Explaining a Productive Decade

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Abstract

This paper analyzes U.S. productivity growth during the initial resurgence in the second half of the 1990s and its continued strength through 2006. At the aggregate level, we extend the traditional growth accounting framework to account for adjustment costs, variable utilization, and intangible capital accumulation. We find that the sources of growth during the second half of the 1990s were quite different from those since 2000, with a larger role for information technology and intangible capital in the 1990s. Moreover, including intangible assets tends to amplify the productivity gains in the 1990s and dampen them after 2000. At the industry level, we compare the origins of the aggregate productivity gains in the second half of the 1990s to the period since 2000 and explore potential explanations for the cross-sectional distribution of productivity growth. Again, we find large differences across periods, with a weaker link between productivity growth and IT after 2000 and some evidence that the post-2000 gains were tied to competitive pressures to reduce costs and increase efficiency. Looking to the future, both econometric and steady-state analyses produce wide confidence ranges for trend growth in labor productivity. These ranges have a midpoint that is consistent with productivity growth remaining well above the sluggish pace observed during the quarter century before 1995.

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1. INTRODUCTION

Productivity growth in the United States rose sharply in the mid-1990s, after a quarter century of sluggish gains. That pickup has been 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 financial collapse in the tech 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 continued to increase robustly, and, according to data reported at the time, actually accelerated further. More recently, the pace of labor productivity growth has slowed, increasing just 1½ percent over the four quarters of 2006.

These developments have raised many questions, three of which we investigate in this paper. First, is an IT-centered story still the right explanation for the resurgence in productivity growth over 1995-2000 and does IT play an important role when considering the entire decade since 1995? Second, what accounts for the continued strength in productivity growth after 2000? Finally, given the answers to the first two questions, what are the prospects for labor productivity growth in coming years?

[1] See Council of Economic Advisors (2001), Basu, Fernald, and Shapiro (2001), Brynjolffson 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 McKinsey Global Institute (2001).

Distinguishing among explanations for the continued strength in productivity growth after 2000 is challenging because much of the strength appeared in measured multi-factor 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 – rapid technological progress in the production of IT and the induced accumulation of IT capital – does not work very well for the period after 2000.

A related story that has received a great deal of attention is that IT investment proxies for complementary coinvestments in intangible capital, and a growing body of research has highlighted the important role played by such intangibles.[2] Moreover, a sizable chunk of the value of dynamic companies appears to arise from the development of intangible capital, such as Walmart's supply-chain technology, Amazon's business model, or Intel's expertise in organizing semiconductor production.

Stepping beyond the standard neoclassical framework, IT is often regarded as a general-purpose technology (GPT) that spurs further innovation over time in a wide range of industries, ultimately boosting growth in multifactor productivity.[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 reflect fundamental technological progress outside of

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[2] See Corrado, Hulten, and Sichel (2005, 2006), Brynjolfsson and Hitt (2003), Basu, Fernald, Oulton, and Srinivasan (2004), and Nakamura (1999, 2001, 2003). The National Income and Product Accounts (NIPAs) exclude virtually all intangibles other than software, although BEA recently released a satellite account for scientific research and development. See Okube, Robbins, Moylan, Sliker, Schultz, and Mataloni (2006).

[3] Bresnahan and Trajtenberg (1995) were the first to write about IT as a GPT. Also, see OECD (2000), Schreyer (2000), van Ark (2000), Basu, Fernald, Oulton, and Srinivasan (2004), and Basu and Fernald (forthcoming).

IT production, as implied by the strong growth in MFP in other sectors (Jorgenson, Ho, and Stiroh (2007)). For example, Bosworth and Triplett (2007) provide evidence that rapid gains in MFP in the service-producing sector continued to contribute importantly to the strength in labor productivity growth in the 2000-2005 period. Alternatively, the advances in labor productivity growth since 2000 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 restructure, cut costs, and raise productivity.[4] The profit-driven cost cutting hypothesis, in particular, has received considerable attention in the business press.[5]

Assessing these hypotheses, as best one can, is important because they have different implications for productivity growth in the future. We explore the questions posed above about the role of IT and the sources of more recent developments using both aggregate data and industry-level data. In terms of aggregate data, we extend the neoclassical growth accounting framework to address for a number of the critiques that have been raised in recent years. The list of such critiques is long, and we augment the standard framework to account for varying utilization of inputs, adjustment costs on capital, and intangibles.[6] For intangibles, we extend the framework of Basu, Fernald,

[4] See Basu, Fernald, and Shapiro (2001) and Kiley (2001) for discussions of the link between adjustment costs and productivity growth.

[5] See Gordon (2003), Baily (2003), Schweitzer (2004), and Stiroh (2006). For references to the business press, see Gordon (2003) and Stiroh (2006).

[6] Other critiques include the possibility that the standard framework overstates the role of IT by failing to account explicitly for the role of management expertise, that mismeasurement – especially of hours – generates an inaccurate picture of labor productivity, that the standard framework may mismeasure the pace of technological progress in IT production, and that outsourcing or offshoring may have affected patterns of productivity growth in ways not captured by the standard growth accounting framework. We do not pursue these critiques here to avoid over complicating an already lengthy analysis. Much has been written about the link between management expertise and productivity, including Bloom and van Reenen (2006),

Oulton, and Srinivasan (2004) to develop time series of investment and capital services for the subset of intangibles related to IT; these estimated time series allow us to investigate the role of intangibles within an augmented growth accounting framework.[7] We then turn to industry data to gain critical insights into the underlying sources of productivity growth as well as additional leverage for distinguishing among alternative explanations.[8]

To explore the prospects for future advances in productivity, we consider the recent experience in light of the history of productivity growth over the past century. We also report updated estimates of trend productivity from a Kalman-filter model developed by Roberts (2001). Finally, we solve for steady-state growth of labor productivity in a multi-sector model under a range of conditioning assumptions.

Our main conclusions are as follows. Both the aggregate and industry-level results indicate that IT is crucial for understanding 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, which implies that the IT story is robust.

McKinsey Global Institute (2001), and Farrell, Baily, and Remes (2005). Sichel (2006) makes the case that management expertise is an essential complement to IT and other sources of growth captured in the standard growth accounting framework. Regarding offshoring and hours mismeasurement, Gordon (2003) and Sichel (2003) provide reasons why these factors may have had a relatively limited effect on labor productivity growth. 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 CBO (2007b).

[7] Using a different methodology, Corrado, Hulten, and Sichel (2005, 2006) developed time series of intangible investment and capital and incorporated these estimates into a standard growth accounting framework.

[8] Several other researchers have examined industry data, including Baily and Lawrence (2001), Stiroh (2002b), Nordhaus (2002b), Corrado, Lengermann, Bartelsman, and Beaulieu (2006), and Bosworth and Triplett (2007). For references to the literature on industry-level data in Europe, see van Ark and Inklaar (2005).

That said, the sources of productivity growth differ in important ways between the 1995-2000 period and the years since 2000. In the published aggregate data (before accounting for intangibles), the smaller – though still sizable – contribution of IT after 2000 was more than offset by faster MFP growth outside the IT-producing sector. Mirroring the pattern in the aggregate data, the industry data also point to significant changes in the composition of labor productivity growth across these periods. Nonetheless, there also are important continuities in the industry data, such as the Bosworth and Triplett (2007) point about MFP growth in the services sector.

The incorporation of intangibles into the aggregate growth accounting framework takes some of the luster off the performance of labor productivity and MFP since 2000 and makes the gains in the 1995-2000 period look even more impressive. This result suggests that the renewed "golden age" of MFP growth may have been centered on the second half of the 1990s, not the period since 2000. Thus, any stories tied to rapid MFP growth (such as IT as a general purpose technology) may apply more to the second half of the 1990s than to recent years. This framework also implies that intangible investment has been 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.

The industry data provide additional insights that cannot be obtained from the aggregate data. First, we report evidence that IT capital was more tightly linked to industry productivity growth in the 1990s than in the period since 2000. Second, the industry data indicate that reallocations of both material and labor inputs have been important contributors to labor productivity growth since 2000, a point also noted by

Bosworth and Triplett (2007). 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 provided support for aggregate productivity growth in recent years by facilitating the shifting of resources among industries. Third, our analysis of the industry data supports the restructuring/cost-cutting story highlighted by Gordon (2003). In particular, industries that saw the sharpest declines in profits from the late 1990s through 2001 also experienced the largest gains in labor productivity in the early years of the 2000s, coupled with relatively slow hours growth. Because these gains are unlikely to be repeated (and could be reversed), this is unlikely to be a source of ongoing support to productivity growth going forward.

Finally, our analysis of the prospects for labor productivity growth in the future highlights the wide range of possible outcomes. Estimates from a Kalman-filter model generate a two-standard-error confidence band extending from 1¼ percent to 3¼ percent, with a point estimate of 2¼ percent. The steady-state machinery also suggests a wide range, extending from 1¾ percent to 3 percent, with a central tendency just above 2¼ percent. Notwithstanding the wide band of uncertainty, this central tendency is consistent with growth remaining significantly above the pace that prevailed in the twenty-five years before 1995, but not equaling the very rapid gains recorded over the past decade.

The paper is organized as follows. The next section reviews the aggregate growth accounting framework, extends this framework to account for variable factor utilization and adjustment costs, and presents baseline results. Section 3 extends the analysis of Basu, Fernald, Oulton, and Srinivasan (2004) to generate time series for intangible investment and capital services and presents growth accounting results for the augmented framework. In section 4, we turn to the industry data to supplement the insights that can be drawn from the aggregate data. In section 5, we discuss the outlook for productivity growth. Finally, section 6 presents some brief conclusions.

2. AGGREGATE GROWTH ACCOUNTING BASED ON PUBLISHED DATA

Analytical Framework

We use an extension of the growth accounting framework in Oliner and Sichel (2000, 2002) to analyze the sources of aggregate productivity growth in the United States. The Oliner-Sichel framework was designed to measure the growth contributions from the production and use of IT capital, which were essential for understanding developments in the second half of the 1990s. The framework, however, has some limitations. 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 in Basu, Fernald, and Shapiro (2001). In addition, we take account of intangible capital by drawing on elements of the modeling in Basu, Fernald, Oulton, and Srinivasan (2004) and Corrado, Hulten, and Sichel (2005, 2006). For the rest of the paper, we will abbreviate Basu, Fernald, and Shapiro (2001) and Basu, Fernald, Oulton, and Srinivasan (2004) as BFS and BFOS, respectively.

Our model includes six sectors. Four of these sectors produce the final nonfarm business output included in the National Income and Product Accounts (NIPAs): Computer hardware, software, communication 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.

Each final-output sector (indexed by i) uses labor (L_i), the capital produced by the final-output sectors $(K_{j,i})$, and purchased semiconductors (S_i) as inputs to production.[9] Labor input in each sector is the product of the number of workers employed (N_i), the length of the workweek (W_i), and an economy-wide index of labor quality (q), which reflects the characteristics of the workforce. Following BFS, we allow for variation over time in labor effort (E_i), the utilization of each type of capital $(u_{j,i})$, and adjustment costs associated with changes in the capital stock. The adjustment-cost function for each sector (Φ_i) represents the resources that are diverted from producing market output to installing new capital.[10] With this notation, the production function for each final-output sector can

[9] The first subscript on K refers to the sector that produces the capital good, while the second subscript refers to the sector using the capital good as an input to production. We use the same convention for investment, I.

[10] BFS also include adjustment costs for labor in their model. However, they zero-out these costs in their empirical work, focusing instead on capital adjustment costs. We simply omit labor adjustment costs from the start.

be written as:

(1) $$Y_i = F_i\left(u_{1,i}K_{1,i},...,u_{5,i}K_{5,i},E_iL_i,S_i,z_i\right)\left[1-\Phi_i\left(I_{1,i}/K_{1,i},...,I_{5,i}/K_{5,i}\right)\right],$$

where z_i measures the level of technology. To ease the notational burden, we have suppressed time subscripts in equation 1 and will do so throughout the paper unless they are required for clarity.

The production function for the semiconductor sector is identical in form to equation 1 except that semiconductors are omitted from the set of inputs:

(2) $$Y_S = F_S\left(u_{1,S}K_{1,S},...,u_{5,S}K_{5,S},E_SL_S,z_S\right)\left[1-\Phi_S\left(I_{1,S}/K_{1,S},...,I_{5,S}/K_{5,S}\right)\right].$$

We assume that the production function in every sector exhibits constant returns to scale and that the firms in each sector operate in a perfectly competitive environment.[11]

Equations 1 and 2 are the building blocks of our growth-accounting framework. Appendix A presents a detailed derivation of our main results, but the basic steps are as follows. We totally differentiate the sectoral (gross output) production functions in equations 1 and 2, replacing the unobserved output elasticities with expressions involving income shares that arise from the firm's cost minimization problem. We then combine the sectoral growth accounting expressions with appropriate weights to arrive at an equation for growth in aggregate value-added. If we denote the growth rate of any variable X by $\dot{X}$, the resulting expression for growth in aggregate labor productivity is:

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

where V is aggregate value-added in nonfarm business, H is aggregate hours worked, K_j

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

is the aggregate amount of type-*j* capital used in the nonfarm business sector, α^L and α_j^K are the income shares for labor and each type of capital, and *MFP* denotes multifactor productivity. Equation 3 is a standard growth decomposition. It expresses the growth in labor productivity as the sum of the contribution from capital deepening (shown by the share-weighted increase in each type of capital per hour worked), the contribution from the increase in labor quality, and growth in aggregate *MFP*.[12]

The equation that aggregates the sectoral *MFP* growth rates is entirely standard as well. In particular, aggregate *MFP* growth equals a share-weighted sum of the sectoral growth rates:

$$(4) \qquad M\dot{F}P = \sum_i \mu_i M\dot{F}P_i + \mu_S M\dot{F}P_S ,$$

where the weight for each sector equals its gross output divided by aggregate value-added. These are the usual Domar (1961) weights that take account of the input-output relationships among industries. Equations 3 and 4 have the same structure as their counterparts in Oliner and Sichel (2002). The only formal difference is that the inclusion of intangible capital increases the number of final-output sectors (*i*) and types of capital (*j*) from four to five.[13]

All of the action involving capital adjustment costs and time-varying factor utilization appears in the expressions for sectoral *MFP* growth that feed into equation 4.

[12] Note that semiconductors do not appear explicitly in equation 3. However, semiconductors do affect aggregate labor productivity through their effect on aggregate *MFP* growth, as discussed below.

[13] In contrast to the expression for aggregate *MFP* growth in BFS, equation 4 contains no terms to account for reallocations of output, labor, or capital across sectors. The particularly clean form of equation 4 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 made a simplifying assumption that eliminates the reallocation term for capital that would otherwise result from the presence of adjustment costs. As noted in Appendix A, we have assumed that any wedge between the shadow value of capital and its competitive user cost is the same in all sectors. Given this assumption, reallocations of capital across sectors do not affect aggregate output. .

As we show in Appendix A, these expressions are:

(5) $$M\dot{F}P_i = \xi_i \dot{W}_i - \sum_j \phi_{j,i} \dot{I}_{j,i} + \dot{z}_i$$

for the final-output sectors and:

(6) $$M\dot{F}P_S = \xi_S \dot{W}_S - \sum_j \phi_{j,S} \dot{I}_{j,S} + \dot{z}_S$$

for semiconductor producers, where the ξ's represent the elasticity of sectoral output with respect to the workweek and the ϕ's represent the elasticity of sectoral output with respect to investment outlays for each type of capital good (the adjustment-cost effect). These elasticities all 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 *MFP* growth in equations 5 and 6 as firms obtain more output from their capital and labor. Regarding adjustment costs, faster growth of investment spending depresses *MFP* growth because firms divert resources from producing market output to the installation of new capital. The effects of factor utilization and adjustment costs drive a wedge between measured *MFP* growth and the true pace of improvement in technology, the final term in equations 5 and 6.

It may seem surprising that adjustment costs enter equations 5 and 6 via the growth in investment spending and not the growth in investment relative to the capital stock, as would be suggested by the sectoral production functions. In fact, adjustment costs do work through the growth in I/K, though this connection is disguised in equations 5 and 6. To see this point, consider a stripped-down version of the model with only one sector, one type of capital, no growth in labor quality $(\dot{q} = 0)$, and no variation in factor utilization $(\dot{W} = 0)$. In that case, equations 3-6 collapse to $\dot{V} - \dot{H} = \alpha^K(\dot{K} - \dot{H}) - \phi\dot{I} + \dot{z}$. Using the fact that $\alpha^L = 1 - \alpha^K$ under constant returns to scale, this equation can be rewritten as:

(7) $$\dot{V} = \alpha^K\dot{K} + \alpha^L\dot{H} - \phi\dot{I} + \dot{z} = (\alpha^K - \phi)\dot{K} + \alpha^L\dot{H} - \phi(\dot{I} - \dot{K}) + \dot{z}.$$

Equation 7 demonstrates that adjustment costs have two effects on output growth. The first effect, captured by $-\phi(\dot{I} - \dot{K})$, arises whenever the growth of investment spending differs from the growth of the capital stock. However, adjustment costs affect output growth even when $\dot{I} = \dot{K}$. This second effect operates through the capital accumulation term as some of the total return to capital (proxied by the income share α^K) reflects compensation for bearing adjustment costs rather than income generated from producing market output. The elasticity of market output with respect to capital is $(\alpha^K - \phi)$, not α^K. Equations 5 and 6 show the net result of these two effects, but both are embedded in those equations.

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

We rely heavily on data from the Bureau of Economic Analysis (BEA) and the Bureau of Labor Statistics (BLS). Our starting point is the dataset assembled by BLS for its estimates of multifactor productivity. These annual data cover the private nonfarm business sector in the United States and provide measures of the growth of real output, real capital input, labor hours, and labor quality. As of early March 2007, the BLS had not yet updated its *MFP* dataset to incorporate the revisions to the NIPAs that were published in July 2006 and covered the period back to 2003.[14] To build in these revisions from 2003 forward, we employ the latest available NIPA data on real nonfarm business output and on real investment outlays; the NIPA investment data generate series on real capital input via the perpetual inventory method. We also incorporate the historical revision to labor hours that BLS released on March 6, 2007. Thus, our dataset represents an up-to-date reading on productivity developments through 2006 based on data available as of early March 2007.

To calculate the income share for each type of capital in our framework, we mimic the BLS procedure that distributes total capital income across assets by assuming that each asset earns the same rate of return net of depreciation in a given year. This assumption – along with estimates of asset-specific depreciation rates, rates of capital gain or loss, and tax parameters – allows us to impute the user cost for each asset. The income earned by each asset is then calculated as the product of this user cost and the stock of each asset. This is the same method used by Oliner and Sichel (2000, 2002) and by Jorgenson, Ho, and Stiroh (2002, 2007). Given the estimated time series for the

[14] BLS released a new *MFP* dataset on March 23, 2007, after we completed work on this draft of the paper. We plan to incorporate those data in the next draft.

capital income shares, the labor share equals one minus the sum of the capital shares in each period.

We follow the standard practice by allowing these income shares to vary year by year. [15] To aggregate across assets, we sum the share-weighted growth rates of individual assets, where the share-weighted growth of any variable from year t to year t+1 is the log difference between those years multiplied by the average share in years t and t+1.

The data and procedures described above, combined with equation 3, generate a series for aggregate *MFP* growth. Given this series as a top-line control, we estimate *MFP* growth in each sector with the "dual" method employed by Jorgenson and Stiroh (2000), Jorgenson, Ho, and Stiroh (2002, 2007), Oliner and Sichel (2000, 2002), and Triplett (1996), among others. 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 are the analogous quantity data. Roughly speaking, the dual method compares the rate of change in a sector's output price and its input costs. Sectors in which prices fall quickly compared to their input costs are estimated to have experienced relatively rapid *MFP* growth. Oliner and Sichel (2002) give a non-technical description of the way in which we implement the dual method, and Appendix A of this paper provides the algebraic details.

[15] The year-by-year share weighting embeds the implicit assumption that firms are re-sizing their capital stocks each year to satisfy the static marginal condition that equates the marginal product of capital with its user cost. Strictly speaking, this assumption is not appropriate in the presence of adjustment costs, as noted by BFS and Groth et al. (2006). Both of those studies replace the year-by-year share weights with the average shares over subperiods 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 subperiod average shares. In light of this result, we decided to adhere to the standard share-weighting practice in the literature.

The expression that links aggregate and sectoral *MFP* growth (equation 4) 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. We obtain data on final sales of computer hardware and software from the BEA and build up an estimate of final sales of communications equipment from BEA data. 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 Fed'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 5 and 6 to calculate the effects at the sectoral level and then aggregate those effects using equation 4. However, as shown by equation 5 and 6, this "bottom-up" approach requires highly disaggregated data on investment and the workweek and equally disaggregated output elasticities with respect to investment and the workweek (the ϕ's and the ξ's). Unfortunately, estimates of the required sectoral elasticities cannot be found in the literature, which makes it difficult to implement this approach.

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 percent 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 $\phi\dot{I}$, where $\dot{I}$ and ϕ denote, respectively, the growth in aggregate real investment spending and the elasticity of aggregate output with respect to this spending. 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 4-6 is as follows (starting with the sectoral equations):

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

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

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

where $\bar{\mu} \equiv \sum_i \mu_i + \mu_S$. One can easily verify that the second equality holds in equation 10 by substituting for $M\dot{F}P_i$ and $M\dot{F}P_S$ from equations 8 and 9. Equations 8-10 serve as our empirical counterpart to equations 4-6.

We follow BFS fairly closely in specifying $\xi\dot{W}$ and $\phi\dot{I}$. 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 8-10 is intended to measure cyclical variation in factor use, we detrend the log of this monthly series with the Hodrick-Prescott filter (with λ = 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 measure $\dot{I}$ as the growth in business fixed investment in the NIPAs and set the output elasticity ϕ equal to 0.035.[16] This elasticity is based on estimates of capital adjustment costs in Shapiro (1986). More recent studies provide estimates of adjustment costs on both sides of $\phi = 0.035$. Hall (2004) 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. Hall finds no evidence of significant capital adjustment costs and thus cannot reject the hypothesis that $\phi = 0$. In contrast, Groth (2005) estimates ϕ to be about 0.055 based on industry-level data for the United Kingdom. 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 $\phi = 0.035$.

To summarize, we use annual data from BEA and BLS through 2006 to implement the aggregate growth-accounting framework in equation 3. This 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 parameters values reported by BFS.

Results

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[16] BFS used a larger value for ϕ, 0.048, but subsequently corrected some errors that had affected that figure. These corrections caused the value of ϕ to be revised to 0.035.

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 is already treated as an investment good in the NIPAs. Accordingly, the results presented in this section capture the growth contributions from the production and use of software, but they omit the contributions from other intangibles. 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 growth in labor productivity picked up from about 1.5 percent per year during 1973-95 to about 2.5 percent during the second half of the 1990s and rose further – to 2.8 percent – in the period after 2000. Our results indicate that an important part of the initial acceleration reflected the greater use of IT capital (line 3). In addition, the growth of multifactor productivity stepped-up notably in the IT-producing sectors (line 13), with an especially large increase for producers of semiconductors. The pickup for the semiconductor sector owes to the unusually rapid decline in semiconductor prices from 1995 to 2000, which the model interprets as a speed-up in *MFP* growth.[17] All told, IT capital deepening and faster *MFP* growth for IT producers (line 19) more than accounted for the 1 percentage point speed-up in labor productivity growth during 1995-2000. This IT-centric story for

[17] 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 down semiconductor prices 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 reflected 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.

the late 1990s confirms the consensus view for this period from previous research (e.g., Oliner and Sichel (2002), Jorgenson, Ho, and Stiroh (2002), and BFS).

The table also quantifies the influence of adjustment costs and changes in utilization during this period. As shown on lines 10 and 11, these two factors, on net, do not explain any of the upward swing in *MFP* growth from 1973-95 to 1995-2000, consistent with the results in BFS. Although the greater utilization of capital and labor had a positive effect on *MFP* growth, this influence was about offset by the negative effect from the higher adjustment costs induced by the investment boom in the late 1990s.

Table 1 tells a sharply different story for the period since 2000. Even though labor productivity accelerated another 0.3 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 (line 18), which added roughly ½ percentage point to labor productivity growth during 2000-06 relative to 1995-2000. In addition, with the deceleration in overall investment spending after 2000, adjustment costs exerted less restraint on output growth. 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.

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 rapid advance in labor productivity as reported in the published data.[18] Nonetheless, for the entire period since 1995, the use and production of IT capital remain 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 by comparing our growth-accounting results to those in Jorgenson, Ho, and Stiroh (2007), which contains the latest estimates from the growth-accounting framework pioneered by Dale Jorgenson. Table 2 presents the comparison, ending in 2005 to match the final year in the Jorgenson, Ho, and Stiroh dataset.[19] As can be seen, the big-picture results from the two frameworks are very similar. Both frameworks link the acceleration in labor productivity during 1995-2000 to a surge in IT capital deepening and faster *MFP* growth in IT-producing sectors, with a smaller contribution from a pickup in *MFP* growth elsewhere. In addition, for the latest period, both frameworks show a much-reduced contribution from the use and production of IT capital, which was more than offset by increased capital deepening for non-IT assets, faster *MFP* growth outside the IT-producing sectors, and faster growth in labor quality.

The differences in the table largely reflect the broader measures of output and capital in Jorgenson, Ho, and Stiroh's framework. Their output measure covers not only the nonfarm business sector but also farms, households, and nonprofit institutions. Consistent with this measure of output, capital input in their framework includes the service flow from owner-occupied housing and consumer durables owned by households.

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

[19] Note that we report the *MFP* contributions from our framework before accounting for adjustment costs or factor utilization as Jorgenson, Ho, and Stiroh do not control for these effects.

These service flows have grown rapidly since the mid-1990s, so Jorgenson, Ho, and Stiroh's estimates of non-IT capital deepening are larger than those reported here.

3. AGGREGATE GROWTH ACCOUNTING WITH INTANGIBLE CAPITAL

The growth-accounting analysis in the previous section relies on published data, which exclude all types of intangible capital except computer software. As discussed in Corrado, Hulten, and Sichel (2005, 2006), 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, Corrado, Hulten, and Sichel (2006) estimated that the amount of intangible investment excluded from the national accounts is very large – on the order of $1 trillion annually over 2000-03 – and they constructed a growth accounting system that includes a broad set of intangibles through 2003.

Among the intangibles excluded from the national accounts, Corrado, Hulten, and Sichel estimate that scientific and nonscientific R&D each account for about 25 percent of the total, brand equity accounts for about 15 percent, and firm-specific organizational capital accounts for the remaining 45 percent. Corrado, Hulten, and Sichel cumulate these investment flows to generate an estimate of the capital stock of intangibles; they estimate that the stock of intangibles omitted from the national accounts amounted to about $3 trillion in 2003, compared with a published nonresidential capital stock measure of about $12 trillion.

The Corrado, Hulten, and Sichel 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 intangibles 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. The series we construct covers only intangibles related to IT, a subset of those considered by Corrado, Hulten, and Sichel.

BFOS used their model for a more limited purpose. Their objective was to specify and estimate regressions to discern whether intangibles could explain the *MFP* growth patterns in published industry data. But they did not formally build intangibles into an integrated growth-accounting framework along the lines of Corrado, Hulten, and Sichel (2005, 2006). That is precisely what we do.[20]

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:

(11) $$F\left[K_t^{NT}, G\left(K_t^{IT}, R_t\right), H_t, z_t\right],$$

where K_t^{IT} is the stock of IT capital, K_t^{NT} is the stock of all other tangible capital, and R_t is the stock of intangible capital. As in our previous notation, H_t denotes hours worked and z_t is the level of technology. For simplicity, BFOS assume that there are no

[20] 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.

adjustment costs and that factor utilization does not vary. The function G that combines IT capital and intangible capital is assumed to take the CES form:

$$(12) \qquad G\left(K_t^{IT}, R_t\right) = \left[a\left(K_t^{IT}\right)^{(\sigma-1)/\sigma} + (1-a)\left(R_t\right)^{(\sigma-1)/\sigma} \right]^{\sigma/(\sigma-1)}$$

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 using this result to select the other inputs. 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:

$$(13) \qquad R_t = K_t^{IT} \left(\frac{1-a}{a} \right)^{\sigma} \left(\frac{r_t^{IT}}{r_t^{R}} \right)^{\sigma}.$$

where r_t^{IT} and r_t^{R} denote the respective user costs. Equation 13 implies the following expression for the growth of intangible capital:

$$(14) \qquad \dot{R}_t = \dot{K}_t^{IT} + \sigma\left(\dot{r}_t^{IT} - \dot{r}_t^{R}\right).$$

Importantly, equation 14 enables us to calculate a model-implied series for 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. The time-series of growth rates from equation 14 can be chained together to produce an indexed series for the level of real intangible capital, R. Given this series, the standard perpetual inventory equation implies a series for real investment in intangibles:

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

The growth in real intangible investment then can be calculated directly from this indexed levels series for N_t.

This framework requires a nominal anchor to convert the indexed levels to current dollars and to calculate current-dollar income and expenditure shares for intangibles. 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). As described in Appendix B, we use data in Corrado, Hulten, and Sichel (2006) to anchor the current-dollar levels of intangible capital and to specify its user cost. We calibrate the current-dollar levels to exclude software – which is already captured in the NIPAs – and to exclude intangibles that are not directly related to IT. In addition, we set σ = 1 (the Cobb-Douglas case), as the data in Corrado, Hulten, and Sichel (2006) show no trend over time in the income share of IT capital relative to the income share for intangible capital.

We now have all the pieces 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 $(\dot{N})$ 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 deepening now includes a term for intangible capital, calculated as the income share for intangible capital times the growth rate of the real stock of this capital, $\alpha^R\dot{R}$. The income shares for all other inputs are scaled down so that the shares (including that for intangible capital) sum to one.[21]

Primary Results

The results from this augmented growth accounting system, shown in table 3, differ in important respects from the results based on published data. As can be seen by comparing lines 1 and 1a, labor productivity growth during 1995-2000 becomes much stronger once we include intangibles, and it becomes less robust during 2000-06. The productivity gains since 2000 are now estimated to be well below the 3¼ percent rate of advance 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 on line 14, intangible investment is estimated to have surged during 1995-2000 – boosting growth in aggregate output – and then retreated during 2000-06.

The growth contribution from intangible capital deepening (line 5) follows the general pattern for IT capital – moving higher during 1995-2000 and then falling back. This similarity reflects the strong association between intangible capital and IT capital in the BFOS model. Lines 15-18 provide full detail on the growth of intangible capital and its determinants from equation 14. Despite the broadly similar growth contour for intangible capital and IT capital across periods, intangible capital increases less rapidly than IT capital in each period, owing to the quality-adjusted declines in computer prices that cause the user cost for IT capital to trend lower. This user-cost effect became more pronounced during 1995-2000 – when the prices for IT capital goods fell especially

[21] See Yang and Brynjolfsson (1999) 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*.

rapidly – preventing the growth of intangible capital from increasing in lockstep with the growth of IT capital.

Taken together, the revisions to the output and the input sides of the growth accounting equation imply a revised path for *MFP* growth, which is shown on line 10 after controlling for the effects of adjustment costs and factor utilization. Similar to the revised path for labor productivity growth, the fastest *MFP* growth now occurs during 1995-2000 rather than 2000-06. *MFP* growth over 1995-2000, at an annual rate of 1.5 percent, is a shade stronger than the corresponding figure based on published data (see table 1, line 12). In contrast, for the period since 2000, the inclusion of intangibles shaved the growth of MFP to 1.2 percent annually from the nearly 1¾ percent pace implied by the published data.

Robustness

The BFOS model imposes a strictly contemporaneous timing relationship between the growth of intangible capital and growth of IT capital. This contemporaneous 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 roll-out.

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 centered moving average or a five-year centered moving average for the growth rate of IT capital and its user cost on the right side of equation 14. 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 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. The case studies in Brynjolfsson and Hitt (2000), Brynjolfsson, Hitt, and Yang (2002), and McKinsey Global Institute (2002) all portray the installation of IT capital and associated changes in business practices and organization as being interwoven rather than strictly sequential. Aral, Brynjolfsson, and Wu (2006, p. 2) confirm 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".[22] Nonetheless, we consider the scenario with the lagged accumulation of intangible capital for the sake of completeness.

The top part of table 4 shows that these alternative timing assumptions have some effect on the period-by-period growth of intangible capital but do not change the result that the growth of this capital has been relatively slow since 2000. The same is true for the implied series for intangible investment, shown in the bottom part of the table. As a further robustness check, the table also displays the Corrado, Hulten, and Sichel (CHS)

[22] 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 are much stronger when evaluated over multi-year 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 multi-year 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.

series for intangible capital and intangible investment, which we have extended through 2005 based on some of the key series 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. As can be seen, the extended CHS series vary less across periods than do ours, but the CHS measures of intangible investment and capital both decelerate sharply after 2000, confirming an important qualitative feature of our estimates. Because the CHS series are constructed independently from the series in this paper, the correspondence between them lends some credibility to the basic thrust of our results.

Table 5 explores the growth-accounting implications of the alternative timing assumptions for intangible capital. For each timing assumption, we show three key variables: the 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). All in all, the basic features of the baseline results appear robust. In every case, the time pattern of labor productivity growth is the same as in the baseline – growth averages nearly 3 percent or more annually during 1995-2000, followed by a stepdown to growth in the neighborhood of 2-1/2 percent during 2000-06. In addition, the growth contribution from intangible capital deepening is always largest during 1995-2000 and then drops back substantially during 2000-06. Finally, while the alternative timing assumptions do not replicate the baseline slowdown in *MFP* growth after 2000, they do show that *MFP* growth was not substantially faster after 2000 than during 1995-2000.

4. INDUSTRY-LEVEL PRODUCTIVITY

We now turn to the industry origins of U.S. productivity growth during the late 1990s and after 2000. As shown in the aggregate data, the sources of productivity seem to have changed with a smaller direct contribution from IT capital deepening and a much larger *MFP* residual outside of IT production. This suggests that the industry-level origins of aggregate productivity growth and the underlying forces may have also changed after 2000, so one might expect, for example, stronger relative performance in those industries outside of the production and most intensive use of IT.

To explore this, we construct an industry-level set of productivity accounts for 60 industries that span the U.S. private economy from 1988 to 2005. This type of cross-sectional analysis complements the earlier aggregate results and our primary goals are to document the industry origins of the evolving aggregate productivity patterns and make inferences about the driving forces such as input accumulation, technological progress, and increased competitive pressures.

While measurement error, omitted variables, and endogeneity problems always make it difficult to identify the sources of productivity gains, we can make some progress by exploiting cross-sectional variation in industry productivity over time and examining how it links with observable factors such as IT-intensity and changing profit shares. Moreover, industry data raise new issues – such as the growing divergence between gross output and value-added measures of output and the increasing importance of industry reallocation terms – that are obscured in aggregate data. Both have implications for our understanding of aggregate U.S. productivity trends and are only apparent with industry-level data.

To preview the results, we find that the industry origins of aggregate productivity growth differed when the late 1990s are compared to the 2000s. This suggests considerable churning beneath the surface as some industries improved, others declined, and inputs were reallocated among industries. Our cross-sectional evidence suggests that the link between IT and productivity was strongest in the late 1990s, but considerably weaker in the 2000s. Rather than an IT-story, the productivity gains in the early 2000s seem more tightly linked to measures of competitive pressures across industries. In particular, industries with the biggest decline in profits through 2001 experienced both relatively fast productivity growth and relatively slow hours growth for 2001 to 2004.

Industry Framework, Data, and Summary Statistics

Industry productivity analysis has a long and distinguished history and we begin our analysis with a quick review of the basic definitions. More detailed derivations and recent references can be found in Jorgenson, Gollop, and Fraumeni (1987), Basu and Fernald (1995, 1997, 2001, forthcoming), Nordhaus (2002b), Stiroh (2002a, 2002b), Triplett and Bosworth (2004), and Bosworth and Triplett (2007). We first describe the framework and then discuss the data.

Industry Framework

Industry output can be defined using either a gross output or a value-added concept. Both are used by productivity analysts and each has advantages and disadvantages. Gross output corresponds closely to the conventional idea of output or sales, and reflects all inputs including capital, labor, and any intermediate materials. Value-added is a somewhat artificial concept that strips out the contribution of intermediate inputs and incorporates only capital and labor.

The gross output production function can be defined as:

(16) $Y = f(K, L, M, z^Y)$,

where Y is gross output, K is capital services, L is labor input, M is intermediate inputs, and z^Y measures the level of technology. Industry and time subscripts have been dropped wherever possible.

Value-added can be defined as a function of the primary inputs (capital and labor) and the level of technology, so that:

(17) $V = g(K, L, z^Y)$ and $Y = f(V, M)$.

While both value-added and gross output are used for productivity analysis, there is reason to favor gross output. Empirical work by Bruno (1978), Norsworthy et al. (1983), Jorgenson et al. (1987) and others rejects the existence of value-added functions on separability grounds. Basu and Fernald (1995, 1997) show that using value-added data leads to biased estimates and incorrect inferences about production parameters, while Basu and Fernald (2001) argue against the value-added function because failure of the neoclassical assumption about perfect competition implies that some of the contribution of intermediate inputs remain in measured value-added growth. 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 official sources. The first two create a panel of average labor productivity (ALP) across U.S. industries, and the third is used to develop an indicator of the intensity of the use of IT. One practical difficulty is the recent conversion of the industry-level 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 to earlier results.

BEA publishes measures of both value-added and gross output by industry that are based on an integrated set of input-output and industry production accounts (Howells et al. (2006)). BEA provides estimates for 65 detailed industries, based on the 1997 NAICS, that comprise the private U.S. economy. These data span 1947 to 2005 for real value-added and 1987 to 2005 for real gross output. BEA also publishes estimates of full-time and part-time employees, full-time equivalents, and persons engaged in production for all industries, but some of these labor data extend back only to 1998 on a NAICS basis.

We obtain hours by industry from the Output and Employment database maintained by the Office of Occupational Statistics and Employment Projections at BLS. These data include total hours of all persons, by 2-4 digit NAICS industries, going back in some cases to 1958, based on the 2002 NAICS industry definitions. Complete data on total hours for all industries, however, begin in 1988. 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, agriculture workers, and household employment), and ES202 Employment and Wage data. These hourly data are currently available only to 2004, however, so we use the growth rate of full-time equivalent employees for detailed industries from BEA to proxy for hours growth in 2005.

We create two measures of industry ALP – real-value-added per total hours and real gross output per total hours – by combining the BEA output data with the BLS employment data across industries for 1988 to 2005.[23]

The third data source is the Fixed Asset accounts from BEA for nonresidential capital. These data include 46 different types of nonresidential capital for 63 detailed NAICS industries since 1987. We use Tornqvist aggregation to create a measure of IT capital from computer hardware, software, and communications equipment. To estimate capital services, we map the asset-specific service prices from Jorgenson, Ho, and Stiroh (2007) to 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. This is an approximation as we miss industry variation in rates of return, asset-specific inflation (which reflects differences in the composition of the BEA asset classes), and tax code-related differences that reflect legal organization, but it should capture the primary features such as the relatively high service prices for short-lived assets like IT.

We combine these three sources of data to form a panel from 1988 to 2005 for a private industry aggregate, 15 broad sectors, and 60 detailed industries. The 15 broad sector breakdown follows BEA's convention, except that manufacturing is broken into Durables and Nondurables. The 60 detailed industries are smaller than the number of industries available from either BEA or BLS due to the need to generate consistently defined industries across all data sources. All aggregation was done via Tornqvist indices, except for hours, which are simply summed. Both the broad sectors and the detailed

[23] The only complication in mapping the BEA output data and BLS hours data regards Internet Publishing, where the 2002 NAICS identifies Internet Publishing and Broadcasting as a separate industry within Information and Data Processing Services, while the 1997 NAICS includes it as part of Publishing. This piece is a very small component, less than 4 percent of Publishing employment, so this is not major concern.

industries sum to the private industry aggregates of nominal output from BEA, hours from BLS, and nominal nonresidential capital from BEA. The list of detailed industries and 2005 value-added are reported in Appendix Table 1.

Before proceeding, we should mention an important caveat. We do not have detailed data on capital services, labor quality, intangible investment or adjustment costs at the industry-level, so we focus on labor productivity. We are fundamentally interested in understanding the industry sources of aggregate labor productivity growth, however, so this focus seems appropriate. Moreover, to the extent that intangible capital is correlated with IT investment, one can interpret all of the IT-intensity results broadly and indicative of the whole suite of activities that are complementary to IT.

Sector Summary Statistics

Table 6 reports estimates of labor productivity growth described in the previous section and compares them to recent estimates from BLS (2006).[24] The first two lines of Panel A report the average annual growth of average labor productivity (ALP) for the business and nonfarm business sectors, and the third reports the private industry aggregate developed from the data described above. These estimates show similar trends – a pick-up of ALP growth of about one percentage point after 1995 and a smaller increase after 2000. The measures developed from the industry-level data are a bit smaller, although the annual growth rates are highly correlated, e.g., the correlation of the annual growth rate of the private industry aggregate with the BLS estimates is near 0.90 for 1988 to 2005.

[24] Note that the BLS estimates for the nonfarm business sector are virtually identical to the top-line estimates in table 2.

Panel B reports estimates for 15 broad NAICS sectors that comprise the U.S. private economy. These sectors range in size from the very large Finance, Insurance, Real Estate, Rental, and Leasing at 23 percent of 2005 value-added to the very small Agriculture, Forestry, Fishing, and Hunting at only 1.1 percent. In terms of ALP growth, 8 of these 15 sectors, which accounted for 73 percent of value-added in 2000, showed accelerating productivity during 1995-2000.[25] After 2000, only 7 sectors that accounted for 45 percent of 2005 value-added show increased productivity growth. The large Retail, Wholesale, and Finance, Insurance and Real Estate sectors showed declines.

An interesting observation is that the aggregate productivity gains appear to originate in different sectors. For example, six sectors (Agriculture, Durable Goods, Wholesale, Retail, Finance, and Art & Entertainment) show an acceleration after 1995, but a slowing after 2000. In contrast, five sectors (Construction, Nondurables, Utilities, Information, and Other Services) show a decline in productivity growth after 1995, but an acceleration after 2000. These eleven changing sectors produced 72 percent of value-added in 2005, suggesting that the industry origins of U.S. productivity growth differed after 2000. In their analysis of MFP growth, Corrado et al. (2006) reach a similar conclusion, although Bosworth and Triplett (2007) emphasize the important role of service industries in both periods.

Industry Results

Table 7 summarizes the more detailed industry data by reporting the mean, median and weighted mean (weights equal beginning of period hours share) productivity growth rates for value-added and gross output measures for the 60 component industries.

[25] As a comparison, Stiroh (2001, 2002b) reported an acceleration of ALP after 1995 for 6 out of 10 broad sectors that accounted for the majority of output using earlier vintages of SIC data.

We also break out the industries into three groups – IT-producing, IT-using, and Other industries as described below – to examine how this classification scheme looks in the 2000s.

The industry data show divergent trends between gross output and value-added measures in Panels A and B, respectively. For the gross output estimates, the industry data show strong gains after 1995, while the value-added data show smaller gains on average and more variation. After 2000, this pattern reverses with gross output productivity growth slowing, while the value-added data show widespread increases. Both series incorporate the same hours data, so this directly reflects differences between gross output and value-added output growth rates.

To understand this divergence, it is useful to be precise about how gross output and value-added relate.[26] As a practical matter, BEA uses the "double deflation" method to estimate real value-added for all industries from observed measures of gross output and intermediate inputs, i.e., real value-added is estimated as the difference between real gross output and real intermediate inputs (Howells et al. (2006)). This can be approximated, as described in Basu and Fernald (1995, 1997, 2001), via a Tornqvist index where value-added growth is defined implicitly from:

(18) $\dot{Y} = \alpha^V \dot{V} + (1 - \alpha^V)\dot{M}$,

where α^V is the two-period average share of nominal value-added in nominal gross output.

[26] This derivation is similar to Basu and Fernald (2001), who usefully interpret the value-added as a "partial Solow residual." To focus on the key relationships, we ignore the returns to scale, adjustment costs, and utilization adjustments. We thank George Smith and Bob Yuskavage of BEA for helpful discussion in interpreting the differences between value-added and gross output growth.

Ignoring the distinction between capital and labor and considering a single primary input, *P*, a standard growth decomposition of gross output is:

$$(19) \qquad \dot{Y} = \alpha^V \dot{P} + (1-\alpha^V)\dot{M} + M\dot{F}P^Y,$$

where $M\dot{F}P^Y$ is measured *MFP* growth using gross output data. Equations 18 and 19 imply that:

$$(20) \qquad \dot{V} = \dot{P} + \frac{1}{\alpha^V} M\dot{F}P^Y$$

so that industry value-added growth depends on growth of primary inputs and *MFP* growth from the gross output production function (appropriately scaled by the value-added share).

An implication of equation 20 is that the standard measure of *MFP* growth from value-added data can be expressed as:

$$(21) \qquad \dot{V} - \dot{P} = M\dot{F}P^V = \frac{1}{\alpha^V} M\dot{F}P^Y$$

so that a value-added MFP residual, $M\dot{F}P^V$, is proportional to the gross output *MFP* residual.

It is also useful to derive a simple expression for the difference in the growth rates of gross output and value-added in terms of inputs and measured *MFP* growth by subtracting equation 20 from equation 18:

$$(22) \qquad \left(\dot{Y} - \dot{V}\right) = \left(1-\alpha^V\right)\left(\dot{M} - \dot{P}\right) - \frac{\left(1-\alpha^V\right)}{\alpha^V} M\dot{F}P^Y.$$

Equation 22 suggests two ways for gross output growth to exceed value-added growth. One, if intermediate input growth exceeds value-added growth, then gross output growth will be relatively strong. This is obvious from the definition of gross output in equation 18 and could occur due to biases in technical change, changes in relative prices that induce input substitution, or new production possibilities such as outsourcing. Second, even if intermediate and primary inputs grow at the same rate, value-added growth will exceed gross output growth if MFP growth is positive. This reflects the double deflation method used by BEA and can be seen in equation 21, which shows that gross output MFP growth is amplified in the value-added measure.[27]

It is beyond the scope of this paper to provide a complete explanation for the gross output/value-added divergence, but it is useful to document some stylized facts. First, we do not see any obvious pattern for which set of industries experienced relatively fast value-added growth, e.g., it was not all manufacturing or all service industries.

Second, intermediate input growth was exceptionally strong during the second half of the 1990s, which partially explains why gross output growth outpaced value-added growth for most industries. According to the aggregate data from BEA for all private industries, the average annual growth rates for 1988-1995, 1995-2000, and 2000-2005 are 2.6 percent, 4.5 percent, and 2.5 percent for value-added; 2.8 percent, 5.8 percent, and 1.3 percent for intermediate inputs; and 2.7 percent, 5.1 percent, and 1.9 percent for gross output. A closer look at the nominal values and prices of intermediate inputs shows that intermediate input prices grew relatively slowly during the second half of the 1990s and much faster during the 2000s. This is consistent with the substitution story if firms responded to relative price changes and substituted toward the relatively cheap intermediate inputs in the late 1990s, but reversed after 2000.

[27] Changes in the value-added and intermediate input shares or substitution between domestic and imported inputs can also affect this divergence.

Third, *MFP* growth was relatively strong in the early 2000s. Because *MFP* growth gets amplified in the value-added estimates, strong *MFP* growth tends to increase value-added growth relative to gross output growth. This is a mechanical explanation that would contribute to the relatively strong value-added growth after 2000.

We conclude that the analyst's choice between gross output and value-added measures of productivity is not inconsequential. This divergence can be wide and shift materially in relatively short periods of time, so productivity analysts should carefully consider the trade-offs when choosing one output measure and recognize that results may be dependent on this choice. In the subsequent analysis, we report both gross output and value-added measures, although we prefer gross output because it is a more fundamental measure of production and does not require additional assumption about the nature of the production function.

Simple IT Comparisons

Table 7 also reports mean productivity growth rates for three subsets of industries – IT-producing, IT-using, and Other. There is always some arbitrariness to this type of breakdown as the many sectors that comprise an aggregate economy can be broken up into any number of arbitrary subsets. Baily and Lawrence (2001), Stiroh (2001, 2002b), and Jorgenson, Ho, and Stiroh (2005), for example, use relative shares of IT capital in total capital to identify the IT-intensive industries in the U.S.[28] In contrast, Triplett and Bosworth (2004, 2006) and Triplett and Bosworth (forthcoming, 2007) focus on the distinction between service and goods-producing industries, while Nordhaus (2002b)

[28]In international applications, O'Mahony and van Ark (2003), van Ark et al. (2003) and Inklaar et al. (2005) apply the U.S IT capital shares to European countries and further break out manufacturing from service industries, while Daveri and Mascotto (2002) use a measure of IT-intensity developed by the U.S. Department of Commerce (2002).

explicitly identifies four SIC-based “new economy” industries (Machinery, Electric Equipment, Telephone and Telegraph, and Software). None of the decompositions is more correct than another as each simply reflects a different cut of the same component industries. A related concern is that the results of any decomposition may be sensitive to the particular definition used. Daveri (2004) argues that the evidence on the productivity advantage of IT-intensive industries depends critically on how the IT-intensive industries are defined.

To identify the three sets of industries, we employ the following definitions in our classification scheme. For IT-producing industries, we follow the definitions developed by BEA and used in Smith and Lum (2005) and Howells et al. (2006) and label four industries as IT-producing: Computer and Electronic Products; Publishing including Software; Information and Data Processing Services; and Computer System Design and Related Services. These industries are primarily involved in the production of computer hardware and software. For IT-using industries, we follow Stiroh (2002b) and identify industries as IT-using if their IT capital share (nominal IT capital as a share of nominal nonresidential capital) is above the median of all industries, excluding the four IT-producing industries. All remaining industries are labeled Other industries.

This breakdown can be summarized as 4 IT-producing industries with 4 percent of aggregate 2005 value-added, 26 IT-using industries with 59 percent, and 30 Other industries with the remaining 37 percent. Appendix Table 1 shows this classification scheme for the 60 detailed industries based on both 1995 and 2000 IT capital shares and reports the 2005 IT capital share.

Table 7 shows that the IT-producing industries dominated when 1995-2000 is compared to 1988-1995. In terms of both ALP measures, these four industries showed both the fastest average growth rate and the largest acceleration, an increase of 1.2 percentage points on average for gross output and 2.4 percentage points for value-added. The IT-using industries also showed a substantial increase of 1.9 percentage points on average for gross output and 1.0 percentage point for value-added, but the Other industries increased 0.5 percentage point after 1995 when measured using gross output and declined 0.7 percentage point using value-added. These NAICS-based estimates support earlier interpretations that IT played a critical role in the post-1995 productivity surge across U.S. industries in the late 1990s.

The more recent productivity gains after 2000, however, appear much less correlated with the IT classifications. All three industry groups saw slower gross output ALP growth after 2000, while all improved using value-added ALP. Moreover, the pattern across groups differs for the post-2000 gains. In particular, the Other industries did slightly worse in terms of gross output productivity, but showed a larger increase than the IT-using industries in terms of value-added productivity.

Industry Origins of the Aggregate Productivity Gains

We now examine how the detailed industry data described above can be aggregated to form economy-wide productivity growth estimates. We first employ a familiar decomposition framework to identify the industry origins of U.S. productivity growth in both the late 1990s and the 2000s, and we then we quantify shifting contribution across industries and time periods to show the different origins of the aggregate productivity gains in the 1990s and the 2000s.

Decomposition and Reallocations

One attractive property of industry value-added is that growth rates can be easily combined to yield value-added growth. In particular, aggregate value-added growth can be defined as a Tornqvist aggregate as:

(23) $$\dot{V} = \sum_i v_i \dot{V}_i,$$

where v_i is the two-period average share of industry *i*'s nominal value-added in aggregate nominal value-added.

Aggregate hours, *H*, worked is the simple sum of industry hours, H_i:

(24) $$H = \sum_i H_i,$$

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

Equations 18, 23, and 24 can be combined, as in Stiroh (2002b), to yield the following decomposition of aggregate labor productivity growth:

(25) $$\begin{aligned} A\dot{L}P^V &= \left(\sum_i v_i A\dot{L}P_i^Y\right) - \left(\sum_i m_i\left(\dot{M}_i - \dot{Y}_i\right)\right) + \left(\sum_i v_i \dot{H}_i - \dot{H}\right) \\ &= \left(\sum_i v_i A\dot{L}P_i^Y\right) - R^M + R^H. \end{aligned}$$

where ALP^Y is industry gross output labor productivity and m_i is the two-period average ratio of nominal industry intermediate inputs to nominal aggregate value-added.

This simplifies to

(26) $$\begin{aligned} A\dot{L}P^V &= \left(\sum_i v_i A\dot{L}P_i^V\right) + \left(\sum_i v_i \dot{H}_i - \dot{H}\right) \\ &= \left(\sum_i v_i A\dot{L}P_i^V\right) + R^H. \end{aligned}$$

The first term in equation 25 is a "direct productivity effect" equal to the weighted average of gross output labor productivity in 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 using more intermediate inputs to raise gross output, $\dot{M} > \dot{Y}$, which 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, so aggregate productivity rises if industries with value-added shares above labor shares – that is, those industries with relatively high (nominal) productivity levels – experience growth in hours. Equation 26 is a simplification using value-added labor productivity for industries.[29]

Table 8 reports estimates of the decomposition framework in equations 23 to 26. The first row in Panel A repeats the productivity estimates that come from the BEA aggregate private industry output and the sum of hours worked from BLS. The second row reports the estimate explicitly derived by aggregating the detailed industries as in equations 23 and 24. There is a small divergence for the middle period, but the aggregated industry data provide the same picture – a large productivity acceleration after 1995 and a smaller one after 2000.[30]

Panel B reports estimates of the decomposition using gross output data from equation 25, while Panel C reports the value-added decomposition from equation 26. Both 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

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[29] This value-added approach is similar to Nordhaus (2002b).

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

for value-added), followed by a large decline after 2000 for gross output (-0.94 percentage points) and no change for value-added.

Both the reallocation of materials and reallocation of hours terms became larger after 2000, which boosted the aggregates and suggest that an important part of the post-2000 productivity gains was the shifting of inputs among industries.[31] In fact, we do not observe a subsequent increase in productivity growth after 2000 when looking only at the direct industry contributions, an insight that is only possible with industry-level productivity data.

The material reallocation term contributes positively to aggregate productivity growth when gross output is growing faster than materials, so that value-added is growing faster than gross output. As discussed earlier, this has been the case after 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.

In terms of the reallocation of hours, this will be positive when industries with relatively high productivity levels (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. Stiroh (2006) discusses some evidence of increased flexibility of U.S. labor markets and provides evidence of increased reallocation across industries. For example, the cross-

[31] Jorgenson et al. (2006) show an increase in both the intermediate input and hours reallocation terms, although both are slightly negative through 2004, while the Bosworth and Triplett (2007) estimates are similar 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 an hours reallocation term that remains negative through 2005. This divergence reflects differences in the estimation of the hours series. Bosworth and Triplett (2007) use the full-time/part-time series from BEA and scale it by the total hours per employee data from BLS for 1987 to 2004 and held hours per full-time/part-time employee constant for 2004-2005.

sectional correlation of hours growth across industries has declined steadily since the early 1980s as industry-level hours growth become less synchronized. One interpretation is that labor market changes have made it less costly to reallocate labor among industries.

To provide an alternative perspective on the reallocation of hours, we estimated the cross-sectional correlation of hours growth and the lagged level of productivity (both gross output and value-added) for 60 industry observations in each year. Figure 1 plots the estimated correlations and the annual estimate of the reallocation of hours in equation 26. All three seem to be trending up, particularly since the early 1990s, which suggests that industries with relatively high productivity levels have become more likely to show strong hours growth in the following year. There also seems to be a cyclical component with relatively large correlations and hours reallocations during recessions, consistent with the notion of cleansing effects of recessions (Caballero and Hammour (1994)).

This interpretation of the reallocation of hours is suggestive; we have not provided 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

The direct industry contributions are simple sums, so we can employ the IT-classification schemes described earlier to quantify the contribution from the IT-producing, IT-using, and Other industries. As in earlier estimates, table 8 shows that the IT-producing and IT-using industries accounted for all of the direct contribution from individual industries to the productivity increase after 1995. After 2000, however, there is less divergence with all three groups of industries posting net declines in terms of gross output and IT-producing industries doing the worst when value-added is measured.[32] We conclude that the IT classification scheme appears less informative in the 2000s when compared to the late 1990s.

We should emphasize, however, that the IT-producing industries remained relatively large contributors to aggregate productivity growth throughout the sample. For 2000-2005, for example, the four IT-producing industries accounted for 19 percent of aggregate productivity growth over the period (0.47/2.52), which is quite large relative to their 4 percent share of value-added. Moreover, the direct contribution from the IT-using industries over both 1995-2000 and 2000-2005 was far larger than it had been over 1988-1995, although it did decline after 2000. In contrast, the direct contribution from other industries remained smaller throughout 1995-2005 than it had been before 1995.

Changing Industry Origins

To identify more precisely which industries contributed to the change in aggregate productivity during each of the periods of accelerating productivity growth, we calculate the average annual contribution of each industry to aggregate value-added productivity growth ($v_i \dot{ALP}^V$) for 1988-1995, 1995-2000, and 2000-2005. We then compare the change across these periods.[33]

Figure 2 plots the change in the average annual contribution for 2000-2005 less 1995-2000 against 1995-2000 less 1988-1995 for the 60 industries. Observations in the north-east quadrant made positive contributions to both productivity accelerations; industries in the south-east quadrant contributed positively to the acceleration after 1995

[32] This decomposition is consistent with more formal econometric results discussed later.
[33] We use value-added productivity growth here because it more closely corresponds to the aggregate results.

but negatively to the gains after 2000; industries in the south-west quadrant contributed negatively to both; and industries in the north-west quadrant contributed positively to the post-2000 gains, but detracted from the post-1995 gains.

The most striking observation is the large number of industries in the north-west and south-east quadrants, where the contributions switched signs. As an extreme example, if the contributions for 1995-2000 were identical to the contributions for 2000-2005, then all industry observations would fall on the horizontal axis. The 19 industries in the north-west quadrant, for example, made a net contribution after 1995 of -0.55 percentage point, but a contribution of 0.77 percentage point to the gains after 2000, a difference of 1.32 percentage points. For the 18 industries in the south-east quadrant, their net contribution reversed from 1.20 percentage points after 1995 to -1.01 percentage points after 2000, an even larger change of –2.21 percentage points. While this undoubtedly reflects some mean reversion, the origins of the aggregate productivity growth across these periods seems to have shifted.

The majority of the shift in the south-east quadrant can be traced to four industries – Computer and Electronic Products, Securities, Wholesale Trade, and Retail Trade – where large increases in productivity growth were followed by a substantial slowdown. In Computers and Electronic Products, for example, the average growth rate increased from 16.2 percent for 1988-1995 to 30.3 percent for 1995-2000 and then declined to 16.9 percent for 2000-2005. This rapid acceleration and subsequent decline can also be seen in the price data and our estimates of *MFP* growth from the price dual discussed earlier. In the Securities industry, the average growth rate increased from 7.7 percent for 1988-1995 to 17.6 percent for 1995-2000 and then declined to 5.8 percent for 2000-2005. This could reflect the increase in financial market activity and productivity during the bull market of the late 1990s, but may also reflect measurement problems.[34] Recent productivity growth in both industries is still above the economy average, so both are still making strong contributions to aggregate productivity growth, but their slowing growth rates made the contributions to the change in aggregate productivity growth after 2000 negative.

This comparison reveals major reversals in the contributions of particular industries to the post-1995 and the post-2000 increases in labor productivity. In sum, 37 industries that accounted for 58 percent of aggregate output saw their contribution switch signs between the two productivity accelerations. This is prima facie evidence of the shift in the industry origins of the productivity gains after 2000 when compared to those after 1995.

Potential Explanations for the Industry Variation

We now explore two specific questions about the cross-sectional distribution of productivity growth. One, is there evidence for a continuation of the link between IT and productivity growth in the 2000s as in the 1990s? The simple comparisons and decompositions discussed earlier suggest not, but we can examine this more formally. Two, is there evidence for the idea that restructuring contributed to the strong productivity gains after 2000? Again, the earlier analysis is suggestive of this and we seek to substantiate those results with more a formal analysis of the industry cross-section.

IT and Productivity Growth

[34] See Triplett and Bosworth (2004) for a discussion of how output is measured in this industry.

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

(27) $$\Delta A\dot{L}P_i = \alpha + \beta IT_i + \varepsilon_i ,$$

where $\Delta A\dot{L}P$ is the change in the average annual growth of productivity over two periods, e.g., 1995-2000 less 1988-1995, 1995-2005 less 1988-1995, or 2000-2005 less 1995-2000.

We use two alternative measures of IT-intensity on the right-hand side of equation 27. First, we use the share of IT capital in total nonresidential capital to create an indicator of relative intensity, i.e., a dummy variable equal to 1 if the IT-share is greater than the industry median and equal to 0 otherwise.[35] This allows a broader interpretation of IT as a proxy for related investments and is robust to measurement error in the capital stock, a prevalent feature described by Becker et al. (2005)), but misses variation in IT-intensity across industries. Second, we use the continuous share of IT capital services in nonresidential capital services. This better captures differences in intensity, but is prone to measurement error.

An important detail is that we always define IT-intensity prior to the period of acceleration, e.g., in 1995 when analyzing the change in productivity growth after 1995

[35] This specification is identical to a difference-in-difference style regression with a post-1995 dummy variable, an IT-intensive dummy, and the interaction estimated with annual data for the full period.

and in 2000 when examining the change after 2000. While not perfect, this helps control for the endogeneity of investment. When interpreting the results, β represents the average difference in the acceleration of productivity for IT-intensive industries relative to other industries when the dummy variable approach is used and represents the increase in the acceleration of productivity growth if IT-intensity were marginally increased.

Table 9 reports results. The first two columns examine only gains in the late 1990s by comparing 1995-2000 to 1988-1995. The middle columns extend the data to 2005, but keep the break point and measure of IT-intensity at 1995. The final two columns focus on the post-2000 gains by comparing the change in productivity from 2000-2005 to 1995-2000. Panel A uses the gross output measure of productivity, while Panel B uses a value-added measure. All estimates are via ordinary least squares (OLS) with robust standard errors.[36]

Beginning with the results through 2000, the results for gross output show that the IT indicator is large and significant, although the IT share is not significant (p-value=0.18), while the value-added regression with the 1995 IT Dummy shows a large, but not quite statistically significant coefficient (p-value=0.11) and no significance with the continuous IT share. When we extend the data to include the post-2000 period, both the gross output and value-added estimates show significant IT effects. The final two columns focus on the productivity gains after 2000 and examine whether IT-intensity in

[36] We estimated (but don't report) weighted least squares estimates with value-added weights, which are appropriate if the somewhat arbitrary nature of the industry classification system makes measurement error more severe in the relatively small industries, i.e., if the variance of residuals is inversely related to industry size. See Kahn and Lim (1998) for a more detailed discussion of weights in industry regressions.

2000 is a useful predictor of relative performance after 2000. It does not appear to be the case as the coefficients are universally small and far from statistical significance.[37]

These results suggest that the most IT-intensive industries in 1995 experienced the largest increase in productivity growth after 1995 and that these gains continued through 2005. Relative to earlier work, these data reflect several annual revisions to the national accounts and reorganization into NAICS industries, so they represent a strong robustness check for the conclusion that IT-use mattered for the productivity gains in the late 1990s.

We also conclude that the post-2000 acceleration in productivity does not appear to be tied to the accumulation of IT assets in the late 1990s. In particular, the cross-sectional results do not support the notion that the industries that sowed lots of IT capital in the late 1990s reaped a large productivity payoff after 2000, owing either to lags in learning to use IT effectively or to lags in building complementary capital. Nonetheless, the results could be consistent with another IT-related explanation – namely, that IT is indeed driving the recent productivity gains, but that its pervasiveness makes it difficult to identify a link econometrically. If IT is integral for all industries, then a simple indicator of IT-intensity may not be able to usefully break industries into different classifications. In this view IT remains central, but it is simply no longer useful to try and differentiate industries by their relative IT-intensity. A difficulty with this view, however, is that it is inherently untestable.

Competitive Pressures and Productivity Growth

[37] Stiroh and Botsch (forthcoming) report similar results.

One idea that received considerable attention is that U.S. firms were under increased pressure in the 2000s to cut costs and raise efficiency in order to compete in a more globalized and competitive environment. If this view is correct, one would expect to see strong productivity growth and weak hours growth in the industries that experienced the biggest decline in profits and were forced to do large amount of restructuring.

Gordon (2003) concludes that a likely explanation of the unusual upsurge of productivity in the early 2000s reflects the "savage cost cutting and layoffs (p. 274)" that followed the profit boom of the late 1990s.[38] Similarly, Schweitzer (2004) notes that firm managers have stressed the need to realign their business processes without hiring additional workers, but admits that empirical verification is difficult. He does provide evidence, however, of increased "business restructuring," measured by the standard deviation of occupation share adjustments. Groshen and Potter (2003) raise the possibility that new management strategies are promoting lean staffing in order to increase efficiency.

The reaction to the competitive pressures may have been facilitated by the ability of business to respond more quickly in an environment of more flexible and efficient labor markets. Schreft and Singh (2003), for example, document the steady rise of "just-in-time employment" and increased flexibility as the U.S. workforce is increasingly made up of temporary workers, part-time workers, and worker with increased overtime hours. Aaronson et al. (2004a) also argue that just-in-time employment changes altered labor market dynamics around the "jobless" recoveries of 1990-91 and 2001.

[38] See Nordhaus (2002a) for details on profit trends over this period.

The implication is that productivity should rise and input growth fall in the industries under the most intense competitive pressures. To examine this, we employed a similar framework to the one above, but compared industry growth from 2001 to 2004 – the period of extremely rapid aggregate productivity gains – to changes in industry-level profits from the peak in the aggregate profit share to the trough (1997 to 2001).

To identify industries under the most intense pressures to restructure, we use a measure of profits derived from the BEA industry data, where we define the annual profit share as gross operating surplus as a share of value-added. Gross operating surplus includes consumption of fixed capital plus business transfers plus other gross operating surplus (profits before tax, net interest, and miscellaneous payments). While one would like 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, therefore, should be viewed as a broad measure inclusive of the gross return to capital. To the extent that capital consumption is relatively stable and unrelated to profits, this should not bias our results.

As a first step to explore these relationships, we compared the growth of industry hours and industry labor productivity for 2001 to 2004 to the change in the profit share from 1997 to 2001. The competitive pressure/restructuring story implies that industries with the biggest decline in profits should be under the greatest pressure and experience relatively slow hours growth and relatively fast productivity growth. Figures 3 and 4 report these scatter plots for the 60 industries, along with an OLS fitted line.
While these are simple relationships, the results are consistent with the competitive pressure/restructuring hypothesis as a decline in profits is associated (significantly) with

slower hours growth and faster ALP growth.[39] To put some magnitude on the relationships, the industries with below median changes in profits experienced hours growth 2 percentage points slower than other industries, but labor productivity growth that was about 3 percentage points faster. There was no difference in average output growth across these two groups.[40]

To examine this more formally, we estimate cross-sectional regressions that compare growth in the early 2000s to the lagged change in the profit share as:

(28) $$\dot{X}_i = \alpha + \beta \Delta PR_i + \gamma Z + \varepsilon_i,$$

where $\dot{X}$ is the average annual growth of hours, intermediate inputs, labor productivity, or output from 2001 to 2004, ΔPR is the change in the profit share from 1997 to 2001, and Z are controls.

The regression in equation 28 is obviously reduced form, so we included a series of controls to soak up some of the variation attributable to other factors. We include the contemporaneous change in the profit share from 2001 to 2004 to control for demand effects. We include lagged growth in the dependent variable from 1997 to 2001 to control for longer run trends, e.g., some industries may be in secular decline or tend to have strong productivity growth throughout the sample. We include the IT service share to control for any impact of IT-intensity. Finally, we include the interaction between the IT service share and the lagged change in profit share to examine whether IT-intensity facilitated adjustment to competitive pressures.

[39] The correlation is robust to dropping the Computer and Electronics and Information and Data Systems industries.

[40] T-tests for differences in the mean growth rates reject equal growth rate for hours and productivity, but fail to reject for output growth.

We report estimates of equation 28 without and with controls in table 10. Panel A uses input growth (hours and intermediate inputs) as the dependent variable, while Panel B uses gross output and value-added labor productivity measures and Panel C uses gross output and value-added output measures. All estimates are via OLS with robust standard errors.

The results show several robust and interesting relationships. In the hours growth regressions, we find that industries with the largest increase (decrease) in profits through 2001 experienced significantly faster (slower) hours growth from 2001 to 2004. There is no link with intermediate inputs. It is perhaps surprising that intermediate inputs did not respond in the same way that labor did as one might expect firms to economize on all margins, but this could simply reflect different adjustment costs for different inputs. In sharp contrast, we find a strongly negative coefficient on the lagged profits change in the productivity growth regressions, implying that industries with declining profits also saw relatively fast productivity growth.[41] Finally, there is some evidence that output growth was slower in the industries with declining profits, but the link is weaker and far less robust.[42]

These results provide support of the competitive pressure/restructuring explanation for the post-2000 productivity gains. One interpretation is that firms in

[41] While measurement error in hours growth would push the hours and labor productivity growth rates to be negatively correlated, it is not obvious why those measurement errors would be correlated with our profit variable.

[42] As a robustness check, we estimated difference-in-difference regressions and found that industries with below-average profits growth from 1997 to 2001 had a bigger decline in the growth rate of hours and a bigger increase in the growth rate of gross output labor productivity than other industries. There was no significant difference for value-added labor productivity growth. We also ran regressions with more detailed measures of intermediate inputs, e.g., energy, materials, and purchased service inputs, as the dependent variable, but those results were uniformly weak and are not reported. As a second robustness check, we compared hours, productivity, and output growth for 1992 to the change in profits from 1989 to 1991 and found weak results, suggesting that the latest episode was different from the earlier one.

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 and the robustness of the results to including the contemporaneous change in profits suggest that this was not just a demand story, but rather reflects how firms chose to trade-off productivity and hours growth to achieve a certain amount of output growth. Similarly, the results are robust to including a lagged dependent variable, so it does not appear that we are capturing just 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 are insignificant in all regressions except the hours regressions.

5. PRODUCTIVITY TRENDS AND OUTLOOK

What do the Recent Data Say?

Assessing the underlying trend in labor productivity growth since 2000 has been complicated by data revisions and by swings in productivity growth that were a surprise to many analysts. Initial estimates of growth in labor productivity from 2000 to 2003 suggested extremely robust gains, and led many analysts to ask why labor productivity growth had accelerated further. But, a combination of downward revisions to output growth and upward revisions to hours growth have caused labor productivity growth to be revised down to lower, but still quite sizable, growth rates.[43] More recently, productivity has registered much smaller advances – with labor productivity reported to

[43] 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.

have risen just 1½ percent over the four quarters of 2006 – raising questions about whether the trend has slowed.

To highlight these developments, table 11 shows average growth rates of labor productivity for different time periods and different vintages of data, denoted by the date of release. Moving down a column shows the effect of successive vintages of data. Moving across a row shows the effect of adding additional years of data to the period over which averaging is done. Regarding data revisions, for the period 2000-2003, the average growth rate of labor productivity was reported initially in March of 2004 to have been 3.8 percent; subsequent revisions brought this down to 3.4 percent, nearly ½ percentage point below the initial estimate. A similar sequence of downward revisions affects the periods 2000-2004 and 2000-2005. Slower growth in labor productivity over the past several quarters also has brought the average growth rate down, as can be seen in the bottom row. In the current vintage of data, growth over 2000-2003 averaged 3.4 percent, but over the longer period from 2000-2006, slower growth in subsequent years pulled the average down to 2.8 percent, only about ¼ percentage point above the average pace during 1995-2000.

Long-Period Averages

Long-period averages of labor productivity growth provide one way to put recent figures into perspective. The first column of table 12 shows productivity growth rates over selected periods extending back to 1909 using data from the BLS. These data cover a broader sector of the economy than nonfarm business and so do not correspond to the figures presented earlier in the paper.[44] That said, labor productivity growth according to these figures averaged 2.2 percent since 1909.[45] The second column shows growth rates over selected periods since 1950 for the nonfarm business sector. In this sector, growth averaged 2.7 percent during the 1995-2006 period, close to that during the so-called "golden era" of productivity from 1950-1973 and well above the post-war average of 2.1 percent per year.

Kalman Filter Estimates

As one approach to obtaining time-varying estimates of the trend in labor productivity, we used a slightly modified version of the Kalman filter model developed by Roberts (2001).[46] Although alternative implementations could yield answers that differ from the one presented here, the model in Roberts (2001) has some appealing features.[47] In particular, the model allows for shocks to both the level and the growth rate of trend productivity and controls for cyclical changes in productivity growth by assuming that hours adjust gradually to output following a cyclical shock. We estimated the model by maximum likelihood, 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, roughly ½ percentage point below the average pace

[44] The long-span BLS series covers the private economy before 1947 (defined as gross national product less general government) and the business sector from 1947 forward.
[45] There are a number of alternative historical series for labor productivity that would yield different results in some periods, but the patterns of growth and long-run averages would tell a qualitatively similar story to the one implied by the BLS data. For example, see Gordon (2006).
[46] In Roberts (2001), the Kalman filter is used to obtain time-varying estimates of trend growth in both potential output and labor productivity. In the implementation here, we first use an HP filter to estimate the trend in hours and feed this exogenous trend to the model. Hence, we need to estimate a trend only for labor productivity.
[47] For other estimates of trend productivity using Kalman-filter techniques, see Brainard and Perry (2000) and Gordon (2003).

of productivity growth since 2000. Evidently, the model interprets some of the extraordinary growth in the years immediately after the 2001 recession as having been transitory. The model also delivers a confidence band around the estimated trend of 2¼ percent; a two-standard-error confidence band extends 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. To carry out this exercise, we use the version of the model based on published data. We focus on this version so that our estimates can be compared to those from other researchers. At the outset, we should stress that we do not regard these steady-state results as forecasts of productivity growth over any specific time period. Rather, this exercise yields "structured guesses" for growth in labor productivity consistent with alternative scenarios for the evolution of 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 (that 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. These conditions can be shown to imply that output in each sector grows at the same rate as the capital stock that consists of the investment goods produced by that sector ($\dot{Y}_i = \dot{K}_i = \dot{I}_i$ for all *i*). Labor hours grow at a constant rate, which is the same in every sector, and the workweek is fixed. Labor quality also grows at a constant rate.

Under these conditions, the steady-state growth rate of aggregate labor productivity can be written as follows (see Appendix A for details):

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

where β_i^S is the share of total costs in sector *i* represented by purchases of semiconductors, $\dot{z}_i$ and $\dot{z}_S$ denote the sectoral rates of improvement in technology, $\dot{z}$ is the (Domar) share-weighted sum of these sectoral rates of improvement, and *A* represents the effect of adjustment costs on output growth in the steady state. 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 appear in equation 29 for capital deepening. However, capital deepening is determined endogenously from the improvement in technology, and the terms in brackets depict the growth contribution from this induced capital deepening. Steady-state growth in labor productivity also depends on the gains in labor quality, the direct effect of improved technology, and adjustment costs.

The fact that adjustment costs affect growth in the steady state may seem surprising. To see that this result holds, consider the stripped-down, one-sector version of the model that we discussed in section 2. For that version of the model, we showed that growth in aggregate output can be expressed as:

(30) $$\dot{Y} = \alpha^K \dot{K} + \alpha^L \dot{H} - \phi \dot{I} + \dot{z} = (\alpha^K - \phi)\dot{K} + \alpha^L \dot{H} - \phi(\dot{I} - \dot{K}) + \dot{z}.$$

Even if we impose the steady-state condition that $\dot{I} = \dot{K}$, adjustment costs do not disappear entirely from this expression, as the term in $(\alpha^K - \phi)\dot{K}$ remains. Adjustment costs – which cause ϕ to be greater than zero – affect growth even in the steady state because some of the return to capital covers the cost of installing that capital and does not contribute to the production of market output. The same intuition holds for the full model portrayed in equation 29, though the algebra becomes much more involved.

The steady-state equation depends on a large number of other parameters (capital and labor income shares, sectoral output shares, semiconductor cost shares, and so on.) We report results for a range of values for these parameters, as detailed in Oliner and Sichel (2002) and Appendix table 2 to this paper. For the most part, steady-state growth is not very sensitive to these parameters individually. However, the results do depend importantly on three parameters: the rate of improvement in labor quality, the effect of adjustment costs, and the *MFP* gains outside the IT-producing sectors ("other nonfarm business") after controlling for adjustment costs and factor utilization. We assume that the effect of adjustment costs on growth in the steady state, *A*, equals 0.14 percent per year, the average effect in our growth-accounting results over 1973-2006 (see table 1). Following Jorgenson, Ho, and Stiroh (2007), we assume that labor quality will improve 0.15 percent per year, well below the historical rate of increase, as the educational attainment of new labor force entrants rises more slowly than in the past. For the value of $\dot{z}$ in other nonfarm business, we consider values ranging from 0.4 percent per year to 0.9 percent per 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 13 presents the results from the steady-state exercise using equation 29. The estimated range for steady-state labor productivity grows runs from 1.66 percent at an annual rate to 2.97 percent. The wide range reflects our uncertainty about the values of the parameters that determine steady-state growth. The range is centered at roughly 2¼ percent, below the average rate of labor productivity growth in recent years. The step-down from the recent average largely reflects the assumption that the improvements in labor quality will slow and that the gains in *MFP* after controlling for adjustment costs and factor utilization will not be as robust as the average pace since 2000.

Wrap-up

Table 14 compares our estimates of steady-state growth in labor productivity and our estimate of the trend from the Kalman filter to forecasts from a variety of sources. All but three of these forecasts have a horizon of ten years. The other three have shorter horizons – five years for Kahn and Rich (2007), six years for CEA (2007), and eight years for Macroeconomic Advisers (2007). These forecasts for average annual growth in labor productivity range from 2 percent to 2.6 percent. As noted above, the midpoint of the estimated range for steady-state growth is about 2¼ percent and the estimate of the trend from the Kalman filter also is 2¼ percent; both of these estimates sit at the center of the range of these forecasts and. Thus, there seems to be considerable agreement that labor-productivity growth over a medium-term horizon will remain well above the sluggish pace that prevailed from the early 1970s through the mid-1990s.

That said, one should be very humble about any exercise like the one here 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, as has occurred in the recent past, and in the future we might be looking at a different picture of actual labor productivity growth for recent years than the one we see today. Finally, economists do not have a stellar track record in forecasting trends in labor productivity. While we think that the analysis here moves the debate forward, we are acutely aware of the inherent limitations.

6. CONCLUSION

Productivity developments since 1995 have raised many important and interesting questions for productivity analysts and policymakers, three of which we address in this paper. First, given the data now available and various critiques of neoclassical growth accounting that have arisen in recent years, is IT still a critical part of the story for why productivity growth picked up over 1995-2000? Second, what is the source of the continued strength in productivity growth since 2000? And, based on our answers to these questions, what is the outlook for gains in productivity? We use a variety of techniques to address these questions, including aggregate growth accounting augmented to incorporate variable utilization, adjustment costs, and intangible asset accumulation; industry-level analysis; and Kalman filter and steady-state analysis.

Both the aggregate and 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 growth contribution is smaller than it had been 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 differed in important ways from the sources at work 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 rotation between the second half of the 1990s and the most recent period in the set of industries with accelerating labor productivity.

Adding intangible capital to our aggregate growth accounting framework changes the time profile for productivity growth since 1995 relative to the picture based on 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, multifactor productivity appears to have advanced at least as rapidly during 1995-2000 as it did over 2000-2006, which contrasts with the impression from published data that the latest period featured the largest increases.

Finally, in terms of the outlook, both the Kalman filter and 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 2 ¼ percent per year, a rate that is consistent with growth remaining well above the lackluster pace that prevailed during the twenty-five years before 1995, but somewhat slower than the 1995-2006 average.

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Table 1

Contributions to Growth in Labor Productivity Based on Published Data

	1973-1995 (1)	1995-2000 (2)	2000-2006 (3)	Change at 1995 (2) – (1)	Change at 2000 (3) – (2)
1. Growth of labor productivity[1]	1.48	2.48	2.81	1.00	.33
Contributions from:[2]					
2. Capital deepening	.74	1.04	.87	.30	-.17
3. IT capital	.41	1.11	.69	.70	-.42
4. Computer hardware	.20	.62	.30	.42	-.32
5. Software	.13	.35	.24	.22	-.11
6. Communication equipment	.08	.15	.15	.07	.00
7. Other tangible capital	.33	-.07	.19	-.40	.26
8. Labor quality	.28	.26	.34	-.02	.08
9. Multifactor productivity (MFP)	.46	1.18	1.60	.72	.42
10. Effect of adjustment costs	-.12	-.34	-.04	-.22	.30
11. Effect of utilization	-.03	.13	-.09	.16	-.22
12. MFP after adjustments	.61	1.38	1.72	.77	.34
13. IT sectors	.29	.79	.54	.50	-.25
14. Semiconductors	.09	.45	.23	.36	-.22
15. Computer hardware	.12	.19	.10	.07	-.09
16. Software	.05	.11	.15	.06	.04
17. Communication equipment	.04	.04	.05	.00	.01
18. Other nonfarm business	.32	.59	1.18	.27	.59
Memo:					
19. Total IT contribution[3]	.70	1.90	1.23	1.20	-.67

1. In the nonfarm business sector. Measured as average annual log difference for years shown multiplied by 100.
2. Percentage points per year.
3. Equals the sum of lines 3 and 13.

Note. Detail may not sum to totals due to rounding.
Source. Authors' calculations based on BEA and BLS data.

Table 2

Comparison to Jorgenson, Ho, and Stiroh (2007)

	1973-1995 (1)	1995-2000 (2)	2000-2005 (3)	Change at 1995 (2) – (1)	Change at 2000 (3) – (2)
Growth of labor productivity[1]					
1. This paper	1.48	2.48	3.07	1.00	.59
2. Jorgenson, Ho, and Stiroh	1.49	2.70	3.09	1.22	.39
Contributions from:[2]					
IT capital deepening					
3. This paper	.41	1.11	.73	.70	-.38
4. Jorgenson, Ho, and Stiroh	.40	1.01	.63	.61	-.39
Other capital deepening					
5. This paper	.33	-.07	.27	-.40	.34
6. Jorgenson, Ho, and Stiroh	.45	.49	.94	.05	.44
Labor quality					
7. This paper	.28	.26	.39	-.02	.13
8. Jorgenson, Ho, and Stiroh	.25	.19	.36	-.06	.17
Multifactor productivity, IT sectors					
9. This paper	.29	.78	.55	.49	-.23
10. Jorgenson, Ho, and Stiroh	.25	.58	.40	.34	-.18
Multifactor productivity, other sectors					
11. This paper	.17	.40	1.13	.23	.73
12. Jorgenson, Ho, and Stiroh	.14	.42	.77	.28	.35

1. Measured as average annual log difference for years shown multiplied by 100.
2. Percentage points per year.

Note. Detail may not sum to totals due to rounding.
Source. Authors calculations based on BEA and BLS data; Jorgenson, Ho, and Stiroh (2007), tables 1 and 2.

Table 3

Contributions to Growth in Labor Productivity: Accounting for Intangibles

	1973-1995 (1)	1995-2000 (2)	2000-2006 (3)	Change at 1995 (2) – (1)	Change at 2000 (3) – (2)
1. Growth of labor productivity[1]	1.68	3.24	2.37	1.56	-.87
1a. Based on published data	1.48	2.48	2.81	1.00	.33
Contributions from:[2]					
2. Capital deepening	1.06	1.75	.93	.69	-.82
3. IT capital	.39	1.03	.62	.64	-.41
4. Other tangible capital	.32	-.06	.17	-.38	.23
5. New intangible capital	.35	.79	.13	.44	-.66
6. Labor quality	.26	.24	.31	-.02	.07
7. Multifactor productivity	.35	1.24	1.13	.89	-.11
8. Effect of adjustment costs	-.15	-.40	.01	-.25	.41
9. Effect of utilization	-.03	.13	-.09	.16	-.22
10. MFP after adjustments	.53	1.50	1.21	.97	-.29
11. IT sectors	.28	.74	.47	.46	-.27
12. Intangible sector	.02	.12	.09	.10	-.03
13. Other nonfarm business	.25	.64	.65	.39	.01
Memo: *Growth rates*[1]					
14. Real intangible investment	8.7	14.5	-2.6	5.8	-17.1
15. Real intangible capital services	9.9	10.3	1.5	.4	-8.8
16. Real IT capital services	15.8	20.5	9.4	4.7	-11.1
17. User cost, intangible capital	4.7	1.2	3.3	-3.5	2.1
18. User cost, IT capital	-1.2	-9.0	-4.6	-7.8	4.4
Memo: Nominal shares, in percent					
19. Expenditure share, intangible inv.	4.3	8.0	7.6	3.7	-.4
20. Income share, intangible capital	4.0	7.8	9.0	3.8	1.2

1. In the nonfarm business sector. Measured as average annual log difference for years shown multiplied by 100.
2. Percentage points per year.

Note. Detail may not sum to totals due to rounding.
Source. Authors' calculations based on BEA and BLS data.

Table 4

Growth of Intangible Capital and Investment: Alternative Timing Assumptions for Intangible Capital
(Average annual rate over period shown, in percent)

	1973-1995 (1)	1995-2000 (2)	2000-2005 (3)
Intangible capital services			
1. Baseline timing for intangible capital growth	9.9	10.3	1.5
2. Three-year centered moving average	10.0	9.7	2.1
3. Five-year centered moving average	10.0	9.2	2.7
4. Lags IT capital growth by one year	10.6	9.4	2.9
5. *Memo:* Corrado, Hulten, and Sichel series	5.1	7.0	2.9
Intangible investment			
6. Baseline timing for intangible capital growth	8.7	14.5	-4.4
7. Three-year centered moving average	9.1	12.2	-3.0
8. Five-year centered moving average	9.3	11.2	-1.8
9. Lags IT capital growth by one year	9.9	12.1	-4.2
10. *Memo:* Corrado, Hulten, and Sichel series	5.1	7.7	1.6

Note. 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.
Source. Lines 1-4 and 6-9: authors' calculations based on BEA and BLS data. Lines 5 and 10: Corrado, Hulten, and Sichel (2006), series for "New CHS intangibles", with preliminary extension to 2005 estimated by the authors.

Table 5

Growth in Labor Productivity and Selected Growth Contributions: Alternative Timing Assumptions for Intangible Capital

	1973-1995 (1)	1995-2000 (2)	2000-2006 (3)	Change at 1995 (2) – (1)	Change at 2000 (3) – (2)
Baseline (from Table 3)					
1. Labor productivity	1.68	3.24	2.37	1.56	-.87
2. Contribution from intangible capital	.35	.79	.13	.44	-.66
3. Contribution from MFP[1]	.53	1.50	1.21	.97	-.29
Three-year centered moving average					
4. Labor productivity	1.69	3.04	2.52	1.35	-.52
5. Contribution from intangible capital	.35	.74	.18	.39	-.56
6. Contribution from MFP[1]	.56	1.32	1.33	.76	.01
Five-year centered moving average					
7. Labor productivity	1.69	2.95	2.59	1.26	-.36
8. Contribution from intangible capital	.35	.70	.21	.35	-.49
9. Contribution from MFP[1]	.55	1.27	1.37	.72	.10
Lags IT capital growth by one year					
10. Labor productivity	1.71	3.06	2.50	1.35	-.56
11. Contribution from intangible capital	.36	.73	.24	.37	-.49
12. Contribution from MFP[1]	.56	1.36	1.25	.80	-.11

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

Note. Growth in labor productivity is measured as average annual log difference for years shown multiplied by 100. Growth contributions are in percentage points.
Source. Authors' calculations based on BEA and BLS data.

Table 6
Labor Productivity Growth for U.S. Aggregates and Sectors

	2005 Value-Added		Average Labor Productivity Growth Rate				
	$B	**Share**	**1988-95**	**1995-00**	**2000-05**	**1995-00 less 1988-95**	**2000-05 less 1995-2000**
Panel A: Aggregate, Value-Added							
BLS Business Sector			1.48	2.69	3.11	1.21	0.42
BLS Nonfarm Business Sector			1.46	2.52	3.07	1.06	0.55
Private Industry Aggregate	10,892	100.0	1.25	2.24	2.52	0.99	0.28
Panel B: Broad Sectors, Value-Added							
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, RE, 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
Ed services, health care, social assist	975	9.0	-2.40	-1.22	0.84	1.18	2.07
Arts, entertain, rec, accomm, 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

Notes: BLS productivity growth is defined as the growth of real value-added per hour worked. Private Industry Aggregate productivity growth is the growth of real value-added per total hours of all persons. Broad sector productivity is the the growth of real value-added per total hours of all persons. Real value-added is from BEA and total hours of all persons are from BLS Office of Employment Projections.

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Table 7
Labor Productivity Growth for Industries and IT Classifications

	1988-95	1995-00	2000-05	1995-00 less 1988-95	2000-05 less 1995-2000
Panel A: Detailed Industries, Gross Output					
Mean	1.80	2.95	2.28	1.15	-0.68
IT-Producing	5.80	7.03	6.45	1.23	-0.58
IT-Using	1.19	3.07	2.60	1.88	-0.46
Other	1.80	2.31	1.43	0.51	-0.88
Median	1.62	2.19	1.88	0.57	-0.30
Weighted Mean	1.59	2.68	2.19	1.09	-0.49
Panel B: Detailed Industries, Value-Added					
Mean	1.78	2.02	2.80	0.24	0.78
IT-Producing	5.21	7.59	10.98	2.38	3.39
IT-Using	1.28	2.29	2.74	1.01	0.45
Other	1.75	1.04	1.76	-0.71	0.71
Median	1.74	1.16	2.82	-0.58	1.66
Weighted Mean	1.33	1.94	2.46	0.62	0.51

Notes: Industry productivity growth is defined as either the growth of real value-added or real gross output per total hours of all persons for 60 component industries. Industry-level summary statistics are calculated across the 60 observations for each period. IT-producing industries include Computer and Electronic Products; Publishing including Software; Information and Data Processing Services; Computer System Design and Related Services, as defined by BEA. IT-using industries include non-IT-producing industries with a 1995 IT capital service share above the median. Other industries include the remaining industries. Weighted estimates use weights equal to shares of total hours worked from the first year in each period. Real value-added and gross output are from BEA and total hours of all persons are from BLS Office of Employment Projections.

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Table 8
Alternative Decomposition of Aggregate Labor Productivity Growth

	No. of	1988-1995		1995-2000		2000-2005		1995-00 less	2000-05 less
	Ind.	Share	Contribution	Share	Contribution	Share	Contribution	1988-1995	1995-00
				Panel A: Aggregates					
Private Industry Aggregate			1.25		2.24		2.52	0.99	0.28
Aggregated Industries	60		1.24		2.20		2.52	0.96	0.32
				Panel B: Decomposition using Industry Gross Output Productivity					
Industry Contribution	60	100.0	1.79	100.0	3.10	100.0	2.16	1.31	-0.94
IT-Producing	4	4.0	0.33	5.0	0.50	4.5	0.25	0.17	-0.25
IT-Using	26	57.3	0.71	58.6	1.99	59.1	1.54	1.28	-0.45
Other	30	38.7	0.75	36.4	0.61	36.4	0.37	-0.14	-0.23
Reallocation of Materials, $-R^M$			-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
				Panel C: Decomposition using Industry Value-Added Productivity					
Industry Contribution			1.59		2.41		2.41	0.83	0.00
IT-Producing			0.36		0.70		0.47	0.34	-0.23
IT-Using			0.48		1.31		1.54	0.82	0.24
Other			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

Notes: Decomposition of aggregate value-added productivity across industries. Private Industry Aggregate is based on BEA and BLS aggregate data from Table F.1. Aggregated Industries is weighted aggregate of industry output and hours data. IT-producing industries include Computer and Electronic Products; Publishing including Software; Information and Data Processing Services; Computer System Design and Related Services, as defined by BEA. IT-using industries include non-IT-producing industries with a 1995 IT capital services share above the 1995 median. Other industries include the remaining industries. Value-added productivity is defined as real value-added per total hours of all persons. Gross output productivity is defined as real gross output per total hours of all persons. Share is nominal value divided by aggregate nominal value-added, multiplied by 100. Contribution is weighted growth of productivity with nominal value-added weights for each year. Reallocation of Materials and Reallocation of Hours are defined in Equation XX.

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Table 9
Link Between IT Use and Productivity Acceleration

	1995-2000 less 1988-1995		1995-2005 less 1988-1995		2000-2005 less 1995-2000	
			Panel A: Gross Output			
1995 IT Dummy	1.277**		1.478***			
	(0.585)		(0.491)			
1995 IT Share		0.038		0.037*		
		(0.028)		(0.020)		
2000 IT Indicator					0.156	
					(0.931)	
2000 IT Share						0.010
						(0.044)
Constant	0.513	0.543	0.074	0.216	-0.756	-0.865
	(0.438)	(0.478)	(0.371)	(0.401)	(0.480)	(0.650)
R^2	0.08	0.06	0.14	0.07	0.00	0.00
			Panel B: Value-Added			
1995 IT Dummy	1.904		1.967**			
	(1.173)		(0.893)			
1995 IT Share		0.029		0.051*		
		(0.044)		(0.026)		
2000 IT Indicator					0.095	
					(1.448)	
2000 IT Share						0.046
						(0.066)
Constant	-0.709	-0.227	-0.352	-0.198	0.730	-0.056
	(0.913)	(0.915)	(0.709)	(0.667)	(0.944)	(1.149)
R^2	0.04	0.01	0.08	0.05	0.00	0.02

Notes: Dependent variable is change in labor productivity growth for 60 industries across periods - 1995-2000 less 1988-1995, 1995-2005 less 1988-1995 and 2000-2005 less 1995-2000. Value-added refers to value-added per total hours. Gross output refers to gross output per total hours. IT Dummy equals 1 for industries with a IT capital share above the median in that year, 0 otherwise. IT Share is IT capital services as a share of nonresidential capital services in that year. Robust standard errors are reported in parentheses.
***, **, * indicate statistical significance at the 1%, 5%, and 10% level, respectively.
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Table 10
Table F.5: Link between Lagged Change in Profits and Productivity and Hours Growth

	Panel A: Inputs					
		Hours			Intermediate Inputs	
Profit Change, 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)
Profit Change, 2001-2004		-0.115	13.389*		8.244	22.546
		(6.159)	(7.952)		(12.592)	(22.270)
Lagged Dep Var, 1997-2001		0.722***	0.782***		0.255	0.28
		(0.155)	(0.128)		(0.165)	(0.168)
IT Service Share, 2001		-0.089***	-0.069***		-0.032	-0.009
		(0.027)	(0.025)		(0.064)	(0.067)
Profit Change, 97-01 x IT Service Share, 01			-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-Squared	0.17	0.51	0.57	0.00	0.10	0.12

	Panel B: Average Labor Productivity					
		Value-Added			Gross Output	
Profit Change, 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)
Profit Change, 2001-2004		5.703	0.563		7.013	4.655
		(11.962)	(15.520)		(8.705)	(8.353)
Lagged Dep Var, 1997-2001		-0.055	-0.041		0.169	0.176
		(0.186)	(0.195)		(0.168)	(0.178)
IT Service Share, 2001		-0.008	-0.018		0.030	0.025
		(0.035)	(0.041)		(0.028)	(0.037)
Profit Change, 97-01 x IT Service Share, 01			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-Squared	0.26	0.27	0.28	0.37	0.44	0.44

	Panel C: Output					
		Value-Added			Gross Output	
Profit Change, 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)
Profit Change, 2001-2004		10.770	11.472		10.342	16.689
		(11.257)	(17.752)		(10.943)	(16.531)
Lagged Dep Var, 1997-2001		-0.043	-0.044		0.294	0.30
		(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)
Profit Change, 97-01 x IT Service Share, 01			-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-Squared	0.11	0.15	0.15	0.04	0.22	0.23

Note: Dependent variables is average annual growth from 2001 to 2004. Profits are defined as the ratio of gross operating surplus to value-added. Profit Change is the change in the ratio between 1997 and 2001. Lagged Dep Var is the average annual growth for 1997-2001. IT Service Share is the share of of IT capital services in nonresidential capital services. Each regression has 60 industry observations. Robust standard errors are reported in parentheses.
***, **, * indicate statistical significance at the 1%, 5%, and 10% level, respectively.
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Table 11

Growth in Labor Productivity: Effects of Data Revisions and Data for Additional Years

(Average log difference over period shown, based on annual average data)

	Period Covered by the Data				
Date of Data Release	1995-2000	2000-03	2000-04	2000-05	2000-06
Mar. 2004	2.4	3.8			
Aug. 2004	2.5	3.7			
Mar. 2005	2.5	3.7	3.7		
Aug. 2005	2.5	3.4	3.4		
Mar. 2006	2.5	3.4	3.4	3.3	
Aug. 2006	2.5	3.4	3.3	3.1	
Mar. 2007	2.5	3.4	3.3	3.0	2.8

Source. BLS.

Table 12

Growth in Labor Productivity: Long-run Averages
(Average log difference over period shown, based on annual average data)

Years	Private Economy/ Business Sector[1]	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

1. Data before 1947 pertain to the private economy, while data for 1947 and later years pertain to the business sector.

Source. BLS.

Table 13

Steady-State Results

	Using Lower Bound Parameters	Using Upper Bound Parameters
1. Growth of labor productivity[1]	1.66	2.97
Contributions from:[2]		
2. Induced capital deepening	.87	1.45
3. Labor quality	.15	.15
4. Multifactor productivity	.78	1.50
5. Adjustment costs	-.14	-.14
Memo:		
6. MFP growth, other nonfarm business[3]	.40	.90

1. In the nonfarm business sector; measured in percent.
2. Percentage points per year.
3. Percent per year.

Note. Detail may not sum to totals due to rounding.

Table 14

Alternative Estimates of Future Growth in Labor Productivity
(Percent per year)

	Date	Estimate
1. This paper – steady-state analysis	Mar. 2007	1.7 to 3.0
2. This paper – Kalman-filter analysis	Mar. 2007	1.3 to 3.2
3. Gordon (2007)	Mar. 2007	2.0
4. Survey of Professional Forecasters (2007)[1]	Feb. 2007	2.2
5. Global Insight (2007)	Mar. 2007	2.2
6. Macroeconomic Advisers (2007)	Mar. 2007	2.2
7. Congressional Budget Office (2007)	Jan. 2007	2.3
8. Jorgenson, Ho, and Stiroh (2007)[2]	Oct. 2006	2.5
9. Kahn and Rich (2007)	Mar. 2007	2.5
10. Council of Economic Advisers (2007)	Jan. 2007	2.6

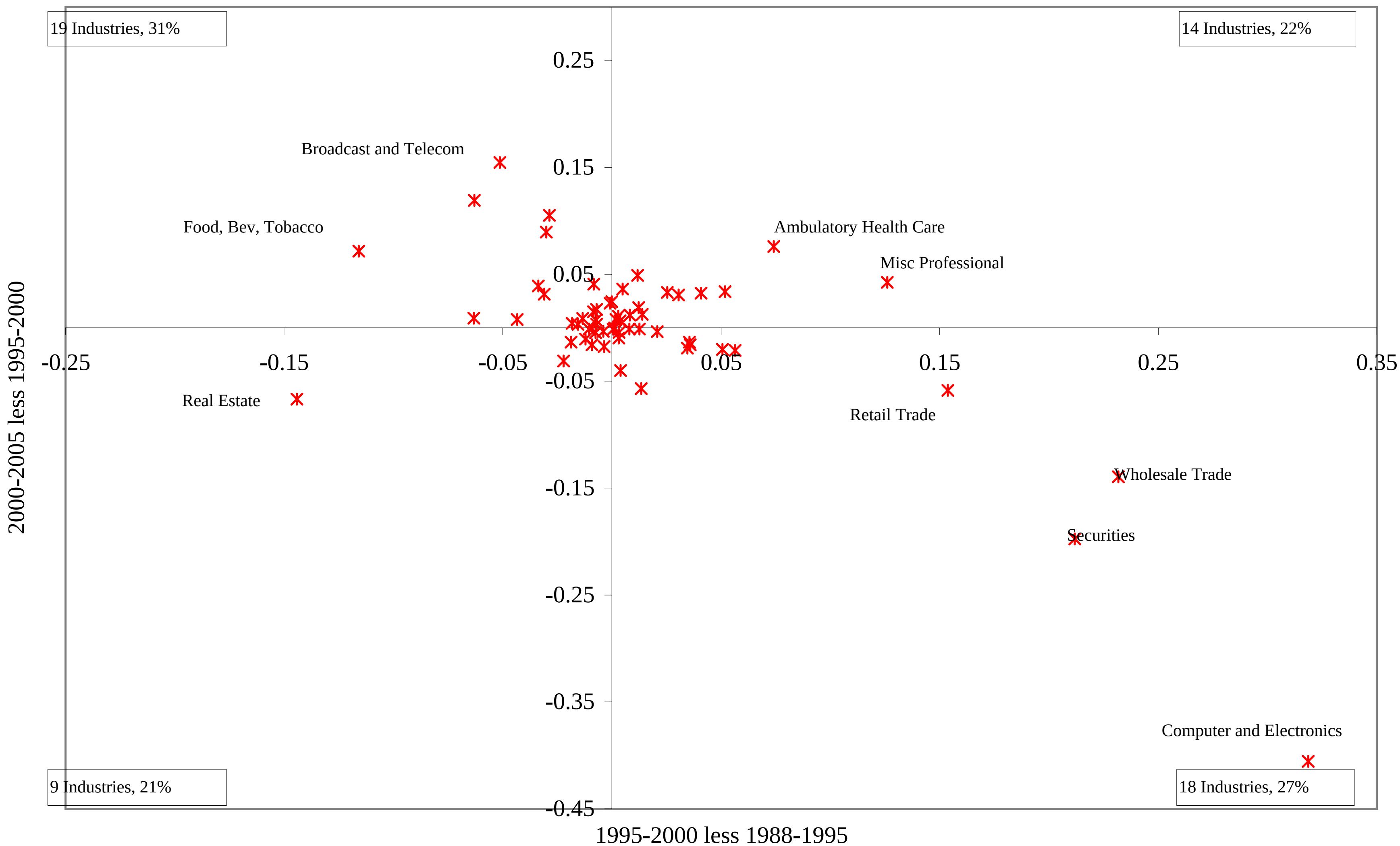
1. Median of the 38 forecasts in the survey.
2. "Base-case" projection.

Sources. Gordon (2007), slide 24; Survey of Professional Forecasters (2007), table 7; Global Insight (2007), page 6; Macroeconomic Advisers (2007), page 11; Congressional Budget Office (2007), table 2-2; Jorgenson, Ho, and Stiroh (2007), table 3; Kahn and Rich (2007), chart 2, and private correspondence with Jim Kahn; Council of Economic Advisers (2007), table 1-2.

Figure 1: Annual Reallocation Effects

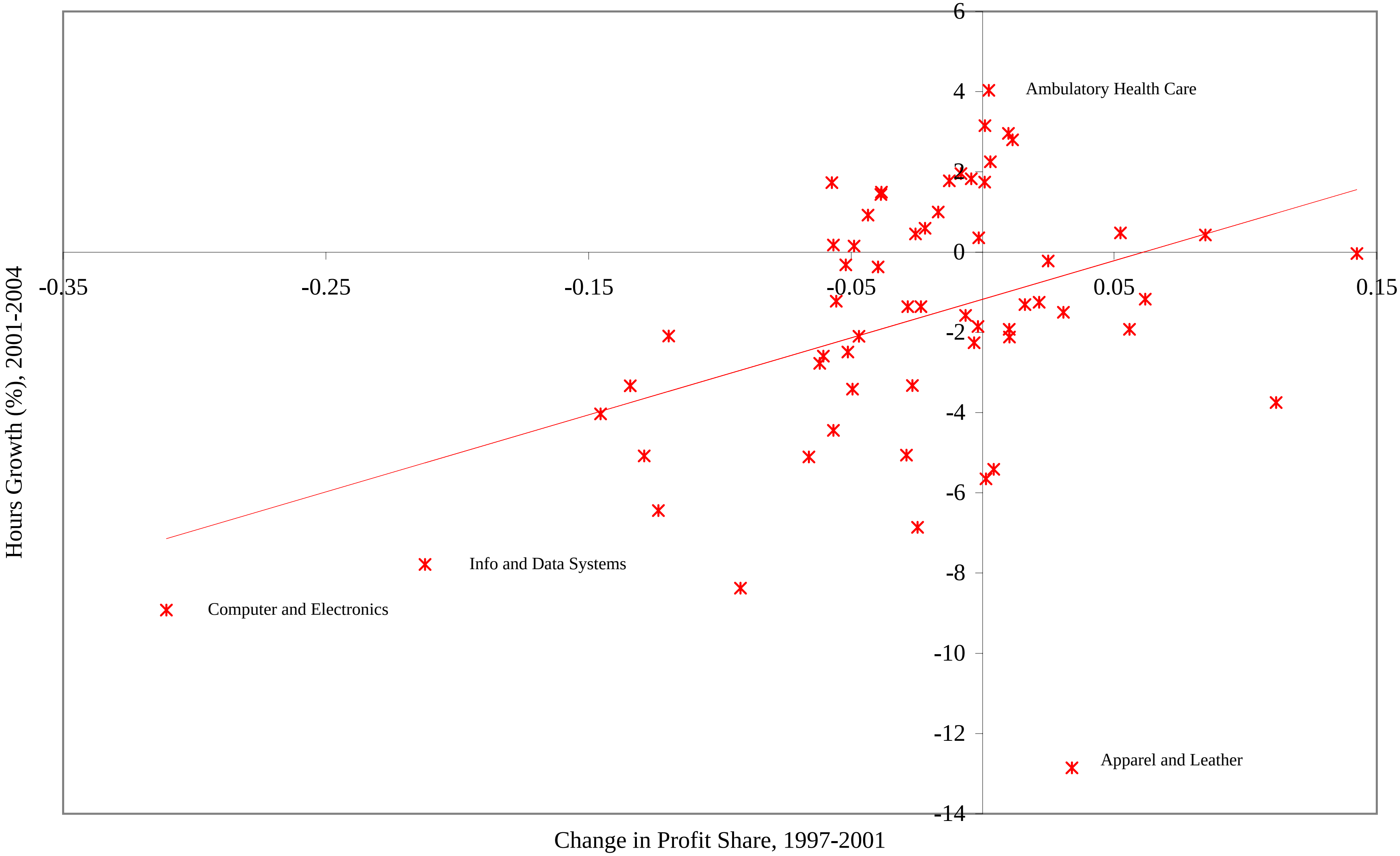
Note: The VA ALP and GO ALP series report the annual cross-sectional correlation for the 60 industries between hours growth and the lagged level of value-added and gross output productivity, respectively. Reallocation of Hours is defined in Equation XX.

Figure 2: Change in Contribution to Aggregate Productivity Growth



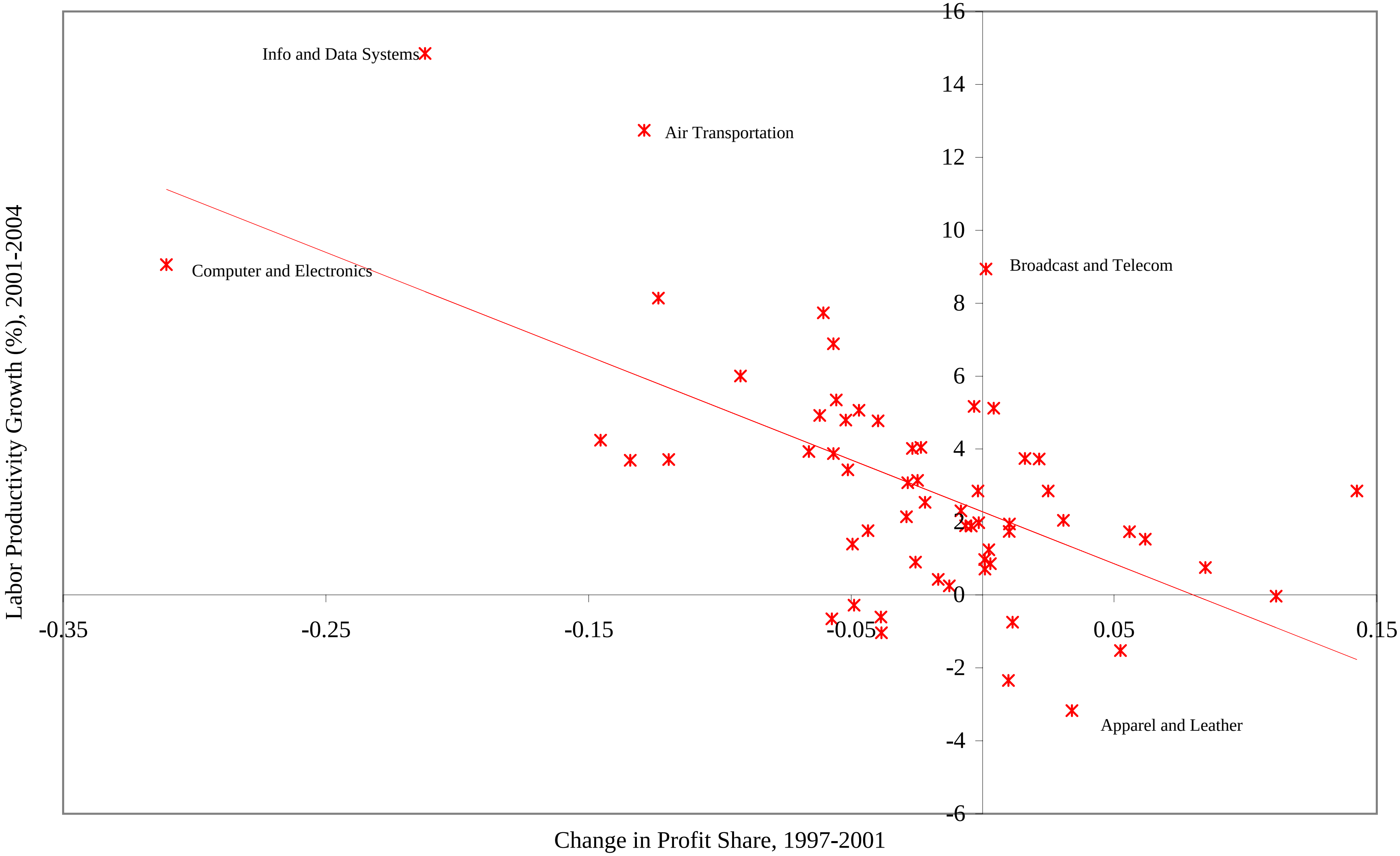
Note: Each observation is the change in the contribution from industry i to aggregete productivity growth across the two periods. A contribution is the average share-weighted growth rate of value-added labor productivity growth. Percent refers to share of aggregate value-added in 2005.

Figure 3: Hours Growth and Changes in the Profit Share



Note: Each point is one of 60 industry observations. X-axis is the change in the profit share (gross operating surplus divided by value-added) from 1997 to 2001. Y-axis is the average annual growth rate in hours from 2001 to 2004. Line reports fitted value from an OLS regression.

Figure 4: Labor Productivity Growth and Changes in the Profit Share



Note: Each point is one of 60 industry observations. X-axis is the change in the profit share (gross operating surplus divided by value-added) from 1997 to 2001. Y-axis is the average annual growth rate in gross output labor productivity from 2001 to 2004. Line reports fitted value from an OLS regression.