Preliminary – Comments Welcome

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

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Abstract

It is now widely recognized that information technology (IT) was critical to the dramatic acceleration of U.S. labor productivity growth in the mid-1990s. This paper traces the evolution of productivity estimates to document how and when this perception emerged. Early studies concluded that IT was relatively unimportant. It was only after the massive IT investment boom of the late 1990s that this investment and underlying productivity increases in the IT-producing sectors were identified as important sources of growth. Although IT has diminished in significance since the dot-com crash of 2000, we project that private sector productivity growth will average around 2.5 percent per year for the next decade, only moderately below the average of the post-1995 period.

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I. Introduction

The mid-1990s were a time of confusion for analysts of U.S. productivity growth. The emergence of information technology (IT) offered the promise of fundamentally changing business practices and raising productivity growth. *Business Week* (1997) touted a "new economy" and proclaimed that IT was a "transcendent technology" that affected virtually everything. Kevin Kelly (1998) claimed IT would spawn a "tectonic upheaval" where vast networks would drive business in an ever more global, intangible, and inter-linked economy.[1] This view was not limited to the business press. Federal Reserve Chairman Alan Greenspan (1996) speculated that the "rapid acceleration of computer and telecommunication technologies can reasonably be expected to appreciably raise our productivity and standards of living in the twenty first century certainly, and quite possibly in some of the remaining years of this century."

These optimistic views of the impact of IT, however, were not supported by the economic data. Despite the rapidly rising power and prevalence of IT, there were few signs that the two-decade long slump in productivity growth was ending.[2] In February 1997, for example, the Bureau of Labor Statistics (BLS) reported that nonfarm business (NFB) productivity growth for the five years from 1991 to 1996 averaged only 1.0 percent (BLS, 1997), substantially below the 2.8 percent for the 1947-73 period (Dean and Harper, 1998).[3] The outlook for economic growth was equally bleak. The Congressional Budget Office (CBO) projected potential GDP growth of 2.1 percent and NFB productivity growth of only 1.2 percent for the next decade (CBO, 1997). The Economic Report of the President, released in February 1997, presented a seven-year forecast of 2.3 percent GDP growth and only 1.2 percent NFB productivity growth (Council of Economic Advisors, 1997).

Weak productivity performance in the face of apparent technological advances was labeled the "computer productivity paradox" and constituted a genuine puzzle for productivity analysts and macroeconomists. This paradox was famously summarized by Robert Solow in 1987 as "you can see the computer age everywhere but in the productivity statistics."[4] Similarly, in a discussion of the confluence of technical progress and weak productivity growth, Paul

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[1]Shephard, Stephen B. "The New Economy: What It Really Means," *Business Week*, November 17, 1997.
[2]See the articles in the "Symposium on the Slowdown in Productivity Growth" in the *Journal of Economic Perspectives*, Fall 1988, for an overview of the "productivity slowdown" literature.
[3]All estimates are average annual growth rates. We use the term "productivity" to refer to average labor productivity, defined as output per hour worked.

Krugman (1993) wrote: "Something is out of kilter here. Either the technology isn't all it's cracked up to be, or we haven't yet seen the impact of the new technology on the economy (pg. 173)." While acknowledging considerable uncertainty, Krugman dismissed the delay hypothesis and concluded "my own view is much more pessimistic…and I worry that productivity growth may actually decline (pg. 174)."

Martin Baily and Robert Gordon (1988) provided an early discussion of slow measured productivity growth in the presence of massive technical progress. They concluded that increasing measurement error explained only a small portion of the productivity slowdown, implying that the disconnect was real. In contrast, Carol Corrado and Larry Slifman (1996) subsequently presented a decomposition of productivity growth that showed the slowest productivity growth in the nonfarm noncorporate sector, where output was most difficult to measure, and raised the possibility that measurement error was seriously distorting the productivity statistics. From a neoclassical perspective, however, the small contribution was not surprising. As pointed out by Oliner and Sichel (1994) and Jorgenson and Stiroh (1995), computers accounted for a very small share of the capital stock in the 1980s and early 1990s and the growth contribution was correspondingly small.

With the benefit of hindsight and substantially revised data, we now know that the IT optimists were right and that the U.S. productivity picture improved sharply in the mid-1990s. In 1997, BLS revised annual productivity growth for 1996 substantially upward and strong productivity growth followed throughout the late 1990s. By early 2001, BLS (2001) estimated NFB productivity growth for the trailing five years as a remarkable 2.8 percent and the "productivity resurgence" took center stage in policy discussions. While acknowledging the uncertainty and difficulty in projecting productivity growth, CBO (2001) featured NFB productivity growth on the cover of its January Budget and Economic Outlook and raised its projections of GDP growth to 3.3 percent and NFB labor productivity growth to 2.7 percent for the next decade. This point is worth emphasizing; in just four years, CBO more than doubled its ten-year projection of NFB productivity growth from 1.2 to 2.7 percent![5]

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[4]*New York Time Book Review*, July 12, 1987, p. 36.
[5]Using real time data, Edge et al. (2004) estimate that the estimate of trend productivity based on a Kalman filter increased from 1.0 percent in 1997 to 2.2 percent in 2001, in line with the evolution of actual projections.

The dramatic improvement in productivity growth in the late 1990s did not go unnoticed by monetary and fiscal policymakers. The rapid price declines in IT assets, for example, acted as a "positive supply shock," the mirror image of the negative oil price shocks in 1970s. On the real side, the growth of IT contributed to the stunning increase in estimates of potential growth for the U.S. economy. This combination of lower inflation and rapid economic growth allowed monetary policymakers to be more accommodating and to pursue a policy of "opportunistic disinflation."[6]

Similarly, stronger productivity and output growth contributed to short-lived fiscal surpluses and more sanguine budget outlooks. In January 1997, CBO projected that the annual federal budget deficit would increase to $278 billion by fiscal year 2007 (CBO, 1997). By January 2001, this had reversed to a projected annual fiscal surplus of $573 billion in 2007 and $796 billion in 2010 (CBO, 2001). While this improvement in the budget outlook cannot be attributed entirely to enhanced productivity growth, much of it can. CBO (2001) concluded that "if productivity growth over the next ten years is slower than its previous trend, thus reversing the gains since 1996, the budget outlook will be substantially worse than even in the pessimistic scenario (pg. 101)." In a study of the evolving CBO budget outlook, Walsh (1999) estimated that a 1% decline in economic growth projections in a five-year period (1999-2004) would reduce the cumulative surplus by about one-quarter.

The purpose of this paper is to compare the current productivity outlook with the evolving perspective over the past decade. By examining the historical record on a real-time basis and reviewing the contemporaneous interpretation and analysis, we are able to uncover the sources and implications of the U.S. productivity resurgence. In particular, we describe the abrupt shift in the perceived importance of information technology (IT). Within the span of the decade, the focus of productivity analysts switched from a "computer productivity paradox" to the near-universal belief in an IT-led "productivity resurgence." This dramatic reversal reflected significant changes in the real economy, such as the accelerating price declines in IT-related equipment in the late 1990s and massive investments in IT as firms responded. Methodological changes, such as the reclassification of software as an investment good by the Bureau of

[6]See Orphanides and Wilcox (2002) and Aksoy, *et al.* (2006), for discussions of the "opportunistic approach to disinflation" for a central bank. Meyer (2000) provides a policymaker's perspective on the implications of rapid productivity growth for a central bank.

Economic Analysis (BEA) in 1999, also contributed to the growing recognition of the critical role of IT in the acceleration of U.S. productivity.

We begin by examining real-time, vintage estimates from the BLS and CBO to track the evolving productivity picture. We also review contemporaneous academic and government research that quantified the role of IT as a source of economic growth to document the dramatic change in the perception of IT.[7] We use the most recent data to update our earlier work and demonstrate the continued strength of U.S. productivity growth and the changing role of IT. Finally, we turn to the future and present new projections of potential U.S. productivity growth over the next decade, excluding cyclical influences.

Our analysis shows that while U.S. productivity growth has remained very robust through 2005, the sources have changed. We document that the role of IT declined in relative importance after the dot-com crash of 2000. Investment in IT equipment and software and rates of productivity growth in the IT-producing sectors have receded considerably from the phenomenal levels of the late 1990s. We emphasize, however, that contributions of IT to productivity growth remain very large in relation to the size of IT in the U.S. economy.

The outlook for potential productivity growth remains optimistic with a base-case estimate for the next decade of 2.5 percent per year. This is very rapid from a historical perspective and only moderately below recent experience. Somewhat slower productivity growth reflects a natural evolution of the U.S. economy toward a more sustainable growth path as the widely anticipated demographic trends unfold. Our estimates are close to the most recent estimates of CBO (2007) and Council of Economic Advisors (CEA, 2007), but substantially above those presented by Gordon (2006) and the Social Security Administration (2006). We conclude that there is little evidence that the U.S. economy will revert to the low rates of productivity growth seen during the slowdown of the 1970s and 1980s.

II. The Evolving Productivity Picture

We begin with a retrospective look at U.S. productivity growth, asking what productivity analysts, macroeconomists, and policy makers knew, or thought they knew, about productivity trends at different points of time during the last decade. As a starting point, it is clear that the

[7]We focus exclusively on the U.S. macro experience. There is also a large literature on the role of IT in productivity growth in other economies, summarized, for example, by van Ark and Inklaar (2005), and a large literature of microeconomic studies, summarized, for example, by Brynjolffson and Hitt (2000, 2003).

post-1995 productivity surge took virtually all observers by surprise as economic growth continually surpassed expectations. We examine this historical record not to criticize specific views, but to obtain a better understanding of how the evolving productivity picture was perceived in real time.

We first report the most recent Bureau of Labor Statistics (BLS) productivity data for the nonfarm business (NFB) sector ending in 2006:Q4 from BLS (2007). Figure 1 plots both four-quarter moving averages and mean growth rates for three eras - 1948:Q4-1973:Q4, 1973:Q4-1995:Q4, and 1995:Q4-2006:Q4.[8] As is well-known, productivity growth slowed during the 1970s, 1980s, and early 1990s, and then increased substantially in the mid-1990s. Productivity data, however, are frequently and substantially revised, so we turn next to the real-time productivity data.

a) The Official Statistics

Our first step is to examine the "headline" productivity estimates produced by the BLS. Different vintages of productivity data are required in order to provide a real-time assessment of productivity trends. The February release of each year reports the annual growth rates for the past 10 years for the major sectors -- private business, nonfarm private business (NFB), and manufacturing. For example, the February 1994 release shows productivity growth rates from 1984 to 1993. Each subsequent release adds a more recent year, drops the earliest year, and incorporates revisions to the underlying data and methods in the intervening releases.

Figure 2 plots productivity growth for 10-year periods using this real-time data from different vintages. The post-1995 increase is very striking. Using data through 1996, for example, the February 1997 BLS press release reported that the average productivity growth rate for the trailing 10 years was only 0.70 percent (BLS, 1997). By February 2001 the trailing 10-year growth rate had risen to 2.2 percent as the strong productivity growth of the late 1990s replaced the weak growth rates of the late 1980s (BLS, 2001). The real-time data show further acceleration in the early 2000s, but the most recent productivity releases show some deceleration. We discuss the impact of this below.

It is also clear that the productivity data are subject large and frequent revisions. The initial estimate of productivity growth for 1996, released in early 1997, was only 0.8 percent for the NFB sector with no indication of resurgence (BLS, 1997). Over the subsequent year, however, incorporation of new data from the 1996 Hours at Work Survey led to a sharp downward revision of 0.6 percent in hours growth and an upward revision in NFB output growth for 1996 resulted in a surge in measured productivity growth to 1.9 percent (BLS, 1998). After further revisions in source data and methodology, the latest data indicate that productivity growth for 1996 was an even stronger 2.7 percent (BLS, 2007). To summarize the magnitude of these revisions, consider that the standard deviation of the first 10 estimates of 1996 productivity growth was 0.58, a wide range that is typical of other years as well. In recent years, the sign of the revisions has switched as productivity growth has typically been revised downward. Substantial revisions obviously complicate the task of monitoring and analyzing productivity trends in real time.

Another perspective on productivity growth is provided by tracking projections of future trends over time.[9] The Congressional Budget Office (CBO) regularly produces projections of real GDP growth and NFB productivity growth, so that changes in these projections can be followed over time. Like the projections we report below, the CBO projections are for potential growth of productivity, controlling for cyclical fluctuations, so these projections embody CBO's views about the strength of the underlying trends. Figure 3 plots the real-time projections of potential output growth and NFB productivity growth from CBO, when available, from The Budget and Economic Outlook, typically released in January of each year.[10] The projections are usually for 10 years into the future, the "budget window" used in analyzing the fiscal outlook. Figure 3 also presents average growth for the trailing 10-year period from BLS for the NFB sector from the same period, typically released in February of the same year.

As in Figures 1 and 2, the acceleration of productivity growth is readily apparent from the rolling BLS data. The CBO projections show a commensurate increase. In January 1997, for example, the CBO 10-year projection of NFB productivity was only 1.15 percent (CBO, 1997). By January 2001, just four years later, this projection had more than doubled to 2.7 percent (CBO, 2001). CBO has interpreted the increase in productivity growth since 2000 as largely a one-time cyclical phenomenon that has increased the level, but not the growth rate of

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[8]These nonfarm business (NFB) estimates are average annual growth rates, calculated as log differences.
[9]Edge et al. (2004) perform similar exercise and examine the evolution of productivity forecasts around the turning points in the early 1970s and mid-1990s. They conclude that it is critical examine real time data to assess the evolution of expectations.

productivity.[11] More recently, the CBO projections have moderated, remaining at 2.4 percent from January 2005 to August 2006. CBO recently lowered its 10-year NFP productivity projection 2.3 percent, in part due to a lower projected level of investment (CBO, 2007). The evolving CBO projection of GDP growth is similar, but less volatile, increasing from 2.1 percent in January 1997 to a peak of 3.3 percent in January 2001 and then receding to 2.8 percent in January 2006 and further to 2.6 percent in January 2007 (CBO, 1997, 2001, 2006a, 2007).

b) Interpretation

We next turn to the interpretation of the productivity data by examining the sources of productivity growth with specific attention on the role of IT. While many economists have examined these data with a variety of methods, we focus on studies by the BLS (1983, 1993, 2000), Gordon (1998, 2000, 2004, 2006), Jorgenson and Stiroh (1995, 2000), Jorgenson, Ho, and Stiroh (2002, 2004, 2006), and Oliner and Sichel (1994, 2000, 2002) because these studies are based on relatively similar methodologies and allow comparisons over time.[12] In addition, we do not review the large literature on the link between IT and productivity growth in other economies (summarized, for example, by van Ark and Inklaar (2005)), industry studies such as Baily and Lawrence (2001), Triplett and Bosworth (2004, 2006), or Stiroh (2002), or the microeconomic literatures reviwed by Brynjolffson and Hitt (2000, 2003). Focusing on the aggregate, we first summarize the standard growth accounting techniques and then describe how the results evolved and new interpretations emerged.

The starting point is the production possibility frontier that describes efficient combinations of outputs and inputs for the economy as a whole. Aggregate output Y consists of outputs of investment goods and consumption goods. These are produced from aggregate inputs of capital services K and labor services L. Total factor productivity A is a "Hicks-neutral" augmentation of aggregate input, so the production possibility frontier takes the form:

$$(1)\quad Y = A \cdot f(K, L)$$

The standard framework can be extended in two ways to highlight IT. First, economy-wide TFP growth can be allocated between gains in the IT-producing sectors and gains in the rest of the economy. Second, capital services can be decomposed into the use of IT capital -

[10]The CBO outlook has been released in January and updated in August since 2001. Prior to that time the updates were published on a similar, but less systematic schedule.

[11]See CBO (2005) for details.

[12]Other notable studies of this type include Haimowitz (1998) and Whelan (2002).

computer hardware, software, and telecommunications equipment - and the use of non-IT capital as:

$$(2)\quad Y(Y_{IT}, Y_n) = A(A_{IT}, A_n) \cdot f(K(K_{IT}, K_n), L),$$

where A_{IT} is TFP in IT production, A_n is TFP in non-IT production, K_{IT} are capital services from IT assets, and K_n are capital services from non-IT assets.

Under the assumption that product and factor markets are competitive, the extended framework in (2) implies the following decomposition:

$$(3)\quad \Delta \ln Y = \overline{v}_{K_n} \Delta \ln K_n + \overline{v}_{K_{IT}} \Delta \ln K_{IT} + \overline{v}_L \Delta \ln L + \overline{w}_n \Delta \ln A_n + \overline{w}_{IT} \Delta \ln A_{IT}$$

where each v represents the input share of the subscripted input and each w represents the share of the subscripted output in aggregate output. A bar over the shares indicates a two-period average.[13]

The results can also be presented in terms of average labor productivity (ALP), defined as $y = Y / H$, the ratio of output Y to hours worked H, and $k = K / H$ is the ratio of capital services to hours worked:

$$(4)\quad \Delta \ln y = \overline{v}_{K_n} \Delta \ln k_n + \overline{v}_{K_{IT}} \Delta \ln k_{IT} + \overline{v}_L \Delta \ln L_Q + \overline{w}_n \Delta \ln A_n + \overline{w}_{IT} \Delta \ln A_{IT}$$

where y is labor productivity or output per hour, k_n is non-IT capital per hour worked, k_{IT} is IT capital per hour worked, and L_Q is labor quality, defined as the ratio of labor input to hours worked.[14]

The BLS has produced the official estimates of TFP growth for the U.S. economy since 1983 when the estimated growth in TFP for the business, nonfarm business, and manufacturing sectors was released for the period 1948-1981 (BLS, 1983). This major achievement reflected the growing realization among economists and policy makers that many factors determine labor productivity growth and that it is useful to distinguish among them.[15] While the early BLS effort

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

[14]Our labor input index reflects the changing composition of the work force, giving a larger weight to the hours worked by highly educated, high-wage workers.

[15]The BLS TFP program was a response to the Panel to Review Productivity Statistics (1979), organized by the National Research Council and chaired Albert Rees. The Rees Report became the cornerstone of the new BLS TFP estimates. See Jorgenson, Ho, and Stiroh (2005) for further details on the history of the official estimates.

did not decompose different types of capital such as IT or quantify the impact of labor quality, it nonetheless represented a significant step forward for productivity analysis.[16]

Oliner and Sichel (1994) and Jorgenson and Stiroh (1995) were the first to quantify the impact of IT within a sources of growth framework, although neither of these papers assessed the contribution of TFP growth in the production of IT. Moreover, both studies examined the contribution of only computers to output growth as in Equation (3) and not to labor productivity growth as in Equation (4). The common conclusion was that IT made a relatively small contribution to output growth. Oliner and Sichel (1994) estimated a contribution of 0.21 percentage points from computer equipment for the period 1980-92. This accounted for about nine percent of the 2.27 percent output growth for the period. A somewhat broader definition of IT that included communication equipment and other information processing equipment such as photocopy, scientific instruments, and other accounting machinery raised the capital growth contribution to 0.35 percentage points. Jorgenson and Stiroh (1995) reported a growth contribution from computers of 0.15 for the period 1985-92.[17]

The modest contributions of IT investment were not surprising, given the relative size and importance of IT equipment and software at the time.[18] Oliner and Sichel (1994), for example, estimated that computer capital accounted for less than one percent of nominal input for 1980-1992. Although they did not measure the ALP contribution specifically, Oliner and Sichel (1994) concluded that "computers probably have not caused much of whatever pickup in aggregate productivity has occurred in recent years (pg. 275)." Jorgenson and Stiroh (1995) reached a similar conclusion and emphasized that rapid price declines induced massive substitution toward computers, but that there was no evidence of "non-pecuniary externalities" or "spill-overs" that would appear as TFP growth.

Subsequently, Gordon (1998) argued that computers had made a small contribution to productivity because "there is something wrong with computers (pg. 5)." In particular, he pointed to limitations of computers in service industries, diminishing returns to computer speed and memory, and the fact that much computer-related activity has zero or negative productivity.

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[16]BLS first incorporated labor quality/composition effects in BLS (1993).

[17]As discussed in the following section, Jorgenson and Stiroh (1995) consider a broader measure of output than the nonfarm business sector, so the results are not directly comparable. Note also that Table 4 in Jorgenson and Stiroh (1995) initially reported an incorrect number.

[18] This point was made by Romer (1988) in his comment on Baily and Gordon (1988).

As evidence, he noted that labor productivity slowed for 1993-1997 in the non-manufacturing sector where most of the computers are located. In this view, the primary macroeconomic impact of the computer revolution was on the inflation front as a beneficial supply shock.

Over the following five years these views changed dramatically. BLS (2000), Jorgenson and Stiroh (2000), and Oliner and Sichel (2000) reported substantial contributions from IT capital to economic growth. This reflected rapidly accelerating investment in these assets during the late 1990s, their growing relative importance, and the broadening of the IT concept to include software and communications equipment.[19] According to recent national income and product accounts (NIPAs) data, for example, the growth of annual investment in computers, software, and telecommunications equipment increased from 13.5 percent for 1987 to 1995 to 22.2% for 1995 to 2000, while the decline of IT prices rose from -3.3% to -7.3%.

BLS, the producers of the official sources of growth and TFP analysis for the U.S. economy, made its first measurement of the contribution of IT-capital services in its 2000 release (BLS, 2000). This included a standard growth accounting analysis through 1998 and BLS reported that information processing equipment—computers and related equipment, communications equipment, instruments and photocopying equipment, and software—contributed 0.8 percentage points to ALP growth for the period 1995-98, while other types of capital made a net contribution of 0.0 percentage points. BLS (2000) did not quantify the impact of IT on TFP growth.

Jorgenson and Stiroh (2000) reported substantially increased contributions of IT during the late 1990s. For the period 1995-1998, they showed that the IT capital services contributed 0.8 percentage points to output growth and about 0.7 to labor productivity growth. In addition, the contribution from TFP growth in IT production was 0.64 percentage points.[20] These components contributed about 55 percent of labor productivity gains for 1995-98. The primary conclusion was that the "pessimism of the famous Solow paradox…has given way to the optimism of the information age (pg. 184)."

Oliner and Sichel (2000) reported a contribution to output growth for the period 1996-99 from IT capital, now defined to include computers, software, and telecommunications

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[19]The 1999 benchmark revision to the NIPAs reclassified software as an investment good. See Moulton, *et al.* (1999), for details.
[20]Jorgenson and Stiroh (2000) did not report the IT-capital deepening contribution, but one can approximate this using the reported growth rates and shares.

equipment, of 1.10 percentage points and a 0.96 percentage point contribution to labor productivity growth. They also extended their analysis to quantify the TFP contribution from IT production, which they estimated to be 0.49 percentage points, more than two-fifths of the aggregate TFP growth for the period 1996-1999. Taken together, the use of IT capital and TFP growth in IT production accounted for nearly 60 percent of labor productivity gains, leading Oliner and Sichel (2000) to conclude the new data "place information technology at center stage (pg. 4)" of the U.S. growth resurgence in the late 1990s.

Gordon (2000) offered a different interpretation for the period 1995-99, by estimating a sizable cyclical component to NFB-productivity growth and attributing the remainder of labor productivity growth, about 0.64 percent, entirely to computer-capital deepening and IT-related TFP. He concluded that "spillover effects on multifactor productivity in the non-computer economy are absent (pg. 56)." While this lack of TFP gains may be viewed as a "profound disappointment (pg. 72)," it is worth emphasizing that these two channels are precisely what one would expect from a neoclassical framework with different rates of technical change and falling relative IT prices.

The next round of productivity estimates, published in 2002, revealed the growing importance of IT as a source of labor productivity growth. Jorgenson, Ho, and Stiroh (2002) estimated contributions from IT use and IT production of 0.76 for 1995-2000, which accounted for 55 percent of the 1995-2000 gains, and over three-quarters of the increase in labor productivity between 1995-2000 and 1973-1995. Oliner and Sichel (2002) reported an IT-capital deepening contribution of 1.02 and a contribution of IT to TFP growth of 0.77 percentage points, which accounted for 75 percent of labor productivity growth for 1996-2001. This more than accounted for the acceleration of aggregate labor productivity between 1996-2001 and 1991-1995. Similarly, BLS (2002) reported that 0.9 percentage points, fully one-third of NFB productivity gains, were attributable to IT capital deepening. Note that this period marked the high-water mark for productivity projections, for example, CBO (2001) presented an 10-year projection of NFB productivity growth of 2.7 percent, its highest estimate.

Gordon (2004) examined data through 2002 and remained skeptical, even though the data showed a strong contribution from IT-capital deepening and IT-TFP growth, as well as accelerating TFP growth outside IT production. The paper argued that one-off factors such as a temporary increase in the pace of technological change in IT production, the one-time invention of the Internet, and excessive investment caused by Y2K preparation tended to exaggerate the importance of IT in the late 1990s. Moreover, diminishing returns and the availability of only "second-rate" innovation made continuation of these trends implausible, in his view.

The productivity picture began to change after 2000. According to recent NIPA data, IT price declines became less dramatic at -3.9 percent (compared to -7.3 percent for 1995-2000) and IT-investment growth slowed noticeably to 1.7 percent, even as labor productivity growth accelerated. As a consequence, the growth accounting results of Jorgenson, Ho, and Stiroh (2004) showed a smaller relative contribution from IT. For the period 1995 to 2003, for example, the combined contribution from IT capital deepening and IT-related TFP accounted for 47 percent of the aggregate gains in labor productivity. As we will show in the following section, this contribution has continued to decline.

We conclude this section with an important point about these studies of the aggregate sources of productivity growth. While IT capital deepening and IT TFP contributions measure the direct contribution from the use and production of IT, respectively, there is a wealth of microeconomic evidence on the complexity of the technology/productivity link. To successfully leverage IT investments, for example, firms must typically make large complementary investments and innovations in areas such as business organization, workplace practices, human capital, and intangible capital (Black and Lynch (2001, 2004), Brynjolffson and Hitt (2000, 2003), and Bresnahan et al. (2002)). It is difficult, however, to incorporate these variables into an aggregate accounting framework, so one should broadly interpret the productive impact of IT-use as inclusive of these complementary factors.[21]

III. Updated Empirical Estimates

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

a) Data

Our output data are based on the U.S. National Income and Product Accounts (NIPA), published by the Bureau of Economic Analysis (BEA). The BLS productivity estimates are focused on the private nonfarm business (NFB) sector; here we include the entire private economy, including the services provided by residential housing and consumer durables.

[21]Corrado et al. (2006) explicitly incorporate intangible capital into the a neoclassical growth accounting framework.

Jorgenson (2001) and Jorgenson, Ho, and Stiroh (2005, 2006) provide estimates for the full economy, including the government sector, using earlier vintages of these data.

Our capital input data are based on the fixed-asset accounts published by BEA. These accounts present business and government investments and consumer durable purchases by detailed asset classes, such as computers, office buildings, and 1-to-4 family homes. We employ a broad measure of capital that includes fixed assets owned by businesses and households, as well as land and inventories. Our prices for capital services use asset-specific values for price changes, service lives, and depreciation rates for each type of asset.

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 BLS and presented in the NIPA. We take total hours worked for domestic employees directly from the NIPA, self-employed hours worked for the nonfarm business sector from the BLS, and self-employed hours worked in the farm sector from the Department of Agriculture. Labor input is a quantity index of hours worked that captures the heterogeneity of the workforce. We classify workers by sex, employment class, age, and education levels and weight the hours 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.[22]

b) Empirical Results

Table 1 presents the growth of output and allocates this growth between hours worked and labor productivity for the broad business sector. We examine the period 1959 to 2005, and four sub-periods 1959-1973, 1973-1995, 1995-2000, and 2000-2005.[23] For comparison purposes, Table 2 uses the "productivity slowdown" era from 1973-1995 as the baseline for both the 1995-2000 and the 2000-2005 period. We are also interested in how the sources of growth differ after 2000, so we compare 2000-2005 directly to 1995-2000.

Private output grew 3.58 percent per year for 1959-2005 with considerable variation across periods from 2.93 percent for 2000-2005 to 4.77 percent for 1995-2000. Perhaps most striking is the sharp slowdown after 2000 in hours growth, which fell from 2.07 percent per year for 1995-2000 to -0.16 percent per year for 2000-2005. The decline in hours worked has been widely discussed and has led to considerable debate about the "jobless recovery" and the dating

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[22]More details on our data are provided by Jorgenson, Ho and Stiroh (2005, Chapter 6).

of the 2001 business cycle.[24] In vivid contrast, labor productivity continued to accelerate, rising from 1.49 percent per year for 1973-1995 to 2.70 percent for 1995-2000 to 3.09 percent for 2000-2005.[25]

The remainder of Table 1 reports the growth accounting decomposition of average labor productivity growth from Equation (4). For the period 1959-2005 ALP grew at 2.20 percent per year. Capital deepening made the greatest contribution of 1.17 percent, followed by total factor productivity growth of 0.77 percent and labor quality growth of 0.27 percent.[26] This ranking also holds for each sub-period and highlights the leading role of investment, as the composition of capital steadily shifted toward a greater role for IT. We note, however, that IT appears less important, both in an absolute and a relative sense, in the period 2000-2005 than before 2000. This reflects slower IT-price declines and slower IT investment.

We next examine changes in the sources of productivity reported in Table 2. We begin with the post-1995 revival and show the now-familiar result that IT played a critical role. IT TFP and IT-capital deepening contributed 0.34 and 0.61 percentage points, respectively, which accounted for almost 80 percent of the increase in productivity growth. Clearly, IT played a dominant role in the productivity surge in the late 1990s. Other forms of capital deepening and labor-quality growth made insignificant contributions, while non-IT TFP contributed 0.28 percentage points. This reflects an increase from the 1970s and 1980s when non-IT TFP was essentially flat, but remains small relative to the IT contribution.

It is also useful to summarize the standard interpretation of the economic forces that drove these developments. The story begins in the IT-producing industries that make IT equipment and software. Rapid technological progress epitomized by "Moore's Law," the doubling of computer chip density every 12-24 months, has allowed each generation of new

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[23]Computer and software investment data begin in 1959 and 2005 is the last year for which complete data on output and inputs are available.

[24]The NBER Business Cycle Dating Committee, pointed to the gap between output and employment growth in 2002 and early 2003 as a major concern in dating the end of the 2001 recession. See the memo from the NBER Business Cycle Dating Committee from October 2, 2003 at http://www.nber.org/cycles/recessions.html.

[25]Note that these estimates differ from the official BLS data reported in Figure 1 because we use annual data, our analysis ends in 2005, and we include consumer durables and residential capital services flows.

[26]The contribution of labor quality, or human capital, to growth has slowed substantially over time, as shown in Table 1. These estimates are similar to DeLong, Goldin and Katz (2003), which provides calculations back to 1915 using somewhat different methodologies.

equipment to greatly outperform prior generations.[27] As a consequence, the performance of IT has improved even as prices have fallen. This is captured in the high rates of TFP growth in IT production. In response to the spectacular price declines for IT investment, firms have quickly substituted IT assets for other productive inputs. Massive investments in IT equipment and software, about one-third of nonresidential fixed investment in 2000, led to the large contribution of IT-capital deepening to labor productivity growth.[28]

The productivity gains after 2000, however, appear quite different. Comparing the period 2000-2005 to the 1973-1995 baseline, the data show a considerably attenuated contribution from IT. Labor productivity growth was stronger, so the smaller IT TFP and IT-capital deepening contributions accounted for only 24 percent of the increase. The majority of the surge in productivity relative to the slowdown era reflects non-IT-capital deepening and TFP growth outside IT production.

The final column of Table 2 compares the first surge in productivity to the second directly by reporting the difference between 2000-2005 and 1995-2000. Over this period, average labor productivity growth increased by 0.39 percent per year, but the contributions of IT TFP and IT-capital deepening both declined markedly. The contributions of non-IT TFP and non-IT-capital deepening accounted for virtually all of the productivity gain between the two periods. The contribution of labor quality also increased as hours growth disappeared.

Gordon (2006), using updated estimates from Oliner and Sichel, shows a similar pattern for data through 2005. For example, the contribution of IT-capital services increases from 0.42 percentage points for 1973-1995 to 1.14 percentage points for 1995-2001 and then falls to 0.58 percentage points for 2001-2005. TFP growth in the production of computers, software, telecommunications equipment, and semiconductors shows a similar pattern, first rising from 0.30 percentage points to 0.74 percentage points, and then retreating to 0.51 percentage points. While Gordon (2006) points out that this accounts for a smaller share of labor productivity than during the slowdown period of 1973-1995, labor productivity growth was more than twice as fast during the more recent period.

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[27]A more detailed discussion of Moore's Law is presented by Jorgenson, Ho, and Stiroh (2005). Aizcorbe, *et al.* (2006), quantify the role of other factors, most importantly the variation in markups, in inferring the pace of underlying technical progress from declines in quality-adjusted price indices.

[28]This share reflects investment by businesses in computers, software, and communications equipment.

The impact of IT has declined in both a relative and an absolute sense, but we emphasize that IT remains a substantial source of growth in the post-2000 period. IT investment is less than five percent of aggregate output, but Table 1 shows that IT has accounted for one third of the productivity growth since 2000. It is only when comparing the second surge of productivity after 2000 with the initial gains of the late 1990s that the change in the IT contribution is negative. This reflects a return to more sustainable growth rates after the IT-investment boom of the late 1990s.[29]

We conclude that IT remains an important source of productivity growth, but that other factors drove the productivity gains after 2000. In other words, IT contributes to productivity, but not all productivity growth is due to IT. Gordon (2006) arrives at a similar conclusion. A closer look at the data reveals that the increase in capital deepening was due to the decline in the growth of hours worked, rather than more rapid capital accumulation. Nonresidential investment declined by 0.1 percent per year for 2000-2005, considerably below the long-run growth rate of 5.4 percent for 1959-2000. This suggests that this larger capital deepening contribution is likely to be temporary as employment growth reverts to trend.

Non-IT TFP is measured as the difference between aggregate TFP and the IT component, so it is difficult to provide a simple interpretation of the jump in the non-IT contribution after 2000. One plausible explanation is that the most recent gains reflect cyclical dynamics, so that these gains are unlikely to be sustained, as suggested by Gordon (2003) and Sichel (2003). Alternative possibilities are that the gains reflect increased competitive pressures in IT-using industries, technical progress outside IT production, IT as a general purpose technology (GPT) that facilitates subsequent innovation, or investment in unmeasured capital inputs such research and development, organizational change, and other business processes. Basu, *et al.* (2003), and Basu and Fernald (forthcoming) provide evidence for the GPT role of IT by examining the link between TFP growth and lagged growth in IT capital. Corrado, Hulten, and Sichel (2006) document the importance of investments in intangible capital, although they conclude that this does not explain the increase in productivity growth rates after 1995.

[29]This slowdown is also apparent in the underlying data. The decline in quality-adjusted prices of IT equipment increased from -3.5 percent per year for 1973-1995 to –8.6 for 1995-2000 and then fell to -4.8 for 2000-2005. Our methods for estimating the IT TFP are based on the price dual, so our TFP estimates mirror the price declines. Similarly, real investment in IT equipment fluctuated from 16.6 percent to 22.2 and back to 1.7 for the same periods.

IV. Projecting Productivity Growth

Future productivity growth is crucial for sustaining the growth of the U.S. economy, but, as indicated earlier, is also hard to project. Projections require assumptions about technical progress and substitution among different types of investment and workers that are difficult to quantify, and a key challenge is to distinguish changes in trend from temporary shocks. We now discuss our methodology, present our empirical results, and compare our estimates to those of the Congressional Budget Office (CBO), Council of Economic Advisors in the Economic Report of the President (CEA), Board of Trustees of the Social Security Administration (SSA), and other economists' estimates.

a) Methodology and Data

We make two key assumptions that are consistent with the experience of the U.S. over time periods longer than a typical business cycle. First, output and the reproducible capital stock are projected to grow at the same rate. This smoothes fluctuations like the investment boom of the late 1990s and the investment bust during the 2001 recession. Second, hours worked are projected to grow at the same rate as the labor force, which implies that the unemployment rate, labor force participation rates, and hours per worker for each age-sex group remain constant. These assumptions are appropriate for projections of the potential growth of output, but would obviously be unsuitable for short-run forecasting of output and productivity growth.

We transform our basic growth accounting identity in Equation (4) into a framework for projecting output and productivity growth:

$$(5)\quad \begin{aligned} \Delta \ln y &= \frac{\overline{v}_K \Delta \ln K_Q - \overline{v}_K (1-\overline{\mu}_R)\Delta \ln H + \overline{v}_L \Delta \ln L_Q + \overline{w}_{IT}\Delta \ln A_{IT} + \overline{w}_n \ln A_n}{1-\overline{v}_K \overline{\mu}_R} \\ \Delta \ln Y &= \Delta \ln y + \Delta \ln H \end{aligned}$$

where y is labor productivity, K_Q is capital quality, defined as the difference between capital input and capital stock, H is hours, and L_Q is labor quality. Each v represents the input share of the subscripted variable and each w represents the output share of the subscripted output. The share of reproducible capital in total capital is denoted u_R; we assume that non-reproducible capital, land and inventories, does not grow.[30]

[30]Additional details about our methodology are presented in Jorgenson, Ho, and Stiroh (2002).

Calibration of Equation (5) requires projections of the output shares of capital and labor, the share of IT output in total output, the share of reproducible-capital stock in total capital, capital-quality growth, labor-quality growth, and TFP growth. Some of these variables can be projected with a relatively high degree of confidence, while others involve considerable uncertainty. We present a single value for the variables we consider relatively easy to project—labor-quality growth, growth in hours, and the shares of capital, reproducible-capital stock, and IT output. For the variables we consider more difficult to project—TFP growth in IT production, non-IT-TFP growth, and capital-quality growth—we present base-case, pessimistic, and optimistic scenarios in order to emphasize the considerable uncertainty that surrounds this type of exercise.

We first discuss the projections for variables held constant across all three scenarios. For growth in hours worked and labor quality, we construct our own projections of demographic trends, based on the demographic model of the Bureau of Census. This breaks the population down by individual year of age, as well as by race and sex. Our estimates suggest that hours growth will be 0.76 percent per year and that growth in labor quality will be 0.15 percent per year for the next decade. Both assumptions differ from our earlier projections due to inclusion of new source data and the later time period for the projections.

The capital share of output fluctuates, but does not show an obvious trend over the past 40 years, so we assume it remains constant at 42 percent, the average for 1959-2005. Similarly, the fixed reproducible-capital share in total capital exhibits no trend and we assume it remains constant at 81 percent, the 1959-2005 average. We also assume the IT-output share stays at 4.6 percent, the average for 1995-2005. This may be conservative as IT has increased in relative importance.

For variables that differ across scenarios—TFP growth in IT production, non-IT-TFP growth, and capital-quality growth—we rely on technical expertise as well as the historical record. Our base-case scenario incorporates data from the period 1990-2005, combining periods before and after the growth acceleration beginning in 1995. The optimistic scenario assumes that the patterns of 1995-2005, including both surges of productivity growth, will persist, while the pessimistic case assumes that the economy reverts to 1973-1995 averages.

For TFP growth in IT production, the year 1995 marked an acceleration of the pace of technical progress that can be seen in the increased speed of IT price declines and faster TFP growth in the IT-producing industries. Jorgenson (2001) argues that this shift was triggered by a much sharper acceleration in the decline of semiconductor prices; this can be traced to a shift in the product cycle for semiconductors from three years to two years in 1995 as competition intensified.[31] As noted above, however, IT-related prices have slowed since 2000 and the critical question is whether this reflects a permanent or transitory development. The 2005 edition of *The International Technology Roadmap for Semiconductors*, a detailed evaluation of semiconductor technology performed annually by a consortium of industry experts, projects a return to three-year product cycles.[32] Our base-case scenario averages the two-year and three-year cycles observed in the 1990s and projects TFP growth for each of the IT components from data for 1990-2005, which yields TFP growth in IT production of 9.52 percent.

Our optimistic projection assumes that the two-year product cycle for semiconductors continues, so that TFP growth in IT production reflects rates for 1995-2005 and continues at 10.77 percent per year. Our pessimistic projection assumes the semiconductor product cycle reverts to the slower pace of 1973-1995, so IT-related productivity growth falls to 8.05 percent per year. In all three cases, the contribution of IT to aggregate TFP growth reflects the 1995-2005 average output share of each IT component.

The TFP contribution from non-IT sources is more difficult to project because the post-1995 performance has been so uneven. We present a range of assumptions consistent with the U.S. historical experience. Our base case uses the average contribution from the period 1990-2005 and projects a contribution of 0.45 percentage points for the intermediate future. This assumes that the myriad factors that drove non-IT-TFP growth through 2005—resource reallocations, technical progress, and increased competitive pressures—will continue. Our optimistic scenario assumes that the contribution for 1995-2005 of 0.59 percentage points per year will continue, while our pessimistic case assumes that the U.S. economy will revert to the slow-growth period from 1973-1995, when this contribution averaged only 0.14 percent per year. We emphasize the intrinsic uncertainty by recalling the wide variation in non-IT-TFP growth after 1973 shown in Table 1.

The final variable required for our projections is the growth in capital quality, reflecting the shift towards assets like IT equipment and software with shorter service lives and high

[31]The product cycle refers to the time between new model introductions.
[32]See *International Technology Roadmap for Semiconductors*, 2005 Edition, http://public.itrs.net.

depreciation rates. Our key assumption is that neither the boom of the late 1990s nor the post-2000 slowdown is sustainable. Our base case uses the average rate of capital-quality growth of 1.72 percent for 1990-2005. Our optimistic projection combines the unsustainably high capital-quality growth of the late 1990s with the slowdown during the recession of 2001 and the recovery that followed. As a result, we assume capital-quality growth continues at the rate of 2.05 percent for 1995-2005, as firms substitute toward relatively inexpensive IT assets. Our pessimistic scenario assumes that the growth of capital quality reverts to the 0.86 growth rate for 1973-1995.

It is important to emphasize that projections of capital-quality growth are not independent of growth rates in production of IT and non-IT assets. We have not represented this explicitly because this would require a model with differences in growth rates of TFP in the production of these assets. We turn to the historical record to project all three variables—IT TFP, non-IT TFP, and capital-quality growth—from similar time periods in order to summarize these effects in a reduced form sense.

b) Productivity Projections

Table 3 combines the components of our projections and presents the three alternative scenarios. The top panel shows the projected growth of output and labor productivity. The second panel reports the five factors that are held constant across scenarios—growth of hours and labor quality and shares of capital, reproducible-capital stock, and IT output. The bottom panel reports the three factors that vary across scenarios—TFP growth in IT production and the implied contribution, the TFP contribution from other industries, and capital-quality growth.

Our base-case scenario puts private labor productivity growth at 2.49 percent per year and private output growth at 3.25 percent per year for the next decade. Projected productivity growth is in line with the 1995-2000 experience, but falls short of the pace of 2000-2005, due to a substantial decline in non-IT TFP 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 and set the contribution of TFP growth in IT production equal to the 1995-2005 average as the semiconductor industry returns to a three-year product cycle. Slower growth is partly offset by a larger IT-output share. Non-IT-TFP growth also makes a smaller contribution than during the post-1995 period and is substantially slower than in 2000-2005.

Our optimistic scenario puts private labor productivity growth at 3.00 percent per year and private output growth at 3.76 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 TFP growth in the production of IT equipment and software, as well as continued substitution toward IT assets and rapid growth in capital quality. In addition, non-IT-TFP growth continues its rapid growth after 1995. Productivity growth is more rapid than during 1995-2005, but falls short of the strong performance since 2000.

Finally, the pessimistic projection of 1.36 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 IT implies that labor productivity growth will fall below the rates of the 1970s and 1980s, even with a projected demographic slowdown. During this earlier period labor productivity averaged only 1.5 percent per year.

c) 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 (CBO), the Council of Economic Advisors (CEA) in the Economic Report of the President, and in the annual report of the Board of Trustees of the Social Security Administration (SSA).[33] 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.

To provide an appropriate context for our results, we compare our estimates with several recent projections by government agencies, academic economists, and private forecasters. Table 4 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, the data vintages differ, and this is not an exhaustive list, these comparisons provide a useful perspective on the range of plausible forecasts.

Beginning with the private economy, the projections of potential NFB productivity growth average 2.4 percent for the next decade. This is somewhat below the 2.7 percent growth observed since 1995. When combined with projected growth of hours worked of 0.8 percent, the consensus estimate is for NFB output growth is about 3.2 percent. Note that the more recent estimates tend to be lower, e.g., Survey of Professional Forecasters (2007), CBO (2007), Gordon (2006), and JPMorgan (2006), which reflects the relatively slow productivity growth in recent years that has been pushing trend estimates down.

There is considerable variation in output estimates for the full economy, ranging from 2.5 percent by Gordon (2006) for the next twenty-five years to 3.0 percent for the next three years from CEA (2007) and the median estimate from the Survey of Professional Forecasters (2007).

We also point out that slower growth of hours worked would result in lower growth of output. Aaronson *et al.* (2006), using a model of participation rates and hours, project a continuation of the recent decline in participation rates and project growth of hours worked of only 0.4 percent per year for the next decade. This is considerably below the 0.7 projections by the SSA (2006) and CBO (2007), as well as our own estimate of 0.8 percent, which fixes participation rates for each demographic group. It is beyond the scope of this paper to evaluate the underlying sources of these differences, but it is important to recognize that the resolution of this issue will have substantial consequences for the potential growth of output and productivity.

V. Conclusions

The key challenges to understanding productivity growth on a real-time basis include large and frequent data revisions and unanticipated shocks that impact both trend and cyclical components. This paper documents how perceptions of U.S. productivity growth and its sources have evolved over time as the economy fluctuated and the historical record was revised. We show how IT emerged as the driving force behind the acceleration of labor productivity growth that began in the mid-1990s, while the strong performance of productivity growth since 2000 reflects non-IT-capital deepening and TFP growth, and thus remains to be explained in a deeper sense.

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[33]See Stiroh (1998) for a review of these approaches. We do not consider the projections in the Analytical Perspectives of the Office of Management and Budget separately because they are very similar to those in the Economic Report of the President.

Understanding the source of the post-2000 productivity gains is clearly of paramount importance to both monetary and fiscal policy makers. In particular, policy makers need to determine what portion of the most recent gains reflects transitory business cycle factors and what portion should be attributed to deeper structural changes in trend growth rates. Given the large and frequent data revisions documented earlier, it is likely too early to make this assessment with any certainty, so it is perhaps not surprising that many productivity observers have remained cautious. CBO, for example, maintained its 10-year projection of nonfarm business productivity at 2.4 percent from January 2005 to August 2006 despite the strong productivity growth in 2002, 2003, 2004, but recently lowered its projections to 2.3 percent as recent productivity slowed. Similarly, Federal Reserve Chairman Ben Bernanke (2006) concluded that the "recent experience does not appear to require a significant rethinking of long-term productivity trends" and notes that the consensus projection remains just below 2.5 percent, as in Table 4. This is above the historical average, but falls short of the pace seen in the 2000s.

The relative stability in the productivity outlooks implies that a substantial portion of the post-2000 productivity gains can be attributed to transitory factors. Nonetheless, there is cautious optimism that the continuation of factors that drove the U.S. productivity resurgence for the entire post-1995 period will persist. These include specific factors such as an expectation that information technology will continue to impact the U.S. economy, as well as broader factors such as flexible labor markets, competitive product markets with relatively low barriers to entry, and deep, sophisticated, capital markets, all of which allow the U.S. economy to innovate and benefit from emerging technologies.[34] As a consequence, there is little evidence to suggest that the technology-led productivity resurgence is over or that the U.S. economy will revert to the slower pace of productivity growth of the 1970s and 1980s.

[34]Baily (2002) discusses the broader changes to the U.S. economy that facilitated productivity growth in the 1990s and the OECD (2006) provides a discussion of specific policy reforms in OECD countries designed to spur productivity growth.

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Table 1: Sources of U.S. Output and Productivity Growth
1959-2005

	1959-2005	1959-1973	1973-1995	1995-2000	2000-2005
Private Output	3.58	4.18	3.08	4.77	2.93
Hours Worked	1.38	1.36	1.59	2.07	-0.16
Average Labor Productivity	2.20	2.82	1.49	2.70	3.09
Contribution of Capital Deepening	1.17	1.40	0.85	1.51	1.56
Information Technology	0.43	0.21	0.40	1.01	0.63
Non-Information Technology	0.73	1.19	0.45	0.49	0.94
Contribution of Labor Quality	0.27	0.28	0.25	0.19	0.36
Total Factor Productivity	0.77	1.14	0.39	1.00	1.17
Information Technology	0.25	0.09	0.25	0.58	0.40
Non-Information Technology	0.52	1.05	0.14	0.42	0.77
Share Attributed to Information Technology	0.31	0.11	0.43	0.59	0.33

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.

Table 2: Changes in the Sources of Productivity Growth

	1995-2000 less 1973-1995	2000-2005 less 1973-1995	2000-2005 less 1995-2000
Average Labor Productivity	1.22	1.60	0.39
Contribution of Capital Deepening	0.66	0.72	0.05
Information Technology	0.61	0.23	-0.39
Non-Information Technology	0.05	0.49	0.44
Contribution of Labor Quality	-0.06	0.11	0.17
Total Factor Productivity	0.62	0.78	0.17
Information Technology	0.34	0.16	-0.18
Non-Information Technology	0.28	0.62	0.35
Share Attributed to Information Technology	0.78	0.24	

Notes: All figures are average annual growth rates taken from Table 1. 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 comparison period.

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Table 3: Output and Labor Productivity Projections

	Projections		
	Pessimistic	**Base-case**	**Optimistic**
		Projections	
Private Output Growth	2.12	3.25	3.76
Average Labor Productivity Growth	1.36	2.49	3.00
		Common Assumptions	
Hours Growth	0.76	0.757	0.76
Labor Quality Growth	0.15	0.149	0.15
Capital Share	0.42	0.423	0.42
Reproducible Capital Stock Share	0.81	0.809	0.81
IT Output Share	0.05	0.046	0.05
		Alternative Assumptions	
TFP Growth in IT	8.05	9.52	10.77
Implied IT-related TFP Contribution	0.37	0.43	0.49
Other TFP Contribution	0.14	0.45	0.59
Capital Quality Growth	0.86	1.72	2.05

Notes: In all projections, hours growth and labor quality growth are from internal projections for 2005-2015, capital share and reproducible capital stock shares are 1959-2005 averages, and the IT output shares is the 1995-2005 average. The pessimistic case uses 1973-1995 average growth of IT-related TFP growth, non-IT TFP contribution, and capital quality growth. The base-case uses 1990-2005 averages, and the optimistic case uses 1995-2005 averages.

Table 4: 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		
Survey of Professional Forecasters (2007)	Feb '07	10-year	2.2		
CBO (2007)	Jan '07	10-year	2.3	0.7	3.0
Jorgenson, Ho, Stiroh (this paper)	Oct '06	10-year	2.5	0.8	3.3
Kahn and Rich (2006)	Dec '06	3-year	2.5		
Goldman Sachs (2006)	Jul '06	4-year	2.6		
CEA (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
SSA (2006)	Mar '06	10-year	1.9	0.7	2.6
CBO (2007)	Jan '07	10-year	2.0	0.7	2.6
Goldman Sachs (2006)	Jul '06	4-year	2.4		
Survey of Professional Forecasters (2007)	Feb '07	10-year			3.0
CEA (2007)	Feb '07	6-year			3.0

Notes: All estimates are average annual growth rates. Jorgenson, Ho, Stiroh estimates are for business sector including consumer durables. SSA (2006) estimate is imputed hours growth. Survey of Professional Forecasters (2007) is the median estimate.

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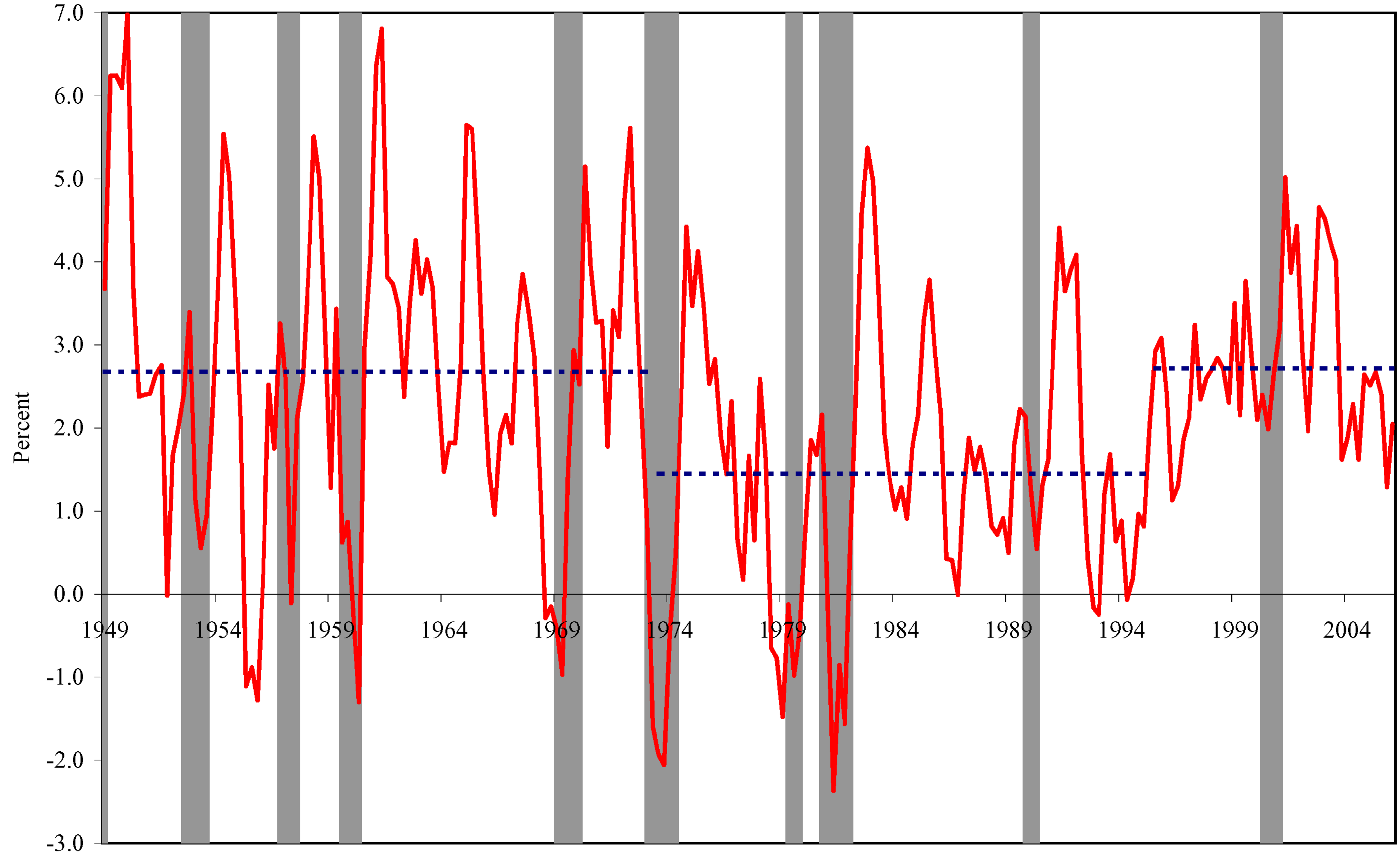
Figure 1: U.S. Productivity Growth

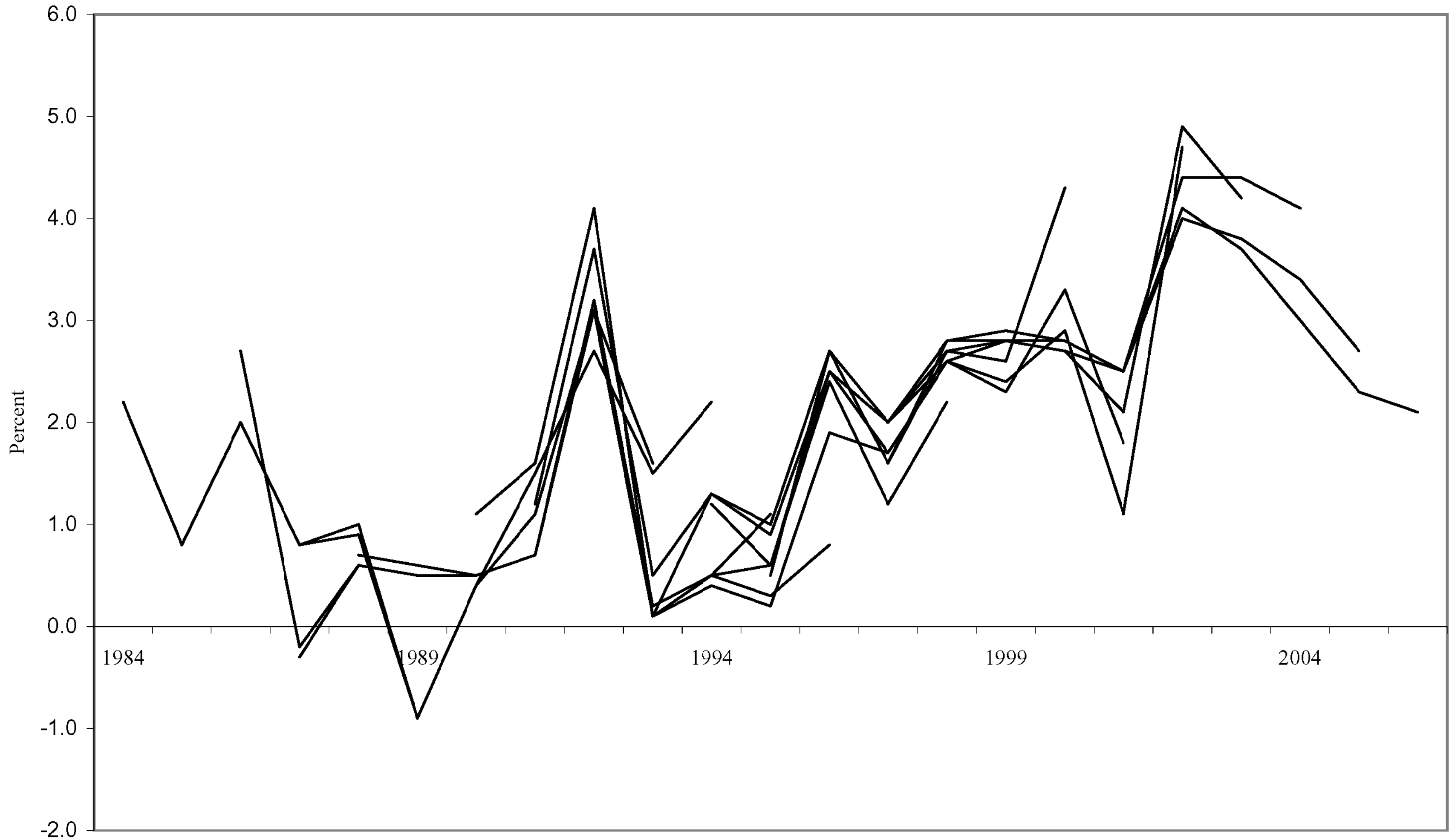
U.S. Nonfarm Business Sector, 1948:Q4-2006:Q4



Note: Dark lines are four-quarter growth rates. Dotted lines are average annaul growth rates for the periods 1948:Q4-1973:Q4; 1973:Q4-1995:Q4; and 1995:Q4-2006:Q4 with average annual growth rates of 2.7%, 1.5%, and 2.7%, respectively. NBER recession periods are shaded. Productivity data are from BLS, February 7, 2007.

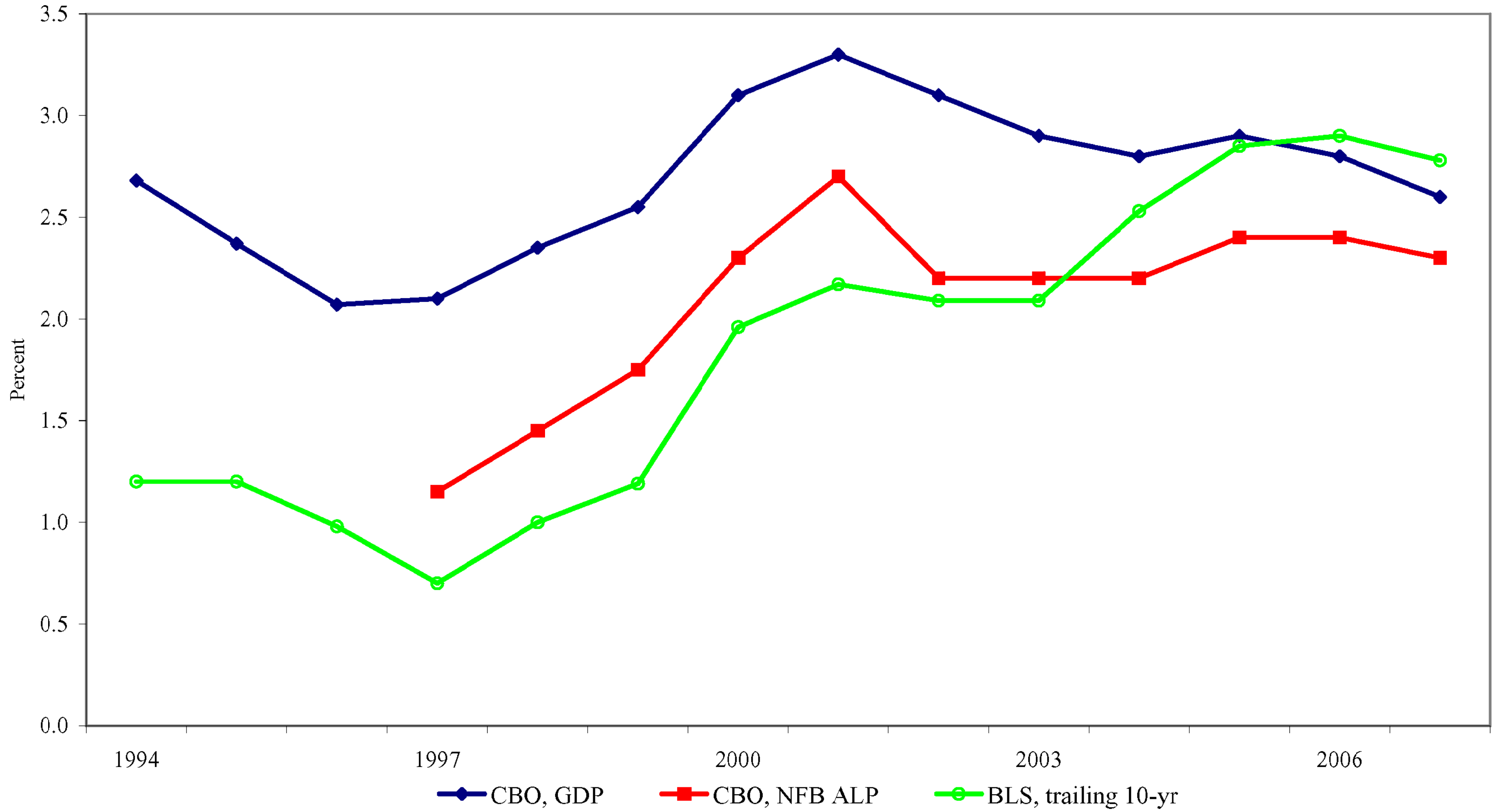
Figure 2: Evolution of U.S. Productivity Data

Nonfarm Business Productivity Growth



Note: Data are the annual growth rates of nonfarm business productivity for the trailing 10 years from February of each year, as reported in various BLS productivity releases.

Figure 3: The Evolving Productivity Outlook



Note: CBO NFB ALP and GDP estimates are 10-year ahead projections from the January report of the Budget and Economic Outlook from each year. BLS data are the average growth rates of nonfarm business productivity for the trailing 10 years from February of each year.