Information Technology and the U.S. Productivity Revival: What Do the Industry Data Say?

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Two of the defining characteristics of the U.S. economy in the late 1990's were faster labor productivity growth and strong investment in information technology (IT) assets. Why? Is there a link? A consensus is now emerging from aggregate growth accounting studies that both the *production* and the *use* of IT have contributed substantially to the U.S. aggregate productivity revival in the late 1990's.[1] These aggregate results add to a large body of earlier microeconomic studies surveyed by Erik Brynjolfsson and Lorin M. Hitt (2000) that typically found a large economic impact from IT use.

Not everyone is convinced, however. Most notably, Robert J. Gordon (2000) argues that the recent productivity revival occurred primarily within durable goods production, particularly IT production. Michael T. Kiley (1999, 2000) reports that large adjustment costs blunt the impact of IT and may reduce productivity growth in periods of rapid IT investment. Stephen S. Roach (1998) concludes much of the productivity revival is a statistical mirage due to the understatement of actual hours worked, which leads productivity growth to be overstated, as the white-collar workweek expands faster than data measure.

This paper addresses the issue by moving beneath the aggregate data to examine the post-1995 productivity performance of the individual industries that either produce IT, use IT, or are relatively isolated from the IT revolution. By examining variation in productivity growth over time and across industries and by exploring the link with IT capital, one can better understand the U.S. productivity revival. Two specific questions are addressed. First, is the U.S. productivity revival widespread, or is it concentrated in relatively few industries? Second, are industry productivity gains linked to IT use?

This type of disaggregated analysis has clear advantages over aggregate studies. First, it quantifies the impact of IT from the bottom up, rather than a top-down decomposition of aggregate data, and thus exploits the variation in industry-level data. Second, this approach allows econometric tests of the economic impact of IT. In contrast, growth accounting essentially assumes the result when factor shares proxy for output elasticities. While growth accounting provides a valuable and well-tested means for understanding the proximate sources of growth, additional tests are needed to corroborate those results.

Industry-level data show that the recent U.S. productivity revival is a broad-based phenomenon that reflects gains in a majority of industries; the mean productivity acceleration from 1987–1995 to 1995–2000 for 61 industries is 0.87 percentage points. Nearly two-thirds of these industries show an acceleration in productivity. Even when the particularly strong productivity industries that produce IT (or even durable goods manufacturing as a whole) are excluded, the data show a significant acceleration in productivity for the remaining industries. This suggests the U.S. productivity revival is not confined to only a few IT-producing industries.

Several complementary tests then show a

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[1] For example, Dale W. Jorgenson and Stiroh (2000), Stephen D. Oliner and Daniel E. Sichel (2000), Karl Whelan (2000), Bureau of Labor Statistics [BLS (2001a)], Council of Economic Advisors [CEA (2001)], and Jorgenson (2001).

robust link between IT and productivity gains. IT-intensive industries experienced a productivity acceleration that is about 2 percentage points greater than other industries, a result that holds when IT-producing industries are excluded. Productivity gains are also linked to IT intensity; the size of the productivity acceleration for 1995–2000 rises with the 1995 share of IT capital services. These types of relationships are noticeably absent in the post-1982 surge in U.S. productivity growth and suggest real productivity benefits from IT use after 1995. If recent productivity gains were primarily cyclical, for example, one would expect them to be independent of IT intensity.

Finally, the paper presents a novel, although relatively straightforward, decomposition of aggregate labor productivity growth that is similar to the total factor productivity decomposition of Evsey Domar (1961). This decomposition quantifies the direct contribution to aggregate labor productivity growth from three distinct groups of industries—those that produce IT, those that use IT most intensively, and the remaining industries that are relatively isolated from the IT revolution.

The data show that IT-producing and IT-using industries accounted for all of the direct industry contributions to the U.S. productivity revival. When 1995–2000 is compared to 1987–1995, for example, 26 IT-using industries contributed 0.83 percentage point to the aggregate productivity acceleration and the two IT-producing industries contributed 0.17. The remaining 33 industries made a negative contribution of 0.21 percentage point, on net, suggesting IT-related industries are indeed driving the U.S. productivity revival.

Both the econometric work and the productivity decomposition point to real productivity benefits from IT use. Industry regressions show a significant link between IT capital and productivity gains, while the decomposition shows these effects to be meaningful at the aggregate level. Taken together, this evidence suggests an important role for IT in the recent U.S. productivity revival.

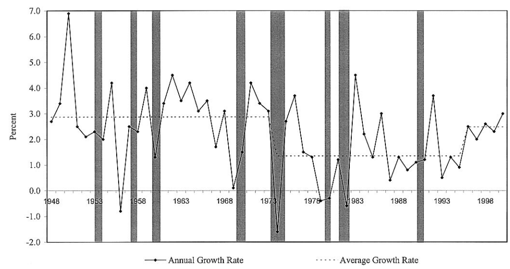

FIGURE 1. U.S. PRODUCTIVITY GROWTH, 1947–2000

Notes: Estimates are annual growth rates for the nonfarm business sector. The average growth rates are for 1947–1973, 1973–1995, and 1995–2000. Shaded areas are NBER recession periods.
Source: BLS (2001b).

I. IT and the U.S. Productivity Revival

After more than two decades of relatively slow growth, both labor and total factor productivity accelerated after 1995. For 1995–2000, the U.S. nonfarm business sector posted annual average productivity growth of 2.48 percent, well above the 1.35 percent average for 1973–1995 but below the 2.87 percent average for 1947–1973 (Figure 1 based on BLS, 2001b). Total factor productivity (TFP) experienced a similar acceleration with the annual rate of growth rising to 1.10 percent for 1995–1999 from 0.41 percent for 1973–1995 and 1.93 percent for 1948–1973 (BLS, 2001a).[2]

Over the same period, U.S. firms have made heavy investment in information technology (IT) assets, defined as computer hardware, software, and telecommunications equipment. In 2000 alone, U.S. firms invested $409B in IT assets, accounting for over 30 percent of nonresidential fixed investment. Stacey Tevlin and Whelan (2000) show that this massive investment is due in part to the relative price declines in these assets, particularly computer hardware. As a result, the stock of IT capital grew much faster than other forms of capital, e.g., 24.6 percent per year for 1990–2000 for computer hardware vs. 2.5 percent for private fixed assets.

This combination of strong productivity growth and rapid IT investment in the 1990's has received considerable attention. Jorgenson and Stiroh (2000), Oliner and Sichel (2000), Whelan (2000), BLS (2001a), CEA (2001), and Jorgenson (2001) have all used aggregate

[2] All data except TFP reflect the August 2001 revisions to GDP that lowered annual labor productivity growth from 2.8 percent to 2.5 percent for 1995–2000. The TFP estimates will likely be restated downward by BLS.

growth accounting techniques to show that a combination of dramatic productivity gains in IT production and massive IT capital deepening are driving the U.S. productivity revival. By incorporating IT-related forces into a well-known framework, these aggregate growth accounting studies provide valuable insight into the impact of IT. In addition, aggregate data are often the only way to address productivity questions in a timely fashion due to long lags in industry data.

Aggregate growth accounting studies are not entirely satisfactory, however. One common criticism is the number of assumptions required for successful implementation, e.g., constant returns to scale and competitive markets.[3] Moreover, using factor shares to proxy for output elasticities essentially assumes the result about capital effects. As long as IT capital deepening occurs, there will be a measured contribution to growth, regardless of whether the IT capital actually contributes to output.[4] Thus, it is critical to econometrically test for a link between IT use and productivity gains to buttress the conclusions from growth accounting studies.

A second concern is that their intrinsic top-down nature misses much of the key variation among industries. Alan Greenspan (2000), for example, concludes that disaggregated data are needed to tie productivity performance to business practices. Both productivity growth and IT intensity vary enormously among component industries and firms, so IT effects may be missed in aggregate studies. This type of heterogeneity, for example, has been an important part of the plant-level work using the Longitudinal Research Database (LRD) and in industry studies.

Despite these limitations, strong results from the aggregate growth accounting studies are driving the emerging consensus that IT is an important source of the resurgence of U.S. productivity growth. This paper addresses two industry-level questions about the U.S. productivity revival.

First, is the U.S. productivity revival widespread or is it concentrated in relatively few industries? This issue directly affects the strength and stability of the recent productivity revival. If all the gains were concentrated in a single industry, for example, then a relatively narrow disruption could unhinge the entire productivity revival. In addition, the breadth of the productivity revival has implications for the distribution of income and wealth; if productivity gains are highly concentrated, one might expect wage gains or returns to capital-owners to also be highly concentrated. While this question is not an IT question per se, it should be of interest in its own right.

Second, can these industry productivity gains be linked to IT use? By quantifying the productivity gains associated with IT, this sheds light on the returns to the massive IT investment. For example, if IT is used largely to reallocate market share between firms, then this might entail no industry gains and no net benefit for society. Alternatively, if IT investment raises productivity through traditional capital deepening channels or production spillovers, this enlarges the production possibility frontier for the society. There are also implications for U.S. international competitiveness, e.g., Christopher Gust and Jaime Marquez (2000) report that most industrialized countries did not experience productivity gains like the United States, which they attribute in part to lower IT investment shares in those countries.

II. Data

A. *Output and Productivity Data*

The Bureau of Economic Analysis (BEA) maintains an industry database, the "gross product originating (GPO)" data, that contains real gross output, labor inputs, and intermediate inputs, described by Sherlene K. S. Lum and Brian C. Moyer (2001). These data include chain-weighted gross output, value-added, and full-time equivalent employees (FTE) for 62 detailed industries (at roughly the 2-digit SIC

[3] Robert E. Hall (1988) relaxes these assumptions. See Susanto Basu and John G. Fernald (1995, 1997a) for a less restrictive growth accounting approach and Charles R. Hulten (2000) for details on the assumptions as typically implemented.

[4] See Kiley (2000) for this type of critique. As an extreme example, consider what growth accounting exercises would show if firms invested heavily in an asset but then never actually use it for productive purposes. Growth accounting would observe this capital deepening effect, measure a contribution from capital, and then, since output growth is fixed, measure a smaller TFP residual. This seems to be the intuition behind Gordon's (2000) critique of the productive impact of IT.

level) for 1987–2000 and for a subset of 49 industries for 1977–2000. I combine two real-estate-related industries into a single industry, leaving 61 detailed industries for the shorter period, and also create various aggregates from the industry data. All aggregation is via a Tornqvist quantity index, which is a superlative index that provides a close approximation to the Fisher index employed by BEA.

Labor productivity is the appropriate concept here because the primary effect of IT use is likely through traditional capital deepening channels as discussed by Martin N. Baily and Gordon (1988), Jorgenson and Stiroh (1999), and Stiroh (1998, 2002). In this view, IT is not a special type of capital, but rather a normal piece of equipment in which firms invest to raise profits. In this neoclassical world, if capital is measured accurately, TFP gains should only be seen in the production of IT, where true technological progress allows the production of improved capital goods at lower prices.

Labor productivity series are defined as real gross output per FTE for individual industries and as real value-added per FTE for aggregates. The focus on gross output measures of productivity reflects empirical rejections of the existence of value-added functions in J. Randolph Norsworthy and David H. Malmquist (1983) and Jorgenson et al. (1987). More recently, Basu and Fernald (1995, 1997a, b) show that value-added data lead to biased estimates and incorrect inferences about production parameters.

Note that the BEA includes the statistical discrepancy in its estimate of "private industries" output, where the statistical discrepancy is GDP expenditures less gross domestic income. BEA views expenditure data as more reliable, so the statistical discrepancy is added as an "industry" in gross domestic income. I exclude the statistical discrepancy because it is impossible to align it with inputs. The statistical discrepancy has been falling in recently, so BEA's aggregate of private sector value-added grows more slowly than an aggregate over the private sectors that excludes it.

B. *Capital Data*

The second major piece of data comes from the BEA "Tangible Wealth Survey," described by Shelby W. Herman (2000). These data provide information on 61 distinct types of capital goods in current and real-cost dollars for 62 industries from 1947 through 1999. IT capital is defined to include eight types of computer hardware (mainframes, personal computers, direct access storage devices, printers, terminals, tape drives, other storage devices, and integrated systems), three types of software (prepackaged, custom, and own-account), and communications equipment.

The appropriate measure of capital is the service flow of capital services developed by Jorgenson and Zvi Griliches (1967), as opposed to the stock of capital. To create capital service flows, I use a Tornqvist index to aggregate individual capital stocks using asset-specific rental prices from Jorgenson and Stiroh (2000). While these rental prices are aggregate estimates and miss industry-level variation, they capture the dominant features of the rental price, e.g., large price declines and rapid depreciation for IT assets, and should yield a good estimate of capital service flows. Capital stocks across assets and industries are from the Tangible Wealth Survey.

C. *Combining Data*

The GPO data and capital stock data are both produced by BEA and both include 62 distinct industries, but they are not the same industries. Therefore, these data were aggregated via Tornqvist quantity indices to form 57 commonly defined industries with output data for 1987–2000 and capital data for 1987–1999. For 1977–1987, the output data include several composite industries, e.g., six industries are collapsed into three, and real gross output data are not available for nine industries, so only 49 industries have complete output data for the longer period 1977–2000. Tables that list the 61 industries with output data, the 57 industries with both output and capital data, and 61 distinct types of nonresidential capital assets are available from the author upon request.

III. Empirical Results

Before discussing the industry results, I consider the appropriate breakpoint for dating the U.S. productivity revival. The earlier studies mentioned above assume a breakpoint in 1995 and casual examination of the time-series data suggest this is reasonable. Bruce E. Hansen

(1992), however, points out the pitfalls of choosing and testing for breakpoints after the data have been examined, so a useful first step is to econometrically estimate an unknown breakpoint in the aggregate productivity data.

Hansen (1997) provides a means to identify a structural break and then test for the significance of the change. I use this methodology to identify a break in productivity growth for the business sector, the nonfarm business sector, and the manufacturing sector using quarterly data from 1974:Q1 to 2001:QIII.[5] The results for the business and nonfarm business sector data indicate a breakpoint in 1995:QIII, essentially the same as used in the aggregate studies, although the asymptotic p-values of the Andrews/Quandt test are not statistically significant. For manufacturing, the estimated breakpoint is 1993:QIII and statistically significant. While the aggregate evidence is not statistically significant, these tests point to a change in 1995 and support the perception that a notable and economically significant productivity acceleration began after 1995. Industry-level data are available only at an annual frequency, so I use the business sector breakdate and identify year-end 1995 as the beginning of the productivity revival.

A. *Is the Productivity Revival Widespread?*

Table 1 presents summary statistics for productivity growth for 1995–2000 compared to the two earlier periods 1987–1995 and 1977–1995. The acceleration of aggregate productivity, 1995–2000 less 1987–1995, for private industries is about 0.9 percentage point when the statistical discrepancy is included (BEA), 1.3 percentage points when it is not (sector aggregate), and 1.0 percentage point for the gross output concept. The BEA version shows a smaller acceleration because it includes the increasingly negative statistical discrepancy. These estimates are similar to the BLS estimates for the nonfarm business sector and imply a reasonable database for productivity analysis.

Table 1 also reports the acceleration of gross output productivity for ten broad sectors; this follows the BEA's sectoral convention except that manufacturing is split into durables and nondurables. Productivity acceleration varies considerably across sectors, ranging from −0.98 percentage point in mining to 2.24 percentage points in durable goods manufacturing when 1995–2000 is compared to 1987–1995. Using value-added measures of productivity, William D. Nordhaus (2000) and CEA (2001) also report a broad productivity acceleration with wide variation across major sectors.

While it is clear that the durable goods sector, which includes the production of IT hardware, showed particularly large gains after 1995, it is also clear that it is not the only sector to show substantial improvement. Only three sectors (agriculture, mining, and construction) show productivity growth far below zero, but they account for just 8 percent of private industry value-added in 2000. Thus, it appears that the productivity revival is broadly based with the vast majority of the U.S. economy showing productivity gains.

The final panel of Table 1 provides summary statistics for gross output productivity growth for the detailed industries. Again, these data suggest a broad productivity revival—the mean and median increase for 61 industries for 1995–2000 vs. 1987–1995 were 0.87 percentage point and 0.32 percentage point, respectively. Relative to 1977–1995, the 49 industries with data for both periods show a mean acceleration of 1.08 percentage points and a median gain of 0.58 percentage point.

At this point it is useful to examine the industry productivity data more directly. Figure 2 plots the 1995–2000 growth rates versus the 1987–1995 growth rates for 61 industries. Points above the line show accelerating productivity, while those below the line show decelerating productivity. The majority of industries—38 out of 61 industries—show a productivity acceleration and the scatterplot again suggests a broad productivity revival.

Figure 2 also shows four outliers that deserve mention. Two of these are high-tech-producing industries [Industrial Machinery and Equipment (SIC #35) and Electronic and Other Electric Equipment (SIC #36)] and two are

[5] This is a simple model where productivity growth equals a constant that is allowed to change once during the sample. The Andrews/Quandt "sup" test identifies a specific estimate of the breakpoint as the maximum value of the Lagrange multiplier statistic of the null of no structural change between any two periods. Use of post-1973 data assumes an earlier break at that point.

TABLE 1—AVERAGE LABOR PRODUCTIVITY GROWTH RATES, 1977–2000

	Annual growth rate (percent)			Acceleration	
	1977–1995	1987–1995	1995–2000	1995–2000 less 1977–1995	1995–2000 less 1987–1995
			Value-Added—Aggregate Measures		
Private industries (BEA)	0.92	1.03	1.92	1.00	0.89
Private industries (sector aggregate)	0.97	0.98	2.29	1.32	1.31
			Gross Output—Aggregate Measures		
Private industries	NA	1.24	2.23	NA	0.99
			Gross Output—Broad Sectors		
Agriculture, forestry, and fishing	1.38	0.58	−0.28	−1.66	−0.86
Mining	2.28	3.14	2.16	−0.12	−0.98
Construction	−1.23	−0.87	−1.65	−0.42	−0.78
Durable goods manufacturing	3.14	3.97	6.20	3.07	2.24
Nondurable goods manufacturing	1.64	1.48	2.72	1.07	1.24
Transportation and public utilities	NA	2.27	2.23	NA	−0.05
Wholesale trade	2.14	3.23	3.99	1.85	0.75
Retail trade	0.42	0.97	3.14	2.71	2.17
Finance, insurance, and real estate	NA	2.33	3.40	NA	1.07
Services	NA	0.40	1.05	NA	0.66
			Gross Output—Industry Averages		
Mean—61 Industries	NA	1.68	2.55	NA	0.87
Median—61 Industries	NA	1.50	1.97	NA	0.32
Mean—49 Industries	1.61	1.80	2.69	1.08	0.89
Median—49 Industries	1.45	1.48	1.83	0.58	0.53

Notes: Labor productivity estimates use either real value-added or real gross output per full-time equivalent employees (FTE). Private industries (BEA) includes statistical discrepancy; private industries (sector aggregate) does not. Number of detailed industries varies with the available data for the period and output measure. Industry mean and medians are for period average changes.

finance-related [Security and Commodity Brokers (SIC #62) and Holding and Other Investment Offices (SIC #67)]. The high-tech industries show gains largely due to the fundamental technological advances in the production of IT, while the finance-related gains may be an artifact of how output and, therefore, productivity are measured in those industries.[6] Subsequent econometric work will be careful

[6] Real gross output for security and commodity brokers is based on commissions, underwriting profits, securities sales, trading accounts, etc., deflated by securities-related implicit price deflators. The large productivity gains in this industry are largely driven by increased trading activity associated with the bull market of the late 1990's. For holding and other investment offices, real gross output is calculated as the sum of GPO plus an extrapolated intermediate input series, deflated by a composite cost-based price index. Lum et al. (2000) provide details.

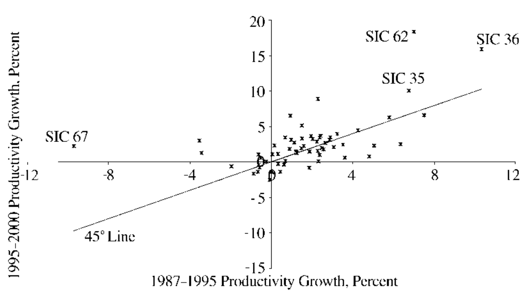

FIGURE 2. CHANGES IN INDUSTRY PRODUCTIVITY GROWTH 1987–1995 VS. 1995–2000

Notes: All labor productivity growth refers to annualized growth in real gross output per FTE. Outlier industries include: Industrial Machinery and Equipment (SIC #35), Electronic and Other Electric Equipment (SIC #36), Security and Commodity Brokers (SIC #62), and Holding and Other Investment Offices (SIC #67).

TABLE 2—DUMMY VARIABLES TESTS OF POST-1995 ACCELERATION OF INDUSTRY LABOR PRODUCTIVITY

	1987–1995 vs. 1995–2000				
Constant	1.678***	1.365**	—	—	—
	(0.394)	(0.497)	—	—	—
Post-1995 dummy	0.870	0.881**	0.964**	0.727*	0.710*
	(0.529)	(0.389)	(0.410)	(0.391)	(0.426)
Weights		yes	yes	yes	yes
Industry fixed effects			yes	yes	yes
Drop IT-producing industries				yes	yes
Drop FIRE outliers				yes	yes
Drop durable goods manufacturing					yes
Number of observations	793	793	793	741	624
Number of industries	61	61	61	57	48
	1977–1995 vs. 1995–2000				
Constant	1.605***	1.139*	—	—	—
	(0.414)	(0.557)	—	—	—
Post-1995 dummy	1.084**	1.259**	1.482***	1.132**	1.143**
	(0.453)	(0.511)	(0.496)	(0.492)	(0.542)
Weights		yes	yes	yes	yes
Industry fixed effects			yes	yes	yes
Drop IT-producing industries				yes	yes
Drop FIRE outliers				yes	yes
Drop durable goods manufacturing					yes
Number of observations	1,127	1,127	1,127	1,058	874
Number of industries	49	49	49	46	38

Notes: Dependent variable is labor productivity growth for industry i in year t. Post-1995 dummy equals 1 if $t > 1995$, 0 otherwise. First column is OLS; other columns are weighted least squares with FTE industry weights. Standard errors are in parentheses. All estimates allow errors to be correlated across industries within the same sector and are corrected for heteroskedasticity. Constant not shown for regressions with industry fixed effects because it depends on which industry effect is arbitrarily dropped. IT-producing industries are Industrial Machinery and Equipment (SIC #35) and Electronic and Other Electric Equipment (SIC #36) for 1987–2000 and Industrial Machinery and Equipment and a combination of Electronic and Other Electric Equipment and Instruments (SIC #38) for 1977–2000. FIRE outliers are Security and Commodity Brokers (SIC #62) and Holding and Other Investment Offices (SIC #67) for 1987–2000 and Security and Commodity Brokers for 1977–2000. Durable goods manufacturing includes SIC #24, 25, 32–39.

* Significant at the 10-percent level.
** Significant at the 5-percent level.
*** Significant at the 1-percent level.

about whether these industries are driving results.

The raw data show that most industries experienced accelerating productivity growth after 1995 and one can gauge the significance of the acceleration with a simple test of the change in the mean growth rate across industries:

$$(1) \qquad d \ln A^{Y}_{i,t} = \alpha + \beta D + \varepsilon_{i,t},$$

$$D = 1 \text{ if } t > 1995, \qquad D = 0 \text{ otherwise}$$

where $A^{Y}_{i,t}$ is industry gross output labor productivity, the estimate of α gives the mean prior to 1995, β gives the mean change, t is either 1977–2000 or 1987–2000, and i is industry. It is unlikely that errors are homoskedastic or are uncorrelated across industries, so standard errors are corrected for heteroskedasticity and to allow for correlation between industries within the same sector.

Table 2 presents results for various estimates of equation (1). The first column is ordinary least squares (OLS) and shows the mean change of 0.87 percentage point for 61 industries for 1987–2000 is not quite significant (p-value = 0.14). These unweighted regressions, however, allow small industries to have a considerable impact on the results. For the 49 industries with data for the longer period 1977–2000, the acceleration is a significant 1.08 percentage points. This suggests a meaningful acceleration of productivity for the typical industry that is not driven by a few outliers.

Due to wide variation in size and the somewhat arbitrary level of aggregation of industry data, i.e., large industries are aggregates of smaller ones, it seems more appropriate to weight industries by their relative size. Moreover, this provides a better historical representation of the U.S. economy and James A. Kahn and Jong-Soo Kim (1998) argue that weighted least squares is appropriate because the variance of residuals is inversely related to industry size, due perhaps to noisier data in smaller industries.

Weighted results are reported in the second column, where weights are FTE and vary over time (effectively multiplying the independent and dependent variables by the square root of contemporaneous FTE). Here, there is a large and significant acceleration in both periods.[7] Including industry-level fixed effects to control for heterogeneity in productivity growth across industries (column 3) leads to a slightly larger acceleration and more significant estimates.[8]

As further robustness checks, the regression is estimated without the four outlier industries (column 4) and without all durable goods manufacturing industries (column 5). The acceleration coefficient falls in size because these industries show large productivity accelerations, but it remains economically large and statistically significant in both cases, 0.71 when 1987–1995 is compared to 1995–2000 and 1.14 when 1977–1995 is the base after durable manufacturing industries are dropped.

It is important to point out that there has been no cyclical adjustment; all analysis is done using actual data as reported by the BEA. This reflects the idea that the recent U.S. productivity revival is different from earlier periods of rising productivity growth. Figure 1 shows that most periods of rising productivity growth occurred after recessions, while the recent productivity revival started late in this economic expansion. Productivity is typically procyclical due to variable utilization and resource reallocation effects (Basu and Fernald, 1999), and one would expect these forces to have largely worked their way out during the long expansion. Yet, annual productivity growth accelerated through 2000, suggesting a different process. Basu et al. (2000) conclude that the recent productivity acceleration stems from faster technological change, and not from temporary factors like factor utilization and factor accumulation. In addition, it is quite difficult to separate trend and cyclical components, particularly when the data do not cover a full cycle, as is currently the case. Finally, because the focus of this paper is on industry-level trends, estimating distinct cyclical adjustments for each individual industry would likely introduce considerable noise into the analysis.

With this caveat in mind, the data show a productivity revival that is broad-based, and clearly not limited to the industries that produce IT or other durable goods manufacturing industries. A variety of samples show a significant acceleration in productivity for the typical industry after 1995. While the question of whether these gains should be attributed to cyclical forces or the underlying trend is not addressed, the recent productivity revival is not only in a few industries.

B. *Is the Productivity Revival Linked to IT Use?*

This section examines the link between productivity acceleration and IT intensity across U.S. industries. If IT is a driving force behind faster productivity growth, then industries that use IT most intensively should show larger productivity gains. Alternatively, if the U.S. productivity revival is largely driven by some other force, e.g., a cyclical phenomenon due to strong aggregate demand, then gains should be independent of IT use.

Two empirical approaches are used. The first is a difference-in-difference methodology, as in Robert H. McGuckin and Stiroh (2001), which discretely identifies an industry as IT intensive and compares the relative productivity gains of IT-intensive industries to other industries. This approach is useful because it is robust to how IT

[7] FTE weights are reported because they are the natural aggregation weights, although results are robust to alternatives. Output weights (either gross output or value-added), robust regressions where weights are determined endogenously based on the size of the error term, and weights based on FTE in the first year of each sample all give qualitatively similar results.

[8] The constant is not reported in the fixed-effects regressions because it depends on which arbitrarily chosen industry effect is dropped. Industry-level fixed effects do not change the acceleration term in a simple OLS regression, but do in a weighted regression.

capital is measured, but a limitation is that it misses variation in IT intensity across industries. A second approach uses a continuous measure of IT intensity and searches for a link between the degree of IT intensity and subsequent productivity acceleration.

Difference-in-Difference Estimates.—Difference-in-difference estimation naturally extends the test for difference in means in equation (1) with an additional constant and interaction term for IT-intensive industries:

$$(2) \quad d \ln A^{Y}_{i,t} = \alpha + \beta D + \gamma C + \delta D \cdot C + \varepsilon_{i,t},$$

$$D = 1 \text{ if } t > 1995, \qquad D = 0 \text{ otherwise}$$

$$C = 1 \text{ if IT intensive}, \qquad C = 0 \text{ otherwise}$$

where the estimate of α is the mean growth rate for non-IT-intensive industries in the period prior to 1996, $\alpha + \gamma$ is the mean growth rate for IT-intensive industries prior to 1996, β is the acceleration for non-IT-intensive industries after 1995, $\beta + \delta$ is the acceleration for IT-intensive industries after 1995, and δ is the differential acceleration of IT-intensive industries relative to others. Standard errors are again corrected for heteroskedasticity and for correlation across industries within sectors.

The key issue in the estimation of equation (2) is how to define C, the indicator of IT intensity. A good indicator is the IT share of capital services because it identifies industries expending tangible investment on IT and reallocating inputs toward high-tech assets. In addition, one would want an exogenous indicator of IT intensity prior to the productivity revival. That is, both the dependent and independent variables should not be defined over the same period because they could reflect the same shocks, e.g., strong demand, and would suffer from simultaneity bias. Therefore, an IT-intensive industry is defined as one with an above median IT share of capital services in 1995. By looking at relative IT intensity *before* the productivity revival, this helps to identify the impact of IT on subsequent productivity growth. Of course, industries that expected future demand increases and productivity gains may have invested in IT in anticipation, so this is not a perfect control.

Table 3 reports results; the top panel is for 57 industries for 1987–2000 and the bottom panel for 49 industries for 1977–2000. The first column reports simple OLS estimates and shows that IT-intensive industries experienced an economically large and statistically significant increase in productivity growth relative to other industries. When FTE weights account for the relative size of industries (column 2) or when weights and fixed effects are included (column 3), the differential increases in both size and significance. When the four outlier industries are dropped (column 4), the point estimate falls but remains large and statistically significant for both periods.[9]

The next three columns report robustness checks using alternative indicators of IT intensity: the IT capital service share of nominal output (column 5), the IT capital services per worker (column 6), and a composite index (column 7). IT-intensive indicators are again set equal to one for those industries with a 1995 value above the median. Although these indicators are not ideal—IT capital to gross output is imperfect because intermediate inputs vary considerably across industries and IT capital per FTE suffers from endogeneity problems because ALP also depends on FTE—they are useful as robustness checks. The composite indicator defines IT-intensive industries as those labeled as IT intensive by any two of the three other indicators.

When the 1995 IT share of output defines IT-intensive industries, the differential acceleration is smaller at 1.32 percentage points for 1987–2000 and 1.74 for 1977–2000, but both remain significant. For 1995 IT capital per FTE, there is a difference of only 0.40 percentage point in the top panel and 1.02 in the bottom, and neither is statistically significant. This seems reasonable: industries with high IT per worker in 1995 invested heavily in IT and/or reduced labor during the early 1990's, both of

[9] Results are similar when the IT share of capital stock is used to define IT intensity. In addition, results are robust to use of gross output weights or FTE weights from the beginning of the period. The constant and IT-intensive coefficient are not reported in the fixed-effects regressions because they depend on which arbitrarily chosen non-IT-intensive and IT-intensive industry effects are dropped.

TABLE 3—DUMMY VARIABLE TESTS OF RELATIVE POST-1995 LABOR PRODUCTIVITY ACCELERATION FOR IT-INTENSIVE INDUSTRIES

	Primary indicator of IT intensity				Alternative indicators of IT intensity		
	IT share of capital services				IT share of output	IT capital per FTE	Composite
	1987–1995 vs. 1995–2000						
Constant	1.912***	1.177*	—	—	—	—	—
	(0.367)	(0.564)					
IT-intensive dummy	−0.252	0.433	—	—	—	—	—
	(0.847)	(0.861)					
Post-1995 dummy	−0.006	−0.604	−0.456	−0.456	0.243	0.873	0.259
	(0.448)	(0.400)	(0.407)	(0.407)	(0.376)	(0.607)	(0.367)
Post-1995 dummy × IT-intensive dummy	1.942**	2.192***	2.109***	1.786***	1.320**	0.403	1.302**
	(0.844)	(0.457)	(0.446)	(0.512)	(0.517)	(0.716)	(0.515)
Weights		yes	yes	yes	yes	yes	yes
Industry fixed effects			yes	yes	yes	yes	yes
Drop IT-producing industries				yes			
Drop FIRE outliers				yes			
Number of observations	741	741	741	689	741	741	741
Number of industries	57	57	57	53	57	57	57
	1977–1995 vs. 1995–2000						
Constant	1.635***	0.799	—	—	—	—	—
	(0.423)	(0.643)					
IT-intensive dummy	−0.061	0.486	—	—	—	—	—
	(0.562)	(0.817)					
Post-1995 dummy	0.291	−0.413	−0.118	−0.118	0.471	1.160	0.352
	(0.309)	(0.225)	(0.201)	(0.201)	(0.261)	(0.658)	(0.263)
Post-1995 dummy × IT-intensive dummy	1.620*	2.355***	2.262***	1.824***	1.739**	1.018	2.085***
	(0.812)	(0.508)	(0.465)	(0.518)	(0.597)	(1.042)	(0.507)
Weights		yes	yes	yes	yes	yes	yes
Industry fixed effects			yes	yes	yes	yes	yes
Drop IT-producing industries				yes			
Drop FIRE outliers				yes			
Number of observations	1,127	1,127	1,127	1,058	1,127	1,127	1,127
Number of industries	49	49	49	46	49	49	49

Notes: Dependent variable is labor productivity growth for industry i in year t. Post-1995 dummy equals 1 if $t > 1995$, 0 otherwise. IT-intensive dummy equals 1 for industries with a 1995 value above the 1995 median, 0 otherwise. Composite index dummy equals 1 if two of the three indicators equal 1, 0 otherwise. First column is OLS; others are weighted least squares with FTE industry weights. Standard errors are in parentheses. All estimates allow errors to be correlated across industries within the same sector and are corrected for heteroskedasticity. The constant and IT-intensive coefficient are not shown for regressions with industry fixed effects because they depend on which IT-intensive and non-IT-intensive industry effects are arbitrarily dropped. IT-producing industries are Industrial Machinery and Equipment (SIC #35) and Electronic and Other Electric Equipment (SIC #36) for 1987–2000 and Industrial Machinery and Equipment and a combination of Electronic and Other Electric Equipment and Instruments (SIC #38) for 1977–2000. FIRE outliers are Security and Commodity Brokers (SIC #62) and Holding and Other Investment Offices (SIC #67) for 1987–2000 and Security and Commodity Brokers for 1977–2000.

* Significant at the 10-percent level.
** Significant at the 5-percent level.
*** Significant at the 1-percent level.

which contributed to faster productivity growth in the early period but made additional productivity gains difficult later. Finally, the composite index shows relative productivity acceleration for IT-intensive industries in both periods; excluding the outliers does not substantively change the results using the alternative measures of IT intensity.

A final robustness check concerns the starting point of the productivity revival. As discussed above, 1995 was chosen based on structural break tests using aggregate productivity data,

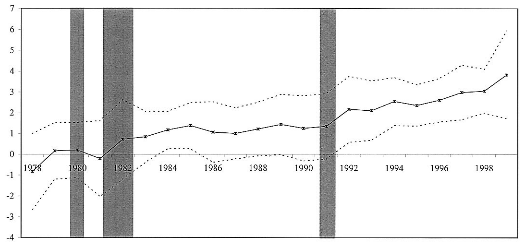

FIGURE 3. RELATIVE LABOR PRODUCTIVITY ACCELERATION FOR IT-INTENSIVE INDUSTRIES

Notes: Figure plots estimated coefficient on the interaction of the time dummy and IT-intensive industry dummy (dark line) and its 95-percent confidence interval (dotted lines) from a regression of annual labor productivity on a constant, a time dummy variable, an IT-intensive dummy variable, and an interaction of the time dummy and the IT-intensive dummy. For each year, the time dummy variable is set equal to 1 for years greater than that year; 0 otherwise. For each year, the IT-intensive dummy is set equal to 1 for industries with an IT share of capital services greater than that year's median. All regressions include 49 industries with data from 1977–2000 and are weighted by FTE, as in Table 3, column 2, bottom panel. Shaded areas are NBER recession periods.

but that evidence was statistically weak and it is useful to examine results for alternative breakpoints. Figure 3 plots the coefficient on the interaction between the post-breakpoint dummy and the IT-intensive dummy, when the breakpoint varies from 1978 to 1999 and IT intensity is defined based on the median of the 49 industries in that year. Dotted lines represent the 95-percent confidence interval.

Figure 3 shows that the difference in productivity acceleration for IT-intensive industries is quite robust in the 1990's and not unique to choosing 1995 as the breakpoint. For all years after 1991, IT-intensive industries show significantly larger productivity gains than other industries. These are not independent confidence intervals, of course, and should not be interpreted as independent evidence of the impact of IT. Rather, this chart simply shows the robustness to the choice of the breakpoint year.

In the early years, the differential between IT-intensive and other industries is much smaller and typically not significant, which likely reflects two factors. First, when the breakpoint is set earlier, it is harder to find a productivity acceleration for any industries because the low productivity years of the early 1990's are averaged with the strong years in the late 1990's. Second, IT intensity is defined here as a relative measure (above the median in the breakpoint year), so even those industries identified as IT intensive in early splits may have quite low levels of IT and may not have attained the critical mass from the massive IT investment in the 1990's.

Continuous IT Regressions.—The difference-in-difference approach provides a robust framework for comparing industries, but it misses potentially important heterogeneity in IT intensity. To address this concern, the discrete IT intensity indicator variable used in equation (2) is replaced with a continuous variable:

$$(3) \quad d \ln A_{i,t}^{Y} = \alpha + \beta D + \gamma IT_{95} + \eta D \cdot IT_{95} + \varepsilon_{i,t},$$

$$D = 1 \text{ if } t > 1995, \qquad D = 0 \text{ otherwise}$$

where IT_{95} is the log of the IT share of capital services in 1995. Thus, η represents the additional productivity acceleration for 1995–2000 associated with an increase in 1995 IT intensity.

Table 4 reports results. Column 1 is estimated without weights and shows a significant, positive link between the IT share of capital services in 1995 and subsequent productivity gains. When industries are weighted by relative size (column 2) or when weights and fixed effects are used (column 3), results remain strong in both panels. When the four outlier industries are dropped (column 4), the coefficient falls and is significant in the bottom panel, but insignificant (p-value $= 0.17$) in the top.

Taken together, these results show that the productivity experience of IT-intensive industries appears quite different than other industries. Using both a discrete indicator and a continuous measure of IT intensity, the industries that invested heavily in IT in the early 1990's experienced significantly larger productivity gains than those that did not. While one could argue that using a pre-productivity revival measure of IT intensity has not completely controlled for causality, IT intensity appears to be an important part of the productivity resurgence across U.S. industries.

TABLE 4—IMPACT OF CONTINUOUS MEASURES OF IT INTENSITY ON RELATIVE POST-1995 LABOR PRODUCTIVITY ACCELERATION

	IT share of capital services			
	1987–1995 vs. 1995–2000			
Constant	1.840**	−0.204	—	—
	(0.757)	(0.937)		
IT intensity	−0.024	0.703	—	—
	(0.344)	(0.467)		
Post-1995 dummy	−0.510	−0.501	−0.341	−0.129
	(0.495)	(0.890)	(0.867)	(0.901)
Post-1995 dummy × IT intensity	0.672**	0.591*	0.568*	0.378
	(0.234)	(0.313)	(0.325)	(0.275)
Weights		yes	yes	yes
Industry fixed effects			yes	yes
Drop IT-producing industries				yes
Drop FIRE outliers				yes
Number of observations	741	741	741	689
Number of industries	57	57	57	53
	1977–1995 vs. 1995–2000			
Constant	2.095***	−0.204	—	—
	(0.611)	(1.126)		
IT intensity	−0.237	0.592	—	—
	(0.288)	(0.563)		
Post-1995 dummy	−0.808	−1.423	−0.931	−0.228
	(0.448)	(0.965)	(0.934)	(0.764)
Post-1995 dummy × IT intensity	0.915**	1.180**	1.062**	0.615**
	(0.381)	(0.446)	(0.461)	(0.261)
Weights		yes	yes	yes
Industry fixed effects			yes	yes
Drop IT-producing industries				yes
Drop FIRE outliers				yes
Number of observations	1,127	1,127	1,127	1,058
Number of industries	49	49	49	46

Notes: Dependent variable is labor productivity growth for industry i in year t. Post-1995 dummy equals 1 if $t > 1995$, 0 otherwise. IT intensity is the log of the IT share of capital services in 1995. First column is OLS; others are weighted least squares with FTE industry weights. Standard errors are in parentheses. All estimates allow errors to be correlated across industries within the same sector and are corrected for heteroskedasticity. The constant and IT-intensity coefficient are not shown for regressions with fixed effects since they depend on which IT-intensive and non-IT-intensive industry effects are dropped. IT-producing industries are Industrial Machinery and Equipment (SIC #35) and Electronic and Other Electric Equipment (SIC #36) for 1987–2000 and Industrial Machinery and Equipment and a combination of Electronic and Other Electric Equipment and Scientific Instruments (SIC #38) for 1977–2000. FIRE outliers are Security and Commodity Brokers (SIC #62) and Holding and Other Investment Offices (SIC #67) for 1987–2000 and Security and Commodity Brokers for 1977–2000.

* Significant at the 10-percent level.
** Significant at the 5-percent level.
*** Significant at the 1-percent level.

C. *Comparison with Labor Productivity Acceleration of the Early 1980's*

Figure 1 shows that aggregate productivity also surged after the recessions of the early 1980's and an interesting question is whether the industry patterns documented in Tables 2 through 4 also existed in that period.[10] Looking at an earlier period puts the current results in

[10] I thank a referee for raising this question.

TABLE 5—COMPARISON WITH LABOR PRODUCTIVITY ACCELERATION OF THE EARLY 1980'S

	1977–1982 vs. 1982–1986		
Constant	−0.363	−0.601	−0.404
	(0.483)	(0.478)	(0.932)
Post-1982 dummy	2.632***	2.130***	2.270***
	(0.484)	(0.456)	(0.486)
IT-intensive dummy		0.521	
		(0.665)	
Post-1982 dummy × IT-intensive dummy		1.077	
		(0.919)	
IT intensity			0.022
			(0.447)
Post-1982 dummy × IT intensity			0.188
			(0.154)
Weights	yes	yes	yes
Number of observations	441	441	441
Number of industries	49	49	49

Notes: Dependent variable is labor productivity growth for industry i in year t. Post-1982 dummy equals 1 if $t > 1982$, 0 otherwise. IT-intensive dummy equals 1 for industries with a 1982 IT capital services share above the 1982 median, 0 otherwise. IT intensity equals the log of the 1982 IT capital services share. All estimates are weighted least squares with FTE industry weights. Standard errors are in parentheses. All estimates allow errors to be correlated across industries within the same sector and are corrected for heteroskedasticity.

*** Significant at the 1-percent level.

historical context and helps to determine if IT is indeed having an unusual impact on productivity. To address this issue, I compare industry-level productivity for 49 industries from 1977–1982 to 1982–1986 (when aggregate productivity growth was strong) using the same specifications as in column 2 of Tables 2, 3, and 4.

Table 5 reports results. Column 1 shows that the typical industry showed a significant gain in productivity in 1982–1986, 2.6 percentage points on a weighted basis, which is indicative of a broad productivity revival as the U.S. economy emerged from the deep recessions of the early 1980's. There is no evidence, however, that IT-intensive industries in 1982 experienced productivity gains relative to other industries. Both the discrete indicator and the continuous measure of IT intensity are much smaller than for the post-1995 productivity revival and statistically insignificant.

These results suggest that IT played a much more important role in the post-1995 productivity revival than in the productivity surge after 1982. One interpretation is that the productivity surge in 1982–1986 was primarily cyclical with all industries showing similar gains. In contrast, the relative gains of IT-intensive industries in the post-1995 revival suggest IT had a real impact. This is consistent with both earlier aggregate work on IT that found small productivity effects in the 1980's, and with the emerging consensus that IT was a driving force behind productivity gains after 1995.

IV. Industry Decomposition of Labor Productivity

The econometric estimates show a link between IT and productivity for individual U.S. industries. Much of the discussion of the U.S. productivity revival focuses on aggregate gains, however, so it is useful to quantify the contribution from these IT-related industries to aggregate labor productivity. This section presents a new decomposition framework to better understand the industry sources of aggregate labor productivity growth. In contrast, earlier decompositions by Domar (1961), Jorgenson et al. (1987), and Basu and Fernald (1997a, 1999) focused on the sectoral origins of TFP growth.

A. *Labor Productivity Decomposition*

At the aggregate level, labor productivity is defined using a value-added concept, say GDP or nonfarm business output, as $ALP^V = V/H$, where V is aggregate real value-added and H is hours, or in this case FTE. Consistent with the chain-weighted approach used by BEA, aggregate value-added can be expressed as an index of value-added growth for the component industries. For simplicity, use a Tornqvist index and define aggregate output growth as:

$$d \ln V = \sum_i \bar{w}_i d \ln V_i \qquad (4)$$

where $\bar{w}_i$ is the average value-added share and V_i is real value-added, all for industry i. Aggregate hours worked is the simple sum of industry labor, H_i, as $H = \Sigma_i H_i$.

BEA currently uses the "double deflation" method for all industries where estimates of real gross output and real intermediate inputs are used to define real value-added (GPO) as described by Robert E. Yuskavage (1996) and Lum et al. (2000). An alternative, advocated by Basu and Fernald (1995, 1997a), defines real value-added growth implicitly as:

$$(5)\quad d\ln Y_i = (1 - \bar{s}_{M,i})d\ln V_i + \bar{s}_{M,i} d\ln M_i$$

where $\bar{s}_{M,i}$ is the two-period average intermediate input share of nominal output for industry i.

Rewriting industry and aggregate labor productivity in terms of growth rates and combining with equations (4) and (5) yields this decomposition of aggregate labor productivity growth:

$$(6)\quad d\ln ALP^V = \left(\sum_i \bar{w}_i d\ln ALP_i^Y\right) - \left(\sum_i \bar{m}_i (d\ln M_i - d\ln Y_i)\right) + \left(\sum_i \bar{w}_i d\ln H_i - d\ln H\right) = \left(\sum_i \bar{w}_i d\ln ALP_i^Y\right) - R^M + R^H$$

which simplifies to:

$$(7)\quad d\ln ALP^V = \left(\sum_i \bar{w}_i d\ln ALP_i^V\right) + \left(\sum_i \bar{w}_i d\ln H_i - d\ln H\right) = \left(\sum_i \bar{w}_i d\ln ALP_i^V\right) + R^H$$

where $\bar{w}_i$ is a two-period average share of industry value-added in aggregate value-added and $\bar{m}_i$ is the two-period average ratio of nominal industry intermediate inputs to nominal aggregate value-added.

The first term in equation (6) is a "direct productivity effect" equal to the weighted average of labor productivity in component industries, where the Y superscript indicates gross output. As industry productivity improves, aggregate productivity rises in proportion to industry size. 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, ($d\ln M_i > d\ln Y_i$) must be netted out to reach aggregate productivity; this interpretation is similar to the intermediate intensity term in Basu and Fernald [1997b, equation (17)]. The third term, R^H, is a "reallocation of hours." Aggregate hours growth, $d\ln H$, approximately weights industries by their (lagged) share of aggregate hours, so aggregate productivity rises if industries with value-added shares above labor shares experience growth in hours. This reallocation effect is a real economic force as the economy move resources among industries.

Equation (7) is a simplification using value-added productivity for industries. Here, aggregate productivity growth reflects the direct contribution from industry value-added productivity growth plus the reallocation of hours worked to high-productivity industries. This value-added approach is similar to Nordhaus (2000), where aggregate productivity growth reflects a "pure productivity effect" (impact of productivity growth in each industry), a "Baumol effect" (impact of difference between current and base-year weights), and a "Denison effect" (impact of changing shares and relative productivity levels). Nordhaus' pure productivity effect is analogous to the first term in equation (7), while his Denison effect is similar to the reallocation effect.

B. *Decomposition Estimates*

Table 6 reports estimates of the labor productivity decomposition in equations (6) and (7). The direct productivity effect is the term of most interest and is broken out for three groups of industries: IT-producing, IT-using, and all others. IT-producing industries are Industrial Machinery and Equipment (SIC #35) and Electronic and Other Electric Equipment (SIC #36).

TABLE 6—AGGREGATE LABOR PRODUCTIVITY DECOMPOSITION, 1987–2000

	1987–1995		1995–2000		Change
Aggregate productivity growth	0.98		2.29		1.30
Decomposition Using Industry Gross Output Productivity					
	Weight	Contribution	Weight	Contribution	
Weighted ALP^Y	1.000	1.86	1.000	2.65	0.79
IT-producing	0.044	0.37	0.042	0.54	0.17
IT-using	0.493	0.75	0.514	1.58	0.83
Other	0.463	0.74	0.444	0.53	−0.21
Material reallocation, $-R^M$		−0.40		−0.02	0.38
Hours reallocation, R^H		−0.47		−0.34	0.13
Decomposition Using Industry Value-Added Productivity					
	Weight	Contribution	Weight	Contribution	
Weighted ALP^Y	1.000	1.45	1.000	2.62	1.17
IT-producing	0.044	0.40	0.042	0.63	0.22
IT-using	0.493	0.38	0.514	1.55	1.16
Other	0.463	0.67	0.444	0.45	−0.21
Hours reallocation, R^H		−0.47		−0.34	0.13

Notes: Decomposition framework is defined in equations (6) and (7). Weights are sum of average nominal, value-added shares; contribution is sum of share-weighted labor productivity growth. Figures may not add precisely due to rounding. IT-producing industries include Industrial Machinery and Equipment (SIC #35) and Electronic and Other Electric Equipment (SIC #36); IT-using industries include 26 industries, defined by above median 1995 IT capital share; other industries include the remaining 33 industries, which include four industries with no detailed capital data.

The 26 IT-using industries have an above-median value of the 1995 IT share of capital services. The remaining 33 industries are included in the all other category, which also includes the four service industries for which capital stock data are not available.

The first row reports aggregate productivity growth for the private economy, excluding the statistical discrepancy. For each period, the first column shows value-added weights ($\sum_i \bar{w}_i$) and the second shows the direct productivity contribution ($\sum_i \bar{w}_i d \ln ALP_i^Y$ or $\sum_i \bar{w}_i d \ln ALP_i^V$) for all industries and the subsets of IT-producing, IT-using, and other industries. The reallocation effects, R^M and R^H, are summed over all industries. The last column reports the change in contribution from 1987–1995 to 1995–2000.

Aggregate labor productivity growth increased by 1.30 percentage points when 1987–1995 is compared to 1995–2000, with 0.79 due to the direct contribution of faster gross output productivity growth in individual industries. An additional 0.38 percentage point is due to a change in materials reallocation, and 0.13 due to a change in hours reallocation.

The breakdown of the direct productivity effect across the three sets of industries shows that productivity gains were concentrated in IT-related industries. For 1995–2000, the relatively small IT-producing industries (4-percent share) contributed 0.54 percentage point, the large IT-using industries (51-percent share) contributed 1.58, and the large set of other industries (44-percent share) contributed only 0.53. The relatively large contributions from IT-related industries reflects their rapid productivity growth rates after 1995, e.g., mean annual growth rates of 13.0 percent per year for the two IT-producing industries, 2.9 percent for the 26 IT-using industries, and only 1.7 percent for the 33 other industries.

The comparison of the three sets of industries is even more dramatic when one examines the U.S. productivity revival by focusing on changes between 1987–1995 and 1995–2000. IT-producing and IT-using industries account for *all* of the change in aggregate productivity that is attributable to individual industries, while the remaining 44 percent of the economy made a *negative* contribution of 0.21 percentage point on net to the change in aggregate productivity growth.

The bottom panel of Table 6 consolidates the material reallocation effects with gross output productivity as in equation (7). The results are similar, with the two sets of IT-related industries accounting for more than the entire productivity acceleration and other industries making a *negative* 0.21 percentage-point contribution on net to the aggregate productivity acceleration.

It is interesting to note that the material and labor reallocation terms are negative in both periods, although they are declining as one might expect in more open markets with less regulation and more efficient resource reallocations. The negative material reallocation means material growth is outpacing gross-output growth on average, which must be netted out from the direct industry contributions because it reflects interindustry trade that does not increase aggregate value-added. In terms of hours reallocation, the negative effect primarily reflects several non-IT-intensive industries with strong labor growth, but value-added shares below labor shares, e.g., construction, social services, and educational services.[11] This is similar to Nordhaus (2000), who also reports a negative labor reallocation term (his Denison effect).

The decomposition shows that the impact of IT-related industries on aggregate U.S. productivity growth is quantitatively large and economically important at the macro level. All of the industry-specific contribution to the aggregate productivity acceleration is originating in the industries that either produce or use IT most intensively, while other industries have made no contribution on net. One may debate the direction of causation, but these results clearly show that IT-related industries are driving the U.S. productivity revival and that other industries are playing a lesser role.

V. Conclusions

IT has emerged as an appealing candidate to explain the acceleration of U.S. productivity growth in recent years and these results strengthen that view by establishing a link between IT capital and subsequent productivity growth across U.S. industries. In particular, industries that made the largest investments in computer hardware, software, and telecommunication equipment in the 1980's and early 1990's show larger productivity gains after 1995.

A decomposition of aggregate productivity growth into the contribution of individual industries and interindustry reallocation effects shows that IT-producing and IT-using industries account for all of the productivity revival that is attributable to the direct contributions from specific industries. In sharp contrast, industries that are relatively isolated from the IT revolution made a negative contribution to the U.S. productivity revival on net. While IT is clearly not the only force behind the U.S. productivity revival, these results suggest that it is probably an important one.

This evidence also supports the idea that the acceleration of aggregate productivity is a real phenomenon and not just a cyclical one. Given the substantial differences in productivity growth between IT-intensive and other industries, cyclical forces would have to be highly concentrated in precisely those industries that are most IT intensive for this to be the whole story. The strong and robust correlation between IT intensity and the subsequent productivity acceleration, however, implies that there may be a deeper relationship between IT investment and productivity growth.

[11] One may be tempted to infer if value-added shares exceed labor shares, then the industry has relatively high productivity levels. This is not necessarily true, however, since value-added shares are calculated in nominal values, while productivity depends on real output.

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