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Explaining a Productive Decade

PRODUCTIVITY GROWTH IN THE United States rose sharply in the mid-1990s, after a quarter century of sluggish gains. That pickup was widely documented, and a relatively broad consensus emerged that the speedup in the second half of the 1990s was importantly driven by information technology (IT).[1] After 2000, however, the economic picture changed dramatically, with a sharp pullback in IT investment, the collapse in the technology sector, the terrorist attacks of September 11, 2001, and the 2001 recession. Given the general belief that IT was a key factor in the growth resurgence in the mid-1990s, many analysts expected that labor productivity growth would slow as IT investment retreated after 2000. Instead labor productivity accelerated further over the next several years. More recently, however, the pace of labor productivity growth has slowed considerably.

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1. See *Economic Report of the President 2001,* Basu, Fernald, and Shapiro (2001), Brynjolfsson and Hitt (2000, 2003), Jorgenson and Stiroh (2000), Jorgenson, Ho, and Stiroh (2002, 2005), and Oliner and Sichel (2000, 2002). In these papers IT refers to computer hardware, software, and communications equipment. This category often also is referred to as information and communications technology, or ICT. For industry-level evidence supporting the role of IT in the productivity resurgence, see Stiroh (2002b). For an interpretation of the industry evidence that puts less emphasis on IT, see Bosworth and Triplett (2007) and McKinsey Global Institute (2001).

In light of these developments, researchers and other commentators have been intensely interested in the course of productivity growth since 2000. Distinguishing among the possible explanations for the continued strength in productivity growth is challenging, because much of that strength appeared in measured multifactor productivity (MFP), the unexplained residual in the standard growth accounting setup. Nevertheless, potential explanations can be divided into two broad categories: those centered on IT and those unrelated or only loosely related to IT.

The simplest IT-centered story—that rapid technological progress in the production of IT and the induced accumulation of IT capital raised productivity growth—does not work for the period after 2000, because the contributions to growth from both the production and the use of IT declined. A second IT-related story that has received a great deal of attention is that IT investment proxies for complementary investments in intangible capital, and a growing body of research has highlighted the important role played by such intangibles.[2] A third IT-related story identifies IT as a general-purpose technology that spurs further innovation over time in a wide range of industries, ultimately boosting growth in MFP.[3] Because this process takes time, the gains in MFP observed since 2000 could reflect the follow-on innovations from the heavy investment in IT in the second half of the 1990s.

Another broad set of explanations highlights forces not specific to IT. Gains in labor productivity since 2000 could have been driven by fundamental technological progress outside of IT production, as implied by the strong growth in MFP in other sectors.[4] Alternatively, the robust advance in labor productivity could reflect broader macroeconomic factors such as normal cyclical dynamics, a decline in adjustment costs after 2000 as investment spending dropped back, greater-than-usual business caution in hiring and investment, or increased competitive pressures on firms to

2. See Corrado, Hulten, and Sichel (2005, 2006), Brynjolfsson and Hitt (2003), Bresnahan, Brynjolfsson, and Hitt (2002), Basu and others (2004), Black and Lynch (2001, 2004), and Nakamura (1999, 2001, 2003). The National Income and Product Accounts (NIPAs) exclude virtually all intangibles other than software, although the Bureau of Economic Analysis, which produces the NIPA data, recently released a satellite account for scientific research and development; see Okubo and others (2006).

3. Bresnahan and Trajtenberg (1995) were the first to write about IT as a general-purpose technology. See also Organization for Economic Cooperation and Development (2000), Schreyer (2000), van Ark (2000), Basu and others (2004), and Basu and Fernald (2007).

4. Jorgenson, Ho, and Stiroh (2007); Bosworth and Triplett (2007).

restructure, cut costs, raise profits, and boost productivity. The profit-driven cost-cutting hypothesis, in particular, has received considerable attention in the business press.[5]

In this paper we try to sort out these issues using both aggregate and industry-level data.[6] We investigate four specific questions. First, given the latest data and some important extensions to the standard growth accounting framework, is an IT-centered story still the right explanation for the resurgence in productivity growth over 1995–2000, and does IT play a significant role when considering the entire decade since 1995? Second, what accounts for the continued strength in productivity growth after 2000? Third, how has investment in intangible capital influenced productivity developments? Finally, what are the prospects for labor productivity growth in coming years?

Our analysis relies in part on neoclassical growth accounting, a methodology that researchers and policymakers have used for many years to gain insights into the sources of economic growth. Notably, the Council of Economic Advisers, the Congressional Budget Office, and the Federal Reserve Board routinely use growth accounting as part of their analytical apparatus to assess growth trends.[7]

Of course, growth accounting is subject to limitations, and in recent years many analysts have leveled critiques at this methodology. For example, the standard neoclassical framework does not explicitly account for adjustment costs, variable factor utilization, deviations from perfect competition and constant returns to scale, outsourcing and offshoring, management expertise, or the intangibles that are omitted from published data. In addition, researchers have raised a host of measurement issues that could affect

5. See Gordon (2003), Baily (2003), Schweitzer (2004), and Stiroh (forthcoming). For references to the business press, see Gordon (2003) and Stiroh (forthcoming).

6. Several other researchers have examined industry data, including Baily and Lawrence (2001), Stiroh (2002b), Nordhaus (2002b), Corrado and others (2007), and Bosworth and Triplett (2007). For references to the literature on industry-level data in Europe, see van Ark and Inklaar (2005).

7. See *Economic Report of the President 2007,* Congressional Budget Office (2007a, 2007b), and the latest available transcripts of the meetings of the Federal Open Market Committee (FOMC). The 2001 FOMC transcripts show that staff presentations on the economic outlook featured growth accounting in the discussion of productivity trends. Private sector analysts also rely on growth accounting; see, for example, Global Insight, *U.S. Executive Summary,* March 2007, and Macroeconomic Advisers, *Macro Focus,* March 22, 2007.

the standard framework.[8] It is well beyond the scope of this paper to deal with all of these critiques, but we augment the standard framework to account for some of the most salient ones. In particular, we take on board time-varying utilization of inputs, adjustment costs for capital, and intangibles. Our intent is to broaden the standard framework to get a fuller view of productivity developments during the past decade.

Briefly, our answers to the four questions we pose are as follows. Both the aggregate and the industry-level results indicate that IT was indeed a key driver of the pickup in labor productivity growth over 1995–2000. IT also is a substantial contributor to labor productivity growth over the full decade since 1995, although its contribution is smaller after 2000. In the aggregate data, this conclusion stands even after accounting for variable factor utilization, adjustment costs, and intangible capital.

Regarding the continued strength in labor productivity growth since 2000 in the published data, our answer has a number of elements. As a matter of growth accounting arithmetic, the smaller—although still sizable—contribution of IT after 2000 was more than offset by several factors, the most important being faster MFP growth outside the IT-producing sector. Just as the aggregate data highlight different sources of productivity growth during 1995–2000 than since 2000, so do the industry data. The industry composition of labor productivity growth across these periods shifted significantly, and we report evidence that IT capital was linked to changes in industry productivity growth in the 1990s but not in the period since 2000.

The industry data also suggest that the rapid post-2000 productivity gains were due, at least in part, to restructuring and cost cutting in some industries as highlighted by Robert Gordon.[9] In particular, those industries that saw the sharpest declines in profits from the late 1990s through 2001 also tended to post the largest gains in labor productivity in the early 2000s. Because these restructuring-induced advances probably were one-

8. Much has been written about the link between management expertise and productivity, including Bloom and Van Reenen (2006), McKinsey Global Institute (2001), and Farrell, Baily, and Remes (2005). Gordon (2003) and Sichel (2003) provide reasons why offshoring and hours mismeasurement may have had a relatively limited effect on labor productivity growth, whereas Houseman (2007) argues that these factors could have had a significant effect in the U.S. manufacturing sector. For a discussion of measurement issues related to the pace of technical progress in the semiconductor industry, see Aizcorbe, Oliner, and Sichel (2006). For further discussion of issues related to critiques of the neoclassical framework, see Congressional Budget Office (2007b).

9. Gordon (2003).

time events (and could be reversed), they are unlikely to be a source of ongoing support to productivity growth.

In addition, the industry evidence indicates that reallocations of both material and labor inputs have been important contributors to labor productivity growth since 2000, a point that Barry Bosworth and Jack Triplett also note.[10] Although it is difficult to pin a precise interpretation on the reallocation results, the importance of these reallocations could be viewed as evidence that the flexibility of the U.S. economy has supported aggregate productivity growth in recent years by facilitating the shifting of resources among industries.

The incorporation of intangibles into the aggregate growth accounting framework takes some of the luster off the performance of labor productivity since 2000 and makes the gains in the 1995–2000 period look better than they looked in the published data. In addition, the step-up after 2000 in MFP growth outside the IT-producing sector is smaller after accounting for intangibles than in the published data. Thus any stories tied to a pickup in MFP growth (such as IT as a general-purpose technology) may apply to the entire decade since 1995 and not simply to recent years. This framework also implies that intangible investment has been quite sluggish since 2000, coinciding with the soft path for IT capital spending. All else equal, this pattern could be a negative for labor productivity growth in the future to the extent that these investments are seed corn for future productivity gains.

Finally, our analysis of the prospects for labor productivity growth highlights the wide range of possible outcomes. We report updated estimates of trend growth in labor productivity from a Kalman filter model developed by John Roberts;[11] these results generate a 2-standard-error confidence band extending from 1¼ percent to 3¼ percent at an annual rate, with a point estimate of 2¼ percent. In addition, we solve for the steady-state growth of labor productivity in a multisector model under a range of conditioning assumptions. This machinery also suggests a wide range of outcomes, extending from about 1½ percent to just above 3 percent, with a midpoint of 2¼ percent. Notwithstanding the wide band of uncertainty, these estimates are consistent with productivity growth remaining significantly above the pace that prevailed in the twenty-five years before 1995, but falling short of the very rapid gains recorded over the past decade.

10. Bosworth and Triplett (2007).
11. Roberts (2001).

The paper is organized as follows. The next section reviews the aggregate growth accounting framework and presents baseline results that account for variable factor utilization and adjustment costs. The section that follows uses the approach of Susanto Basu and coauthors to generate time series for intangible investment and capital services and presents growth accounting results for the augmented framework.[12] This approach complements that in the 2005 and 2006 papers by Carol Corrado, Charles Hulten, and Daniel Sichel, who also developed time series of intangible investment and capital and incorporated those estimates into a standard growth accounting framework. We then turn to the industry data to supplement the insights that can be drawn from the aggregate data. Finally, we discuss the outlook for productivity growth and present some brief conclusions.

Aggregate Growth Accounting: Analytical Framework and Baseline Results

We use an extension of the growth accounting framework developed by Oliner and Sichel to analyze the sources of aggregate productivity growth in the United States.[13] That framework was designed to measure the growth contributions from the production and use of IT capital, key factors that emerged in the second half of the 1990s. The framework has some limitations, however. It excludes intangible capital, which has received much attention in recent research on the sources of productivity gains. It also imposes the strict neoclassical assumption of a frictionless economy and thus abstracts from cyclical influences on productivity growth and from the effects of adjustment costs arising from the installation of new capital goods.

The growth accounting framework in this paper incorporates all of these considerations. We meld the original Oliner-Sichel model with the treatment of adjustment costs and cyclical factor utilization developed by Basu, John Fernald, and Matthew Shapiro.[14] In addition, we take account of intangible capital by drawing on the model of Basu, Fernald, Nicholas Oulton, and Sylaja Srinivasan.[15]

12. Basu and others (2004).
13. Oliner and Sichel (2000, 2002).
14. Basu, Fernald, and Shapiro (2001; hereafter BFS)
15. Basu and others (2004; hereafter BFOS).

Analytical Framework

The model that underlies our analytical framework includes six sectors. Four of these produce the final nonfarm business output included in the National Income and Product Accounts (NIPAs): computer hardware, software, communications equipment, and a large non-IT-producing sector. The NIPAs omit production of virtually all intangible capital other than software. Our model accounts for this capital by adding a fifth final-output sector that produces the intangible assets excluded from the NIPAs. In addition to the five final-output sectors, our model includes a sector that produces semiconductors, which are either consumed as an intermediate input by the final-output sectors or exported to foreign firms. To focus on the role of semiconductors in the economy, the model abstracts from all other intermediate inputs.

Following BFS, we allow the length of the workweek, labor effort, and the utilization of capital to vary over time. We also assume that the installation of new capital diverts resources from the production of market output. As in BFS, these adjustment costs depend on the amount of investment relative to existing capital. Boosting the ratio of investment to capital increases the fraction of output that is lost to adjustment costs.[16] To complete the model specification, we assume that the production function in every sector exhibits constant returns to scale and that the economy is perfectly competitive.[17]

Given this model, the appendix in the working paper version of this paper shows that growth in aggregate labor productivity can be expressed as[18]

$$(1) \qquad A\dot{L}P \equiv \dot{V} - \dot{H} = \sum_j \left(\alpha_j^K - \phi_j\right)\left(\dot{K}_j - \dot{H}\right) + \alpha^L \dot{q} + M\dot{F}P,$$

where a dot over a variable signifies the growth rate of that variable, V is aggregate value added in nonfarm business, H is aggregate hours worked, K_j is the aggregate amount of type-j capital used in the nonfarm business

16. Although BFS also include adjustment costs for labor in their model, they zero out these costs in their empirical work. We simply omit labor adjustment costs from the start. For additional discussion of capital adjustment costs and productivity growth, see Kiley (2001).

17. The results in BFS and in Basu, Fernald, and Kimball (2006) strongly support the assumption of constant returns for the economy as a whole. We invoke perfect competition as a convenience in a model that already has many moving parts.

18. Oliner, Sichel, and Stiroh (2007).

sector, α^L and α_j^K are, respectively, the income shares for labor and each type of capital, ϕ_j is the adjustment cost elasticity of output with respect to type-j capital, q is an index of labor quality, and *MFP* denotes multifactor productivity. The various types of capital include computer hardware, software, communications equipment, other tangible capital, and intangible capital other than software; each type of capital is produced by the corresponding final-output sector in our model. Except for the adjustment cost effect captured by ϕ_j, equation 1 is a standard growth decomposition. It expresses growth in labor productivity as the sum of the contribution from the increase in capital per hour worked (capital deepening), the contribution from the improvement in labor quality, and growth in aggregate MFP.[19]

Aggregate MFP growth, in turn, equals a share-weighted sum of the sectoral MFP growth rates:

$$\text{(2)} \qquad M\dot{F}P = \sum_i \mu_i M\dot{F}P_i + \mu_S M\dot{F}P_S,$$

where S denotes the semiconductor sector and i indexes the final-output sectors in our model (listed above). The weight for each sector equals its gross output divided by aggregate value added. These are the usual Domar weights that take account of the input-output relationships among industries.[20] Equation 2 has the same structure as its counterpart in an earlier paper by Oliner and Sichel.[21] The only formal difference is that including intangible capital increases the number of final-output sectors from four to five.[22]

19. The weight on $\dot{K}_j - \dot{H}$ represents the output elasticity of type-j capital. In the case without adjustment costs, $\phi_j = 0$, and so the income share α_j^K proxies for this output elasticity. However, in the presence of adjustment costs, the first-order condition for the optimal choice of capital yields the more general result shown in equation 1. In effect, the income share captures both the direct contribution of capital to production and the benefit of having an extra unit of capital to absorb adjustment costs. The weight in equation 1 nets out the portion of the income share that relates to adjustment costs, as this effect is embedded in the MFP term discussed below.

20. Domar (1961).

21. Oliner and Sichel (2002).

22. In contrast to the expression for aggregate MFP growth in BFS, equation 2 contains no terms to account for reallocations of output, labor, or capital across sectors. The particularly clean form of equation 2 arises, in large part, from our assumption of constant returns to scale and the absence of adjustment costs for labor (which implies that competitive forces equate the marginal product of labor in all sectors). In addition, we have assumed that any wedge between the shadow value of capital and its user cost owing to adjustment costs is the same in all sectors. Given this assumption, reallocations of capital across sectors do not affect aggregate output.

Finally, the sectoral MFP growth rates in equation 2 can be expressed as

$$(3) \qquad \dot{MFP}_i = \xi_i \dot{W}_i - \sum_j \phi_{j,i}\left(\dot{I}_{j,i} - \dot{K}_{j,i}\right) + \dot{z}_i$$

for the final-output sectors and

$$(4) \qquad \dot{MFP}_S = \xi_S \dot{W}_S - \sum_j \phi_{j,S}\left(\dot{I}_{j,S} - \dot{K}_{j,S}\right) + \dot{z}_S$$

for semiconductor producers, where the ξ's represent the elasticity of sectoral output with respect to the workweek (W), the I's and K's denote sectoral investment and capital services for each type of capital, the ϕ's represent the sectoral adjustment cost elasticities for each type of capital, and the z's represent the true level of technology. All of the ξ's and ϕ's take positive values.

In the BFS model that we adopt, firms vary the intensity of their factor use along all margins simultaneously, which makes the workweek a sufficient statistic for factor utilization in general. Lengthening the workweek boosts measured MFP growth in equations 3 and 4 as firms obtain more output from their capital and labor. Regarding adjustment costs, faster growth of investment spending relative to that of capital depresses measured MFP growth as firms divert resources from producing market output to installing new plant and equipment. The effects of factor utilization and adjustment costs drive a wedge between measured MFP growth and the true pace of improvement in technology $\dot{z}$.

Data, Calibration, and Measurement Issues

This section provides a brief overview of the data used for our aggregate growth accounting, discusses the calibration of key parameters, and addresses some important measurement issues.[23] The national accounts data that we discuss here exclude virtually all forms of intangible capital except for investment in computer software. We defer the consideration of intangible capital until the next section.

Our dataset represents an up-to-date reading on productivity developments through 2006 based on data available as of the end of March 2007. We rely heavily on the dataset assembled by the Bureau of Labor Statistics (BLS) for its estimates of MFP in the private nonfarm business sector. This

23. For details on data sources, see the data appendix to Oliner and Sichel (2002).

dataset extended through 2005 at the time we conducted the analysis for this paper. We extrapolated the series required for our framework through 2006, drawing largely on corresponding series in the NIPAs.

To calculate the income share for each type of capital in our framework, we follow the BLS procedure that distributes total capital income across assets by assuming that each asset earns the same rate of return net of depreciation.[24] This is the same method used by Oliner and Sichel and by Jorgenson, Ho, and Stiroh.[25] Consistent with the standard practice in the productivity literature, we allow these income shares to vary year by year.[26]

These data and procedures generate a series for aggregate MFP growth via equation 1. Given this series as a top-line control, we estimate MFP growth in each sector with the "dual" method employed by various researchers in the past.[27] This method uses data on the prices of output and inputs, rather than their quantities, to calculate sectoral MFP growth. We opt for the dual approach because the sectoral data on prices are available on a more timely basis than the corresponding quantity data. Roughly speaking, the dual method compares the rate of change in a sector's output price with that of its input costs. Sectors in which prices fall quickly compared with their input costs are estimated to have experienced relatively rapid MFP growth.[28]

24. The weight on the capital deepening term in equation 1 for type-j capital equals its income share minus its adjustment cost elasticity. As discussed below, empirical estimates of these asset-specific elasticities are not available, which forces us to approximate the theoretically correct weights. Note that the weights on the capital deepening terms in equation 1 sum to one minus the labor share under constant returns to scale. We replace the theoretically correct weights with standard income-share weights that also sum to one minus the labor share. This approximation attaches the correct weight to aggregate capital deepening but may result in some misallocation of the weights across asset types.

25. Oliner and Sichel (2000, 2002); Jorgenson, Ho, and Stiroh (2002, 2007).

26. Year-by-year share weighting embeds the implicit assumption that firms satisfy the static first-order condition that equates the marginal product of capital with its user cost. Strictly speaking, this assumption is not valid in the presence of adjustment costs, as noted by BFS and by Groth, Nuñez, and Srinivasan (2006). Both of those studies replace the year-by-year share weights with the average shares over periods of five years or more, in an effort to approximate a steady-state relationship that might be expected to hold on average over longer periods. We found, however, that our results were little changed by replacing year-by-year shares with period-average shares. Accordingly, we adhere to the usual share weighting practice in the literature.

27. Jorgenson and Stiroh (2000), Jorgenson, Ho, and Stiroh (2002, 2007), Oliner and Sichel (2000, 2002), and Triplett (1996), among others.

28. Oliner and Sichel (2002) give a nontechnical description of the way in which we implement the dual method, and the appendix in the working paper version of this paper (Oliner, Sichel, and Stiroh, 2007) provides the algebraic details.

The expression that links aggregate and sectoral MFP growth (equation 2) involves the Domar weight for each sector, the ratio of the sector's gross output to aggregate value added. For the four NIPA-based final-output sectors, gross output simply equals the value of the sector's final sales, which we estimate using data from the Bureau of Economic Analysis (BEA). For the semiconductor sector we calculate gross output based on data from the Semiconductor Industry Association as well as data constructed by Federal Reserve Board staff to support the Federal Reserve's published data on U.S. industrial production.

The final step is to calculate the influence of adjustment costs and factor utilization on the growth of both aggregate and sectoral MFP. In principle, we could use equations 3 and 4 to calculate the effects at the sectoral level and then aggregate those effects using equation 2. However, as equations 3 and 4 show, this bottom-up approach requires highly disaggregated data on investment and the workweek and equally disaggregated output elasticities with respect to adjustment costs and the workweek (the ϕ's and the ξ's). Unfortunately, estimates of the required sectoral elasticities are not available.

To make use of readily available estimates, we work instead from the top down. That is, we model the effects of adjustment costs and the workweek for the nonfarm business sector as a whole and then distribute the aggregate effects across sectors. Let $\dot{W}$ and ξ denote, respectively, the percentage change in the workweek for aggregate nonfarm business and the elasticity of nonfarm business output with respect to this aggregate workweek. Then the workweek effect for aggregate nonfarm business equals $\xi\dot{W}$. Similarly, we measure the aggregate effect of adjustment costs as $\phi(\dot{I} - \dot{K})$, where $\dot{I}$, $\dot{K}$, and ϕ denote, respectively, growth in aggregate real investment spending, growth in aggregate real capital services, and the aggregate adjustment cost elasticity. To complete the top-down approach, we assume that the adjustment cost and workweek effects are uniform across sectors. Under this assumption, the top-down version of equations 2 through 4 is as follows (starting with the sectoral equations):

$$(5) \qquad M\dot{F}P_i = \frac{1}{\bar{\mu}}\left[\xi\dot{W} - \phi(\dot{I} - \dot{K})\right] + \dot{z}_i$$

$$(6) \qquad M\dot{F}P_S = \frac{1}{\bar{\mu}}\left[\xi\dot{W} - \phi(\dot{I} - \dot{K})\right] + \dot{z}_S$$

$$(7) \qquad M\dot{F}P = \sum_i \mu_i M\dot{F}P_i + \mu_S M\dot{F}P_S = \xi\dot{W} - \phi(\dot{I} - \dot{K}) + \sum_i \mu_i \dot{z}_i + \mu_S \dot{z}_S,$$

where $\bar{\mu} \equiv \sum_i \mu_i + \mu_S$. One can easily verify that the second equality holds in equation 7 by substituting for $M\dot{F}P_i$ and $M\dot{F}P_s$ from equations 5 and 6. Equations 5 through 7 serve as our empirical counterpart to equations 2 through 4.

We follow BFS in specifying ξ, $\dot{W}$, and ϕ. Starting with the workweek effect, we specify the aggregate elasticity ξ to be a weighted average of BFS's sectoral estimates of ξ for durable manufacturing, nondurable manufacturing, and nonmanufacturing. Using weights that reflect current-dollar output shares in these sectors, we obtain an aggregate value of ξ equal to 1.24. To measure the workweek itself, we use the BLS series for production or nonsupervisory workers from the monthly survey of establishments. Because the workweek in equations 5 through 7 is intended to measure cyclical variation in factor use, we detrend the log of this monthly series with the Hodrick-Prescott filter (with $\lambda = 10{,}000{,}000$ as in BFS) and use the detrended series to calculate $\dot{W}$ on an annual basis.

With regard to adjustment costs, we set the output elasticity ϕ equal to 0.035.[29] This elasticity is based on estimates of capital adjustment costs by Shapiro.[30] More recent studies provide estimates of adjustment costs on both sides of $\phi = 0.035$. Robert Hall estimates capital adjustment costs in an Euler equation framework similar to Shapiro's but uses more-disaggregated data and a different set of instruments for estimation.[31] Hall cannot reject the hypothesis that $\phi = 0$. In contrast, Charlotta Groth, using industry-level data for the United Kingdom, estimates ϕ to be about 0.055.[32] The divergent results in these studies highlight the uncertainty surrounding estimates of capital adjustment costs but do not suggest the need to move away from a baseline estimate of $\phi = 0.035$. We apply this elasticity to the difference between the growth rates of aggregate real business fixed investment from the NIPAs and the corresponding capital services series $(\dot{I} - \dot{K})$.

To summarize, we use annual data from BEA and BLS through 2006 to implement the aggregate growth accounting framework in equation 1. This

29. BFS used a larger value for ϕ, 0.05, but subsequently corrected some errors that had affected that figure. These corrections caused the value of ϕ to be revised to 0.035.

30. Shapiro (1986).

31. Hall (2004).

32. Groth (2005).

framework yields an annual time series for aggregate MFP growth. We then use the dual method to allocate this aggregate MFP growth across sectors. Finally, we calculate the effects of adjustment costs and changes in factor utilization on both aggregate and sectoral MFP growth, drawing heavily on parameter values reported by BFS.

Results

Table 1 presents our decomposition of labor productivity growth in the nonfarm business sector using the published data described above. These data exclude intangible capital other than business investment in software, which, again, is already treated as an investment good in the NIPAs. The next section fully incorporates intangible capital into our measurement system and presents an augmented set of growth accounting results.

Focusing first on the published data, table 1 shows that average annual growth in labor productivity picked up from about 1.5 percent a year during 1973–95 to about 2.5 percent during the second half of the 1990s and then rose further, to more than 2.8 percent, in the period after 2000. Our results indicate that an important part of the initial acceleration (about 0.6 percentage point of the total speedup of just over 1 percentage point) reflected the greater use of IT capital. In addition, growth of MFP rose notably in the IT-producing sectors, with an especially large increase for producers of semiconductors. The pickup for the semiconductor sector mirrors the unusually rapid decline in semiconductor prices from 1995 to 2000, which the model interprets as a speedup in MFP growth.[33] The last line of the table shows that, all told, IT capital deepening and faster MFP growth for IT producers more than accounted for the total speedup in labor productivity growth during 1995–2000. These results confirm that the IT-centric story for the late 1990s holds up after incorporating the latest vintage of data and extending the framework to account for adjustment costs and utilization effects.

33. Jorgenson (2001) argues that the steeper declines in semiconductor prices reflected a shift from three-year to two-year technology cycles starting in the mid-1990s. Aizcorbe, Oliner, and Sichel (2006) report that shorter technology cycles drove semiconductor prices down more rapidly after 1995, but they also estimated that price-cost markups for semiconductor producers narrowed from 1995 to 2001. Accordingly, the faster price declines in the late 1990s—and the associated pickup in MFP growth—partly reflected true improvements in technology and partly changes in markups. These results suggest some caution in interpreting price-based swings in MFP growth as a proxy for corresponding swings in the pace of technological advance.

Table 1. Contributions to Growth in Labor Productivity Based on Published Data[a]

Item	*1973–95 (1)*	*1995–2000 (2)*	*2000–06 (3)*	*Change at 1995 (2) – (1)*	*Change at 2000 (3) – (2)*
Growth of labor productivity in the nonfarm business sector (percent a year)[b]	1.47	2.51	2.86	1.04	0.35
Contributions from (percentage points):					
Capital deepening	0.76	1.11	0.85	0.35	–0.26
IT capital	0.46	1.09	0.61	0.63	–0.48
Computer hardware	0.25	0.60	0.28	0.35	–0.32
Software	0.13	0.34	0.20	0.21	–0.14
Communications equipment	0.07	0.15	0.14	0.08	–0.01
Other tangible capital	0.30	0.02	0.24	–0.28	0.22
Improvement in labor quality	0.27	0.26	0.34	–0.01	0.08
Growth of MFP	0.44	1.14	1.67	0.70	0.53
Effect of adjustment costs	0.04	–0.11	0.08	–0.15	0.19
Effect of utilization	–0.03	0.13	–0.09	0.16	–0.22
Growth of MFP excluding above effects	0.42	1.11	1.68	0.69	0.57
IT-producing sectors	0.28	0.75	0.51	0.47	–0.24
Semiconductors	0.09	0.45	0.23	0.36	–0.22
Computer hardware	0.12	0.19	0.10	0.07	–0.09
Software	0.04	0.08	0.13	0.04	0.05
Communications equipment	0.04	0.04	0.05	0.00	0.01
Other nonfarm business	0.15	0.36	1.17	0.21	0.81
Memorandum: total IT contribution[c]	0.74	1.84	1.12	1.10	–0.72

Source: Authors' calculations.
a. Detail may not sum to totals because of rounding.
b. Measured as 100 times the average annual log difference for the indicated years.
c. Sum of capital deepening for IT capital and growth of MFP in IT-producing sectors.

The table also quantifies the influence of adjustment costs and changes in utilization during this period (the two lines under "Growth of MFP"). These two factors, on net, do not explain any of the upward swing in MFP growth from 1973–95 to 1995–2000, which is consistent with the results in BFS. Although the greater utilization of capital and labor had a positive effect on MFP growth during 1995–2000, this influence was offset by the negative effect from the higher adjustment costs induced by the investment boom of that period.

Table 1 tells a sharply different story for the period since 2000. Even though labor productivity accelerated another 0.35 percentage point, the growth contributions from IT capital deepening and MFP advances in IT-producing sectors dropped back substantially. At the same time, MFP growth strengthened in the rest of nonfarm business, adding roughly ¾ percentage point to annual labor productivity growth during 2000–06 from its 1995–2000 average. And, given the minimal growth in hours worked after 2000, even the anemic advance in investment outlays led to a positive swing in the growth contribution from non-IT capital deepening ("Other tangible capital").[34]

All in all, table 1 indicates that IT-related factors retreated from center stage after 2000 and that other factors—most notably, a surge in MFP growth outside the IT-producing sectors—were responsible for the continued rapid advance in labor productivity as reported in the published data.[35] Nonetheless, averaging over the period 1995–2006, the use and production of IT capital are important, accounting for roughly two-thirds of the post-1995 step-up in labor productivity growth. The next section of the paper examines whether the inclusion of intangible capital changes this characterization.

We conclude this discussion with two points. The first concerns the use of the year 2000 as the breakpoint for comparing the boom period of the late 1990s with more recent years. We chose 2000 rather than 2001 to avoid splitting the two periods at a recession year, which would have accentuated the need for cyclical adjustments. However, our main findings are robust to breaking the two periods at 2001. Second, our big-picture results are very similar to those in Jorgenson, Ho, and Stiroh,[36] which contains the latest estimates from the framework pioneered by Dale Jorgenson. Consistent with our findings, their framework emphasizes the role of IT in explaining the step-up in labor productivity growth during 1995–2000. It also shows a reduced contribution from IT after 2000, which was more than offset by other factors. The differences in results are relatively minor and largely stem from the broader sectoral coverage in the Jorgenson, Ho, and Stiroh

34. The combined effect of adjustment costs and factor utilization remained essentially zero after 2000. Although the deceleration in investment spending after 2000 eliminated the negative effect of adjustment costs, the net decline in the workweek pushed the utilization effect into negative territory.

35. Of course, MFP growth is a residual, so this result speaks only to the proximate sources of growth and does not shed light on the more fundamental forces driving MFP growth.

36. Jorgenson, Ho, and Stiroh (2007).

framework. In particular, their framework incorporates the flow of services from owner-occupied housing and consumer durable goods into both output and capital input. The stocks of these assets have grown rapidly since the mid-1990s, and so Jorgenson, Ho, and Stiroh's estimates of non-IT capital deepening are larger than those reported here.

Aggregate Growth Accounting with Intangible Capital

The growth accounting analysis in the previous section relies on published data, which exclude virtually all types of intangible capital except software. As argued by Corrado, Hulten, and Sichel,[37] any intangible asset that generates a service flow beyond the current period should be included in the capital stock, and the production of such assets should be included in current-period output. Applying this standard, in their 2006 paper (henceforth CHS) Corrado, Hulten, and Sichel estimated that the intangible investment excluded from the NIPAs amounted to roughly $1 trillion annually over 2000–03, an amount nearly equal to outlays for business fixed investment included in the national accounts, and they constructed a growth accounting system that includes a broad set of intangibles through 2003.

Of total business investment in intangibles, CHS estimate that scientific and nonscientific R&D each accounted for about 19 percent during 2000–03; computerized information, which consists mostly of the software category already included in the NIPAs, accounted for 14 percent; brand equity accounted for 13 percent; and firm-specific organizational capital accounted for about 35 percent. The last category contains many well-known examples of the successful deployment of intangible capital, including Wal-Mart's supply-chain technology, Dell's build-to-order business model, and Intel's expertise in organizing semiconductor production.[38]

The CHS estimates of intangible investment and capital are a valuable addition to the literature, but the source data for their series are currently available only through 2004 or 2005. Thus their approach cannot be used to develop growth accounting estimates that are as timely as those based on published data. As an alternative, we construct a data system for intangi-

37. Corrado, Hulten, and Sichel (2005, 2006).

38. See Brynjolfsson and Hitt (2000), Brynjolfsson, Hitt, and Yang (2002), and McKinsey Global Institute (2002) for interesting case studies regarding the creation of organizational capital.

bles that runs through 2006, based on the framework in BFOS. In the BFOS model, firms use intangible capital as a complement to their IT capital. Because of this connection to IT capital, we can generate estimates of intangible investment and capital from published data on IT capital and related series.

BFOS used their model for a more limited purpose: to specify and estimate regressions to discern whether intangibles could explain the MFP growth patterns in published industry data. They did not formally build intangibles into an integrated growth accounting framework along the lines of CHS. That is precisely what we do here.[39]

Description of the Model

The basic features of the BFOS model are as follows. Firms have a (value-added) production function in which IT capital and intangible capital are complementary inputs:

$$V_t = F\left[G\left(K_t^{IT}, R_t\right), K_t^{NT}, L_t, z_t\right], \tag{8}$$

where K_t^{IT}, R_t, and K_t^{NT} denote IT capital, intangible capital, and tangible capital other than IT capital, respectively; L_t is labor input; and z_t is the level of technology. For simplicity, BFOS assume that there are no adjustment costs and that factor utilization does not vary. The function G that combines IT capital and intangible capital is assumed to take the constant elasticity of substitution form:

$$G\left(K_t^{IT}, R_t\right) = \left[a\left(K_t^{IT}\right)^{(\sigma-1)/\sigma} + (1-a)\left(R_t\right)^{(\sigma-1)/\sigma}\right]^{\sigma/(\sigma-1)} \tag{9}$$

where σ is the elasticity of substitution between K_t^{IT} and R_t, and a governs the income share of each type of capital.

Because K_t^{IT} and R_t are separable from other inputs, firms minimize costs by first choosing the optimal combination of K_t^{IT} and R_t and then selecting

39. The BFOS model focuses on intangibles that are related to information technology. This is a narrower purview than in Corrado, Hulten, and Sichel (2005, 2006), who develop estimates for a full range of intangible assets, regardless of their connection to IT. Although we do not provide a comprehensive accounting for intangibles, we highlight the intangible assets that are central to an assessment of the contribution of information technology to economic growth.

other inputs conditional on this choice. For the first-stage optimization, the usual first-order condition sets the ratio of the marginal products of K_t^{IT} and R_t equal to the ratio of their user costs, which implies

$$R_t = K_t^{IT}\left(\frac{1-a}{a}\right)^{\sigma}\left(\frac{r_t^{IT}}{r_t^{R}}\right)^{\sigma}, \tag{10}$$

where r_t^{IT} and r_t^R denote the respective user costs. Equation 10 implies the following expression for the growth of intangible capital:

$$\dot{R}_t = \dot{K}_t^{IT} + \sigma\left(\dot{r}_t^{IT} - \dot{r}_t^{R}\right). \tag{11}$$

Importantly, equation 11 enables us to calculate a model-implied series for the growth rate of intangible capital based solely on data for IT capital and user costs and on an assumed value for the elasticity of substitution between intangible capital and IT capital. No direct data on intangible capital are required. We chain together the time series of growth rates from equation 11 to produce an indexed series for the level of real intangible capital, R.

To implement equation 11, we calculate $\dot{K}_t^{IT}$ and $\dot{r}_t^{IT}$ from the same BLS data that we used in the previous section. We also need to specify the user cost for intangible capital (r_t^R) and the elasticity of substitution between IT capital and intangible capital (σ). We use data from CHS to calculate $\dot{r}_t^R$ and σ, as described next.

CHS measure the user cost of intangible capital in accord with the standard Hall and Jorgenson formulation:[40]

$$r^R = p^R\left(\rho + \delta^R - \Pi^R\right)T^R, \tag{12}$$

where p^R is the price index for this type of capital, ρ is the nominal rate of return net of depreciation, δ^R is the depreciation rate, Π^R is the expected capital gain over and above that captured in the depreciation rate, and T^R accounts for the tax treatment of intangible assets. Equation 12 is identical to the user cost formula that we employ for all other types of capital in our growth accounting framework. We adopt CHS's specification of each term in the user cost formula.

40. Hall and Jorgenson (1967).

To select a value for the elasticity of substitution σ, we examined the CHS series for the income shares of IT capital and intangible capital.[41] If σ were equal to one (the Cobb-Douglas case), the ratio of the IT income share to the intangible income share drawn from data in CHS (which we denote by $\alpha_t^{R,CHS}$) would be constant. In fact, the ratio of the IT income share to the intangible income share trends upward in the CHS data. Given that the user cost of IT capital has fallen relative to that of intangible capital, the upward trend in the share ratio implies more substitution toward IT capital than would occur in the Cobb-Douglas case. We find that setting σ to 1.25 approximates the upward trend in the share ratio.

To complete the system, we need a nominal anchor to convert the indexed series for R_t to dollar values. For the nominal anchor, we require that the average income share of intangible capital in our framework over 1973–2003 (denoted $\bar{\alpha}_t^{R,BFOS}$) equal the average value of the CHS-based share over the same period:[42]

$$\bar{\alpha}^{R,BFOS} = \bar{\alpha}^{R,CHS}. \tag{13}$$

To satisfy equation 13, we scale the indexed levels series for intangible capital, R_t, by ψ. The income share for intangible capital in year t is then

$$\alpha_t^{R,BFOS} = \frac{r_t^R R_t \psi}{p_t V_t + r_t^R R_t \psi}, \tag{14}$$

where the denominator equals the sum of published nonfarm business income and the income accruing to intangible capital. We average equation 14 over the period 1973–2003, substitute the average share into the left-hand side of equation 13, and solve for the scaling factor ψ. We then apply this scaling factor to the indexed levels series for R_t and denote the resulting series for real intangible capital by R_t^*. Given R_t^*, the associated

41. Specifically, for the income share of intangible capital, we use the income share series for "New CHS intangibles," that is, those intangibles over and above those included in the NIPAs. We then adjust this series downward to account for the fact that some CHS intangibles are not related to IT and thus do not fit in the BFOS framework. As a crude adjustment, we remove the income share associated with brand equity and one-third of the income share for other components of "New CHS intangibles."

42. We use 2003 as the final year for this calculation because that is the last year of data in CHS.

series for real intangible investment comes from the standard perpetual inventory equation:

$$N_t^* = R_t^* - \left(1 - \delta^R\right) R_{t-1}^*. \tag{15}$$

We calculate growth in real intangible investment from the series for N_t^*.

We now have all the pieces we need to incorporate intangibles into our growth accounting framework. An important point is that including intangible assets affects both the output and the input sides of the production accounts. On the output side, the growth of production equals a weighted average of growth in real intangible investment N^* and growth in published real nonfarm business output. The weight for each component equals its share in the augmented measure of current-dollar output. On the input side, the total contribution from capital now includes a term for intangible capital, calculated as the income share for intangible capital times the growth rate of this capital in real terms, $\alpha_t^{R,BFOS} \times \dot{R}$. The income shares for all other inputs are scaled down so that the shares (including that for intangible capital) sum to one.[43]

Results

The results from this augmented growth accounting framework, shown in table 2, differ in important respects from the results based on published data. As can be seen by comparing the first two lines, labor productivity growth during 1995–2000 becomes stronger once we include intangibles, but it becomes less robust during 2000–06. Indeed, in the augmented framework, the productivity advance since 2000 is estimated to be well below that posted during 1995–2000, reversing the relative growth rates for the two periods based on published data. This reversal arises from the time profile for real investment in intangibles. As shown in the lower part of the table, real intangible investment is estimated to have surged during 1995–2000, boosting growth in aggregate output, and then retreated during 2000–06.

43. See Yang and Brynjolfsson (2001) for an alternative approach to incorporating intangibles into a standard growth accounting framework. Their approach relies on financial market valuations to infer the amount of unmeasured intangible investment and shows that, through 1999, the inclusion of intangibles had potentially sizable effects on the measured growth of MFP.

Table 2. Contributions to Growth in Labor Productivity: Accounting for Intangibles[a]

Item	*1973–95 (1)*	*1995–2000 (2)*	*2000–06 (3)*	*Change at 1995 (2) – (1)*	*Change at 2000 (3) – (2)*
Growth of labor productivity in the nonfarm business sector (percent a year)[b]					
Based on published data[c]	1.47	2.51	2.86	1.04	0.35
Accounting for intangibles[d]	1.58	2.95	2.43	1.37	–0.52
Contributions from (percentage points):[e]					
Capital deepening	0.94	1.40	0.75	0.46	–0.65
IT capital	0.44	1.02	0.57	0.58	–0.45
Other tangible capital	0.29	0.02	0.22	–0.27	0.20
New intangible capital	0.22	0.36	–0.04	0.14	–0.40
Improvement in labor quality	0.26	0.25	0.32	–0.01	0.07
Growth of MFP	0.37	1.31	1.36	0.94	0.05
Effect of adjustment costs	0.04	–0.12	0.10	–0.16	0.22
Effect of utilization	–0.03	0.13	–0.09	0.16	–0.22
Growth of MFP excluding above effects	0.36	1.30	1.34	0.94	0.04
IT-producing sectors	0.26	0.72	0.47	0.46	–0.25
Intangible sector	0.01	0.08	0.07	0.07	–0.01
Other nonfarm business	0.09	0.50	0.81	0.41	0.31
Memoranda: Growth rates (percent a year)[b]					
Real intangible investment	5.7	12.0	–4.6	6.3	–16.6
Real intangible capital services	6.8	7.7	–0.7	0.9	–8.4
Real IT capital services	15.6	20.4	8.9	4.8	–11.5
User cost, intangible capital	4.6	1.2	3.6	–3.4	2.4
User cost, IT capital	–2.4	–9.0	–4.1	–6.6	4.9
Nominal shares (percent)					
Expenditure share, intangible investment	4.6	6.2	5.1	1.6	–1.1
Income share, intangible capital	4.7	6.4	6.5	1.7	0.1

Source: Authors' calculations.

a. Detail may not sum to totals because of rounding.

b. Measured as 100 times the average annual log difference for the indicated years.

c. From table 1.

d. Derived using methodology discussed in the text.

e. Contributions to growth of nonfarm business labor productivity with accounting for intangibles.

The growth contribution from intangible capital deepening ("New intangible capital" in table 2) follows the general pattern for IT capital, moving higher during 1995–2000 and then falling back. This similarity reflects the explicit link between intangible capital and IT capital in the BFOS model. The lower part of the table provides full detail on the growth of intangible capital and its determinants from equation 11. Despite the broadly similar growth contour for intangible capital and IT capital across periods, intangible capital increases much less rapidly than IT capital in each period, because of the quality-adjusted declines in IT prices that cause the user cost of IT capital to trend lower. This user cost effect became more pronounced during 1995–2000—when the prices for IT capital goods fell especially rapidly—restraining the growth of intangible capital even though the growth of IT capital jumped.

Taken together, the revisions to the output and the input sides of the growth accounting equation imply a revised path for MFP growth, after controlling for the effects of adjustment costs and factor utilization ("Growth of MFP excluding above effects"). The inclusion of intangibles leaves a somewhat smaller imprint on MFP growth than on the growth of labor productivity, as the revisions to the two sides of the growth accounting equation are partly offsetting. Consistent with the more muted revision from the published data, the path for MFP continues to show the fastest growth after 2000. However, the pickup in MFP growth from 1995–2000 to 2000–06, at 0.04 percentage point, is negligible compared with that indicated by published data (see the equivalent line in table 1).

Robustness Checks

The BFOS model imposes a strictly contemporaneous relationship between the growth of intangible capital and the growth of IT capital. This relationship may be too tight, as the two forms of capital accumulation may be subject to (unmodeled) adjustment costs and differences in project length from the planning stage to final rollout.

To examine the robustness of our results, we consider alternative timing assumptions for the growth of intangible capital. The first two alternatives smooth the growth of intangible capital without introducing leads or lags relative to the growth in IT capital. The idea is that some projects to produce intangible capital may be long-lived and thus may not display the same stops and starts as purchases of IT capital. We implement this timing change by using a three-year or a five-year centered moving average for the growth rate of IT capital and its user cost on the right-hand side of equation 11. The third timing change allows intangible capital growth to lag IT capital growth by a year but does not affect the relative volatility of the series. This timing assumption embeds the often-expressed view that firms take time to accumulate the intangible capital needed to fully leverage their IT investments.

Our reading of the literature suggests that the first two alternatives fit the facts better than the introduction of a systematic lag from IT capital to intangible capital. Case studies published elsewhere portray the installation of IT capital and associated changes in business practices and organization as interwoven rather than strictly sequential.[44] Sinan Aral, Erik Brynjolfsson, and D. J. Wu support this view, noting that "[as] firms successfully implement IT (and complementary intangible investments) and experience greater marginal benefits from IT investments, they react by investing in more IT," a process they characterize as a "virtuous cycle."[45] Nonetheless, we consider the scenario with the lagged accumulation of intangible capital for the sake of completeness.

As the top panel of table 3 shows, these alternative timing assumptions have some effect on the period-by-period growth of real intangible capital but do not change the basic result, namely, that this type of capital essentially has not grown since 2000. The series for intangible investment, shown in the bottom panel of the table, is also reasonably robust to alternative timing assumptions. In each case, real intangible investment is estimated to have declined since 2000. As a further robustness check, the table also displays the CHS series for intangible capital and intangible investment, which we have extended through 2005 based on some of the key source

44. Brynjolfsson and Hitt (2000), Brynjolfsson, Hitt, and Yang (2002), and McKinsey Global Institute (2002).

45. Aral, Brynjolfsson, and Wu (2006, p. 2). Some interpret the econometric results in Brynjolfsson and Hitt (2003) as support for a lag between the installation of IT capital and the accumulation of complementary capital. We believe this interpretation is incorrect. Brynjolfsson and Hitt show that the firm-level effect of computerization on MFP growth is much stronger when evaluated over multiyear periods than when evaluated on a year-by-year basis. Importantly, however, the variables in their regression are all measured contemporaneously, whether over single-year or multiyear periods. Accordingly, their results suggest that the correlation between the growth of IT capital and intangible capital may be low on a year-by-year basis, but that a stronger *contemporaneous* correlation holds over longer periods, boosting the measured effect on MFP growth.

Table 3. Growth of Intangible Capital and Investment Under Alternative Timing Assumptions for Intangible Capital[a]
Percent a year

	Average annual rate		
Timing assumption	*1973–95*	*1995–2000*	*2000–05*
Intangible capital services			
Baseline timing for intangible capital growth	6.8	7.7	–0.9
Three-year centered moving average	6.9	7.1	–0.3
Five-year centered moving average	6.8	6.7	0.4
One-year lag relative to baseline	7.4	7.1	–0.2
Memorandum: Corrado, Hulten, and Sichel series[b]	5.2	7.3	2.8
Intangible investment			
Baseline timing for intangible capital growth	5.7	12.0	–6.2
Three-year centered moving average	6.1	9.1	–5.2
Five-year centered moving average	6.1	8.5	–4.1
One-year lag relative to baseline	6.9	8.8	–8.7
Memorandum: Corrado, Hulten, and Sichel series[b]	5.2	8.3	1.1

Source: Authors' calculations.

a. The alternative timing assumptions pertain to growth of intangible capital. The effect on intangible investment is calculated through the perpetual inventory relationship linking investment and capital.

b. From Corrado, Hulten, and Sichel (2006), series for "New CHS intangibles," with preliminary extension to 2005 estimated by the authors.

data in their framework. (This is a preliminary extension of the CHS series for illustrative purposes only and should not be regarded as official CHS data.) The extended CHS series for intangible investment and capital exhibit patterns across periods that are broadly similar to those in our series. Notably, the CHS series decelerate sharply after 2000, and the growth rates for 2000–05 are the weakest for the three periods shown, confirming an important qualitative feature of our estimates. Because the CHS series are constructed independently from the series in this paper, the qualitative correspondence between them lends credibility to the basic thrust of our results, if not to the precise figures.

Table 4 explores the growth accounting implications of the alternative timing assumptions for intangible capital. For each timing assumption we show three key variables: growth in labor productivity, the growth contribution from intangible capital deepening, and MFP growth (after controlling for the effects of adjustment costs and factor utilization). Most features of the baseline results are robust to the alternative assumptions. In every case,

Table 4. Growth in Labor Productivity and Selected Growth Contributions Under Alternative Timing Assumptions for Intangible Capital[a]

Item	*1973–95 (1)*	*1995–2000 (2)*	*2000–06 (3)*	*Change at 1995 (2) – (1)*	*Change at 2000 (3) – (2)*
Baseline[b]					
Labor productivity growth	1.58	2.95	2.43	1.37	–0.52
Contribution from intangible capital	0.22	0.36	–0.04	0.14	–0.40
Contribution from MFP growth[c]	0.36	1.30	1.34	0.94	0.04
Three-year centered moving average					
Labor productivity growth	1.59	2.77	2.56	1.18	–0.21
Contribution from intangible capital	0.22	0.32	0.00	0.10	–0.32
Contribution from MFP growth[c]	0.38	1.13	1.45	0.75	0.32
Five-year centered moving average					
Labor productivity growth	1.59	2.72	2.59	1.13	–0.13
Contribution from intangible capital	0.22	0.29	0.02	0.07	–0.27
Contribution from MFP growth[c]	0.38	1.11	1.46	0.73	0.35
One-year lag relative to baseline					
Labor productivity growth	1.62	2.77	2.51	1.15	–0.26
Contribution from intangible capital	0.23	0.32	0.01	0.09	–0.31
Contribution from MFP growth[c]	0.39	1.13	1.39	0.74	0.26

Source: Authors' calculations.

a. Growth of labor productivity is in percent a year and is measured as 100 times the average annual log difference for the indicated years. Growth contributions are in percentage points.

b. From table 2.

c. After controlling for effects of adjustment costs and utilization.

labor productivity is estimated to have grown more rapidly during 1995–2000 than during 2000–06, reversing the relative growth rates based on published data. In addition, the growth contribution from intangible capital deepening is always largest during 1995–2000 and then drops back to essentially zero during 2000–06. Finally, although the alternative timing assumptions generate a larger step-up in MFP growth after 2000 than in the baseline, they nonetheless temper the increase by 0.2 to 0.3 percentage point relative to the published data.

Industry-Level Productivity

We now turn to the industry origins of U.S. productivity growth during the late 1990s and after 2000. The aggregate data show that the sources of productivity growth changed after 2000, which suggests that the industry-level origins of aggregate productivity growth and the underlying forces may also have changed. To explore this, we construct productivity accounts for sixty industries that span the U.S. private economy from 1988 to 2005. Although measurement error, omitted variables, and endogeneity problems always make it difficult to identify the sources of productivity gains, we make some progress by exploiting cross-sectional variation in industry productivity over time and by examining the link between productivity and observable factors such as IT intensity and changing profit shares.

The industry analysis presented here focuses on labor productivity, reflecting our interest in understanding the industry origins of aggregate labor productivity growth. Moreover, we do not have the detailed data on labor quality, intangible investment, or adjustment costs at the industry level necessary to create comparable estimates of MFP growth. To the extent that intangible capital is correlated with IT investment, however, one can interpret the IT intensity results as broadly indicative of the whole suite of activities that are complementary to IT.

Output Measures, Data, and Summary Statistics

OUTPUT MEASURES. Industry output can be measured using either a gross output or a value-added concept, each with its advantages and disadvantages.[46] Gross output corresponds closely to the conventional idea of output or sales and reflects all inputs including capital, labor, and intermediate energy, materials, and services. Value added, by contrast, is a somewhat artificial concept that strips out the contribution of intermediate inputs and incorporates only capital and labor.

Although both value added and gross output are used for productivity analysis, we favor gross output. Empirical work by, among others, Michael Bruno; J. R. Norsworthy and David Malmquist; Jorgenson, Frank Gollop,

46. For background on industry productivity analysis, see Jorgenson, Gollop, and Fraumeni (1987), Basu and Fernald (1995, 1997, 2001, 2007), Nordhaus (2002b), Stiroh (2002a, 2002b), Triplett and Bosworth (2004), and Bosworth and Triplett (2007).

and Barbara Fraumeni rejects the existence of value-added functions on separability grounds.[47] Basu and Fernald show that using value-added data leads to biased estimates and incorrect inferences about production parameters.[48] A later contribution by the same authors argues against the value-added function because failure of the neoclassical assumption about perfect competition implies that some of the contribution of intermediate inputs remains in measured value-added growth.[49] Value added has the advantage, however, that it aggregates directly to GDP.

DATA. We use three pieces of U.S. industry-level data—output, hours, and capital stock—from government sources. The first two create a panel of average labor productivity (ALP) across U.S. industries, and the third is used to develop measures of the intensity of the use of IT. One practical difficulty is the recent conversion of the industry data from the Standard Industrial Classification (SIC) system to the North American Industrial Classification (NAICS) system, which makes it difficult to construct long historical time series or to directly compare the most recent data with earlier results.

BEA publishes annual data on value added and gross output for sixty-five industries that together make up the private U.S. economy.[50] These data, which are based on an integrated set of input-output and industry production accounts, span 1947–2005 for real value added and 1987–2005 for real gross output. Although BEA also publishes various measures of employment by industry, it does not provide industry-level series on hours worked. We obtain hours by industry from the Output and Employment database maintained by the Office of Occupational Statistics and Employment Projections at BLS. Complete data on total hours for all industries begin in 1988.[51] Because these hours data are currently available only to 2004, we use the growth rate of full-time equivalent employees for the disaggregated industries, from BEA data, to proxy for hours growth in 2005.

47. Bruno (1978); Norsworthy and Malmquist (1983); Jorgenson, Gollop, and Fraumeni (1987).

48. Basu and Fernald (1995, 1997).

49. Basu and Fernald (2001).

50. Howells, Barefoot, and Lindberg (2006).

51. The underlying sources of these data are the BLS Current Employment Survey (for wage and salary jobs and average weekly hours), the Current Population Survey (for self-employed and unpaid workers, agricultural workers, and within-household employment), and unemployment insurance tax records.

We create two measures of industry ALP—real value added per hour worked and real gross output per hour worked—by combining the BEA output data with the BLS hours data across industries for 1988 to 2005.

The third data source is the Fixed Asset accounts from BEA for nonresidential capital. These data include forty-six different types of nonresidential capital for sixty-three disaggregated NAICS industries since 1987. To estimate capital services we map the asset-specific service prices from Jorgenson, Ho, and Stiroh onto these assets and employ Tornqvist aggregation using the service price and a two-period average of the capital stock for each asset in each industry.[52] The resulting measure of capital services is an approximation, because we miss industry variation in rates of return, asset-specific inflation, and tax code parameters. Nevertheless, it captures the relatively high service prices for short-lived assets such as IT capital, defined as above to include computer hardware, software, and communications equipment.

We combine these three sources of data to form a panel from 1988 to 2005 for a private industry aggregate, fifteen broad sectors, and sixty disaggregated industries. The fifteen-sector breakdown follows BEA's convention, except that manufacturing is broken into durables and nondurables. The number of disaggregated industries is smaller than that available from either BEA or BLS, because of the need to generate consistently defined industries across all data sources. All aggregation is done via Tornqvist indices, except for hours, which are simply summed. Both the broad sectors and the disaggregated industries sum to the private industry aggregates of nominal output from BEA, hours from BLS, and nominal nonresidential capital from BEA. The list of industries and their 2005 value added are reported in appendix table A-1.

SUMMARY STATISTICS. Table 5 reports estimates of labor productivity growth from our industry data and compares them with the latest estimates from BLS. The first two lines of the top panel report average annual growth of ALP for the BLS business and nonfarm business sectors, and the third line reports the private industry aggregate described above. Although our private industry aggregate grows somewhat less rapidly than the BLS aggregates, all three series show similar trends: a pickup of ALP growth of about 1 percentage point after 1995 and a smaller increase after 2000.

52. Jorgenson, Ho, and Stiroh (2007).

The second panel of table 5 reports estimates for the fifteen broad NAICS sectors. These sectors range in size from the very large finance, insurance, real estate, rental, and leasing sector, at 23.3 percent of 2005 value added, to the very small agriculture, forestry, fishing, and hunting sector, at only 1.1 percent. In terms of ALP growth, eight of these fifteen sectors, which accounted for 73 percent of value added in 2005, showed faster productivity growth over 1995–2000 than over 1988–95.[53] The further acceleration in aggregate productivity after 2000 occurred in seven sectors, which accounted for only 44 percent of 2005 value added. Although productivity in the large retail trade, wholesale trade, and finance sectors all decelerated after 2000, the two trade sectors continued to post impressive productivity gains through 2005.

The pickup in aggregate productivity growth in the mid-1990s appears to have originated in different sectors than did the subsequent step-up in 2000. Six sectors (agriculture, durable goods, wholesale trade, retail trade, finance, and arts and entertainment) show an acceleration after 1995 but a deceleration after 2000, whereas five sectors (construction, nondurables, utilities, information, and other services) show the opposite pattern. Together these eleven sectors produced 72 percent of value added in 2005. In their analysis of MFP growth, Corrado and others reach a similar conclusion, although Bosworth and Triplett emphasize the continued importance of service industries as a source of aggregate productivity growth.[54]

Table 5 also summarizes, in the third and fourth panels, the disaggregated industry data by reporting the mean, median, and hours-weighted mean productivity growth rates across these industries for gross output and value added, respectively. One interesting observation is the divergence in trends between gross output and value-added measures of productivity: the post-1995 gains are strongest for gross output, whereas the post-2000 gains are strongest for value added. Both series incorporate the same hours data, so that this divergence directly reflects differences between the gross output and value-added output measures.

It is beyond the scope of this paper to investigate this divergence further. For completeness, we report results for both gross output and value added,

53. As a comparison, Stiroh (2001, 2002b) reported an acceleration of ALP after 1995 for six of ten broad sectors, which accounted for the majority of output using earlier vintages of SIC data.

54. Corrado and others (2007); Bosworth and Triplett (2007).

Table 5. Estimates of Labor Productivity Growth in the Aggregate and by Sector

Item	*Value added, 2005*		*Average growth rate of labor productivity (percent a year)*			*Change in productivity growth rate (percentage points)*	
	Billions of dollars	*Share (percent)*	*1988–95*	*1995–2000*	*2000–05*	*1988–95 to 1995–2000*	*1995–2000 to 2000–05*
Value added, aggregate measures[a]							
BLS business sector			1.48	2.69	3.07	1.21	0.38
BLS nonfarm business sector			1.46	2.52	3.02	1.06	0.50
Private industry aggregate, this paper	10,892	100.0	1.25	2.24	2.52	0.99	0.28
Value added by broad sector[a]							
Agriculture, forestry, fishing, and hunting	123	1.1	1.95	5.31	5.13	3.36	–0.19
Mining	233	2.1	3.54	0.59	–4.59	–2.95	–5.19
Construction	611	5.6	–0.32	–1.19	–0.98	–0.87	0.22
Durable goods	854	7.8	3.57	7.69	6.04	4.13	–1.65
Nondurable goods	658	6.0	2.26	1.78	4.26	–0.48	2.49
Utilities	248	2.3	5.14	3.43	4.03	–1.70	0.60
Wholesale trade	743	6.8	2.24	5.41	3.64	3.17	–1.77
Retail trade	824	7.6	2.69	4.66	4.00	1.97	–0.66

Transportation and warehousing	345	3.2	3.00	2.48	2.12	–0.52	–0.36
Information	555	5.1	3.70	2.48	8.85	–1.23	6.37
Finance, insurance, real estate, rental, and leasing	2,536	23.3	1.77	1.83	1.73	0.07	–0.11
Professional and business services	1,459	13.4	–0.94	0.16	2.33	1.11	2.16
Education services, health care, social assistance	975	9.0	–2.40	–1.22	0.84	1.18	2.07
Arts, entertainment, recreation, accommodation, and food services	445	4.1	0.65	1.12	0.13	0.46	–0.99
Other services, except government	283	2.6	–0.31	–1.45	–0.32	–1.14	1.13
Gross output by detailed industry[b]							
Mean			1.80	2.95	2.28	1.15	–0.68
Median			1.62	2.19	1.88	0.57	–0.30
Weighted mean[c]			1.59	2.68	2.19	1.09	–0.49
Value added by detailed industry[b]							
Mean			1.78	2.02	2.80	0.24	0.78
Median			1.74	1.16	2.82	–0.58	1.66
Weighted mean[c]			1.33	1.94	2.46	0.62	0.51

Sources: Authors' calculations.

a. Growth of real value added per hour worked, measured as 100 times the average log difference for the indicated years.

b. Calculated across the sixty observations in each period using real gross output or real value added per hour worked.

c. Industries are weighted by hours at the beginning of each period.

although, again, we prefer gross output because it is a more fundamental measure of production and does not require additional assumptions about the nature of the production function.

Finally, we emphasize that there is enormous heterogeneity among the disaggregated industries that lie beneath these summary statistics, both within time periods and across time. For example, thirty-seven of the sixty industries, which accounted for nearly 60 percent of aggregate output, experienced an acceleration of productivity after 1995 but a decline after 2000, or vice versa. This highlights the widespread churning and reallocation of resources among industries, which we show to be an important source of aggregate productivity gains.

Industry Origins of the Aggregate Productivity Gains

We now review how the data for the disaggregated industries can be aggregated to form economy-wide productivity estimates, and we employ this familiar framework to identify the industry origins of the aggregate productivity gains over 1988–2005.

DECOMPOSITION AND REALLOCATIONS. At the industry level, real value added is defined implicitly from a gross output production function as

$$\dot{Y}_i = \alpha_i^V \dot{V}_i + (1 - \alpha_i^V)\dot{M}_i, \tag{16}$$

where α_i^V is the average share of nominal value added in nominal gross output for industry i, and M_i denotes real intermediate inputs.[55] One attractive property of industry value added is that it aggregates to a simple expression for growth in aggregate value added:

$$\dot{V} = \sum_i v_i \dot{V}_i, \tag{17}$$

where v_i is the average share of industry i's nominal value added in aggregate nominal value added. Aggregate hours worked, H, is the simple sum of industry hours, H_i,

55. BEA uses the "double deflation" method to estimate real value added for all industries as the difference between real gross output and real intermediate inputs (Howells, Barefoot, and Lindberg, 2006). Basu and Fernald (2001) show that this can be approximated, as in equation 16, by defining gross output growth as a weighted average of value added and intermediate input growth.

$$H = \sum_i H_i, \tag{18}$$

and aggregate labor productivity is defined as $ALP^V = V/H$.

Equations 16, 17, and 18 can be combined to yield the following decomposition of ALP growth:[56]

$$\begin{aligned} \dot{ALP^V} &= \left(\sum_i v_i \dot{ALP_i^Y}\right) - \left[\sum_i m_i \left(\dot{M}_i - \dot{Y}_i\right)\right] + \left(\sum_i v_i \dot{H}_i - \dot{H}\right) \\ &= \left(\sum_i v_i \dot{ALP_i^Y}\right) - R^M + R^H, \end{aligned} \tag{19}$$

where ALP^Y is industry labor productivity based on gross output and m_i is the average ratio of nominal industry intermediate inputs to nominal aggregate value added. This equation simplifies to

$$\begin{aligned} \dot{ALP^V} &= \left(\sum_i v_i \dot{ALP_i^V}\right) + \left(\sum_i v_i \dot{H}_i - \dot{H}\right) \\ &= \left(\sum_i v_i \dot{ALP_i^V}\right) + R^H. \end{aligned} \tag{20}$$

The first term in equation 19 is a "direct productivity effect" equal to the weighted average of growth in gross output labor productivity in the component industries. The second term, R^M, is a "reallocation of materials," which reflects variation in intermediate input intensity across industries. It enters with a negative sign because when more intermediate inputs are used to raise gross output, $\dot{M} > \dot{Y}$, these must be netted out to reach aggregate productivity. The third term, R^H, is a "reallocation of hours." Aggregate hours growth, $\dot{H}$, approximately weights industries by their (lagged) share of aggregate hours, and so aggregate productivity rises if industries with value-added shares above their hours shares—that is, those industries with relatively high (nominal) productivity levels—experience growth in hours. Equation 20 is a simplification using value-added labor productivity at the industry level.[57]

Table 6 reports estimates of the decomposition framework in equations 16 to 20. The first line in the top panel repeats the productivity estimates that come from the BEA data on aggregate private industry output and the sum of hours worked from BLS. The second line reports the estimates we

56. As in Stiroh (2002b).

57. This value-added approach is similar to the decomposition in Nordhaus (2002b).

Table 6. Decompositions of Aggregate Labor Productivity Growth

Item	*No. of industries*	*1988–95* Share of total value added[a] (%)	*1988–95* Contribution to ALP growth[b] (% pts)	*1995–2000* Share of total value added (%)	*1995–2000* Contribution to ALP growth (% pts)	*2000–05* Share of total value added (%)	*2000–05* Contribution to ALP growth (% pts)	*Change in contribution (percentage points)* 1988–95 to 1995–2000	*Change in contribution (percentage points)* 1995–2000 to 2000–05
Aggregates									
Private industry aggregate[c]			1.25		2.24		2.52	0.99	0.28
Aggregated industries[d]	60		1.24		2.20		2.52	0.96	0.32
Decomposition using industry real gross output per hour worked									
Industry contribution	60	100.0	1.79	100.0	3.10	100.0	2.16	1.31	–0.94
IT-producing industries[e]	4	4.0	0.33	5.0	0.50	4.5	0.25	0.17	–0.25
IT-using industries[f]	26	57.3	0.71	58.6	1.99	59.1	1.54	1.28	–0.45
Other industries	30	38.7	0.75	36.4	0.61	36.4	0.37	–0.14	–0.23
Reallocation of materials, $-R^M$ [g]			–0.20		–0.68		0.26	–0.48	0.94
Reallocation of hours, R^H			–0.34		–0.21		0.10	0.13	0.31
Decomposition using industry real value added per hour worked									
Industry contribution			1.59		2.41		2.41	0.83	0.00
IT-producing industries			0.36		0.70		0.47	0.34	–0.23
IT-using industries			0.48		1.31		1.54	0.82	0.24
Other industries			0.74		0.41		0.40	–0.33	0.00
Reallocation of hours, R^H			–0.34		–0.21		0.10	0.13	0.31

Sources: Authors' calculations.

a. Nominal value added in indicated industries divided by aggregate nominal value added for each period, multiplied by 100.

b. Growth of industry productivity, weighted by nominal value-added shares in each year.

c. Based on BEA and BLS aggregate data from table 5.

d. Weighted aggregate of industry output and hours data.

e. Includes computer and electronics products, publishing including software, information and data processing services, and computer system design and related services, as defined by BEA.

f. Includes all non-IT-producing industries with a 1995 IT capital services share above the 1995 median.

g. Reallocations are defined as in equations 19 and 20.

derive by explicitly aggregating the detailed industries as in equations 17 and 18. There is a small divergence for the middle period, but the two estimates tell the same story of a large productivity acceleration after 1995 and a smaller one after 2000.[58]

The second and third panels of table 6 report the decomposition from equations 19 and 20 using gross output data and value-added data, respectively. Both panels indicate a substantial increase in the direct contribution of industry-level productivity after 1995 (1.31 percentage points for gross output and 0.83 percentage point for value added), followed by a large decline after 2000 for gross output (–0.94 percentage point) and no change for value added.

Both the materials and hours reallocation terms turn positive after 2000, boosting the aggregates and suggesting that an important part of the post-2000 productivity gains stemmed from the shifting of inputs among industries.[59] In fact, we do not observe an increase in productivity growth after 2000 when looking at the direct industry contributions, an insight that is only possible with industry-level data.[60]

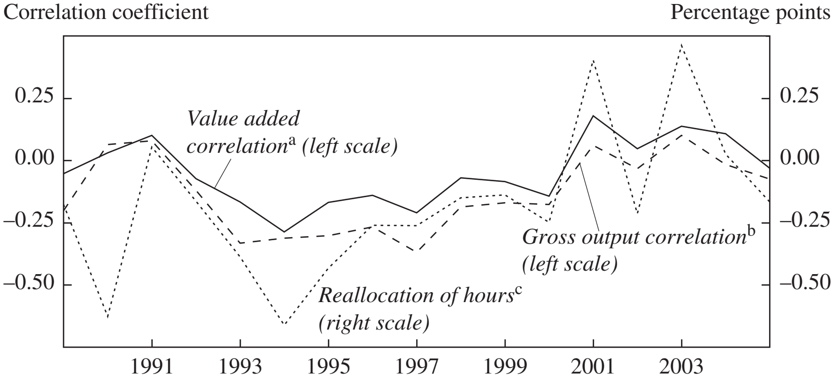
The materials reallocation term contributes positively to aggregate productivity growth when gross output is growing faster than materials, which implies that value added is growing faster than gross output (see equation 16). This pattern has held since 2000 and likely reflects some combination of substitution among inputs, biased technical change, and new production opportunities such as outsourcing. Better understanding of these forces is an important area for future work.

58. We also aggregated the industry output data using a Fisher (rather than the Tornqvist) index and still found a small difference for the period 1995–2000. We do not have an explanation for this.

59. Jorgenson and others (forthcoming) show an increase in both the intermediate input and hours reallocation terms, although both are slightly negative through 2004. The results in Bosworth and Triplett (2007) are similar to ours in some respects (rising direct contribution of gross output productivity through 2000 followed by a substantial fall, and an intermediate reallocation term that switches from negative to positive after 2000), but their hours reallocation term remains negative through 2005. This divergence reflects differences in the estimation of the hours series. Bosworth and Triplett (2007) use the BEA series on full-time/part-time employees, which they scale by total hours per employee from BLS for 1987 to 2004. They hold hours per full-time/part-time employee constant from 2004 to 2005.

60. This is analogous to the analysis of the sources of productivity growth within the U.S. retail trade sector by Foster, Haltiwanger, and Krizan (2002), who report that the majority of productivity gains reflect entry and exit, with a very small contribution from productivity gains within continuing establishments.

Figure 1. Link between Productivity and Hours Reallocation, 1989–2005



Source: Authors' calculations using BLS and BEA data.

a. Annual cross-sectional correlation between hours growth and the lagged level of productivity for the sixty industries in appendix table A-1, calculated using industry value added.

b. Above correlation calculated using industry gross output.

c. Reallocation of hours to high-productivity industries as defined in equation 19. This is the difference between the aggregate growth rate of hours weighted by industry value added and the aggregate growth rate of hours weighted by hours in each of the sixty industries.

The reallocation of hours is positive when industries with relatively high productivity (in nominal terms) have strong hours growth. Growing reallocations are consistent with the notion that increased competitive pressures, flexible labor markets, and restructuring were part of the productivity story in recent years. Elsewhere Stiroh discusses some evidence of increased flexibility of U.S. labor markets and reports evidence of increased reallocation across industries.[61]

To provide an alternative perspective, we calculate the annual cross-sectional correlation between hours growth and the lagged level of ALP for the sixty disaggregated industries. Figure 1 plots the estimated correlations for both the value-added and gross output measures of labor productivity; the figure also shows the term from equation 19 for the annual reallocation of hours to high-productivity industries. All three series seem to have trended upward, particularly since the early 1990s, which suggests that industries with relatively high productivity have become more likely to show strong hours growth in the following year. There also seems to be a

61. Stiroh (forthcoming).

cyclical component, as the correlations and hours reallocations rise during recessions, consistent with the notion of a cleansing effect of recessions.[62]

This interpretation of the reallocation of hours is suggestive; we have provided neither a deep economic explanation nor sophisticated econometric evidence that might identify the causal factors. Rather we are highlighting what appears to be an increasingly important source of aggregate productivity growth and pointing toward further research.

ROLE OF IT CLASSIFICATIONS. Table 6 also quantifies the direct contributions from IT-producing, IT-using, and other industries. Consistent with the classification scheme used by BEA,[63] we identify four industries as IT-producing: computer and electronic products, publishing including software, information and data processing services, and computer system design and related services. Following Stiroh,[64] we identify industries as IT-using if their IT capital income share (nominal IT capital income as a share of nominal nonresidential capital income) is above the median for all industries, excluding the four IT-producing industries. All remaining industries are labeled "other industries." This leaves four IT-producing industries with nearly 5 percent of aggregate value added in the most recent period, twenty-six IT-using industries with 59 percent, and thirty "other industries" with the remainder.[65]

As shown in table 6, the IT-producing and IT-using industries more than account for the direct contribution from individual industries to the productivity acceleration during 1995–2000. After 2000, however, the impact of IT is much less clear-cut, with the swing in the growth contributions from all three groups of industries concentrated in a fairly narrow range.

For the full decade from 1995 to 2005, the direct contribution from the IT-using industries was far larger than it had been over 1988–1995, despite the decline after 2000 based on gross output data. In contrast, the direct contribution from "other industries" remained smaller throughout

62. Caballero and Hammour (1994).

63. See, for example, Smith and Lum (2005) and Howells, Barefoot, and Lindberg (2006).

64. Stiroh (2002b).

65. Appendix table A-1 shows this classification scheme for the sixty detailed industries based on both 1995 and 2000 IT capital income shares and reports the 2005 share. Baily and Lawrence (2001), Stiroh (2001), and Jorgenson, Ho, and Stiroh (2005) also use relative shares of IT capital in total capital to identify IT-intensive industries in the United States, and Daveri and Mascotto (2002), Inklaar, O'Mahony, and Timmer (2005), O'Mahony and van Ark (2003), and van Ark, Inklaar, and McGuckin (2003) do so in international studies.

1995–2005 than it had been before 1995. This distinction highlights the important role for IT use in driving the faster growth in productivity that has prevailed over the entire period since the mid-1990s.

The contribution from the IT-producing industries moved up during 1995–2000 and back down during 2000–05, with the size of the swing depending on which output measure one uses. That said, both output measures show that the IT-producing industries made relatively large contributions to aggregate productivity growth throughout the sample period. For example, using the value added figures, the four IT-producing industries accounted for 19 percent (0.47 ÷ 2.52) of aggregate productivity growth over 2000–05, far above their 4 percent share of value added.

Potential Explanations for the Industry Variation

We now explore two specific questions about the cross-sectional distribution of productivity growth. First, was the link between IT and productivity growth after 2000 as strong as in the second half of the 1990s? The simple decompositions presented above suggest that it was not, but we examine this more formally here. Second, is there evidence for the idea that competition and restructuring contributed to the strong productivity gains after 2000?

IT AND PRODUCTIVITY GROWTH. This section examines the link between industry-level productivity growth and IT intensity. The intuition is straightforward: if IT plays an important role in productivity growth through either the direct capital deepening effect, a complementary but omitted input, or productivity spillovers, one should expect the most IT-intensive industries to show the largest productivity gains. We estimate cross-sectional regressions that relate the *change* in productivity growth over two periods to IT intensity at the end of the first period as

$$\Delta A\dot{L}P_i = \alpha + \beta IT_i + \varepsilon_i, \tag{21}$$

where $\Delta A\dot{L}P$ is the change in productivity growth between two periods (from 1988–95 to 1995–2000, from 1988–95 to 1995–2005, or from 1995–2000 to 2000–05).

We use two alternative measures of IT intensity. The first is a qualitative indicator of relative intensity: a dummy variable equal to one if the IT share of total nonresidential capital income exceeds the industry median and zero otherwise.[66] This qualitative approach allows a broad interpretation of IT as a proxy for related investments such as intangible capital and the improved management practices that typically accompany IT. Moreover, this type of indicator variable is robust to the type of measurement error in the capital stock described by Randy Becker and coauthors,[67] but it misses the variation in IT intensity across industries. Our second measure is the actual share of IT capital services in total nonresidential capital services. This quantitative measure better captures differences in IT intensity but is more prone to measurement error. We estimate the IT share regressions with data from all sixty industries and from fifty-six industries after dropping the four IT-producing industries; the latter sample removes some outliers and focuses on the impact of the use of IT.

We define IT intensity as that just before the period of acceleration, for example in 1995 when analyzing the change in productivity growth after 1995, and in 2000 when examining the change after 2000. Although this procedure is not perfect, it helps control for the endogeneity of investment. In the dummy variable specification, β represents the change in productivity growth across periods for IT-intensive industries relative to the change for other industries; in the quantitative specification, β represents the increase in the change of productivity growth associated with a marginal increase in IT intensity.

Table 7 presents the results. The first three columns examine changes in the second half of the 1990s by comparing 1995–2000 with 1988–95. The middle three columns extend the data to 2005 but keep the breakpoint and the measure of IT intensity at 1995. The final three columns focus on the post-2000 gains by comparing the change in productivity from 2000 to 2005 with that from 1995 to 2000. The top panel uses gross output as the output measure, and the bottom panel uses value added. All estimates use ordinary least squares (OLS) with robust standard errors.[68]

66. This specification is identical to a difference-in-difference-style regression with a post-1995 or post-2000 dummy variable, an IT intensity dummy, and the interaction estimated with annual data for the full period.

67. Becker and others (2005).

68. We also estimated (but do not report) weighted least squares estimates, which are appropriate if the somewhat arbitrary nature of the industry classification system makes measurement error more severe in the relatively small industries. See Kahn and Lim (1998) for a more detailed discussion of weights in industry regressions. These weighted estimates are similar to those reported in table 7.

Table 7. Regressions Relating Labor Productivity Growth to IT Capital Intensity[a]

Output measure and independent variable	*Regression (Dependent variable: change in labor productivity growth over indicated period)*								
	1988–95 to 1995–2000			*1988–95 to 1995–2005*			*1995–2000 to 2000–05*		
Gross output									
1995 IT dummy[b]	1.277**			1.478***					
	(0.585)			(0.491)					
1995 IT share[c]		0.038	0.081***		0.037*	0.060***			
		(0.028)	(0.027)		(0.020)	(0.019)			
2000 IT dummy							0.156		
							(0.931)		
2000 IT share								0.010	–0.031
								(0.044)	(0.048)
Constant	0.513	0.543	0.009	0.074	0.216	–0.040	–0.756	–0.865	–0.206
	(0.438)	(0.478)	(0.478)	(0.371)	(0.401)	(0.382)	(0.480)	(0.650)	(0.651)
IT-producing industries included in sample?	No	No	Yes	No	No	Yes	No	No	Yes
R^2	0.08	0.06	0.18	0.14	0.07	0.12	0.00	0.00	0.02
Value added									
1995 IT dummy	1.904			1.967**					
	(1.173)			(0.893)					
1995 IT share		0.029	0.066		0.051*	0.048			
		(0.044)	(0.054)		(0.026)	(0.035)			
2000 IT dummy							0.095		
							(1.448)		
2000 IT share								0.046	–0.041
								(0.066)	(0.055)
Constant	–0.709	–0.227	–0.828	–0.352	–0.198	–0.284	0.730	–0.056	1.225
	(0.913)	(0.915)	(1.009)	(0.709)	(0.667)	(0.725)	(0.944)	(1.149)	(1.017)
IT-producing industries included in sample?	No	No	Yes	No	No	Yes	No	No	Yes
R^2	0.04	0.01	0.03	0.08	0.05	0.026	0.00	0.02	0.01

Source: Authors' regressions.

a. Data are for the sixty industries listed in appendix table A-1 (fifty-six industries when the four IT-producing industries are dropped). Numbers in parentheses are robust standard errors. Asterisks indicate statistical significance at the ***1 percent, **5 percent, and *10 percent level.

b. Dummy variable equal to 1 for industries with an IT capital share above the median in the indicated year, and zero otherwise.

c. IT capital services as a share of nonresidential capital services in the indicated year.

The estimates through 2000 suggest a link between IT intensity and the change in productivity growth using the gross output data, but the results are weaker using the value-added data. When we extend the data to include the post-2000 period and compare 1995–2005 with 1988–95, both sets of estimates show large and significant IT effects. The final three columns indicate that IT intensity in 2000 is not a useful predictor of the change in productivity growth after 2000.[69]

These results show that the most IT-intensive industries in 1995 experienced larger increases in productivity growth after 1995 and that these gains lasted through 2005. Although the IT intensity variable explains only a relatively small portion of the overall variation across industries, the size of the IT effect is economically large: IT-intensive industries showed an increase in productivity growth that was between 1.5 and 2.0 percentage points greater than in other industries when 1995–2005 is compared with 1988–95. Despite data revisions and the shift to NAICS, the results are similar to those in earlier work, indicating strong support for the view that IT use mattered for the productivity gains after 1995. Of course, to the extent that IT capital is correlated with other factors such as management skills or intangible capital, these gains should be attributed to the whole suite of business activities that accompany IT investment, and not narrowly to changes in physical capital.

By contrast, the post-2000 acceleration in productivity does not appear to be tied to the accumulation of IT assets in the late 1990s. In particular, we find no evidence that industries that sowed lots of IT capital in the late 1990s reaped a particularly large productivity payoff after 2000. Although these results are surely confounded by cyclical dynamics that were especially severe in the high-technology sectors, analysis of an earlier vintage of the industry data by Stiroh shows that the reduced correlation between IT and productivity is not due solely to the high-technology slowdown in 2001.[70]

COMPETITIVE PRESSURES AND PRODUCTIVITY GROWTH. One idea that has received considerable attention is that U.S. firms may have been under increased pressure in the 2000s to cut costs and raise efficiency in order to

69. Stiroh and Botsch (2007) report similar results.

70. Stiroh (2006). These results could be consistent with an IT-based explanation if the pervasiveness of IT makes it difficult to identify a link econometrically. That is, if IT is integral for all industries, then measures of IT intensity may not be useful for classification purposes. This view, however, is inherently untestable.

maintain profitability in a more globalized and competitive environment.[71] Robert Gordon, for example, concludes that the "savage cost cutting and layoffs" that followed the profit boom of the late 1990s likely explain the unusual surge of productivity in the early 2000s.[72] Mark Schweitzer notes that managers have stressed the need to realign business processes without hiring additional workers, although he admits that empirical support is limited.[73] Erica Groshen and Simon Potter raise the possibility that new management strategies promoted lean staffing in order to increase efficiency.[74] Firms may have been better able to carry out these strategies in an environment of more flexible and efficient labor markets.[75]

If the cost-cutting hypothesis is true, productivity growth should have been relatively strong and hours growth relatively weak after 2000 in those industries that experienced the biggest decline in profit in earlier years and thus were under the most intense pressure to restructure. To identify those industries, we examine the change in the profit share derived from the BEA industry data, where the profit share is defined as gross operating surplus (consumption of fixed capital; business transfers; other gross operating surplus such as profits before tax; net interest; and miscellaneous payments) as a share of value added. Although one might want to remove the consumption of fixed capital and the normal return to capital, those data are not available at a detailed level. Our profit share measure should be viewed as a broad measure that includes the gross return to capital.

We then compared industry growth from 2001 to 2004—the period of extremely rapid aggregate productivity gains—with changes in industry-level profit shares from the 1997 peak in the aggregate profit share to the 2001 trough. As a first pass, figures 2 and 3 plot the growth of hours and labor productivity from 2001 to 2004 against the change in the profit share from 1997 to 2001 for sixty industries. These scatterplots offer some support for the restructuring hypothesis, as a decline in the profit share is

71. Baily (2004) discusses the case study evidence of the impact of competitive intensity on firms' need to innovate and increase productivity and argues that competitive pressure gradually increased during the 1970s and 1980s.

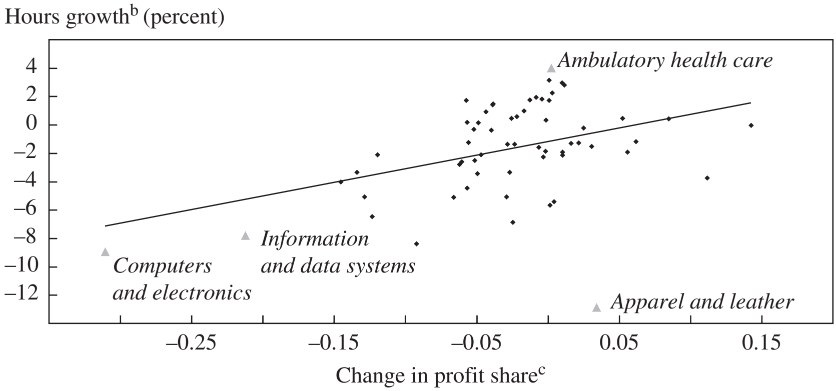
72. Gordon (2003, p. 274). See Nordhaus (2002a) for details on profit trends over this period.

73. Schweitzer (2004).

74. Groshen and Potter (2003).

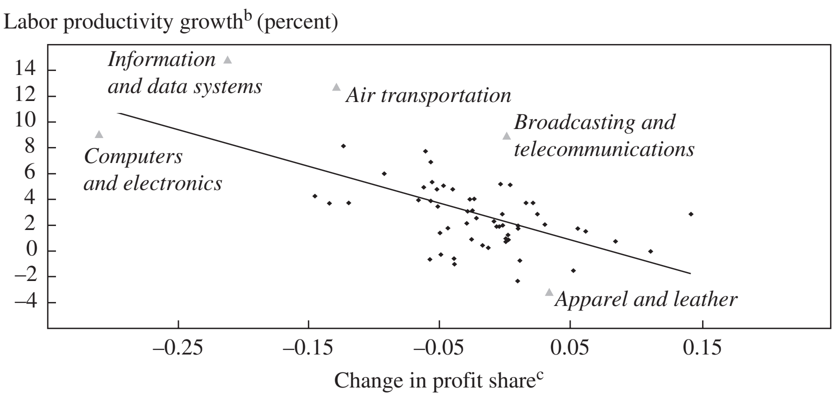
75. This has been documented by Schreft and Singh (2003) and by Aaronson, Rissman, and Sullivan (2004).

Figure 2. Hours Growth over 2001–04 versus Change in the Profit Share over 1997–2001, by Industry[a]



Source: Authors' calculations using BLS and BEA data.
a. Each point is one of sixty industry observations; line plots fitted values from an OLS regression.
b. Average annual rate of growth in hours worked from 2001 to 2004.
c. Change in the ratio of gross operating surplus to value added from 1997 to 2001.

Figure 3. Labor Productivity Growth over 2001–04 versus Change in the Profit Share over 1997–2001, by Industry[a]



Source: Authors' calculations using BLS and BEA data.
a. Each point is one of sixty industry observations. Line plots fitted values from an OLS regression.
b. Average annual rate of growth of labor productivity from 2001 to 2004 based on gross output.
c. Change in the ratio of gross operating surplus to value added from 1997 to 2001.

associated (significantly) with slower hours growth and faster ALP growth.[76] To gauge the magnitude of this effect, note that industries with below-median changes in the profit share experienced hours growth 2 percentage points slower on average than did other industries and labor productivity growth about 3 percentage points faster.[77]

We also estimate cross-sectional regressions that relate growth in the early 2000s to the lagged change in the profit share as

$$\dot{X}_i = \alpha + \beta \Delta PR_i + \gamma \mathbf{Z}_i + \varepsilon_i, \tag{22}$$

where $\dot{X}$ is average annual growth of either hours, intermediate inputs, labor productivity, or output from 2001 to 2004, ΔPR is the change in the profit share from 1997 to 2001, and $\mathbf{Z}$ are controls. Equation 22 is obviously a reduced-form regression, and the controls are therefore intended to soak up variation attributable to other factors. $\mathbf{Z}$ includes the contemporaneous change in the profit share from 2001 to 2004, to control for demand effects; lagged growth in the dependent variable from 1997 to 2001, to control for longer-run trends (for example, the possibility that some industries may be in secular decline); and the IT capital service share, to control for IT intensity. Finally, we interacted the IT capital service share with the lagged change in the profit share, to examine whether IT intensity facilitated adjustment to competitive pressures.

Table 8 reports estimates of equation 22 without and with these controls. The top panel uses input growth (either hours or intermediate inputs) as the dependent variable, the middle panel uses labor productivity measures based on gross output or value added, and the bottom panel uses the two output measures. All estimates use OLS with robust standard errors.

The hours growth regressions reveal a strong positive link, as industries with large declines in the profit share over 1997–2001 experienced significantly slower hours growth from 2001 to 2004. There is no similar link with intermediate inputs. Firms might have been expected to economize on all margins, but differences in adjustment costs could explain the different

76. The significance of the cross-sectional correlation is robust to dropping the two major outliers—computers and electronics, and information and data systems—on the far left of figures 2 and 3.

77. *t*-tests for differences in the mean growth rates between the two groups of industries reject the hypothesis that the two had equal growth rates for hours and productivity, but fail to reject the hypothesis that the two had equal output growth rates.

Table 8. Regressions Relating Growth in Inputs, Productivity, and Output to Earlier Changes in the Profit Share[a]

	Regression (Dependent variable: average annual growth rate of indicated input type)					
Independent variable	*Hours*			*Intermediate inputs*		
Change in profit share,[b] 1997–2001	19.212***	16.413***	16.170***	−0.069	1.864	1.502
	(4.940)	(5.126)	(5.273)	(10.339)	(10.789)	(11.398)
Change in profit share, 2001–04		−0.115	13.389*		8.244	22.546
		(6.159)	(7.952)		(12.592)	(22.270)
Lagged dependent variable, 1997–2001		0.722***	0.782***		0.255	0.280
		(0.155)	(0.128)		(0.165)	(0.168)
IT service share,[c] 2001		−0.089***	−0.069***		−0.032	−0.009
		(0.027)	(0.025)		(0.064)	(0.067)
Change in profit share, 1997–2001 × IT service share, 2001			−0.444**			−0.474
			(0.173)			(0.522)
Constant	−1.175**	0.239	−0.193	0.533	0.104	−0.459
	(0.459)	(0.478)	(0.463)	(0.733)	(1.076)	(1.499)
R^2	0.17	0.51	0.57	0.00	0.10	0.12
	Regression (Dependent variable: average annual growth rate of labor productivity)					
	Value added			*Gross output*		
Change in profit share, 1997–2001	−38.487***	−40.655***	−39.835***	−28.456***	−20.929***	−20.851***
	(11.253)	(14.067)	(14.230)	(6.437)	(7.116)	(7.379)
Change in profit share, 2001–04		5.703	0.563		7.013	4.655
		(11.962)	(15.520)		(8.705)	(8.353)
Lagged dependent variable, 1997–2001		−0.055	−0.041		0.169	0.176
		(0.186)	(0.195)		(0.168)	(0.178)

(*continued*)

Table 8. Regressions Relating Growth in Inputs, Productivity, and Output to Earlier Changes in the Profit Share[a] (*Continued*)

	Regression (Dependent variable: average annual growth rate of indicated input type)					
Independent variable		*Hours*			*Intermediate inputs*	
IT service share, 2001		−0.008	−0.018		0.030	0.025
		(0.035)	(0.041)		(0.028)	(0.037)
Change in profit share, 1997–2001 × IT service share, 2001			0.177			0.077
			(0.297)			(0.294)
Constant	3.283***	3.332***	3.540***	2.279***	1.319**	1.404**
	(0.745)	(0.882)	(0.871)	(0.341)	(0.522)	(0.555)
R^2	0.26	0.27	0.28	0.37	0.44	0.44
	Regression (Dependent variable: average annual growth rate of output)					
		Value added			*Gross output*	
Change in profit share, 1997–2001	−19.274**	−19.781*	−19.826*	−9.243	−0.785	−0.707
	(9.511)	(10.820)	(10.794)	(6.933)	(7.645)	(7.729)
Change in profit share, 2001–04		10.770	11.472		10.342	16.689
		(11.257)	(17.752)		(10.943)	(16.531)
Lagged dependent variable, 1997–2001		−0.043	−0.044		0.294	0.300
		(0.150)	(0.152)		(0.211)	(0.216)
IT service share, 2001		−0.006	−0.005		−0.014	−0.002
		(0.028)	(0.034)		(0.041)	(0.040)
Change in profit share, 1997–2001 × IT service share, 2001			−0.023			−0.203
			(0.290)			(0.356)
Constant	2.108***	2.058***	2.029**	1.105**	0.529	0.281
	(0.679)	(0.680)	(0.780)	(0.486)	(0.552)	(0.867)
R^2	0.11	0.15	0.15	0.04	0.22	0.23

Source: Authors' regressions.

a. Growth rates of inputs, labor productivity, and output are from 2001 to 2004. Each regression has sixty industry observations. Numbers in parentheses are robust standard errors. Asterisks indicate statistical significance at the ***1 percent, **5 percent, and *10 percent level.

b. Profit share is defined throughout as the ratio of gross operating surplus to value added.

c. Share of IT capital services in nonresidential capital services.

results for hours and intermediate inputs. The results in the middle panel show a strong negative link between the lagged change in the profit share and productivity growth. Finally, the bottom panel reports some evidence that output growth was faster in the industries with a declining profit share, but the link is weaker and far less robust than that between labor productivity and the profit share.[78]

These results support the hypothesis that competitive pressure and restructuring help explain the post-2000 productivity gains. One interpretation is that firms in those industries where profits fell most dramatically through 2001 became cautious, hired fewer workers, and improved productivity and efficiency after 2001. Moreover, the absence of strongly significant effects in the output regressions, together with the robustness of the results to the inclusion of the contemporaneous change in the profit share, suggests that this was not just a demand story, but rather reflects how firms chose to produce a given amount of output. Similarly, the results are robust to including a lagged dependent variable, and so it does not appear that we are merely capturing long-run trends. Finally, these estimates provide additional evidence that IT was not a driving factor in the early 2000s, as both the level of IT intensity and the interaction term are insignificant in all except the hours regressions.

Productivity Trends and Outlook

This section turns to the outlook for productivity growth. After highlighting issues with the recent data, we report long-period averages of labor productivity growth to provide a benchmark for assessing the strength of recent growth. We also present trend estimates from a Kalman filter model and estimates of the steady-state growth implicit in our aggregate growth

78. As a robustness check, we estimated difference-in-difference regressions and found that industries with a below-median change in the profit share from 1997 to 2001 had a bigger decline in the growth of hours and a bigger increase in the growth of gross output labor productivity than did other industries. No significant difference emerged for value-added labor productivity growth. We also ran regressions with more detailed measures of intermediate inputs, including energy, materials, and purchased service inputs, as the dependent variable, but those results were uniformly insignificant and are not reported. As a second robustness check, we compared hours, productivity, and output growth for 1992 with the change in the profit share from 1989 to 1991 and found largely insignificant results, suggesting that the latest cyclical episode was different from the previous one.

Table 9. Effects of Data Revisions and Data for Additional Years on Measured Growth of Labor Productivity[a]

	Period covered by the data				
Vintage of data	*1995–2000*	*2000–03*	*2000–04*	*2000–05*	*2000–06*
March 2004	2.4	3.8			
August 2004	2.5	3.7			
March 2005	2.5	3.7	3.7		
August 2005	2.5	3.4	3.4		
March 2006	2.5	3.4	3.4	3.3	
August 2006	2.5	3.4	3.3	3.1	
March 2007	2.5	3.4	3.3	3.0	2.8

Source: Authors' calculations using BLS data.
a. Measured as 100 times the average log difference over the indicated period, based on annual average data.

accounting model. Finally, we compare these trend estimates with those reported by other analysts.

What Do the Recent Data Say?

Assessing the underlying trend in labor productivity growth since 2000 has been complicated by major data revisions to both output and hours worked and by swings in actual productivity growth. Table 9 displays both dimensions of the recent data. Moving down a column in the table shows the effect of revisions across successive vintages of data, while moving across a line shows the effect of adding additional years to the period covered by the data.[79]

For 2000–03, the average growth of labor productivity was reported initially in March 2004 to have been 3.8 percent. This surprisingly robust gain led many analysts to ask why labor productivity growth had accelerated further despite sluggish investment spending, the 2001 recession, and other adverse shocks. However, subsequent revisions reduced the rate of

79. The figures in table 9 are calculated from BLS's quarterly Productivity and Costs data. The definition of nonfarm business in these data includes government enterprises. In contrast, the definition of nonfarm business in BLS's MFP data, the data we use to calculate the labor productivity growth rates in table 1, excludes government enterprises. This slight difference in sectoral coverage explains why labor productivity growth for 2000–06 differs by 0.1 percentage point across the two tables. The same explanation accounts for the slight difference in the average growth rate for 1973–95 between table 1 and the column for nonfarm business in table 10 below.

Table 10. Growth of Labor Productivity: Long-Period Averages[a]

Period	*Private economy or business sector*[b]	*Nonfarm business sector*
1909–1928	1.4	
1928–1950	2.5	
1950–1973	2.9	2.6
1973–1995	1.5	1.4
1995–2006	2.8	2.7
1909–2006	2.2	
1950–2006	2.3	2.1

Source: Authors' calculations using BLS data.

a. Measured as 100 times the average log difference over the indicated period based on annual average data.

b. Data before 1947 pertain to the private economy (defined as gross national product less general government), whereas data for 1947 and later years pertain to the business sector.

advance to 3.4 percent.[80] The initial estimates for 2000–04 and 2000–05 were revised downward in a similar fashion, tempering some of the earlier optimism about the underlying trend. In addition to these revisions, smaller gains in labor productivity over the past few years have brought down the average growth rate, reported in the bottom line of the table. In the current vintage of data (March 2007), growth over 2000–06 averaged 2.8 percent, a full percentage point below the initial reading for the first three years of this period.

Long-Period Averages

Long-period averages of labor productivity growth provide one way to put the recent figures into perspective. The first column of table 10, using data from BLS, shows productivity growth rates over several periods extending back to 1909. These data cover a broader sector of the economy than nonfarm business and so do not line up perfectly with the estimates presented earlier in the paper. That said, labor productivity growth according to these figures has averaged 2.2 percent a year since 1909.[81] The second column shows productivity growth rates over selected periods since 1950 for the nonfarm business sector; here growth averaged 2.7 percent a

80. Jorgenson, Ho, and Stiroh (2007) show that such revisions are not unusual; for example, there was a steady stream of upward revisions to productivity growth in the mid-1990s.

81. There are a number of alternative historical series for labor productivity. Although they yield different results in some periods, the patterns of growth and long-run averages are qualitatively similar to the BLS data presented here. For example, see Gordon (2006).

year during 1995–2006, similar to that during the so-called "golden era" of productivity from 1950 to 1973 and well above the postwar average of 2.1 percent a year. Thus by historical standards the performance of labor productivity since 1995 has been quite strong.

Kalman Filter Estimates

As one approach to obtaining time-varying estimates of the trend in labor productivity, we use a slightly modified version of the Kalman filter model developed by John Roberts.[82] Although alternative implementations could yield answers that differ from the one presented here, the Roberts model has some appealing features.[83] In particular, it allows for shocks to both the level and the growth rate of trend productivity, and it controls for cyclical changes in productivity growth by assuming that hours adjust gradually to output following a cyclical shock. We estimate the model by the maximum likelihood method, using standard BLS data on labor productivity in the nonfarm business sector from the first quarter of 1953 to the fourth quarter of 2006.

For the fourth quarter of 2006, this procedure estimates that the trend in labor productivity growth was 2¼ percent a year, roughly ½ percentage point below the average pace of productivity growth since 2000. Put another way, the model interprets some of the extraordinary growth in the years immediately after the 2001 recession as transitory. The model also delivers a 2-standard-error confidence band around the estimated trend, ranging from 1.3 percent to 3.2 percent. Thus considerable uncertainty surrounds this estimate of trend productivity growth.

Steady-State Analysis of Labor Productivity Growth

As a complement to the Kalman filter estimate of the trend in labor productivity growth, we calculate the growth rate that would prevail in the steady state of our aggregate growth accounting model. For this exercise we use the version of the model that excludes our added intangibles, so

82. In Roberts (2001) the Kalman filter is used to obtain time-varying estimates of trend growth in both potential output and labor productivity. Our implementation first uses a Hodrick-Prescott filter to estimate the trend in hours and then feeds this exogenous trend to the model. Hence we need to estimate a trend only for labor productivity.

83. For other estimates of trend productivity using Kalman filter techniques, see Brainard and Perry (2000) and Gordon (2003).

that our estimates can be compared with those of other researchers. We stress at the outset that we do not regard these steady-state results as forecasts of productivity growth over any period. Rather this exercise yields "structured guesses" for growth in labor productivity consistent with alternative scenarios for certain key features of the economy.

The steady state in our model is characterized by the following conditions. Real output in each sector grows at a constant rate (which can differ across sectors), and real investment in each type of capital grows at the same constant rate as the real stock of that capital. Because $\dot{I} = \dot{K}$ for each type of capital, adjustment costs have no effect on MFP growth (sectoral or aggregate) in the steady state. On the labor side, we require that hours worked grow at the same constant rate in every sector, that the workweek be fixed, and that labor quality improve at a constant rate.

Under these conditions the steady-state growth rate of aggregate labor productivity can be written as follows:[84]

$$(23) \qquad A\dot{L}P = \sum_i \left[\left((\alpha_i^K - \phi_i)/\alpha^L \right) \left(\dot{z}_i + \beta_i^S \dot{z}_S \right) \right] + \dot{q} + \dot{z},$$

where the α's denote income shares, the ϕ's denote the adjustment cost elasticity of output with respect to each type of capital, β_i^S is the share of total costs in final-output sector *i* represented by purchases of semiconductors, $\dot{q}$ is the rate of increase in labor quality, $\dot{z}_i$ and $\dot{z}_s$ denote the rates of improvement in sectoral technology, and $\dot{z}$ is the Domar share-weighted sum of these sectoral rates of improvement. Recall that the $\dot{z}$ terms (sectoral or aggregate) equal the growth of MFP after controlling for the effects of changes in factor utilization and adjustment costs. No explicit terms for capital deepening appear in equation 23. However, capital deepening is determined endogenously from the improvement in technology, and the terms in brackets account for the growth contribution from this induced capital deepening.[85]

84. See the appendix to the working paper version of this paper (Oliner, Sichel, and Stiroh, 2007) for details.

85. Even though adjustment costs have no direct effect on growth in the steady state, the adjustment cost elasticities (ϕ_i) appear in the weights on the capital deepening terms in equation 23, just as they did in the growth accounting equation that applies outside the steady state (equation 1). As in that case, we lack the information to specify these asset-specific elasticities. We proceed as we did before, by replacing the theoretically correct weights with standard income-share weights that sum to the same value (one minus the labor share).

The steady-state equation depends on a large number of parameters (income shares, sectoral output shares, semiconductor cost shares, and so on). We consider a range of parameter values.[86] For the most part, steady-state growth is not very sensitive to these parameters individually. However, the results do depend importantly on two parameters: the rate of improvement in labor quality and the rate of advance in technology outside the IT-producing sectors ("other nonfarm business").[87] Following Jorgenson, Ho, and Stiroh,[88] we assume that labor quality will improve by 0.15 percent a year, well below the historical rate of increase, as the educational attainment of new labor force entrants rises more slowly than in the past and experienced workers reach retirement age. For the value of $\dot{z}$ in other nonfarm business, we consider values ranging from 0.19 to 0.98 percent a year. The lower-bound figure equals the average annual growth of $\dot{z}$ in this sector over 1973–2000, which allows for reversion to the longer-term average prevailing before the recent period of rapid gains. The upper-bound figure equals the average annual increase over 2000–06, minus ¼ percentage point to account for the likelihood that some of the advance during this period was transitory.

Table 11 presents the results from the steady-state exercise using equation 23. The estimated range for steady-state labor productivity growth runs from 1.46 percent at an annual rate to 3.09 percent. The wide range reflects our uncertainty about the values of the parameters that determine steady-state growth. The center of the range is 2¼ percent, about ½ percentage point below the average rate of labor productivity growth since 2000. This step-down from the recent average largely reflects the assumption that improvements in labor quality will slow and that gains in MFP, after controlling for adjustment costs and factor utilization, will not be as robust as the average pace since 2000.

Comparing Results

Table 12 compares the results from our steady-state and Kalman filter analyses with forecasts of labor productivity growth from a variety of sources. All but three of these forecasts have a horizon of ten years. The other three

86. These are listed in the appendix to Oliner, Sichel, and Stiroh (2007).

87. For the IT-producing sectors, the rate of advance in technology is determined endogenously from the assumed rates of change in prices for IT capital and a variety of other parameters.

88. Jorgenson, Ho, and Stiroh (2007).

Table 11. Growth of Labor Productivity: Steady-State Results[a]

Item	*Using lower-bound parameters*	*Using upper-bound parameters*
Growth of labor productivity in the nonfarm business sector (percent a year)	1.46	3.09
Contributions from (percentage points):		
Induced capital deepening	0.75	1.39
Improvement in labor quality	0.15	0.15
Growth of MFP	0.56	1.55
Memorandum: MFP growth, other nonfarm business (percent a year)	0.19	0.98

Source: Authors' calculations.

a. Calculated from equation 23 in the text. Values for the parameters that appear in equation 23 are listed in the appendix to Oliner, Sichel, and Stiroh (2007).

Table 12. Alternative Estimates of Future Growth in Labor Productivity
Percent a year

Source	*Date of projection*	*Estimate*
This paper: steady-state analysis	March 2007	1.5 to 3.1
This paper: Kalman filter analysis	March 2007	1.3 to 3.2
Robert Gordon	March 2007	2.0
Survey of Professional Forecasters[a]	February 2007	2.2
Global Insight	March 2007	2.2
Macroeconomic Advisers	March 2007	2.2
Congressional Budget Office	January 2007	2.3
Dale Jorgenson, Mun Ho, and Kevin Stiroh[b]	October 2006	2.5
James Kahn and Robert Rich	March 2007	2.5
Council of Economic Advisers	January 2007	2.6

Sources: Gordon (2007, slide 24); Federal Reserve Bank of Philadelphia, *Survey of Professional Forecasters,* February 13, 2007; Global Insight, *U.S. Executive Summary,* March 2007, p. 6; Macroeconomic Advisers, *Macro Focus,* March 22, 2007, p. 11; Congressional Budget Office (2007a, table 2-2); Jorgenson, Ho, and Stiroh (2007, table 3); Kahn and Rich (2006), updated to March 2007 based on the productivity model update posted at www.newyorkfed.org/research/national_economy/richkahn_prodmod.pdf; *Economic Report of the President 2007,* table 1-2.

a. Median of the thirty-eight forecasts in the survey.

b. "Base-case" projection.

have shorter horizons.[89] These forecasts for average annual growth in labor productivity range from 2 percent to 2.6 percent. As noted above, the midpoint of our estimated range for steady-state growth and the estimated trend from the Kalman filter are both 2¼ percent, near the center of the range of these forecasts. Thus there seems to be considerable agreement that labor productivity growth will remain reasonably strong over a medium-term horizon.

89. The horizon in Kahn and Rich (2006) is five years, that in *Economic Report of the President 2007* is six years, and that in the March 2007 Macroeconomic Advisers report is eight years.

That said, one should be humble about this type of exercise, for a number of reasons. First, both the Kalman filter and our steady-state machinery point to a very wide confidence band around the point estimates. Second, the data on labor productivity through 2006 still could be revised significantly. In the future we might be looking at a picture of actual labor productivity growth for recent years that is different from the one we see today. Finally, as a general matter, economists do not have a stellar track record in forecasting trends in labor productivity. Although we think the analysis here moves the debate forward, we are acutely aware of the inherent limitations.

Conclusion

Productivity developments since 1995 have raised many important and interesting questions for productivity analysts and policymakers, four of which we address in this paper. First, given the data now available and the various critiques of neoclassical growth accounting that have arisen in recent years, is IT still a critical part of the story for the observed acceleration in productivity growth over 1995–2000? Second, what is the source of the continued strength in productivity growth since 2000? Third, how has the accumulation of intangible capital influenced recent productivity developments? And, finally, based on our answers to these questions, what is the outlook for productivity growth? We have used a variety of techniques to address these questions, including aggregate growth accounting augmented to incorporate variable utilization, adjustment costs, and intangible asset accumulation; an assessment of industry-level productivity patterns; and Kalman filter and steady-state analysis to gauge trend productivity.

Both the aggregate and the industry-level results confirm the central role of IT in the productivity revival during 1995–2000. IT also plays a significant role after 2000, although its impact appears smaller than it was during 1995–2000. These results stand even after accounting for variable factor utilization, adjustment costs, and intangible capital and so provide strong support for the consensus view that IT was a key source of growth for the U.S. economy over the past decade.

Our results suggest that the sources of the productivity gains since 2000 differ in important ways from those during 1995–2000. Along with the smaller direct role for IT in the latest period, aggregate productivity growth since 2000 appears to have been boosted by industry restructuring in response to profit pressures and by a reallocation of material and labor inputs across industries. We also find considerable churning among industries, with some industries showing accelerating productivity in the second half of the 1990s and different ones accelerating in the most recent period.

Adding intangible capital to our aggregate growth accounting framework changes the time profile for productivity growth since 1995 relative to the published data. The measure of intangible assets used in this paper implies that the fastest gains in labor productivity occurred during 1995–2000, with some step-down after 2000. In addition, the inclusion of intangibles tempers the size of the pickup in MFP growth from 1995–2000 to 2000–06.

Finally, in terms of the productivity outlook, both the Kalman filter and the steady-state analyses deliver broadly similar results and highlight the wide range of uncertainty surrounding estimates of growth in trend labor productivity. In both cases the central tendencies suggest a rate for trend productivity gains of around 2¼ percent a year, a rate that is consistent with productivity growth remaining well above the lackluster pace that prevailed during the twenty-five years before 1995, but somewhat slower than the 1995–2006 average.

APPENDIX A

Industry Data

Table A-1. Value Added, IT Share, and IT Classification of U.S. Industries

Name	Value added, 2005 (millions of dollars)	IT share, 2005[a]	IT classification		
			IT_{1995}[b]	IT_{2000}[c]	IT-producing[d]
Agriculture, forestry, fishing, and hunting	123.1	1.4	0	0	0
Oil and gas extraction	159.6	1.8	0	0	0
Mining, except oil and gas	31.5	6.0	0	0	0
Support activities for mining	42.2	8.9	0	0	0
Construction	611.1	19.0	1	1	0
Wood products	39.0	6.4	0	0	0
Nonmetallic mineral products	53.3	9.1	0	0	0
Primary metals	61.1	5.3	0	0	0
Fabricated metal products	130.5	9.3	0	0	0
Machinery	111.1	23.3	1	1	0

(*continued*)

Table A-1. Value Added, IT Share, and IT Classification of U.S. Industries (*Continued*)

Name	*Value added, 2005 (millions of dollars)*	*IT share, 2005*[a]	*IT classification*		
			IT_{1995}[b]	IT_{2000}[c]	*IT-producing*[d]
Computer and electronic products	135.3	23.4	1	1	1
Electrical equipment, appliances, and components	47.8	12.8	1	1	0
Motor vehicles, bodies and trailers, and parts	95.4	15.2	1	1	0
Other transportation equipment	71.1	28.4	1	1	0
Furniture and related products	37.1	9.6	0	0	0
Miscellaneous manufacturing	72.6	16.0	1	1	0
Food and beverage and tobacco products	175.7	8.8	0	0	0
Textile mills and textile product mills	23.8	4.0	0	0	0
Apparel and leather and allied products	16.8	7.2	0	0	0
Paper products	54.6	6.5	0	0	0
Printing and related support activities	46.9	12.4	0	1	0
Petroleum and coal products	63.5	9.4	0	0	0
Chemical products	209.2	17.1	1	1	0
Plastics and rubber products	67.7	5.6	0	0	0
Utilities	248.0	5.5	0	0	0
Wholesale trade	743.2	25.4	1	1	0
Retail trade	823.5	14.6	1	0	0
Air transportation	41.0	42.7	1	1	0
Rail transportation	32.3	2.0	0	0	0
Water transportation	9.0	42.3	1	1	0
Truck transportation	114.1	11.5	0	0	0
Transit and ground passenger transportation	17.1	16.8	1	1	0
Pipeline transportation	9.3	27.6	1	1	0
Other transportation and support activities	89.1	15.1	0	1	0
Warehousing and storage	32.7	19.0	0	0	0
Publishing industries (includes software)	150.2	49.8	1	1	1
Motion picture and sound recording industries	40.5	16.5	1	1	0
Broadcasting and telecommunications	304.1	46.5	1	1	0
Information and data processing services	60.4	81.7	1	1	1

(*continued*)

Table A-1. Value Added, IT Share, and IT Classification of U.S. Industries (*Continued*)

Name	*Value added, 2005 (millions of dollars)*	*IT share, 2005*[a]	*IT classification*		
			IT_{1995}[b]	IT_{2000}[c]	*IT-producing*[d]
Federal Reserve banks, credit intermediation, and related activities	474.7	28.6	1	1	0
Securities, commodity contracts, and investments	167.4	51.8	1	1	0
Insurance carriers and related activities	296.1	38.9	1	1	0
Funds, trusts, and other financial vehicles	19.5	6.6	0	0	0
Real estate	1,472.6	8.7	0	0	0
Rental and leasing services and lessors of intangible assets	105.8	23.1	1	1	0
Legal services	180.9	47.7	1	1	0
Computer systems design and related services	140.8	89.3	1	1	1
Miscellaneous professional, scientific, and technical services	542.5	67.5	1	1	0
Management of companies and enterprises	225.8	45.6	1	1	0
Administrative and support services	336.6	45.5	1	1	0
Waste management and remediation services	32.3	6.2	0	0	0
Educational services	115.8	22.1	0	1	0
Ambulatory health care services	441.9	14.5	1	0	0
Hospitals and nursing and residential care facilities	342.2	13.1	1	0	0
Social assistance	75.4	21.3	1	1	0
Performing arts, spectator sports, museums, and related activities	54.0	10.2	0	0	0
Amusements, gambling, and recreation industries	60.1	4.8	0	0	0
Accommodation	104.6	5.0	0	0	0
Food services and drinking places	225.9	5.8	0	0	0
Other services, except government	282.8	13.8	0	0	0

Source: Authors' calculations based on BEA data.

a. Nominal value of IT capital services divided by nominal value of total nonresidential capital services.

b. Equals 1 if 1995 IT capital service share is greater than 1995 median, and zero otherwise.

c. Equals 1 if 2000 IT capital service share is greater than 2000 median, and zero otherwise.

d. As defined by BEA.

Comments and Discussion

Martin Neil Baily: The three authors of this paper have made some of the strongest contributions to the productivity literature in recent years, and it is terrific to see them team up to provide an important new analysis of the productivity acceleration that started in the mid-1990s. In particular, I liked the creative way they have adapted the growth accounting framework to take account of intangible capital, and I welcome the new insights provided by their industry-level regression analysis, particularly those highlighting the role for competitive pressure.

Labor productivity accelerated in the United States starting in 1996, after over twenty years of slow growth. That acceleration has been widely attributed to the revolution in information technology, a natural enough inference given that the acceleration coincided with a wave of capital investment in IT hardware and software. Indeed, some fraction of the productivity acceleration can certainly be attributed directly to an acceleration within the IT hardware-producing sector. Around 2000–01, however, the IT bubble burst, and IT investment slumped as the economy went into a mild recession. Yet, surprisingly, productivity growth did not slow down but actually grew even faster over 2002–04. This meant that the simple correlation between IT investment and productivity broke down after 2000.

There are three possible responses to what happened. The first is to conclude that perhaps IT was not as important to the post-1995 productivity acceleration as had been thought. Second, one could argue that IT investment has a lagged effect on productivity, so that the high-technology investment boom in the late 1990s had an impact that spilled over into the post-2000 period. A third hypothesis is that IT investment creates intangible capital that should be counted as part of total output. This last option is the approach taken in the growth accounting section of this paper, and it shifts some of the productivity acceleration from the post-2000 period backward in time to 1995–2000, where it coincides with the surge in IT investment.

Working only with aggregate productivity data, one has very limited information available to identify which (if any) of these three options is correct. Indeed, on the productivity side, there are really only three observations to work with: slow growth until 1995, faster growth after 1995, and even faster growth after 2000. Meanwhile much of the accumulation in intangible capital is very difficult to observe. The paper by Corrado, Hulten, and Sichel discussed by the authors develops measures of intangible capital based on a variety of data sources and includes software investment, company training, consulting, and the labor input of employees in job categories that contribute to organizational capital.[1] The estimates from this work were not available beyond 2003, and so the present authors do a quick update through 2005. They report, in their table 3, that intangible capital accumulation by this measure turned down sharply after 2000.

In this paper the authors do not use the Corrado, Hulten, and Sichel estimates directly but turn instead to the paper by Basu and others to develop their new approach to growth accounting.[2] Basu and others is an interesting and helpful paper, but I am not persuaded that their approach is a real substitute for direct observation of intangibles. The basic assumption is that intangible capital investment is tied very closely to investment in IT hardware, so that the time-series pattern of the former is derived from that of the latter. It is entirely plausible that high investment in IT demands an increase in intangible investment, but whether or not this is the dynamic driving the observed pattern of productivity growth remains unknown. I note also that the Basu and others paper has a mixed record in tracking productivity trends. They do find regression coefficients for the United States that suggest that heavy IT investment can depress measured productivity contemporaneously. But as they themselves note, “For the United Kingdom, the same regression shows little. Almost nothing is statistically significant, and the signs are reversed from what theory suggested.”[3]

The growth accounting section of the present paper takes a perfectly sensible approach. The authors observe a puzzle and then construct an analytical framework that explains the puzzle in a manner consistent with

1. Corrado. Hulten, and Sichel (2006).
2. Basu and others (2004).
3. Basu and others (2004, p. 52)

established theory and methods. They then check the consistency of their inferred measure of intangible capital with the Corrado, Hulten, and Sichel approach, which relies more on direct measurement. My own view, however, is that this section of the paper relies too heavily on an IT-related explanation of productivity without addressing the restructuring issue that is supported by the industry section of this paper.

The industry analysis adds an important additional source of information to the story, but this section of the paper is not well integrated with the growth accounting section. There is no effort to measure intangible capital investment by industry or to link such investment directly with the relative productivity performances of the different industries. The authors make the general observation that the role of IT capital is explored in a way that is consistent with the first half of the paper. However, the industry analysis draws inferences from the timing of productivity acceleration that would presumably change quite a bit if the intangible capital approach were used.

An immediate impression from the industry results is that there is a lot of noise in the industry growth rates. The productivity estimates based on value added differ substantially from the estimates based on gross output. The results reported in the second panel of table 5 suggest regression to the mean, as eleven industries show a reversal in sign (an industry with an acceleration of productivity after 1995 slows after 2000, or vice versa). Having worked with both industry and establishment data myself, I sympathize with the authors as they face this problem, but this analysis makes heavy demands on the data by drawing lessons not from productivity levels or growth rates but from accelerations or decelerations. In part the problem may be that price and quantity information in the United States is much better for final goods than for intermediate goods. This problem, which is one that Edward Denison emphasized,[4] has been alleviated by recent improvements in the data, but not eliminated.

A key result the authors are looking for is whether or not the pattern of productivity acceleration by industry is consistent with an important role for IT investment. In earlier work, Kevin Stiroh reported a strong link between industries that had a high share of IT capital input in total capital input in 1995 and the extent to which their productivity accelerated during 1995–2000.[5] This result remains valid here, but the same approach for the

4. See Denison (1989).
5. Stiroh (2002b).

post-2000 period does not work. As the authors note, "By contrast, the post-2000 acceleration in productivity does not appear to be tied to the accumulation of IT assets in the late 1990s."

Thus the breakdown in the correlation between IT capital and productivity growth that I noted earlier for the aggregate time-series data also extends to evidence from the industry-level analysis. The same result is stated even more strongly by Bosworth and Triplett.[6] They report an assertion in a recent survey of the literature that there is a consensus among economists that the U.S. productivity acceleration was the result of innovations in semiconductor manufacturing. Bosworth and Triplett respond, on the basis of their own industry-level research, that "If this is indeed the [economists'] consensus, we contend it is wrong."[7] No one doubts that IT has been an important enabling innovation, but it is not the whole story.

Oliner, Sichel, and Stiroh point to the intense restructuring pressure that occurred after 2000 as a key contributor to growth in productivity, and I agree with this, as I said earlier. We know that in 2001–03 total hours worked in the nonfarm business sector declined quite sharply while output and productivity were both strong. This differs from the traditional pattern of cyclical productivity where employment declines are associated with weak productivity growth. Companies faced intense pressure to improve profits in the wake of the technology bust and the accounting scandals of the period. They reduced employment, kept investment low, and found ways to cut costs. The authors test this hypothesis by showing that the industries that had faced profit pressure before 2000 were the ones that saw the greatest improvement of productivity after 2001. Given the noisiness of the data, there is a case for caution in interpreting these results, but overall I found them interesting.

In 2005 and 2006 labor productivity growth in the nonfarm business sector was 2.1 percent and 1.6 percent, respectively, well below the pace of the recent past and even below the 2.5 percent a year trend of the late 1990s. Is the productivity boom over? The final section of this paper offers a look at the future, and the authors use the John Roberts smoothing model as a basis for estimating the productivity growth trend. They conclude that the trend is now 2¼ percent a year—a more optimistic figure than some, but slower than the 2000–05 rate. I am a little more optimistic (my estimate of the trend is

6. Bosworth and Triplett (2007).
7. Bosworth and Triplett (2007, p. 17).

2½ percent),[8] and I am not comfortable with the Kalman filter approach to figuring it out. The smoothing algorithms became much too optimistic about the trend in 2002–04 and are turning too pessimistic now. U.S. labor productivity has the property that trend growth remains stable for extended periods and then changes abruptly: generally strong growth in 1947–73 was followed by generally weak growth in 1973–95, which was followed in turn by generally strong growth in 1995–2006. It is hard to see why this would be the case, but empirically it is hard to mistake. The trend accelerated after 1995 to 2.5 percent a year, and the corporate restructuring discussed in this paper induced temporarily above-trend growth. It was to be expected that a period of slower-than-trend growth would follow, and that is what we are seeing now. It is certainly possible that the productivity boom has ended. But it is the strong competitive intensity in the U.S. economy, combined with technological opportunities and rapid globalization, that has driven faster productivity growth in the past ten years. Their effects are likely to continue a while longer.

N. Gregory Mankiw: I enjoyed the opportunity to read and reflect on this paper by Stephen Oliner, Daniel Sichel, and Kevin Stiroh. I am an outsider to the vast literature on growth accounting, and this paper does a good job of bringing the reader up to date on the current state of play. I want to begin by reflecting on the broader literature before turning to the results in this paper that I found most intriguing.

To be honest, in my own life as a practical macroeconomist, I do not spend a lot of time thinking about growth accounting. In fact, I can estimate with a fair degree of precision that I spend fifteen minutes a year on the activity. Those are the fifteen minutes that I teach growth accounting to undergraduate students in my macroeconomics course. I write down a production function, explain how Robert Solow taught us to compute his famous residual, and then show some representative calculations for the U.S. economy. I explain that this residual might be interpreted as a measure of the rate of technological progress, but I then explain how it might reflect other phenomena as well, especially over the short time spans that characterize the business cycle. Having done all this, I then ignore growth

8. Baily and Kirkegaard (2007).

accounting for approximately the next 364 days (365 days in leap years) until it is time to give the same spiel to the next cohort of undergraduates.

While reading this paper I found myself reflecting on my almost complete lack of attention to the growth accounting literature, to which this paper very ably contributes. My guess is that my experience is not all that atypical. There is a small and hardworking band of brothers (and sisters), including Oliner, Sichel, and Stiroh, toiling in the fields of growth accounting. But most macroeconomists, like me, do not spend a lot of time focusing on the results that this literature produces.

One reason is that this literature seems mired in a host of issues that quickly make a reader's eyes glaze over. Some of these issues are technical, such as distinctions between gross output and value added and the index number theory that bridges that gap. Others involve data availability, such as the potentially important role of unmeasured intangible capital. Out of necessity, many of these issues get resolved by imposing assumptions on the production process which, although not outlandish, are neither compelling nor verifiable. This paper, for example, at times makes an assumption about the complementarity between information technology and intangible capital that seems to be just pulled out of a hat.

But I think there is a more fundamental reason why the growth accounting literature fails to have a larger impact. Even if one grits one's teeth to make it through all the technical issues, and even if one has enough credulity to buy into all the necessary assumptions, the exercise does not deliver what we really want. Ultimately, God put macroeconomists on earth for two reasons: forecasting and policy analysis. We want to know how the world is likely to look in the future, and we want to know how alternative policies would change the future course of history. Unfortunately, growth accounting contributes relatively little to either forecasting or policy analysis. Instead it is a deeply data-intensive exercise that often gets so deeply enmeshed in its own internal logic that it never returns to the big questions of macroeconomics.

Long ago, some economist—I believe it was Moses Abramovitz—called multifactor productivity "a measure of our ignorance." That is, we account for changes in capital, labor, labor quality, and the many other determinants of output we can measure, and the changes in output left unexplained are called "multifactor productivity." But that is really just giving a fancy name to something about which we are pretty clueless. When reading this paper I started playing a game where every time I read the authors say something about "multifactor productivity," I imagined putting some version of "a measure of our ignorance" in its place.

Let me give an example. At one point the authors write, "MFP growth strengthened in the rest of nonfarm business, adding roughly ¾ percentage point to annual labor productivity growth during 2000–06 from its 1995–2000 average." I rewrote the sentence as follows: "our ignorance strengthened in the rest of nonfarm business, adding roughly ¾ percentage point to annual labor productivity growth during 2000–06 from its 1995–2000 average." Framed in this alternative way, the statement carries an almost comical hollowness. It also makes it clear why statements about multifactor productivity are of limited use for either forecasting or policy analysis. Measured ignorance is probably better than unmeasured ignorance, but it would be a mistake to confuse it for real knowledge.

The section of this paper I like best is the one that departs most from the standard growth accounting paradigm and instead performs regression analysis on a cross section of industries. The most striking result is illustrated in the paper's figure 3 and confirmed in regressions in table 8. Industries that experienced declining profit from 1997 to 2001 had more rapid productivity growth from 2001 to 2004. This fact is, on its face, consistent with some of the stories popular in the press that increased competitive pressure forced companies to restructure and increase productivity. As a matter of theory, of course, the story is not very complete, as it fails to explain why industries were once content to operate unproductively. But at the very least, the cross-sectional correlation is sufficiently strong and intriguing that it is worthy of further attention in both empirical and theoretical work.

In closing, let me note that the authors have done a vast amount of work here. They have brought to bear a large quantity of data, applying tools that are state-of-the-art within this literature. But when one is working with so much data, it is easy to lose the forest among the trees. This paper presents an impressively large number of trees. What I am less confident about is whether the literature on growth accounting adds up to an equally impressive forest.

General discussion: Robert Gordon agreed with the discussants that the link between investment in information technology and the acceleration of productivity is much weaker after 2000 than in the late 1990s. He compared the paper's analysis of developments after 2000 with that in his own

2003 Brookings Paper, which was based on quarterly data through the middle of that year. Both papers found that the lag of hours behind output was important to understanding the initial postrecession surge in productivity. However, Gordon noted that the quarterly data show a sharp slowdown in productivity in the second half of 2004, which the authors do not explore using their annual data.

Gordon applauded the paper's impressive empirical support for the idea that profit pressures led to unusual cost-cutting efforts after 2000. And he welcomed the attempt to model formally how IT benefits might have had important delayed effects on productivity. However, he questioned the authors' assumption that variations in capacity utilization are proportional to hours worked per employee. The standard counterexample to this assumption is the factory that is operating two assembly lines before the economy goes into recession. The factory chooses to shut down one assembly line, laying off half the workers, so that capacity utilization drops by half, while hours per remaining employee remain unchanged. Stephen Oliner replied that scope for such adjustments exists in only a few industries and that a strong aggregate cyclical relationship can be demonstrated between the work week and output growth.

Richard Cooper pointed out that two of the outliers in the authors' figure 3 are important IT sectors and conjectured that they importantly influence the precision of the regression results. He suggested that using the information available by sector could inform the analysis of the post-2000 productivity increase. For example, it is known that it was not mainly competitive pressure, but rather technological advances, that pushed up labor productivity growth in these two IT sectors. George Perry suggested that the paper's results may be sensitive to the choice of 2000 as the breakpoint. In particular, for the value-added calculations, the behavior of imports of intermediate goods appears very sensitive to that choice. William Brainard remarked that the correlation between industry productivity and profits in the early 2000s could reflect costs of employment adjustment rather than unusual pressures to improve profits. Because such costs lead employers to smooth employment fluctuations, output increases much faster than employment during a recovery, and this produces corresponding changes in productivity and profits.

Benjamin Friedman replied to Gregory Mankiw's comment regarding the usefulness of growth accounting. He noted that, a few years back, productivity in the core European countries had been catching up to that in the

United States, but in more recent years the gap has widened again. Through the work of Dale Jorgenson and others, growth accounting has provided an explanation of this closing and reopening of productivity differentials. Eswar Prasad noted that, according to the authors' appendix table A-1, the retail trade sector's share of IT capital services falls from above the median in 1995 to below the median in 2000. This seems at odds with the stylized fact that large retailers such as Wal-Mart, where technology adoption is very important, are taking over from small mom-and-pop stores, where IT has a much more limited role. This changing composition within retailing should result in a growing rather than declining role for IT in this industry. Kevin Stiroh replied that the IT use indicators are relative, and the data are not inconsistent with the trends Prasad cited. The results do not show that IT became less important in retailing, but only that the rest of the economy was catching up with retailing.

Peter Henry asked the authors for their projection of multifactor productivity. Oliner replied that their forecast of annual labor productivity growth of 2¼ percent is consistent with a growth rate of multifactor productivity of approximately 1 percent, with the rest coming from improvements in labor quality, which are assumed to be small, and capital deepening.

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