovations in both products and processes. Economic growth can take place without innovation—or total factor productivity growth—by replicating products and processes through investment in existing technologies and the hiring of more workers.

We have augmented the standard framework for growth accounting in two ways to capture the role of information technology. First, economy-wide growth in total factor productivity can be allocated between gains in the information-technology–producing industries—computers, telecommunications equipment, and software—and gains in the rest of the economy. This decomposition isolates innovation in the production of information technology equipment and software, such as the ability to produce faster and more powerful computers at lower prices.[2] Second, capital deepening can be decomposed into more intensive use of information technology capital and the capital deepening through investment in other types of capital (Jorgenson, Ho, and Stiroh, 2002, 2005).

The Bureau of Labor Statistics has produced estimates of total factor productivity growth for the U.S. economy since 1983.[3] This effort reflected the realization that it is useful to distinguish among the many factors that determine labor productivity growth. The early studies at the Bureau of Labor Statistics did not distinguish whether capital deepening was rooted in information technology or in other types of capital goods, nor did they quantify the effect of growth in the quality of labor. However, these calculations did employ capital services rather than capital stock as a measure of capital input, which represented a significant step forward for productivity analysis.

Oliner and Sichel (1994) and Jorgenson and Stiroh (1995) were the first to

[2] Analysts have often employed the price dual of productivity to generate estimates of total factor productivity growth in the production of information technology assets. The intuition is that declines in relative prices for information technology goods reflect total factor productivity growth in the information-technology–producing industries. These relative price declines are weighted by the shares in output of each of the information technology investment goods in order to estimate the contribution of information technology production to economy-wide total factor productivity growth. The contribution of the non–information-technology sectors is the residual after removing the information technology contribution.

[3] The Total Factor Productivity program at the Bureau of Labor Statistics was a response to the Panel to Review Productivity Statistics (1979), organized by the National Research Council and chaired by Albert Rees. See Jorgenson, Ho, and Stiroh (2005, chap. 2) for further details on the history of the official estimates.

quantify the impact of information technology capital within a growth accounting framework. The common conclusion was that information technology had made a relatively small contribution to output growth up to the mid 1990s. The modest contribution of information technology investment, however, was not surprising given the relative size of investments in information technology equipment and software at the time. Also, these studies looked at how investment in information technology contributed to productivity growth, but did not look at how improved productivity in the production of information technology might contribute to aggregate productivity growth.

After productivity growth improved dramatically in the last half of the 1990s, the Bureau of Labor Statistics (2000), Jorgenson and Stiroh (2000), and Oliner and Sichel (2000) all reported substantial contributions from information technology capital to economic growth. This pattern reflected rapidly accelerating investment in these information technology assets during the late 1990s, their growing relative importance, and the broadening of the information technology concept in 1999 to include software and telecommunications equipment.[4] According to recent national income and product accounts data, for example, the growth rate of annual investment in computers, software, and telecommunications equipment increased from 13.5 percent for 1987–1995 to 22.2 percent for 1995–2000, while the decline of information technology prices accelerated from –3.3 to –7.3 percent per year.

The standard interpretation of the role of information technology in the U.S. growth resurgence begins with rapid technological progress in the information-technology–producing industries, epitomized by "Moore's Law," the doubling of computer chip density every 18–24 months, which has allowed each generation of new computer equipment to outperform prior generations so substantially.[5] In these studies, Moore's Law is captured in the high rates of total factor productivity growth in the production of information technology—that is, more output of computers, software, and telecommunications equipment can be produced from a given input of capital and labor services, which results in spectacular declines in information technology prices. In response, firms rapidly substituted information technology assets for other productive inputs and this massive investment, about one-third of nonresidential fixed investment by 2000, led to a huge increase in the contribution of information-technology capital deepening to labor productivity growth. These two factors in combination—improved total factor productivity in the production of information technology, and capital deepening from the use of

[4] The 1999 benchmark revision to the national income and product accounts reclassified software from being an intermediate good to an investment good that is part of GDP. See Moulton, Parket, and Seskin (1999) for details.

[5] A more detailed discussion of Moore's Law is presented by Jorgenson, Ho, and Stiroh (2005, chap. 1). Aizcorbe, Oliner, and Sichel (2006) quantify the role of other factors, most importantly the variation in mark-ups, in inferring the pace of underlying technical progress from declines in quality-adjusted price indices.

information technology—constitute the direct contribution from information technology to productivity growth.

We emphasize that there is nothing special about information technology in this explanation. In particular, the neoclassical framework of constant returns to scale and competitive markets remains in place and there is no need to search for "nonpecuniary externalities," where the actions of either producers or users of information technology spill over to other market participants. Rather, it is a strictly neoclassical world of rapid (exogenous) technological progress in information-technology–producing industries where the benefits get passed on to users as a "pecuniary externality" in the form of lower prices. Jorgenson and Stiroh (1999) discuss this distinction further.

As labor productivity growth remained strong into the early 2000s and data revisions made productivity growth in the second half of the 1990s look even better than had been previously believed, studies found an even more striking contribution of information technology to growth in total factor productivity. In Jorgenson, Ho, and Stiroh (2002), we concluded that information technology capital and information-technology–related total factor productivity explained more than three-quarters of the post-1995 increase in productivity growth, while Oliner and Sichel (2002) estimated that it explained essentially all of it. Information technology had clearly moved to the center stage in understanding the U.S. productivity resurgence. This period also marked the high-water mark for productivity projections, as the Congressional Budget Office (2001) projected that nonfarm business productivity growth would be 2.7 percent per year for the next decade, its highest estimate on record.

While information-technology capital deepening and total factor productivity growth in information-technology–producing sectors measure the direct contribution to growth from the use and production of information technology, a wealth of microeconomic evidence emphasizes the complexity of the link from technology to productivity. To leverage information technology investments successfully, firms must typically make large complementary investments and innovations in areas such as business organization, workplace practices, human capital, and intangible capital (for example, Black and Lynch, 2004; Brynjolfsson and Hitt, 2003; Bresnahan, Brynjolfsson, and Hitt, 2002). Important progress has been made in incorporating these variables into a growth accounting framework, and it may soon be possible to isolate the productive impact of the deployment of information technology from these complementary factors (Corrado, Hulten, and Sichel, 2006; Oliner, Sichel, and Stiroh, 2007).

As a final question, one may ask why the productivity gains only emerged in the mid 1990s, though the first commercial computer (the UNIVAC designed for large-scale data processing applications) was introduced by Remington Rand in the 1950s. Jorgenson (2001) pointed to a fundamental shift in the production cycle of semiconductors involving the more rapid introduction of faster, better chips, which spurred massive investment. As a result, both the total factor productivity and capital deepening contributions related to information technology increased. More generally, firms had by then made significant investment in the complementary capital that is necessary for the successful implementation of new technologies and also learned how to implement information technology more efficiently.

Empirical Estimates

We next present our estimates of the sources of U.S. economic growth. We begin with a short description of the data and then give the empirical results.

Data

Our output data are based on the U.S. National Income and Product Accounts, published by the Bureau of Economic Analysis. The productivity estimates from the Bureau of Labor Statistics are focused on the private nonfarm business sector. We cover the entire private sector, incorporating the imputed capital services provided by residential housing and consumer durables, which has typically grown faster than the nonfarm sector. In Jorgenson (2001) and Jorgenson, Ho, and Stiroh (2005, 2006), we provide estimates for the full economy, including the government sector. Thus, our estimates differ from those of the Bureau of Labor Statistics for several reasons: we use annual data, a broader sector of the economy, somewhat different methodologies, and different time periods.

Our capital input data begin with the fixed-asset accounts published by the Bureau of Economic Analysis. These accounts present business and government investments and consumer durable purchases by detailed asset classes, such as computers, office buildings, and one-to-four-family homes. We employ a broad measure of capital services that includes assets owned by businesses and households, as well as land and inventories. Our prices for capital services use asset-specific asset prices, service lives, and depreciation rates.

Our labor input data incorporate the decennial Censuses of Population for 1960–2000, the annual Current Population Surveys (CPS), beginning in 1964, as well as labor statistics compiled by the Bureau of Labor Statistics and presented in the national income and product accounts. We take total hours worked for domestic employees directly from the national income and product accounts, self-employed hours worked for the nonfarm business sector from the Bureau of Labor Statistics, and self-employed hours worked in the farm sector from the Department of Agriculture. We classify workers by sex, employment class, age, and education levels and weight the hours worked for each type of worker by labor compensation. Labor quality growth reflects the difference between the growth rates of the compensation-weighted index of labor input and hours worked.

Empirical Results

Table 1 presents the growth of output in the top row. In the next two rows, it allocates this growth between hours worked and labor productivity for the private sector. We consider the period 1959–2006 and four subperiods: 1959–1973, 1973–1995, 1995–2000, and 2000–2006. Computer and software investment data begin in 1959 and at the time of this analysis, 2006 is the last year for which complete data on output and inputs are available.[6]

Private output grew 3.58 percent per year for 1959–2006 with considerable variation across periods, from 3.01 percent for 2000–2006 to 4.77 percent for 1995–2000. Perhaps most striking is the sharp slowdown after 2000 in growth of hours worked, which fell from a growth rate of 2.07 percent per year for 1995–2000 to 0.51 percent per year for 2000–2006. The decline in hours worked has been widely discussed and has led to considerable debate about the "jobless recovery" and the dating of the 2001 business cycle. Labor productivity growth rose from 1.49 percent per year for 1973–1995 to 2.70 percent for 1995–2000 and remained strong at 2.50 percent for 2000–2006.

The remainder of Table 1 reports the decomposition of average labor productivity growth into several parts: capital deepening, divided into both information-technology and non–information-technology investments; growth in labor quality; and total factor productivity growth in both information-technology–producing and non–information-technology sectors. For the entire period 1959–2006, average labor productivity grew at 2.14 percent per year. Capital deepening made the largest contribution of 1.14 percent, followed by total factor productivity growth of 0.75 percent and labor quality growth of 0.26 percent. This ranking also holds for each subperiod and highlights the leading role of investment, as the composition of capital has steadily shifted toward a greater role for information technology. Labor quality rose relatively quickly prior to 1973 with the more rapid improvement in education, but these improvements in aggregate labor quality slowed with education gains tapering off and the rapid entry of young workers during the post-1995 boom. After 2000, this temporary surge of less-educated workers ceased and the contribution of labor quality increased due to a resumed rise in educational attainment and aging of the workforce.

Our estimates confirm earlier results by showing that information technology played a critical role in the post-1995 productivity resurgence. Growth of total factor productivity in the production of information technology and in capital deepening related to information technology contributed 0.33 and 0.61 percentage points, respectively, to the change in labor productivity growth from 1973–1995 to

[6] Gordon (2006), using an unpublished update of Oliner and Sichel (2002), reports similar data through 2005, while Oliner, Sichel, and Stiroh (2007) extend their data to 2006 and include adjustments for variable utilization, adjustment costs, and intangible assets.

Table 1
Sources of U.S. Output and Productivity Growth 1959–2006
(average annual growth rates)

	1959–2006	*1959–1973*	*1973–1995*	*1995–2000*	*2000–2006*
Private output	**3.58**	**4.18**	**3.08**	**4.77**	**3.01**
Hours worked	1.44	1.36	1.59	2.07	0.51
Average labor productivity	2.14	2.82	1.49	2.70	2.50
Contribution of capital deepening	**1.14**	**1.40**	**0.85**	**1.51**	**1.26**
Information technology	0.43	0.21	0.40	1.01	0.58
Non–information technology	0.70	1.19	0.45	0.49	0.69
Contribution of labor quality	**0.26**	**0.28**	**0.25**	**0.19**	**0.31**
Total factor productivity	**0.75**	**1.14**	**0.39**	**1.00**	**0.92**
Information technology	0.25	0.09	0.25	0.58	0.38
Non–information technology	0.49	1.05	0.14	0.42	0.54
Share attributed to information technology	**0.32**	**0.11**	**0.43**	**0.59**	**0.38**

Notes: Data are for the U.S. private economy. All figures are average annual growth rates. A contribution of an input reflects the share-weighted growth rate. Capital is broadly defined to include business capital and consumer durables. Information technology includes computer hardware, software, and communications equipment. "Share attributed to information technology" is the average contribution of information-technology capital deepening plus the average contribution of information-technology total factor productivity divided by average labor productivity for each period.

1995–2000 (calculated by the difference in these numbers across the columns)[7]—thus accounting for almost 80 percent of the increase in productivity growth.[8] Other forms of capital deepening and labor-quality growth made insignificant contributions to the acceleration after 1995, while growth in total factor productivity not related to information technology contributed 0.28 percentage points. This last factor does reflect an increase from the 1970s and 1980s when growth in total factor productivity not related to information technology was essentially flat.

After 2000, however, the sources of U.S. productivity changed and the contribution of information technology to productivity growth fell significantly. Although labor productivity growth was almost as rapid, the post-2000 gains mainly reflect capital deepening and total factor productivity growth that occurred outside information technology. A closer look at the components reveals that the increase in capital deepening reflects a decline in hours worked rather than more rapid capital accumulation. Nonresidential investment increased by only 1 percent per year

[7] Numbers may not sum precisely due to rounding.

[8] The rapid increase in the contribution of total factor productivity in the production of information technology reflects both more rapid total factor productivity growth and a growing share of the information-technology–producing industries. The rate of total factor productivity growth in the sector increased from 8.4 percent for 1973–1995 to 12.7 percent for 1995–2000, while the share of the sector increased from 3.0 percent to 4.7 percent for the same periods.

2000–2006, considerably below the long-run growth rate of 5.4 percent for 1959–2000, but the slowdown in hours growth generated more capital per hour worked. This larger capital deepening contribution is likely to be temporary and will end even with a recovery of investment when employment growth reverts to trend.

The growth in total factor productivity not related to information technology is measured as the difference between aggregate total factor productivity growth and the information technology component, so the calculation does not reveal why this category jumped after 2000. One plausible explanation is that the most recent gains reflect the cyclical recovery after the recession of 2001, which in turn would imply that these gains are unlikely to be sustained, as suggested by Gordon (2003) and Sichel (2003). Oliner, Sichel, and Stiroh (2007) provide evidence for the role of increased competitive pressures by showing that industries where profits fell the most through the 2001 recession also experienced the strongest productivity growth, but the weakest hours growth.

Additional possible explanations include 1) information technology as a general purpose technology that facilitates subsequent innovation, and 2) investment in unmeasured capital inputs such as research and development, organizational change, and other business processes. Moreover, if it takes some time for firms to make these complementary investments and learn how to utilize their information technology investments most efficiently, then the gains may occur only with some lag. Basu, Fernald, Oulton, and Srinivasan (2004) and Basu and Fernald (2007) provide evidence for this general purpose role of information technology by examining the link between total factor productivity growth and earlier growth in information technology capital. Bosworth and Triplett (2007), however, report that such linkages are fragile. Corrado, Hulten, and Sichel (2006) document the importance of investments in intangible capital and conclude that this does not explain the increase in productivity growth rates after 1995.

While the impact of information technology declined in both a relative and an absolute sense in the first half of the 2000s, we conclude this section by emphasizing that information technology remains a substantial source of growth, even in the post-2000 period. Information technology investment is less than 5 percent of aggregate output, but Table 1 shows that information technology has accounted for one-third of the labor productivity growth since 2000. The declining contribution of information technology reflects a return to more sustainable growth rates after the information technology investment boom of the late 1990s. Although information technology has remained an important source of productivity growth, other factors drove the productivity gains from 2000 to 2006.

Projecting Productivity Growth

Forecasts of future productivity growth are inherently difficult; for example, they require estimating future rates of technical progress and rates of substitution among different types of investment and categories of workers. Some obvious questions arise: How relevant is the rapid pace of information technology quality change and price declines in the late 1990s for the next decade? Will firms continue to invest in information technology as rapidly as they have in the past, or have diminishing returns set in? Which recent changes represent transitory shocks and which represent changes in the underlying trend?

In previous work, we developed a framework for projecting productivity growth that combines historical data, demographic projections, and assumptions about the future pace of technological change (Jorgenson, Ho, and Stiroh, 2002, 2004). This framework is based on the steady state of a neoclassical growth model. This section provides a heuristic description of our approach and discusses alternative scenarios with a range of possible productivity outcomes.

Projecting Productivity Growth

We calibrate the steady state of a growth model by making two key assumptions. First, we begin by assuming that output and the reproducible capital stock will grow together at the same rate. This assumption smoothes out fluctuations like the investment boom of the late 1990s and the investment bust after the 2001 recession. Second, hours worked are projected to grow at the same rate as the labor force. These assumptions are plausible for projections of the potential growth of output, but would obviously be unsuitable for short-run forecasts of output and productivity growth.

Some of the variables required to implement our approach can be projected with a relatively high degree of confidence, while others involve considerable uncertainty. For variables that we consider relatively easy to project—labor quality growth, growth in hours, and the shares of capital, reproducible-capital stock, and information technology output—we make a single set of projections. For the variables we consider more difficult to project—growth in total factor productivity in information technology production, growth in total factor productivity not in information technology, and growth in the quality of capital—we consider a range of plausible alternatives that generate three scenarios.

Potential Scenarios

Our productivity projections depend critically on the outlook for continued technological advance in information technology. As shown earlier, information technology played a dominant role in the productivity surge after 1995, but a smaller role during 2000–2006. Is the role of information technology in the future more likely to mirror the late 1990s or the early 2000s? We cannot provide a definitive answer to this question, but find it useful to raise some of the issues and consider their implications for future productivity growth.

A driving force behind the investment-technology–led boom of the late 1990s was a marked acceleration in the pace of technical progress—reflected in the increased rate of information technology price declines and measured as faster total factor productivity growth in the industries producing information technology—and massive investment in information technology equipment and software. Jorgenson (2001) argues that this shift was triggered by a much sharper acceleration in the decline of semiconductor prices. In turn, this more rapid decline in semiconductor prices can be traced to a shift in the product cycle (the time between new model introductions) for semiconductors from three years to two years around 1995 as competition intensified.

As information-technology–related price declines have slowed since 2000, a critical question is whether this reflects a permanent or transitory shift in the rate of technological advance. The 2005 edition of *The International Technology Roadmap for Semiconductors*, a detailed evaluation of semiconductor technology performed annually by a consortium of industry experts available at ⟨http://public.itrs.net⟩, projects a return to three-year product cycles. Aizcorbe, Oliner, and Sichel (2006) provide additional evidence for a technological break in the mid 1990s, but argue that the slower price declines since 2001 do not reflect a deceleration of technological advance, but rather a combination of changes in economies of scale and a shift in product mix toward more costly computer chips. Our alternative productivity scenarios vary based on our assumptions of future rates of total factor productivity growth in the production of information technology.

Rapid total factor productivity growth in the production of information technology is only part of the story of the productivity resurgence after 1995, however. Massive investments in information technology equipment and software were even more important, but after the boom of the late 1990s, the investments of U.S. firms in information technology slowed. During 2000–2006, for example, real investment in information technology grew only 3.9 percent year per year, compared to 22.2 percent annually during the period 1995–2000.

An optimistic interpretation of the recent slowdown in information technology investment emphasizes temporary factors, such as the overhang of investment from the 1990s boom and increased uncertainty for businesses during the 2001 recession. After all, firms will continue to invest and substitute toward the latest information technology gear so long as relative prices decline and new applications emerge. Hubbard (2003) and Athey and Stern (2002), for example, provide compelling examples of how information technology equipment has been implemented in novel ways to boost performance and productivity in the trucking and health care industries. Pessimists such as Gordon (2006) counter that diminishing returns must eventually set in and that falling prices for information technology must necessarily imply lower marginal value applications. This view suggests that the capital deepening contribution of information technology will decline. The second variable that determines the range of our productivity projections, therefore, is the growth of capital quality, which measures the substitution toward investment goods with relatively high marginal products such as information technology.

A final critical question is what explains the strong performance of total factor productivity growth outside of information technology production during the early 2000s. In Jorgenson, Ho, Samuels, and Stiroh (2007), we and our coauthor show that much of the post-2000 gains reflect faster total factor productivity growth in industries that were the most intensive users of information technology, and Basu and Fernald (2007) argue that these gains reflect earlier investments in information technology through the general purpose technology nature of these goods. Oliner, Sichel, and Stiroh (2007) argue that much of the rapid productivity growth from 2002 to 2004 reflects a set of transitory forces related to the recovery from the 2001 recession. These forces include increased competitive pressure and the savage corporate cost-cutting emphasized by Gordon (2003). Finally, Bosworth and Triplett (2007) and Oliner, Sichel, and Stiroh (2007) report that reallocation effects among industries contributed to the aggregate productivity gains, which are also unlikely to persist.

More broadly, some of the productivity success in the last decade likely reflects the overall competitive and flexible nature of the U.S. business environment. Much has been written about why productivity growth in Europe has decelerated since 1995 while accelerating in the United States (for examples, see van Ark, O'Mahony, and Timmer in this issue, as well as Baily, 2002; OECD, 2006; Gomez-Salvador, Musso, Stocker, and Turunen, 2006). More flexible labor markets, more competitive and open product markets, and more innovative management in the United States have all played a role. Inklaar, Timmer, and van Ark (2007) conclude that limited regulation matters for market services, where productivity growth has been particularly slow in Europe. To the extent that the United States maintains these advantages, it bodes well for the future productivity outlook. Our assumptions about the future pace of total factor productivity growth outside of the production of information technology is the third key variable for our productivity projections.

We incorporate these alternative views into three scenarios for the productivity outlook. The optimistic scenario assumes that technological progress and substitution toward information technology capital continue at the average pace seen since 1995. The pessimistic scenario assumes that the overall pace of technological progress reverts to the much slower pace seen during the period 1973 to 1995. Finally, our base case puts relatively less weight on the strong productivity growth since 1995 and incorporates data from the early 1990s to calibrate the key technology parameters.[9]

[9] As a practical matter, we calibrate the three key technology parameters—total factor productivity growth in information technology production, total factor productivity growth outside of information technology production, and the growth rate of capital quality—using data for 1995–2006, 1990–2006, and 1973–1995 for the optimistic, base-case, and pessimistic scenarios, respectively. It is important to emphasize that these variables are not independent: for example, capital quality growth reflects the growth in total factor productivity in different sectors. We do not model this interaction explicitly, which would require a model with differences in growth rates of total factor productivity in the production of these assets. Rather, we turn to the historical record and calibrate these variables from similar time periods to summarize this interdependence in a reduced form sense. Finally, projections of labor-quality

Table 2
Output and Labor Productivity Projections for the Next Decade

	1995–2006	Range of Projections: Pessimistic case	Base case	Optimistic case
		Projections		
Private Output	**3.8**	**2.1**	**3.1**	**3.5**
Hours worked	1.2	0.7	0.7	0.7
Average labor productivity	2.6	1.4	2.4	2.8
		Key Assumptions		
Total factor productivity contribution	**0.96**	**0.50**	**0.81**	**0.95**
Information technology	0.47	0.36	0.42	0.47
Non–information technology	0.49	0.14	0.39	0.49
Capital quality growth	**1.97**	**0.86**	**1.69**	**1.97**

Notes: In all projections, hours growth and labor quality growth are from our internal projections for 2006–2016. The pessimistic projection uses 1973–1995 average growth of information-technology–related total factor productivity growth, non–information-technology total factor productivity contribution, and capital quality growth. The base case uses 1990–2006 averages, and the optimistic case uses 1995–2006 averages. All variables are average annual growth rates, except the total factor productivity contributions which are share-weighted growth rates.

Our range of productivity projections and the critical assumptions are presented in Table 2, alongside historical data for 1995–2006. Our base-case scenario puts private labor productivity growth at 2.4 percent per year and private output growth at 3.1 percent per year for the next decade. Projected productivity growth is below the 1995–2006 experience due to a decline in non–information-technology growth in total factor productivity and capital deepening. Output growth faces the additional drag of slower growth in hours. These projections reflect the slowdown in the rate of technical progress in semiconductors as the semiconductor industry returns to a three-year product cycle, but the slower growth is partly offset by a larger share of information technology in output.

Our optimistic scenario puts private labor productivity growth at 2.8 percent per year and private output growth at 3.5 percent per year, due to the assumption of continued rapid technical progress. In particular, the two-year product cycle in semiconductors is assumed to persist, which drives rapid total factor productivity growth in the production of information technology equipment and software, as well as continued substitution toward information technology assets and rapid growth in capital quality. In addition, in this scenario total factor productivity

growth, growth in hours, and the shares of capital, reproducible-capital stock, and information technology output are held constant across all scenarios.

outside information technology continues the more rapid growth it has experienced since 1995. Overall productivity growth is more rapid than during 1995–2006.

The pessimistic projection of 1.4 percent annual growth in labor productivity assumes that trends revert to the sluggish pace of 1973–1995 and that the three-year product cycle for semiconductors begins immediately. The substantial share of information technology implies that labor productivity growth will fall only slightly below the rates of the 1970s and 1980s, even with a projected slowdown in labor quality growth and other variables.

We note that our range of productivity projections is not symmetric around the base case as there is a much larger downside risk. This primarily reflects our modeling assumption as the base case and optimistic scenarios are calibrated using data that overlap for a considerable period, while the pessimistic case is based on data from the slowdown era. It is important to note, however, that while these projections represent a range of plausible scenarios, we do not attach specific probabilities to them or assume that the upside and downside risks are balanced.

Alternative Projections

The future trend of economic growth is obviously critical for a wide range of public- and private-sector policy issues and considerable effort has been expended on projections. Within the federal government, medium-run projections of potential output are presented on a regular basis by the Congressional Budget Office, the Council of Economic Advisors in the *Economic Report of the President*, and in the annual report of the Board of Trustees of the Social Security Administration. Given the uncertainties we have emphasized, it is not surprising that there is considerable divergence among these projections and that the estimates are frequently, and often substantially, revised.

We compare our estimates with several recent projections by government agencies, academic economists, and private forecasters. Table 3 summarizes the productivity, hours, and output projections from a variety of sources. The top panel reports estimates for the private economy, typically the nonfarm business sector, while the bottom panel reports estimates for the full economy. While not all analysts report all estimates, the time periods are not all the same, and the data vintages differ, these comparisons provide a useful perspective on the range of plausible forecasts.

The projections of potential nonfarm productivity growth average around 2.3 percent for the next decade. This rate is somewhat below the 2.5 percent growth observed since 1995. When combined with projected growth of hours worked of 0.8 percent, the consensus estimate for nonfarm output growth is about 3.2 percent. An important caveat when reviewing these forecasts is that they represent different vintages of data; of these estimates only Kahn and Rich (2007), Goldman Sachs (2007), and this paper incorporate the most recent annual revision to the national income and product accounts from July 2007, which reduces recent

Table 3
Alternative Growth Projections

	Date	Horizon	Productivity +	Hours =	Output
Nonfarm business					
JPMorgan (2006)	Sep ’06	4-year	2.0		
Gordon (2006)	Sep ’06	25-year	2.1		
Kahn and Rich (2007)	Sep ’07	5-year	2.1		
Survey of Professional Forecasters (2007)	Feb ’07	10-year	2.2		
Oliner, Sichel, and Stiroh (2007)	Mar ’07	trend	2.3		
Congressional Budget Office (2007)	Aug ’07	10-year	2.3	0.8	3.0
Jorgenson, Ho, Stiroh (this paper)	Sep ’07	10-year	2.4	0.7	3.1
Goldman Sachs (2007)	Jul ’07	trend	2.5		
Council of Economic Advisors (2007)	Feb ’07	6-year	2.6	0.8	3.4
GDP					
Aaronson et al. (2006)	Sep ’06	10-year		0.4	
JPMorgan (2006)	Sep ’06	4-year	1.7	0.8	2.5
Gordon (2006)	Oct ’06	25-year	1.8	0.7	2.5
Social Security Administration (2007)	Mar ’07	10-year	1.8	0.7	2.5
Congressional Budget Office (2007)	Aug ’07	10-year	1.9	0.7	2.7
Survey of Professional Forecasters (2007)	Feb ’07	10-year			3.0
Council of Economic Advisors (2007)	Feb ’07	6-year			3.0

Notes: All estimates are average annual growth rates. Sums may not add due to rounding. Jorgenson, Ho, Stiroh estimates are for business sector including consumer durables. The Social Security Administration (2007) estimate is imputed hours growth. Survey of Professional Forecasters (2007) is the median estimate.

productivity growth. There is also variation in output estimates for the full economy, ranging from 2.5 percent by Gordon (2006) for the next 25 years to 3.0 percent for the next three years from the Council of Economic Advisers (2007) and the median estimate from the Survey of Professional Forecasters (2007).

Slower growth of hours worked would result in lower growth of output. Aaronson, Fallick, Figura, Pingle, and Wascher (2006) use a model of labor force participation rates and hours to project a continuation of the recent decline in participation rates. They project growth of hours worked of only 0.4 percent per year for the next decade. This estimate is considerably below the 0.7 percent projections by the Social Security Administration (2007) and Congressional Budget Office (2007b), as well as our own estimate of 0.7 percent, which fixes participation rates for each demographic group.

Conclusions

Understanding productivity growth in real time poses difficult challenges, due to large and frequent data revisions and unanticipated shocks that have different effects on trend and cyclical components. This paper documents how perceptions of U.S. productivity growth and its sources have evolved since the 1990s, as the economy fluctuated and the historical record was revised. Information technology emerged as the driving force behind the acceleration of labor productivity growth that began in the mid-1990s, while capital deepening and total factor productivity growth outside of information technology increased in relative importance after 2000.

Understanding the sources of the productivity gains through 2004 and the more recent slowdown is clearly of paramount importance to policymakers. Given the uncertainties involved, many productivity observers have remained cautious. For example, the Congressional Budget Office maintained its 10-year projection of non-farm business productivity at 2.4 percent from January 2005 to August 2006, despite the strong productivity growth in 2002, 2003, and 2004, but near the end of 2006 lowered its projections slightly to 2.3 percent as observed rates of productivity slowed. More recently, in his Semiannual Monetary Policy Report to the Congress, Federal Reserve Chairman Ben Bernanke (2007) observed that "the cooling of productivity in recent quarters is likely the result of cyclical or other temporary factors, but the underlying pace of productivity gains may also have changed somewhat."

The relative stability in the productivity outlooks implies that a substantial portion of the very strong productivity gains from 2002 to 2004 can be attributed to transitory factors and that the more recent slowdown may be similarly transitory. As a result, there is widespread if cautious optimism that a substantial portion of the U.S. productivity resurgence for the entire post-1995 period will persist. Information technology will continue to have a positive impact on the U.S. economy. Given flexible labor markets, competitive product markets with relatively low barriers to entry, and the deep, sophisticated, capital markets that characterize the U.S. economy, the country should be well-position to continue to innovate and benefit as improved technologies emerge.[10] As a consequence, there is little reason to expect that the U.S. economy will revert all the way back to the slower pace of productivity growth of the 1970s and 1980s.

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[10] Aghion and Howitt (2006) discuss linkages among innovation, institutions, and regulation.

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