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Productivity Growth and the New Economy

WHAT, ANOTHER PAPER ON the new economy? When financial markets are raking through the debris of $8 trillion in lost equity value, and ".com" is a reviled four-symbol word, a paper on the impact of the new economy on productivity would seem as welcome as an analysis of the role of whales in the lighting revolution.

In fact, the new economy (or, more precisely, information technologies) continues to raise important puzzles about productivity growth. Variations in productivity growth have proved to be one of the most durable puzzles in macroeconomics. After a period of rapid growth following World War II, productivity stagnated in the early 1970s. There was no shortage of explanations offered, including rising energy prices, high and unpredictable inflation, rising tax rates, growing government, burdensome environmental and health regulation, declining research and development, deteriorating labor skills, depleted possibilities for invention, and societal laziness.[1] Yet these explanations seemed increasingly inadequate as inflation fell, tax rates were cut, regulatory burdens stabilized, government's share of output fell, research and development and patents granted grew sharply, real energy prices fell back to pre-1973 levels, and a burst of invention in the new economy and other sectors fueled an investment boom in the 1990s.

The productivity slowdown puzzle of the 1980s evolved into the Solow paradox of the early 1990s: computers were everywhere except in the

The author is grateful for comments from Ray Fair, Robert Yuskavage, and members of the Brookings Panel.

1. See Nordhaus (1972), Baily (1982), and Denison (1980).

productivity statistics. The penetration of the American workplace by increasingly sophisticated and powerful computers and software apparently failed to give an upward boost to productivity growth, for through thin and thick, labor productivity growth seemed to be on a stable track of slightly over 1 percent a year.

Then, in the mid-1990s, productivity growth rebounded sharply. Beginning in 1995, productivity in the business sector grew at a rate close to that in the pre-1973 period. The causes of the rebound were widely debated, but at least part was clearly due to astonishing productivity growth in the new economy sectors of information technology and communications. This period led to yet another paradox, identified by Robert Gordon, who argued that, after correcting for computers, the business cycle, and changes in measurement techniques, there was no productivity rebound outside the computer industry.

This paper attempts to sort out the productivity disputes by using a new technique for decomposing sectoral productivity growth rates and using a new data set that relies primarily on value added by industry. In addition to examining the recent behavior of productivity, the paper adds a few new features to the analysis.

First, it lays out a different way of decomposing productivity growth, one that divides aggregate productivity trends into factors that increase average productivity growth through changes in the shares of different sectors. Second, it develops an alternative way of measuring aggregate and industrial productivity based on industrial data built up from the income side rather than the product side of the national accounts. By relying on the industrial data, I can focus on different definitions of output and get sharper estimates of the sources of productivity growth. Third, by working with the new industrial data, I can make more accurate adjustments for the contribution of the new economy than has been possible in earlier studies. Finally, this new data set allows creation of a new economic aggregate, which I call "well-measured output," that excludes those sectors where output is poorly measured or measured by inputs.

Productivity Accounting

Measuring productivity would appear to be a straightforward issue of dividing output by inputs. In fact, particularly with the introduction of chain-weighted output measures, disentangling the different components of productivity growth has become quite complex. In this section I explore how to decompose productivity growth into three components: a fixed-weight aggregate productivity index, a "Baumol effect" that reflects the effect of changing shares of output, and a "Denison effect" that reflects the effect of differences between output and input weights.[2]

Consider indexes for the major aggregates. Define aggregate output as X_t, composite inputs (here, hours of work) as S_t, and aggregate productivity as $A_t = X_t/S_t$. The share of output of sector i in nominal GDP is $\sigma_{i,t}$, and the growth of output or other variables is designated by $g(X)$. Output is measured as a chained index, whereas labor inputs and productivity are sums and ratios, respectively. In this paper all growth rates will be calculated in logarithmic terms, so that $g(X_t) = \Delta\ln(X_t) = \ln(X_t) - \ln(X_{t-1})$.

The growth of labor productivity in logarithmic terms is

$$\Delta\ln(A_t) = \Delta\ln(X_t) - \Delta\ln(S_t).$$

Considering only the first term, after some manipulation I get

$$\Delta\ln(X_t) = \ln\left[1 + \sum_i g(X_{it})\sigma_{i,t-1}\right] \approx \sum_i g(X_{it})\sigma_{i,t-1}.$$

Using the same methodology, I derive the growth of productivity as $g(A_t) = \Delta\ln(A_t)$, which after some manipulation gives

$$g(A_t) = \Delta\ln(A_t) = \sum_i g(A_{it})\sigma_{i,t-1} + \sum_i g(S_{it})(\sigma_{i,t-1} - w_{i,t-1}), \tag{1}$$

where $w_{i,t-1}$ is the share of inputs in sector i in total inputs. The interpretation of equation 1 is that the rate of aggregate productivity growth is equal to the weighted-average productivity growth of the individual sectors plus the difference-weighted average of input growth. The weights on productivity growth are the lagged shares of nominal outputs, whereas the difference weights on input growth are the differences between output and input shares. (A symmetrical formula could be derived where the roles of input and output shares are reversed.)

2. The formulas in this section are derived and discussed more extensively in Nordhaus (2002).

It will be convenient to add a term to capture the role of changing shares of output. Add and subtract $\sum_i g(A_{i,\text{ base}})\sigma_{i,\text{ base}}$ from equation 1 and rearrange terms, where "base" indicates a base year. This yields

$$(2) \qquad g(A_t) = \sum_i g(A_{i,t})\sigma_{i,\text{base}} + \sum_i g(A_{it})(\sigma_{i,t-1} - \sigma_{i,\text{base}}) + \sum_i g(S_{it})(\sigma_{i,t-1} - w_{i,t-1}).$$

Interpretation

Equation 2 shows that aggregate productivity growth can be broken down into three components: a pure (fixed-weight) productivity growth term that uses fixed base-year nominal output weights, a term that reflects the difference between current nominal output weights and base-year nominal output weights, and a term that reflects the interaction between the growth of inputs and the difference between output and input weights. For convenience, I will designate these three terms as follows.

THE PURE PRODUCTIVITY EFFECT. The first term on the right-hand side of equation 2 is a fixed-weighted average of the productivity growth rates of different sectors. More precisely, this term measures the sum of the growth rates of different industries weighted by base-year nominal output shares of each industry. Another way of interpreting the pure productivity effect is as the productivity effect that would occur if there were no change in the shares of nominal output among industries.

THE BAUMOL EFFECT. The second term captures the interaction between the differences in productivity growth and the changing shares of nominal output among different industries over time. This effect has been emphasized by William Baumol in his work on unbalanced growth.[3] According to Baumol, those industries that have relatively slow output growth are generally accompanied by relatively slow productivity growth (services being a generic example, and live performances of a Mozart string quartet a much-cited specific example). This conjunction of factors leads to Baumol's "cost disease," a syndrome in which the drag of slow-

3. See Baumol (1967). This study was updated and revised in Baumol, Blackman, and Wolff (1985). A recent discussion focusing on the services sector is contained in Triplett and Bosworth (2002).

productivity-growth industries retards the growth of aggregate productivity. In terms of equation 2, if the share of nominal output $\sigma_{i,t}$ devoted to slow-productivity-growth industries rises over time, the second term will also be rising, and overall growth will thereby be driven downward.

THE DENISON EFFECT. The third term in equation 2 captures level effects due to differences in shares. I label this the Denison effect, after Edward Denison, who pointed out that the movement from low-productivity-level agriculture to high-productivity-level industry would raise productivity even if the productivity growth rates in the two sectors were zero. Denison showed that this effect was an important component of overall productivity growth when fixed-weight indexes are used to measure output.[4]

Earlier work on productivity decomposition implicitly or explicitly included a fourth effect, called the fixed-weight drift term.[5] That effect arises when real output is measured using Laspeyres indexes of output. Real output measured with a Laspeyres fixed-base quantity index tends to grow more slowly than output measured by a chain index in periods before the base year and more rapidly in periods after the base year. The divergence of relative real outputs from relative nominal outputs with "old-style" fixed-weight quantity indexes motivates the name. This term vanishes (or almost vanishes) with the introduction of chain indexes (or, more precisely, well-constructed superlative index numbers) because real output shares used in calculating the growth rates are equal (or almost equal) to nominal output shares. A careful examination of the measure of productivity growth that most closely corresponds to the welfare-theoretic measure of the growth of real income shows as well that the fixed-weight drift term should be omitted.[6] All in all, moving to chain weights and removing the fixed-weight drift term marked a major advance in productivity measures.

4. A number of studies found this syndrome. See in particular Denison's studies of postwar Europe (Denison, 1967).

5. More precisely, when output is measured using fixed weights, the fixed-weight drift term is $\sum_i g(X_{it})[z_{it} - \sigma_{it}]$, where z_{it} is the share of industry i in total output when output is measured by a Laspeyres index. This term is zero when output is measured using chain weights.

6. See Nordhaus (2002).

Review of Alternative Productivity Measures

The Underlying Productivity Data

The productivity data used in this paper differ from standard measures used to track productivity. The output data are based on income-side value-added data (gross domestic income, or GDI) developed by the Bureau of Economic Analysis (BEA).[7] The BEA provides data on nominal output by industry (value added), Fisher indexes of real output and prices by industry, and hours of work. For this paper I have created Fisher indexes of output for different aggregates as well as estimates of labor productivity by industry and for different aggregates.[8]

The major advantage of the income-side measures is that they present a consistent set of detailed industrial accounts in which the nominal values sum to nominal GDP; by contrast, very little industrial detail is available on the product side of the accounts. The disadvantage is that the real output data using chain weights are available only for the period 1977–2000.

Because of interest in the new economy, I have also constructed a set of new economy accounts. For the purpose of this paper, I define the new economy as machinery, electric equipment, telephone and telegraph, and software. The combined share of these sectors in real GDP grew from 2.9 percent in 1977 to 10.6 percent in 2000. These sectors are somewhat more inclusive than a narrow definition of the new economy but are the narrowest definition for which a complete set of accounts is available. I discuss details of the new economy below.

In addition, I develop productivity measures for three different broad output concepts that can be used in productivity studies. One of these is standard GDP (measured from the income side of the accounts). A second is what the Bureau of Labor Statistics (BLS) defines as nonfarm business sector output. A third concept responds to concerns in productivity studies about the poor quality of the price deflation in several sectors. For this purpose I have constructed a set of accounts that I call "well-measured output," which includes only those sectors for which output is relatively well measured. I begin with a review of standard labor productivity mea-

7. The BEA data are available on the BEA website. Details on the construction of the data sets are provided in Nordhaus (2002).

8. A discussion of the use of Fisher indexes in the national income and product accounts is found in Triplett (1992) and Landefeld and Parker (1997).

sures and then turn to a comparison of standard measures with the measures constructed for this study.

The BLS Productivity Data

The most widely followed productivity measures are constructed and published by the BLS. Figure 1 shows the behavior of the BLS series for the business sector; for this purpose I have used a three-year moving average of labor productivity growth. Table 1 shows a simple regression with two breaks in trend, one in 1973 and another in 1995.

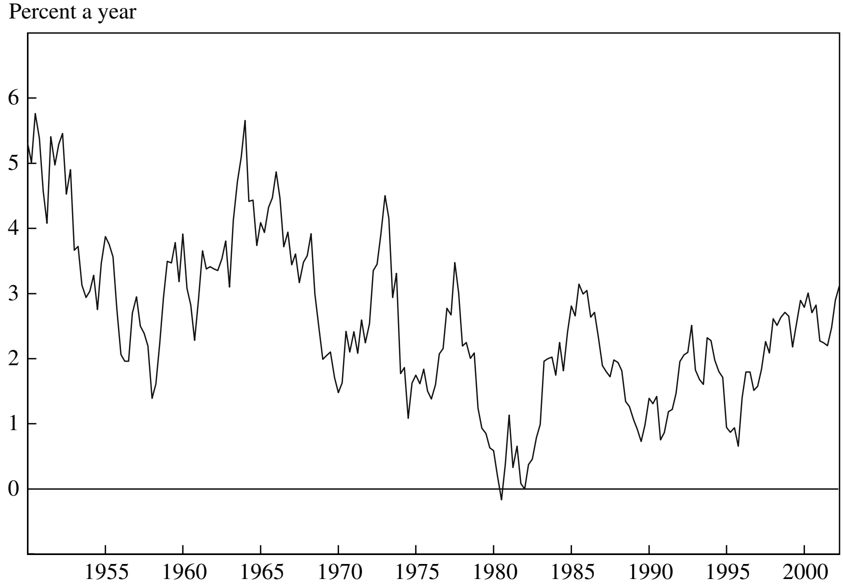
Three points are worth noting. First, the labor productivity growth data in figure 1 do not show dramatic and obvious breaks in trend. Labor productivity began deteriorating in the late 1960s, and the really terrible period was in the early 1980s. An untutored analyst would probably not recognize any sharp break in trend labor productivity after 1973. Second, the productivity upsurge in the late 1990s was not a particularly rare event. Productivity accelerations of greater magnitude were seen in the early 1960s, the early 1970s, and the early 1980s—indeed, there were changes in "trend" in virtually every decade. The volatile nature of productivity growth is a warning that one should not read too much into a period even as long as five years. Third, even with the rapid productivity growth observed since 1995, labor productivity growth is still below four other postwar highs. The early 1950s, the mid-1960s, the early 1970s (briefly), and the mid-1980s were periods when labor productivity grew more rapidly than it has in the last three years.

Notwithstanding these cautions, it is important to examine the current upturn in productivity with an eye to understanding its sources. In particular, we will want to determine the role of the new economy in the recent productivity rebound.

Comparison of Labor Productivity Growth Rates between Product Side and Income Side

The BLS business output series is a product-side index provided by the BEA. It is useful to compare the standard BLS series with the income-side productivity measures developed here. This is not straightforward because (in addition to the problem of dealing with the statistical discrepancy) the BLS business output ("Bus-Prod") series does not correspond to a straightforward combination of the income-side industries. I have

Figure 1. Labor Productivity Growth in the Business Sector[a]



Source: Bureau of Labor Statistics.
a. Three-year moving average of logarithmic growth rates.

prepared an income-side business output measure ("Bus-Inc") by combining the major industries as best I can. The nominal values of the two aggregates are reasonably close, with a root mean square error of 0.16 percent over the 1977–2000 period.[9]

As far as productivity per hour worked is concerned, the two series agree reasonably well. For the entire 1977–2000 period the income-side productivity growth of nonfarm business output was about 0.07 percent a year faster. On the whole, the income-side and the product-side data are reasonably consistent. Table 2 shows a comparison of estimates of productivity growth from the two series for three subperiods of the 1977–2000 period. The basic story is the same except in the last period, when the income-side measure grew substantially faster; this difference is

9. The Bus-Inc variable excludes general government and private households along with most of housing and the nonprofit sectors of the service industries. For the comparison in the text, I have subtracted the statistical discrepancy from the income-side measure.

Table 1. Trends in Labor Productivity in the Business Sector, 1948–2002

Variable[a]	*Regression coefficient*	*Standard error*	*t Statistic*
Constant	3.34	0.36	9.4
DUM73[b]	–1.93	0.52	–3.7
DUM95[c]	1.17	0.77	1.5
Summary statistic			
R^2	0.060		
Standard error of regression	3.58		
No. of observations	218		

Source: Author's regressions using data from the Bureau of Labor Statistics.
a. The dependent variable is the annualized one-quarter change in the logarithm of labor productivity. The sample period is 1948:1 to 2002:2.
b. Dummy variable that takes the value of 1 after 1973:2.
c. Dummy variable that takes the value of 1 after 1995:2.

due primarily to the mysterious statistical discrepancy, which rose sharply from 1977 to 2000.

Well-Measured Output

The final output measure is one that includes only those sectors where output is relatively well measured. It is widely accepted today that, in many sectors, real output is poorly measured in the national income accounts. In some cases, such as general government and education, there is no serious attempt to measure output, and instead the indexes of activity are inputs such as employment. In other cases the BEA (or the BLS, which prepares the underlying price data) uses deflation techniques that are potentially defective.

The idea of well versus poorly measured sectors was introduced by Zvi Griliches in his 1994 presidential address to the American Economic Association:

> Imagine a "degrees of measurability" scale, with wheat production at one end and lawyer services at the other. One can draw a rough dividing line on this scale between what I shall call "reasonably measurable" sectors and the rest, where the situation is not much better today than it was at the beginning of the national income accounts.[10]

Defective deflation occurs for two quite different reasons. First, in some sectors, of which construction, insurance, and banking are examples, the

10. Griliches (1994, p. 10).

Table 2. Alternative Measures of Productivity Growth in the Nonfarm Business Sector, 1977–2000[a]

Percent a year

Measure	*1977–89*	*1989–95*	*1995–2000*	*Change, 1977–89 to 1989–95*	*Change, 1977–89 to 1995–2000*
BLS (product side)[b]	1.21	1.46	2.45	0.25	1.24
BEA (income side)[c]	1.26	1.26	2.87	0.00	1.61
Difference	–0.05	0.20	–0.41	0.25	–0.36

Source: Bureau of Economic Analysis data.

a. Growth in output per hour worked; annual averages.

b. Product-side output of the nonfarm business sector, based on BLS hours-worked measures, and used by the BLS in its business sector productivity measures.

c. Uses income-side output and hours measures derived in this paper and using BEA hours data.

BEA does use price indexes for deflation of nominal magnitudes, but the price indexes are for goods or services that are not representative of the range of outputs in that sector. Second, and this has received much more attention, in some sectors the underlying price index does not adequately capture quality change or the introduction of new goods and services. An excellent historical example of this syndrome is computers. Before hedonic techniques were introduced, the government assumed that the price of computers was constant in nominal terms. When hedonic price indexes for computers were introduced, the earlier assumption was found to overstate the "true" price increase by around 20 percent a year for the last three decades.

It is difficult for an outsider to assess the quality of the deflation of each sector included in the industrial accounts. There have been many studies of this issue.[11] Nonetheless, after discussion with experts inside and outside the BEA, I have constructed a new measure of output for sectors that have relatively well measured outputs. The sectors included are

Agriculture, forestry, and fishing
Mining
Manufacturing
Transportation and public utilities
Wholesale trade

11. Griliches's (1994) definition of "measurable" sectors is identical to that of well-measured output except that he puts trade in the unmeasurable sector.

Retail trade
Certain services (software, other business services, hotels, repair).

Five major sectors are excluded:

Construction*
Finance,* insurance,* and real estate
Most services*
General government
Government enterprises*.

The sectors marked by asterisks are included in the BLS's measure of business output. Nonfarm business output remained about 75 percent of nominal GDP over the 1977–2000 period, whereas well-measured output declined from 68 percent of nominal GDP in 1948 to 57 percent in 1977 and 50 percent in 2000. Thus, well-measured output is currently only about half of GDP, and the share of output that is well measured has been declining steadily since World War II. This trend confirms, using a different approach and data set, Griliches's observation that the degree of "measurability" of real output has been declining over time. At the same time, the BEA has made considerable progress in introducing improved deflation techniques. Whether the progress of improved deflation has outstripped the decline in measurability is an interesting but open question.

Table 3 shows the growth of output per hour for the three major aggregates—GDP, nonfarm business output, and well-measured output—for different subperiods of the 1977–2000 period. Productivity in the business sector has grown faster than productivity for total GDP, primarily because of the slow growth of productivity in the government sector. Productivity in the well-measured sectors has grown about 0.65 percentage point a year faster than in the nonfarm business economy because of poor performance in the construction and services industries.

The New Economy

This study also develops input and output data for the new economy. For the purpose of this study, I use the following formal definition: The new economy involves acquisition, processing and transformation, and distribution of information. The three major components are the hardware (primarily computers) that processes the information, the communications

Table 3. Productivity Growth for Alternative Measures of Aggregate Output and the New Economy, 1977–2000[a]

Percent a year

Measure	*1977–89*	*1989–95*	*1995–2000*	*1977–2000*	*Change, 1977–89 to 1989–95*	*Change, 1977–89 to 1995–2000*	*Change, 1989–95 to 1995–2000*
Total economy							
GDP	1.20	1.11	1.73	1.29	–0.09	0.53	0.62
GDI	1.21	0.96	2.24	1.37	–0.25	1.04	1.28
Nonfarm business sector							
Income-side	1.26	1.26	2.87	1.61	0.00	1.61	1.61
BLS measure	1.21	1.46	2.45	1.54	0.25	1.24	0.99
Well-measured output	2.00	1.93	3.29	2.26	–0.07	1.29	1.36
New economy	6.25	6.37	9.98	7.09	0.12	3.73	3.61

Source: Author's calculations using BEA and BLS data.

a. Growth in output per hour worked; data are annual averages. Details may not sum to totals because of rounding.

systems that acquire and distribute the information, and the software that, with human help, manages the entire system.

Which sectors are included in practice under this definition? Table A1 in the appendix shows the new economy sectors as defined by the Commerce Department for its study *The Emerging Digital Economy*.[12] That definition overlaps with the formal definition, and it includes some old economy sectors as well as some sectors with questionable price indexes.

For purposes of this study, we are hamstrung because comprehensive data are limited to major industries. I therefore include in the new economy the four major industries that contain the new economy industries: industrial machinery and equipment (Standard Industrial Classification 35), electronic and other electric equipment (SIC 36), telephone and telegraph (SIC 48), and software (SIC 873). The BEA has developed detailed industrial data for the first three of these, but there is incomplete detail for software.

This definition of the new economy is somewhat broader than would be ideal for the present purposes. For example, SIC 35 contains computers and office equipment, but the computer industry accounts for less than 25 percent of the total 1996 value added in that sector. Other parts of SIC 35 include ball bearings and heating and garden equipment, which are dubious candidates for inclusion in the new economy. A prominent component of SIC 36 is semiconductors, an industry central to the new economy, but semiconductors constitute only 8 percent of the 1996 value added in SIC 36. This sector includes communications equipment, one part of which has hedonic deflation. This sector also contains many old economy industries, including incandescent bulbs, and a wide array of consumer electronics, whose prices are probably poorly measured. Similarly, although the telephone and telegraph sector is central to the communications components of the new economy, it also includes some paleoindustries like telegraph, whose commercial applications date from 1844, and telephone, which premiered in 1876.

Software is genuinely a new economy industry. However, only the data for the prepackaged component (slightly larger than one-fourth of the total) are hedonically deflated at present. The data on software are incomplete, and some crude assumptions are necessary to fit software into the present database.

12. U.S. Department of Commerce (2000).

Because of the importance of the new economy in the present analysis, it is worth emphasizing that relatively few industries are measured using hedonic price indexes that systematically attempt to capture new goods and components or quality change. The BEA reports that systematic hedonic prices are used for only four major industries (all in new economy sectors): computers and peripheral equipment, semiconductors, prepackaged software, and digital switching equipment. In 1998 these sectors accounted for about 2.2 percent of GDP, while the four industries included in the broad definition of the new economy in this study accounted for 9.6 percent of GDP. This suggests that only a quarter of what I have labeled as the new economy has careful hedonic measurement of prices and output.

Productivity Resurgence and the New Economy

I now turn to the central questions about productivity performance in the late 1990s: What was the magnitude of the productivity upturn? How much of it was due to each of the three factors derived above—pure productivity acceleration, the Baumol effect, and the Denison effect? What was the contribution of the new economy to the productivity acceleration? And is there a different view for the well-measured part of the economy than for the entire economy?

How Large a Productivity Acceleration?

Returning to table 3, we see that labor productivity growth in the three major aggregates showed little change in the two subperiods between 1977 and 1995, averaging around 1.1 percent a year for the income-side measure of the total economy and around 1.3 percent a year for income-side nonfarm business output. Well-measured output showed more robust productivity growth, averaging around 2.0 percent a year, but was relatively stable over this period. The new economy showed substantial productivity growth, averaging over 6 percent a year in the first two subperiods, but with little acceleration.

The last five years of the period showed a dramatic upturn in labor productivity growth in all of the measures (last column of table 3). For the total economy the acceleration from the first to the last subperiod was

0.53 percentage point using the output-side measure and almost twice as much, 1.04 percentage points, using the income-side measure. Accounting for the difference is the huge growth in the statistical discrepancy from 1997 to 2000.

The nonfarm business sector showed an upturn of 1.61 percentage points using the income-side measure and a slightly smaller increase of 1.24 percentage points according to the BLS measure. The difference between the two estimates is partly due to more rapid growth in the income-side estimate of nonfarm business output and partly due to somewhat faster growth in the BLS's estimate of hours for that sector.

Well-measured output is estimated to have seen faster productivity growth over the entire period than the other major aggregates. Over the entire period, productivity growth was 0.65 percentage point faster in the well-measured sectors than in the income-side measure of nonfarm business, and 0.89 percentage point faster than in income-side total output. The acceleration in productivity in the last five years of the period in the well-measured sectors was slightly smaller than that in income-side nonfarm business output, but larger than for either of the definitions of the entire economy. The new economy logged a breathtaking acceleration in productivity of 3.7 percentage points a year over the last five years of the period, to a growth rate of 10 percent a year. In short, the last five years of the period witnessed a major upturn in productivity growth for all the major aggregates.

Decomposition of the Productivity Acceleration

Productivity growth is determined both by the rates of productivity growth within industries and by changes in the composition of industries. How much of the recent growth in productivity was due to each of the three factors—pure productivity growth, the Baumol effect, and the Denison effect—derived above?

The first panel of table 4 shows the basic results for the overall economy, as measured from the income side. The pure productivity effect was virtually identical to overall productivity growth over the entire period. However, the pure productivity effect was slightly (0.15 percentage point) higher than conventionally measured average productivity growth in the most recent period. Even larger differences are seen for the nonfarm business sector and for well-measured output (bottom two panels of table 4).

Table 4. Decomposition of Labor Productivity Growth for Alternative Measures of Aggregate Output, 1978–2000[a]

Percent a year

Measure	*1977–89*	*1989–95*	*1995–2000*	*Change, 1977–89 to 1989–95*	*Change, 1977–89 to 1995–2000*
GDI	1.21	0.96	2.24	–0.25	1.04
Pure productivity effect[b]	1.27	0.73	2.39	–0.54	1.13
Baumol effect[c]	0.18	–0.01	0.04	–0.18	–0.14
Denison effect[d]	–0.18	0.32	–0.12	0.50	0.06
Residual[e]	–0.05	–0.08	–0.07	–0.03	–0.02
Nonfarm business sector	1.26	1.26	2.87	0.00	1.61
Pure productivity effect	1.29	1.45	3.09	0.16	1.80
Baumol effect	0.15	–0.01	0.03	–0.16	–0.12
Denison effect and residual	–0.18	–0.19	–0.25	–0.01	–0.07
Well-measured output	2.00	1.93	3.29	–0.07	1.29
Pure productivity effect	2.17	2.20	3.66	0.03	1.49
Baumol effect	0.15	0.00	–0.04	–0.14	–0.19
Denison effect and residual	–0.31	–0.27	–0.33	0.04	–0.01

Source: Author's calculations.

a. Growth in output per hour worked; data are annual averages. Details may not sum to totals because of rounding.

b. Weighted average of sectoral productivity growth using fixed nominal output weights for 1996; corresponds to first right-hand term in equation 2.

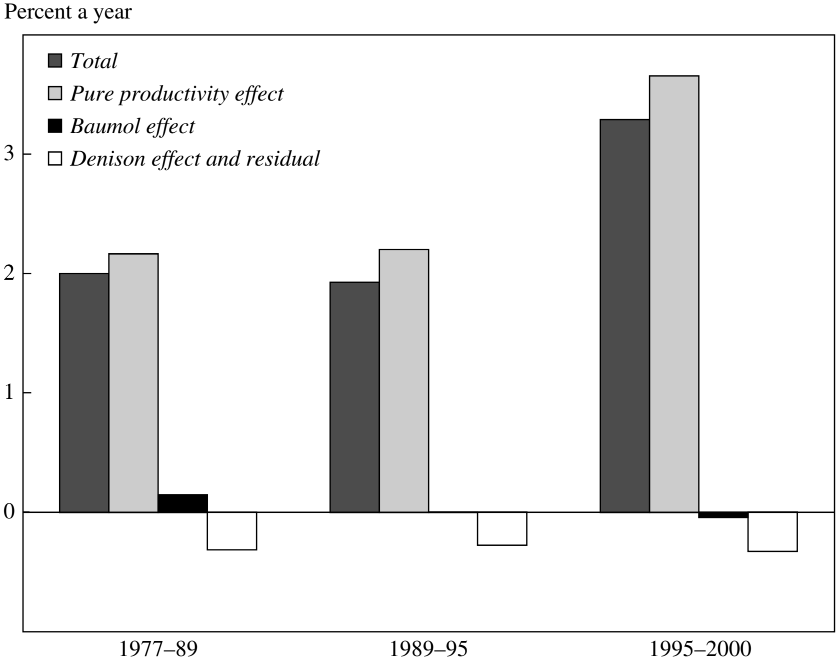
c. Difference between the variable productivity effect and the pure productivity effect; corresponds to second right-hand term in equation 2.

d. Impact of reallocation among industries that have different shares of labor incomes; corresponds to third right-hand term in equation 2.

e. Interaction terms and second-order effects.

How much of the productivity acceleration in the last five years was due to the different effects? Figure 2 shows the results for the well-measured sectors; the underlying data are presented in the bottom panel of table 4. These data show that all of the recent productivity acceleration was due to the pure productivity effect rather than the sectoral reallocations. In fact the pure productivity effect was almost exactly equal to the overall productivity acceleration for the income-side measure. For the other two concepts of output, the productivity acceleration from the pure productivity effect was about 0.2 percentage point larger than the total. This implies that the productivity improvement arose largely because

Figure 2. Components of Productivity Growth in Well-Measured Output, 1977–2000



Sources: Author's calculations using data from Bureau of Economic Analysis.

weighted-average productivity growth in the underlying industries increased, not because of sectoral shifts or other factors.

The basic conclusion regarding the decomposition of productivity growth is that pure productivity growth in the most recent period has been even more rapid than total productivity growth. This is most clearly seen for overall output, where the conventional product-side estimates of productivity growth (table 3) are well below pure productivity growth (table 4) because of the statistical discrepancy as well as modest Baumol and Denison effects. The understatement is even larger for the nonfarm business sector and for the well-measured sector.

We can also use these results to determine the gravity of the Baumol effect. In a series of pioneering works, William Baumol analyzed the impact of differential productivity growth on different sectors and institutions such as services, health care, the cities, and the performing arts.[13] His basic story is that those sectors whose productivity growth rates are below the economy's average will tend to experience above-average cost increases and a growing share of total spending. The resulting "cost disease" may, according to Baumol, lead to above-average price increases, financial pressures on suppliers, and a reduction in the economy's overall rate of productivity growth.

Table 4 shows the Baumol effect over the 1977–2000 period. In fact the effect was slightly positive over the period as a whole for all three output concepts, indicating that changing sectoral shares added slightly to aggregate productivity. Recall from equation 2 that the Baumol effect captures the interaction of changing shares of nominal output and productivity growth. As it turns out, those sectors with rising nominal output shares have experienced higher than average productivity growth rates (the new economy sectors are a good example). Baumol's cost disease has been cured, or at least is in remission.

Contribution of the New Economy to the Productivity Rebound

The next question involves using the new data set to ask, What is the contribution of the new economy to the remarkable resurgence in productivity over the last few years? In this exercise the answer is limited to the direct contribution of more rapid productivity growth in new economy industries, or to the production of new economy goods and services. This analysis omits the important question, addressed later in this paper, of the use of new economy goods and services elsewhere in the economy, through the contribution of capital deepening and of spillover effects from the information economy to productivity.

The technique for calculating the impact of the new economy is as follows. For each output concept, output and hours indexes are calculated with and without the four new economy sectors. In other words, in calculating the chain indexes, the index with the new economy sectors takes the Fisher index including the four industries, whereas the index without the new economy omits those and rescales the weights and recalculates Fisher indexes so that the output and labor indexes sum to 100 percent of the total. This entire procedure is conceptually straightforward primarily because I have constructed a consistent set of value-added accounts.

13. See the references in note 3.

Figure 3 shows the pattern of productivity growth in the four new economy sectors. The most impressive acceleration in the late 1990s was in the electronics sector (SIC 36), which contains microprocessors. In addition, industrial machinery (SIC 35), which contains computers, showed impressive gains in the late 1990s. The other two new economy sectors had healthy but not spectacular measured productivity gains. The software sector contains one component (prepackaged software) with rapid price declines, but the other two components (custom and own-account software) do not have hedonic estimates of prices and show modest price declines.

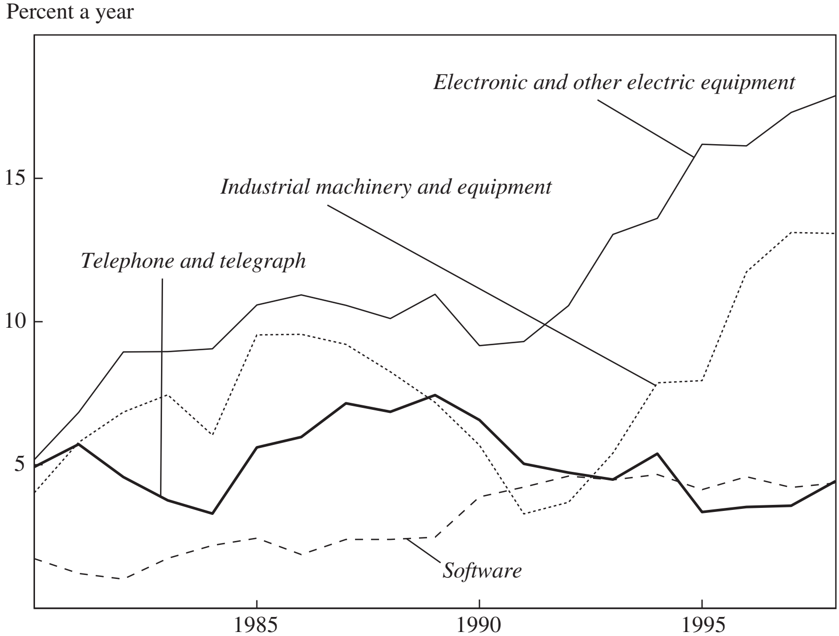
Table 5 shows the results for all three major sectors. Focusing first on the nonfarm business sector, we see that relatively little of the productivity acceleration in that sector in the late 1990s was due to the new economy. Productivity in the nonfarm business output measure that includes the new economy accelerated by 1.61 percentage points from the 1977–89 period to the 1995–2000 period. But only 0.29 percentage point, or one-sixth, was due to acceleration in the new economy sectors. The balance of 1.32 percentage points came in old economy sectors. The results are roughly the same for the overall economy. For the well-measured sectors, one-third of the productivity acceleration from the first half to the second half of the 1990s was due to the new economy.

Although the new economy contributed relatively little to the acceleration in productivity growth, it nonetheless provided a substantial part of total productivity growth. In the last five years of the period, as shown in table 5, the new economy contributed 0.64, 0.78, and 1.16 percentage points to the total for GDP, nonfarm business, and well-measured output, respectively.

Figure 4 shows the contribution of the four new economy sectors to overall GDP productivity. These calculations weight the productivity growth rates of each of the four sectors by its share in nominal GDP (following the approach of the ideal welfare-theoretic formula). The total impact on GDP productivity, shown in the far-right-hand bar in each group, was 0.46 percentage point in the first two subperiods and then rose to 0.72 percentage point for the 1995–2000 period. The largest single contributor for the period as a whole was electric and electronic equipment, followed by machinery, except electrical.[14]

14. The estimates here vary from those in the tables because the weighting procedure is slightly different.

Figure 3. Productivity Growth in Four New Economy Industries, 1980–98



Source: Author's calculations using Bureau of Economic Analysis data.

Evaluation of the Gordon Hypothesis

Equipped with this new data set, I can now evaluate the Gordon hypothesis. This view holds that most if not all of the productivity acceleration in the late 1990s was due to higher productivity in the computer industry. As summarized in *The Economist:*

> Robert Gordon of Northwestern University, one of the country's top authorities on the subject, has found that more than 100% of the acceleration in productivity since 1995 happened not across the economy as a whole, nor even across IT [information technology] at large, but in computer manufacturing, barely 1% of the economy. Elsewhere, growth in productivity has stalled or fallen.[15]

Since the first statement of the Gordon hypothesis in 1999, there has been some backtracking. The most recent estimates associated with the

15. "How Real Is the New Economy?" *The Economist,* July 24, 1999. Also see Gordon (2000). Further discussions can be found in Oliner and Sichel (2000). The latest published version is Gordon (2002).

Table 5. Productivity Growth with and without the New Economy for Alternative Measures of Aggregate Output, 1978–2000[a]
Percent a year

Measure	*1977–89*	*1989–95*	*1995–2000*	*Change, 1977–89 to 1989–95*	*Change, 1977–89 to 1995–2000*
GDI					
With new economy	1.21	0.96	2.24	–0.25	1.04
Without new economy	0.84	0.56	1.60	–0.28	0.76
Difference	0.37	0.39	0.64	0.03	0.27
Nonfarm business sector					
With new economy	1.26	1.26	2.87	0.00	1.61
Without new economy	0.76	0.73	2.08	–0.03	1.32
Difference	0.50	0.53	0.78	0.03	0.29
Well–measured output					
With new economy	2.00	1.93	3.29	–0.07	1.29
Without new economy	1.38	1.21	2.13	–0.17	0.74
Difference	0.61	0.72	1.16	0.10	0.55

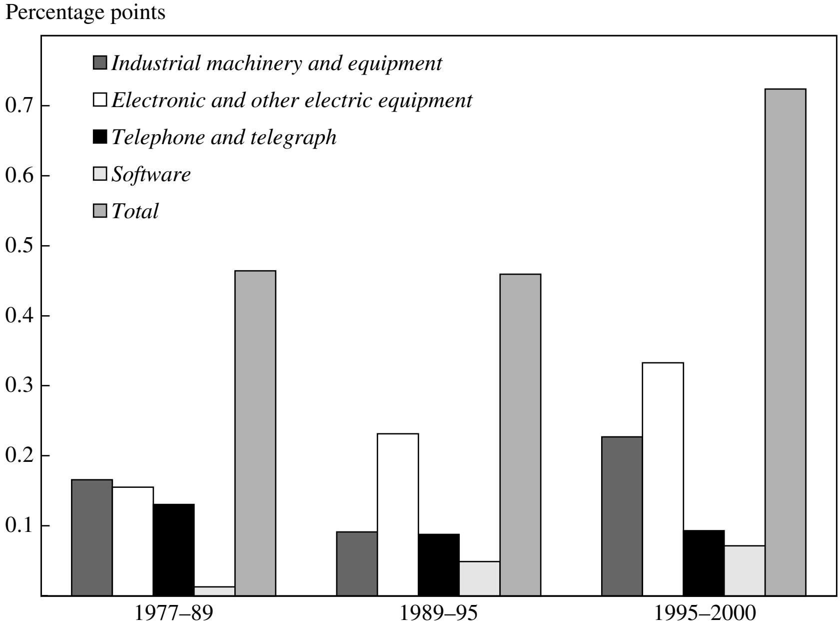
Source: Author's calculations.
a. Growth in output per hour worked; data are annual averages. Details may not sum to totals because of rounding.

Gordon hypothesis (presented by Gordon in his comment on this paper) find that, outside of durable manufacturing, private business experienced an acceleration of labor productivity growth of only 0.22 percentage point for the period 1995:4 to 2000:4 relative to the period 1972:2 to 1995:4; this estimate has drifted upward since Gordon's early calculations.

The results developed here definitely reject the Gordon hypothesis over the period studied. For all three broad output concepts (GDP, the nonfarm business sector, and well-measured output), labor productivity growth in the economy excluding the new economy showed a marked upturn over 1995–2000 relative to the 1977–95 period (table 5). The acceleration in non–new economy productivity growth was 0.85 percentage point for the overall economy (measured from the income side), 1.33 percentage points for nonfarm business output, and 0.80 percentage point for well-measured output (these can be calculated from the data in table 5). The new economy contributed directly about one-quarter of the total acceleration in labor productivity growth for total output, one-sixth for nonfarm business, and two-fifths for well-measured output.

A final decomposition of productivity growth examines how much each industry contributes to the total. Table 6 does this for the nonfarm

Figure 4. Contribution of New Economy Industries to Productivity Growth for the Total Economy, 1977–2000[a]



Source: Bureau of Economic Analysis.
a. Total economy is measured by income-side GDP. Estimates use nominal output weights.

business sector. For this calculation I measured productivity growth as the chain-weighted average of sectoral productivity growth rates; this is equal to the pure productivity effect plus the Baumol effect (see the discussion above). This measure is the closest to the welfare-theoretical ideal of the different indexes. The advantage of using this measure is that the sum of the individual-sector figures equals the total.

Not surprisingly, three of the four new economy sectors are among the top ten contributors to the productivity upturn. Some of the other sectors are more surprising. For example, retail and wholesale trade have each made a major contribution to overall productivity growth in the latest period. Indeed, the contribution of each of these two sectors to the *acceleration* of productivity for the 1995–2000 period was larger than that of any of the new economy sectors. The data in these sectors are somewhat of a mystery, however, which emphasizes the importance of closer atten-

Table 6. Contribution of Selected Industries to Productivity Acceleration in the Nonfarm Business Economy[a]

Percent a year except where stated otherwise

Industry	*Productivity growth* *1975–89*	*Productivity growth* *1995–2000*	*Contribution to productivity acceleration (percentage points)*
Leaders			
Retail trade	1.30	5.25	0.46
Security and commodity brokers	2.80	18.15	0.32
Wholesale trade	2.80	5.86	0.27
Electronic and other electric equipment	8.49	17.87	0.23
Other real estate	1.01	5.64	0.18
Other services	–1.12	1.40	0.08
Electric, gas, and sanitary services	–0.08	2.59	0.08
Industrial machinery and equipment	7.17	13.07	0.08
Software	2.01	4.36	0.08
Chemicals and allied products	2.56	4.87	0.06
Laggards			
Nonfarm housing services	2.52	–0.62	–0.06
Petroleum and coal products	8.43	1.32	–0.07
Other services	0.86	–1.59	–0.09
Food and kindred products	3.85	–2.94	–0.15
All other	n.a.	n.a.	0.22
All industries	1.26	2.87	1.61

Source: Bureau of Economic Analysis data.
a. New economy sectors are shown in boldface.

tion to measuring their output. At the bottom of the league, meanwhile, are food manufacturing, petroleum and coal, and nonfarm housing services. These sectors generally show a negative contribution because of very good productivity performance in the first subperiod followed by a poor performance in recent years.[16] This is a reminder that the underlying industrial data are noisy and should be viewed as at best an approximation to the true performance.

Productivity growth in manufacturing has been an important contributor to growth in aggregate labor productivity. Manufacturing productivity

16. These results are on the whole similar to the results of Jorgenson and Stiroh (2000a), who use an accounting framework that includes all inputs and explains the movement of gross output.

growth clocked 4.1 percent a year in the 1977–95 period according to the income-side data, and that rate moved up to 5.5 percent a year in the 1995–2000 period. Figure 5 shows the major contributors by industry in manufacturing. The importance of industrial machinery (notably computers) and electronic machinery (notably semiconductors) is striking: these two industries contributed 4.5 percentage points of the 5.5-percentage-point total growth.[17] Manufacturing productivity growth outside of the new economy was positive if modest.

On the other hand, the totality of non–new economy manufacturing industries showed a marked productivity deceleration in the latest period, from 2.00 to 0.97 percent a year between 1977–89 and 1995–2000. (This result was shown by Gordon using a different data set.) Of this 1.03-percentage-point slowdown, food processing is responsible for 0.81 percentage point, which raises questions about either the data or the performance of that industry. If the two major new economy industries and the oldest old economy industry (food) are removed from the total, the latest data for manufacturing do not appear to show a major change in productivity growth. It seems reasonable to conclude, as has been argued by Gordon, that up through 2000 the acceleration in manufacturing productivity was limited to the two major new economy sectors led by computers and semiconductors.

Qualifications

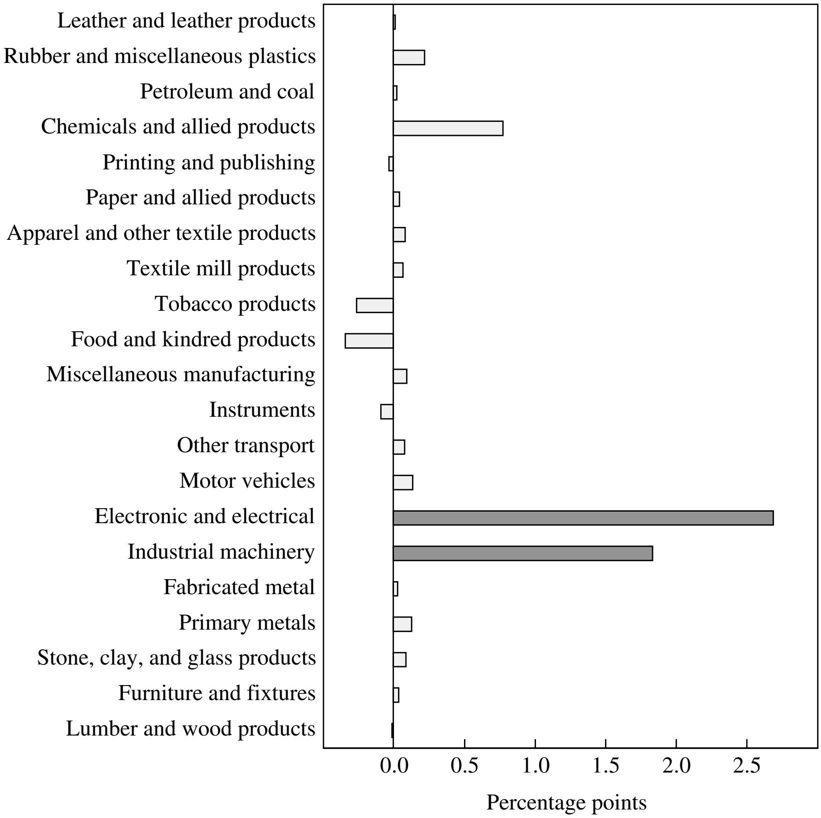
The present study is but one of many that have analyzed recent productivity trends and the role of the new economy. Before concluding, it will be useful to highlight some of the qualifications that attach to the results.

To begin with some technical details, the data for this study pertain exclusively to gross product (that is, value added), which is derived from the industry accounts and primarily based on income rather than product data. Moreover, in these data the nominal output data are directly estimated from income data, whereas the real output data are derived from gross output and intermediate inputs by double deflation.[18] In the aggre-

17. Within SIC 35 and 36, appendix table A2 shows the major data on shipments and the price of shipments. The industries with sharply falling price indexes have hedonic treatment.

18. Yuskavage (2000, 2002).

Figure 5. Contribution to Manufacturing Productivity Growth by Industry, 1995–2000[a]



Source: Bureau of Economic Analysis.

a. Each bar measures productivity growth in one industry times the share of that industry in total manufacturing output. Shaded bars indicate new economy industries.

gate, the income-side industry data differ from the conventional product-side data by the statistical discrepancy; this discrepancy has moved in such a way that nominal GDI grew 0.33 percentage point a year more rapidly than nominal GDP over the 1995–2000 period. Additionally, because of technical issues involving aggregation and differences in deflators, estimates of chained real GDP based on industry real gross product numbers differ somewhat from product-side real GDP even after correcting for the statistical discrepancy. Finally, the industry accounts are on a different revision cycle from the product accounts, and it seems likely that some of the downward product account revisions in mid-2002 will also occur in the industry accounts revision.

From an operational point of view, the major implication of using income-side industry data is that real GDI calculated from these data is estimated to have grown faster than the usual product-side estimates. Over the 1995–2000 period, real income-side GDI had an average annual growth rate of 4.46 percent, versus 3.95 percent for real GDP, for an average difference of 0.51 percentage point. Since this difference is a substantial part of the 1.04-percentage-point acceleration in GDI productivity, these numbers are subject to substantial uncertainty and potential revision.

A second qualification is that the productivity estimates presented here refer to gross product (value added) rather than total output—the difference being purchased goods and services. In principle, there should be no difference between the two approaches if the aggregation technique and the source data are perfect, since it makes no difference whether the weighted sum of inputs is subtracted from the left side or the right side of the total factor input productivity equation. Subtle differences can creep in, however, if purchased goods and services are not measured accurately or if the index numbers suffer from aggregation nonneutrality,[19] both of which apply to the data and to the Fisher indexes. I am unaware of any studies indicating which approach is less prone to aggregation nonneutrality or which approach is more accurate given the inaccuracies of the source data on purchased goods and services.

A third and more important qualification concerns omitting the contribution of capital services to the productivity upturn. This omission is particularly important given the substantial increase in measured capital services in recent years. Studies by Stephen Oliner and Daniel Sichel, Dale Jorgenson, and Kevin Stiroh, among others, suggest that most if not all of the acceleration in labor productivity in the late 1990s was due to capital deepening.[20]

Although estimating total factor productivity is a central technique for understanding trends in productivity, labor productivity also has a useful,

19. An index is aggregation neutral if $F(x_1, x_2, x_3, x_4) = F[F(x_1, x_2), F(x_3, x_4)]$ for all elemental series $x_1, x_2, \ldots$, where F is an aggregator such as the Fisher or Tornqvist index.

20. Oliner and Sichel (2000); Jorgenson and Stiroh (2000a, 2000b); Jorgenson (2001); Stiroh (forthcoming).

independent role to play. To begin with, growth in labor productivity is a central policy concern given its strong linkage to the growth of real wages. Moreover, from a technical point of view, it should be recalled that total factor productivity depends upon *estimating* rather than *measuring* the inputs of capital services. Estimates of capital services depend upon several important and often-criticized assumptions. The major assumptions implicit in this model include such things as the existence of perfect rental markets for capital, no difference between ex ante and ex post substitutability, no break-in or adjustment costs or learning costs, perfect competition, factor rewards proportional to marginal products, and so forth.

These assumptions are likely to be stretched particularly in periods, such as the late 1990s, when new technologies with very high rates of depreciation dominate the data on the growth of capital services. Furthermore, measures of capital services generally use a cost-of-capital formula based on interest rates and therefore do not reflect the extraordinary equity valuations of the late 1990s; the effect of this is to overestimate the user cost and implicit marginal cost of capital, particularly in high-technology industries. The data for this period are especially problematical given that the high-technology stock market bubble probably led to overinvestment in several sectors, telecommunications in particular, and that some of the investments (such as the ominous sounding "dark fiber") turned out to be useless and have zero productivity.

A final shortcoming is that the production function includes only the return to fixed capital as a nonlabor market input. It excludes the return to other assets such as land, inventories, intangible assets (such as patents and trademarks, brand value, and marketing), and subsoil assets such as oil and gas reserves. Given the list of unrealistic assumptions that underlie the total factor productivity model, it is useful to examine techniques, such as estimation of labor productivity, that do not depend on the multitude of assumptions that underpin that model.

One can illustrate the issues involved in moving from labor productivity to total factor productivity by estimating the extent to which capital deepening was associated with the recent changes in labor productivity. For this question I looked at the relationship between output growth and the growth of labor and capital inputs over the 1977–2000 period in those twenty-nine industries included in well-measured output for which the BEA prepares net capital stock data. Pooling the data with industry and time effects along with cross-sectional equation weighting yields the following estimated equation:

$$g(X_{i,t}) = \underset{(0.049)}{0.605}\, g(L_{i,t}) - \underset{(0.085)}{0.0308}\, g(K_{i,t}) + \text{industry effects} + \text{year effects}$$

$$R^2 = 0.515;\ n = 667,$$

where $g(X_{i,t})$, $g(L_{i,t})$, and $g(K_{i,t})$ are growth of gross output, growth of hours worked, and growth of the net capital stock, respectively, for industry i in year t.

If the assumptions underlying the calculation of total factor productivity were correct, the coefficients on $g(L_{i,t})$ and $g(K_{i,t})$ should correspond to the factor shares in the different industries. Although the coefficient on labor is close to the average share of compensation for all industries, the coefficient on capital is negative. This equation indicates that the acceleration in the net capital stock made a small but insignificant *negative* contribution to the growth of gross output in these industries in the sample period. Since the average share of property-type income is around 40 percent of total output, the estimated coefficient is around four standard errors from accepting the null hypothesis that the coefficient equals the income share of capital; this indicates that, although the coefficient is not well determined, it is significantly different from the theoretical assumptions that underpin the calculation of total factor productivity.

An alternative specification defines capital inputs as proportional to the depreciation of fixed capital plus an opportunity cost of fixed capital; this specification, however, did not improve the estimates on capital growth. The coefficient on capital in this specification was very close to zero, with a standard error of the coefficient of 0.048, again significantly different from the theoretical coefficient of around 0.4. Other specifications did not come to the rescue of the standard model.

These results should not be taken too seriously, as they involve a highly oversimplified specification of the link between capital and productivity. Moreover, they do not affect the *accounting* relationship involved in total factor productivity indexes that depend basically on some identities and a host of underlying assumptions. But they should caution practitioners that the empirical relationship between the capital stock or capital services and productivity is at best weak and at worst unrelated to the model underlying typical total factor productivity calculations.

A final qualification concerns the role of business cycles in productivity growth. This issue is particularly relevant given the strong economic expansion during the 1995–2000 period. Annual growth of real GDP averaged 4.0 percent in that period, compared with 2.9 percent in the 1977–95 period. The reason for concern is that productivity growth has typically been procyclical.

I have not undertaken a systematic assessment of the cyclical effects for the industry data. Doing this would require confronting the potentially serious estimation bias due to measurement errors in output at the industry level. For example, because of data peculiarities involving indirect taxes, the gross output of the tobacco industry fell by 63 percent (in logarithmic terms) in 1999. Productivity in that year also fell sharply, by 53 percent, primarily because of the strange output numbers. Not surprisingly, therefore, there is a strong positive association of output and productivity in tobacco manufacturing.

A full investigation of the cyclical properties of productivity on an industry level is beyond the scope of this study. It is possible, however, to perform two simple tests to determine whether introducing an aggregate cyclical term in the industry productivity equations changes the pattern of productivity growth shown in the tables and figures. For the first test I estimated a productivity equation adding the growth of real GDP, as a proxy for aggregate cyclical conditions, into industry equations. The idea here is that shocks to aggregate demand will change real GDP in the short run, and these changes in real GDP will in turn affect the demand for output in different industries. This test led to the following result:

$$g(A_{i,t}) = \text{industry effects} + \underset{(0.060)}{0.093}\, g(\text{GDP}_t)$$

$$R^2 = 0.256;\ n = 667.$$

This test is not entirely satisfactory because the estimates from the pooled regressions are inverse variance-weighted averages of industry productivity growth rates rather than averages weighted by nominal output shares. The coefficient estimates will therefore not correspond exactly to the aggregate productivity estimates in the tables and figures. Moreover, there will be some residual spurious correlation between aggregate output and industry output. Nonetheless, the test is illuminating. It is clear that introducing growth of real GDP as a cyclical variable makes very little difference to average productivity growth. The coefficient on aggregate output indicates that a 1 percent increase in aggregate output would increase productivity in the average industry by only 0.09 percent. Real GDP grew at a rate of 0.80 percentage point a year faster in 1995–2000 than the average for the sample period. This indicates that the rapid growth in the 1995–2000 period raised average productivity growth by 0.072 percentage point; this compares with an acceleration of 0.44 percentage point in GDP productivity and 0.92 percentage point in GDI productivity.

An alternative approach is to use the overall unemployment rate as the cyclical variable; this approach has the advantage of completely removing any spurious measurement error that infects both aggregate and industry output. Additionally, it is particularly illuminating to the extent that movements in the unemployment rate are a good index of movements in aggregate demand. This equation yields

$$g(A_{i,t}) = \text{industry effects} + \underset{(0.084)}{0.218}\, U_t$$

$$R^2 = 0.253; n = 667.$$

Using the unemployment rate as a cyclical variable indicates that industrial productivity is *anticyclical*. Using an Okun's Law coefficient of 2, this equation indicates that growth in aggregate output by 1 percent would *decrease* productivity in the average industry by 0.1 percent.

In summary, although these tests of the cyclical impact are hardly definitive, they do suggest that, on average, cyclical forces played but a small role in the productivity upsurge in the 1995–2000 period. However, more work needs to be done at the industry level to test the role of cyclical conditions.

Conclusion

This paper has considered issues in the recent behavior of productivity and productivity growth. The major points can be summarized as follows.

First, the paper introduces a new approach to measuring industrial productivity. It develops an income-side database on output, hours worked, and labor productivity, relying on data published by the BEA. The data are internally consistent and add up to income-side GDP. The advantage of the unified income-side measures is that they present a consistent set of industrial accounts. The disadvantage is that they are available only for the period 1977–2000.

Second, the paper presents a set of labor productivity measures for four different definitions of output:

—GDP from the income side (GDI)

—The BLS's nonfarm business sector output from the income side

—A new measure called well-measured output, which includes only those sectors for which output is relatively well measured

—The "new economy."

Third, there has definitely been a rebound in productivity growth since 1995. The rebound is observed in all three broad aggregates developed for this study. The labor productivity acceleration in the last five years of the period (1995–2000) relative to the 1977–95 period was 1.12 percentage points for income-side GDP, 1.61 percentage points for the nonfarm business sector, and 1.31 percentage points for well-measured output.

Fourth, the paper explores a new technique for decomposing changes in labor productivity growth by source. This decomposition identifies a pure productivity effect (which is a fixed-weighted average of the productivity growth rates of different industries), a Baumol effect (which captures the effect of changing shares of nominal output on aggregate productivity), and a Denison effect (which captures the interaction between the differences in productivity growth and the changing hours shares of different industries over time). Total productivity growth is the sum of these three effects.

Fifth, the estimates show that the pure productivity effect in recent years has exceeded total productivity growth. For example, in the nonfarm business sector for the period 1995–2000, total labor productivity growth was 2.87 percent a year, and the pure productivity effect was 3.09 percent a year. The difference was due to a mixture of the Baumol and Denison effects. Moreover, in analyses using the data for all industries, the Baumol effect has been very close to zero over this period, indicating that composition shifts in output have had little effect on aggregate productivity growth over the last quarter century.

Sixth, a key question is the contribution of the new economy to the productivity rebound. For the purpose of this study I have defined the new economy as machinery, electric equipment, telephone and telegraph, and software. These sectors grew from 3 percent of real GDP in 1977 to 11 percent in 2000. Productivity growth in the new economy sectors has made a significant contribution to economy-wide productivity growth. In the nonfarm business sector over the last five years, labor productivity growth excluding the new economy sectors was 2.08 percent a year compared with 2.87 percent a year including the new economy.

Seventh, the major new economy contributors to the productivity rebound have been nonelectric and electric machinery, the major subsectors of which are computers and semiconductors. These two sectors, which accounted for less than 4 percent of nominal GDP, contributed 0.56 percentage point to income-side GDP productivity growth of 2.24 percent a year in the 1995–2000 period.

Finally, to what extent has there been an acceleration of productivity growth outside the new economy? According to all three output measures, there has been a substantial upturn in non–new economy productivity growth. After the new economy sectors are stripped out, the productivity acceleration from 1977 to 1989 was 0.76 percentage point for income-side GDP, 1.32 percentage points for business output, and 0.74 percentage point for well-measured output. It is clear that the productivity rebound is not narrowly focused in a few new economy sectors.

APPENDIX A

Supplemental Tables

Table A1. Value Added by Information Technology Industries, 1995 and 1998
Millions of current dollars except where stated otherwise

Industry	*SIC code*	*1995*	*1998*
Hardware			
Computers and equipment	3571,2,5,7	32,931.2	45,081.8
Computers and equipment, wholesale sales	5045 (part)	50,756.0	74,173.3
Computers and equipment, retail sales	5734 (part)	2,513.6	3,441.3
Calculating and office machines, n.e.c.[a]	3578–9	3,036.2	3,478.1
Electron tubes	3671	1,472.9	1,716.8
Printed circuit boards	3672	5,718.5	7,602.8
Semiconductors	3674	51,272.0	70,092.0
Passive electronic components	3675–9	19,097.6	29,801.9
Industrial instruments for measurement	3823	4,998.5	5,546.9
Instruments for measuring electricity	3825	7,512.3	8,399.0
Laboratory analytical instruments	3826	4,270.6	4,780.9
Total		183,579.6	254,115.0
Software and services			
Computer programming services	7371	26,178.3	n.a.[b]
Prepackaged software	7372	19,971.7	n.a.
Prepackaged software, wholesale sales	5045 (part)	2,564.0	n.a.
Prepackaged software, retail sales	5734 (part)	126.1	n.a.
Computer integrated systems design	7373	15,025.1	n.a.
Computer processing and data preparation	7374	17,924.5	n.a.
Information retrieval services	7375	3,768.5	n.a.
Computer services management	7376	2,135.2	n.a.
Computer rental and leasing	7377	1,329.0	n.a.
Computer maintenance and repair	7378	5,023.7	n.a.
Computer-related services, n.e.c.	7379	8,549.1	n.a.
Total	7371–9	102,595.2	151,999.3
Communications hardware			
Household audio and video equipment	3651	2,343.0	2,767.6
Telephone and telegraph equipment	3661	14,925.2	17,373.7
Radio and television and communications equipment	3663	19,862.0	27,854.3
Magnetic and optical recording media	3695	2,787.8	3,293.0
Total		39,918.0	51,288.0

(*continued*)

Table A1. Value Added by Information Technology Industries, 1995 and 1998 (*continued*)

Millions of current dollars except where stated otherwise

Industry	*SIC code*	*1995*	*1998*
Communications services			
Telephone and telegraph communications	481,22,99	144,100.0	163,674.4
Radio broadcasting	4832	6,149.6	8,695.8
Television broadcasting	4833	17,102.7	20,975.6
Cable and other pay television services	4841	24,247.7	31,838.3
Total		191,600.0	225,184.0
All information technologies		517,692.8	225,184.0
As a share of the economy (percent)		7.1	8.1

Source: U.S. Department of Commerce (2000).
a. Not elsewhere classified.
b. Not available.

Table A2. Shipments by Selected New Economy Industries and Changes in Output Prices, 1987–98

Units as indicated

Industry	*SIC code*	*Shipments, 1998 (millions of dollars)*	*Change in price index, 1987–98*[a] *(percent a year)*
SIC 35			
Electronic computers	3571	74,720	–17.9
Computer storage devices	3572	15,734	–7.2
Computer terminals	3575	1,180	–10.7
Computer peripheral equipment, n.e.c.	3577	31,100	–12.0
Calculating and accounting machines	3578	2,308	–1.5
Total for included industries		125,042	–14.5
Total for SIC 35		442,315	–2.3
SIC 36			
Household audio and video equipment	3651	9,882	–1.0
Phonograph records and audio	3652	2,504	–0.1
Telephone and telegraph apparatus	3661	40,080	–3.4
Printed circuit boards	3672	12,916	–2.0
Semiconductors	3674	86,189	–20.1
Electronic components, n.e.c.	3679	39,790	–1.5
Magnetic and optical recording media	3695	5,143	–1.0
Total for included industries		196,504	–7.4
Total for SIC 36		375,968	–4.2

Source: Bureau of Economic Analysis at www.bea.doc.gov/bea/dn2/gpo.htm.
a. Price indexes for totals are "mongrels" rather than true chain indexes, and they double-count because they are based on gross output rather than value-added weights.

Comments and Discussion

Robert J. Gordon: Economists were slow to recognize the post-1995 productivity growth revival in its early stages. Those of us who participated in panels on productivity issues at the January 1998 meetings of the American Economic Association recall no such recognition. Rather there was a singular focus on explaining the long, dismal period of slow productivity growth dating from 1972, especially in the context of Robert Solow's much-cited quip that "we can see the computer age everywhere except in the productivity statistics." From today's perspective it is understandable that several years had to elapse before the post-1995 revival could be distinguished from previous short-lived upward blips in productivity growth such as occurred in 1991–92.

Since 1999, however, the analysis of the post-1995 revival has become a growth industry, featuring an outpouring of analyses that attempt to quantify the sources of the revival, and especially the contribution of the "new economy," that is, of investment in information technology (IT). The paper by William Nordhaus joins a substantial literature that assesses the role of the new economy in the revival; it also provides original analyses of other aspects of the revival that have previously been ignored. I will begin by discussing Nordhaus's findings on these other issues and then turn to his controversial treatment of the new economy's contribution. Along the way I will try to reconcile Nordhaus's finding of a small new economy contribution with contrasting results in research by Steven Oliner and Daniel Sichel that the new economy *overexplains* the revival. I will conclude with the suggestion that Oliner and Sichel may have exaggerated the role of IT investment in the revival, thus leaving open some support for Nordhaus's contrary conclusion, through another line of reasoning.

Nordhaus's paper is based on what he calls a "new approach to measuring industrial productivity." This measures productivity as the ratio of real value added by industry divided by hours of labor input, with both the numerator and denominator taken from published tables in the National Income and Product Accounts (NIPA). As Nordhaus emphasizes in his concluding section, this industrial decomposition of productivity growth in the NIPA provides a measure of the income side of GDP, which is smaller than the product side of GDP by the amount of the NIPA statistical discrepancy. Since the statistical discrepancy shifted from 0.4 percent of GDP in 1995 to –1.3 percent in 2000 (that is, the income measure was smaller than the product measure in 1995 and larger in 2000), the exclusive use of income-side measures in Nordhaus's paper adds 0.34 percentage point a year to the annual growth rate of productivity during the 1995–2000 interval compared with studies based on product-side data.

Three caveats apply to his approach. First, it differs from other analyses, for example those in the 2000 and 2001 *Economic Report of the President*, which regard an average of the product-side and the income-side measures as superior to exclusive reliance on one or the other; to use only the income-side measure assumes knowledge about the sources of the statistical discrepancy that does not exist. Second, this approach is not "new." Use of NIPA data to analyze productivity behavior by industry goes back at least three decades to Nordhaus's own pioneering paper on this topic,[1] if not before, and the same data have been compiled in the same way in several recent papers.[2] Third, Nordhaus's database is limited to output and hours and contains no information on capital input by industry; so, unlike the recent paper by Jack Triplett and Barry Bosworth,[3] Nordhaus has nothing to say about the behavior of total factor productivity and particularly about the role of IT capital deepening as a source of the productivity growth revival across industries.

None of these caveats apply to Nordhaus's original and ingenious decomposition of changes in productivity growth into a pure productivity effect, a Baumol effect, and a Denison effect. This decomposition is

1. Nordhaus (1972).

2. Including Jorgenson and Stiroh (2000a), Gordon (2001), and Triplett and Bosworth (2002).

3. Triplett and Bosworth (2002).

closely related to the pioneering analysis in his 1972 paper, differing only in that the recent conversion of the NIPA from a fixed base year for deflation to a chain-weighting methodology alters the details of the earlier 1972 formulas. The new conclusion, that "composition shifts in output have had little effect on aggregate productivity over the last quarter century," differs from Nordhaus's 1972 conclusion that the productivity growth slowdown of the late 1960s and early 1970s was primarily due to a shift in the composition of output to industries with low levels of productivity. The decomposition analysis yields a pure post-1995 productivity acceleration (compared with 1977–95) that is higher than the acceleration in the raw productivity data by a mere 0.14 percentage point a year, as shown in table 4 of the paper.

Another novel contribution in the paper is the attention to Zvi Griliches's distinction between poorly measured and well-measured output.[4] Although one can quibble with how Nordhaus allocates industries across the boundary of good measurement, his analysis does represent a significant advance over Griliches's initial effort.[5] The post-1995 revival in the well-measured sectors (compared, as before, with 1977–95) is 1.31 percentage points compared with 1.61 percentage points in the total nonfarm business sector, indicating that a disproportionate share of the revival was contributed by the poorly measured sectors. The decomposition analysis yields a pure productivity acceleration for the well-measured sectors that is 0.17 percentage point higher than in the raw data, a slightly larger adjustment than for the total nonfarm business sector.

This brings us to the core of the paper and its controversial finding that the new economy was relatively unimportant as a source of the post-1995 productivity revival; that conclusion stands in diametric opposition to the recent findings of Oliner and Sichel that new economy capital *over-explains* the revival. Nordhaus's baseline result is found in his table 5. If one averages the economy's performance in the two pre-1995 periods, the post-1995 productivity growth acceleration was 1.61 percentage points

4. Griliches (1994).

5. Nordhaus classifies both retail and wholesale trade as well measured, but Gordon (2001) shows that there is substantial ambiguity in the NIPA data on output growth in these two sectors, due to an implausible discrepancy between the behavior of the value-added data used by Nordhaus and the gross output data (including intermediate inputs) also available in the NIPA. The value-added data portray a post-1995 productivity revival that is much stronger in retail and wholesale trade, and much weaker in manufacturing, than that portrayed by the gross output data.

for the nonfarm business sector and 1.33 percentage points when the new economy sectors are stripped out, for a net new economy contribution of a mere 0.28 percentage point, or only 17 percent of the total revival. When one makes the same calculation for the well-measured sectors in table 5, the new economy's contribution jumps to 38 percent (a revival of 1.31 percentage points for all well-measured sectors and only 0.81 percentage point excluding the new economy industries). This larger contribution is not surprising, since the new economy's contribution occurs entirely within the well-measured sector and contributes nothing to the more-than-proportionate revival in the poorly measured sector. Overall, then, Nordhaus concludes that the new economy has been overhyped as a source of the revival and that its true sources lie elsewhere, but where exactly remains entirely unexplained.

Why does Nordhaus's baseline finding, that the new economy sectors contributed only 17 percent of the revival, differ so much from other research? Table 1 in Daniel Sichel's comment on the paper takes us part of the way toward an answer, showing that much of the revival that Nordhaus attributes to non–new economy causes is due to capital deepening, that is, accelerating growth after 1995 in the ratio of IT capital to labor. Recall that Nordhaus has no data on capital and thus no way of providing a complete analysis of the contribution of the new economy. It is desirable to use Sichel's table to provide a comparison of the 1995–2000 period with the full 1977–95 interval, and this yields a growth acceleration of 1.53 percentage points: a contribution from IT production of 0.47 percentage point, a contribution from IT capital deepening of 0.50 percentage point, and an unexplained residual of 0.56 percentage point. Nordhaus's new economy contribution of 17 percent contrasts sharply with the Oliner-Sichel IT contribution of 63 percent.

But the contrast between Nordhaus's core finding and the most recent research of Oliner and Sichel is much starker than is apparent from Sichel's table, because Sichel has made three changes that all favor Nordhaus's conclusion. First, Sichel has used income-side data rather than the product-side data that formed the basis of the previous Oliner-Sichel research. Second, he ends the post-1995 period in 2000 rather than in 2001, the final year of the Oliner-Sichel study that he cites. Third, he bases his pre-1995 comparison on 1977–95 data, to match Nordhaus's data, rather than on 1973–95 as in the Oliner-Sichel research. When product-side data are used and the terminal year is 2001, Oliner and Sichel obtain a contribution from IT investment of 115 percent, not 63 percent.

It may help readers of both Nordhaus's paper and Sichel's comment if I provide here a concordance table that largely reconciles their results. All numbers represent percentage points of growth acceleration from 1973–95 or 1977–95 to 1995–2000 or 1995–2001. First I "peel the onion," showing how Nordhaus's large estimate of the revival is influenced by the choice of GDP concept, by revisions to the data, and by time intervals. Then I show how the new economy's contribution also changes when Oliner and Sichel's work is used instead of Nordhaus's:

	Percentage points
Nordhaus nonfarm business productivity, income side	1.61
Equivalent data from the product side (1.61 – 0.34)	1.27
Effect of August 2002 NIPA revisions on 2000 data	1.20
Switch from 2000 to 2001 as terminal year, including 2002 revisions	0.97
Switch from 1977–95 to 1973–95 as comparison period	0.84

Thus the contribution of the new economy is no longer based, as in Nordhaus's paper, on a productivity growth revival of 1.61 percentage points, but rather one of 0.84 percentage point, or little more than half Nordhaus's figure. The contribution of the new economy to productivity growth can be examined in a similar way:

	Percentage points
Nordhaus contribution of new economy sectors	0.28
Oliner-Sichel contribution of IT production (from Sichel's table)	0.47
Oliner-Sichel contribution of IT including capital deepening (from Sichel's table)	0.97
Change in comparison to 1973–95 versus 1995–2001	0.98

Clearly, there are numerous contributions to this reconciliation. If one takes the approach of the 2000 and 2001 *Economic Report of the President*, which is that the *average* of the income and product sides is a better measure than either alone, the result is to add back 0.17 percentage point (half of 0.34) to the productivity revival, boosting it from 0.84 to 1.01 percentage points. The Oliner-Sichel IT contribution of 0.98 percentage point now explains virtually all of the revival.

This summary of the differences constitutes a mini-critique of the Nordhaus paper. First, by relying only on income-side data rather than introducing an adjustment for half of the statistical discrepancy, Nordhaus overstates the productivity growth revival. Second, by relying on industry data that are currently available only through 2000, Nordhaus ignores the sharp deceleration of productivity growth in 2001 and the implication that his 1995–2000 results are artificially inflated by a cyclical effect. Third, and similarly, by relying on industry data for 2000 that have not yet been revised down to match the overall downward revisions in the NIPA announced in August 2002, Nordhaus further exaggerates the size of the revival. Fourth, and most important, by limiting his study to labor productivity and failing to take account of capital deepening, he ignores the major contribution of IT capital.

The difference between the results when 2000 and 2001 are used as terminal dates reflects my long-standing argument that productivity growth was inflated in 1998–2000 by a cyclical effect.[6] This concept of "cyclical" is not related to the dating of recessions and expansions but reflects the sluggish response of labor input to changes in output growth, which was extraordinary and unsustainable in 1998–2000. In another paper I have recently estimated that fully 0.40 percentage point of the 1995–2000 productivity acceleration was cyclical and did not represent a true "trend" or "structural" acceleration.[7] More recent work using a different technique estimates a cyclical effect for the same 1995–2000 period of almost exactly the same amount (0.44 percentage point).[8] With either technique, the sharp slowdown in both output and productivity growth between 2000 and 2001 eliminates the cyclical effect; the estimated cyclical effect for 1995–2001 is close to zero.

Stepping back from the details of the Nordhaus-Oliner-Sichel debate, one may wonder whether the upsurge in productivity growth in 2002, evident in the quarterly Bureau of Labor Statistics releases based on product-side data, shifts the weight of the conclusion toward Nordhaus.[9] Growth

6. Gordon (2000, 2001).

7. Gordon (2002).

8. The technique used in Gordon (2000, 2001) to estimate the cyclical effect was developed in Gordon (1993) and involves carrying out a grid search for the productivity growth trend that optimizes the fit of an equation relating growth in hours to growth in output. The alternative results emerge from the straightforward estimation of a Hodrick-Prescott trend to the history of the log-level of nonfarm business productivity over the 1955–2002 period.

9. Nonfarm business productivity growth was 5.0 percent in the four quarters ending in 2002:3.

of IT capital investment decelerated sharply during this period, while productivity growth was robust. The performance of productivity growth in 2002 would be the basis for optimism if it were not for the false hope created by similar behavior in the past. If one compares nonfarm business productivity growth in the first four quarters of previous recoveries with that in the subsequent eight quarters, a distinct productivity "bubble" emerges, followed by mediocre growth. The four-quarter annual rate of change followed by the eight-quarter change starting in 1975:1 is 4.63 percent followed by 0.99 percent, that starting in 1982:3 is 5.19 percent followed by 1.58 percent, and that starting in 1991:1 is 4.01 percent followed by 1.15 percent. The substantive explanation of this bubble behavior is that, in the early stages of a recovery, profits are still squeezed and business firms continue to cut labor costs aggressively, but subsequently the economic expansion leads to renewed hiring. If this happens again, productivity growth in 2002–04 will be much slower than in the past four quarters.

The debate between Nordhaus and Oliner-Sichel extends to substantive issues beyond numbers and measurement. There are two nagging reasons for doubt about the Oliner-Sichel results. First, as shown in Nordhaus's table 6, the most important contribution of any industry to the post-1995 productivity growth revival was made by retail trade. Was that really achieved entirely by the purchase of IT equipment, as the Oliner-Sichel capital deepening results would seem to imply? Second, how does one explain the failure of the leading nations of Western Europe to enjoy a productivity growth revival in the late 1990s, when casual observation suggests that Europeans are using the same computer hardware and software as Americans? Why did IT equipment and software emerge as the sole cause of the productivity growth revival in the United States even as productivity growth was slumping in Europe?

One reason to suspect that the technique of Oliner and Sichel exaggerates the role of IT capital is that they introduce the IT effect instantly, with no delay. If there is a substantial delay in the real world due to the time taken to learn how to use the new IT capital and reorganize production around it, their approach may exaggerate the contribution of IT capital deepening to the 1995–2000 revival. In years like 2001 and 2002, when IT investment has declined, there may be substantial leftover benefits from the IT boom of the late 1990s, which may support productivity growth even if IT investment remains in a slump.

Another qualification relates to the robust productivity revival recorded in the retail sector, as documented in Nordhaus's table 6. A recent finding of a study of a large set of individual retail establishments shows that *all* of retail productivity growth (not just the revival but the entire measured amount of productivity growth) in the 1990s can be attributed to more-productive new establishments displacing much less productive existing establishments.[10] The average establishment that continued in business exhibited zero productivity growth, and this despite massive investment by the retail industry in IT equipment, which presumably went to both new and old establishments, including the mom-and-pop stores that have long used bar-code scanning at checkout. In the study just cited, recent productivity growth reflects the greater efficiency of newly opened stores: the proverbial "big boxes" like Wal-Mart, Home Depot, Best Buy, Circuit City, and the new large supermarkets. The possibility that Oliner and Sichel exaggerate the role of IT capital deepening, or indeed of IT gains in total factor productivity, would imply that the residual role of non-IT total factor productivity growth is greater, supporting Nordhaus's conclusion at least to some extent.

What about the puzzle that IT boosted American productivity growth while exhibiting no such payoff in Europe? Another recent study supports the widespread impression that America accelerated while Europe fell behind.[11] The core of the U.S. success story appears to lie in the same industries highlighted in Nordhaus's table 6: retail, wholesale, and securities trading, which the study shows are the leading *users* of IT capital that contribute to Oliner and Sichel's capital deepening effect. In fact, the study shows that literally *all* of the productivity growth differential between the United States and Europe in the late 1990s came from these three industries, with retail contributing about 55 percent of the differential, wholesale 24 percent, and securities trade 20 percent.[12]

These results for Europe shed some light on the contrast between Nordhaus and Oliner-Sichel. Just as I argued above that the U.S. retailing sector has achieved efficiency gains for reasons not directly related to computers, so I can suggest in parallel that Europe has fallen back because European firms are much less free to develop the big-box retail

10. Foster, Haltiwanger, and Krizan (2002).
11. van Ark, Inklaar, and McGuckin (2002).
12. van Ark, Inklaar, and McGuckin (2002, figure 2a).

formats. Impediments include land use regulations that prevent the carving out of new greenfield sites for big-box stores in suburban and exurban locations, shop-closing regulations that restrict the revenue potential of new investments, congestion in central-city locations that are near the nodes of Europe's extensive urban public transit systems, and restrictive labor rules that limit flexibility in organizing the workplace and make it expensive to hire and fire workers with the near-total freedom to which U.S. firms are accustomed.

In conclusion, it is clear that Nordhaus has overstated the magnitude of the post-1995 productivity growth revival, because of the many factors quantified above: the use of only income-side output measures in preference to a mix of income- and product-side measures, a data-driven choice of initial and terminal years that exaggerates the magnitude of the revival, an inability to take account of the most recent data revisions, and a failure to take any account of the most important aspect of new economy capital investment, namely, capital deepening. Yet the contrasting results of Oliner and Sichel may overstate *their* conclusion that, for a time ending in 2001, IT investment explains *all* of the post-1995 productivity growth revival. Recent microeconomic evidence on retail productivity suggests strongly that IT investment was a sideshow, perhaps necessary but not sufficient for the retail productivity explosion. Finally, the failure of Europe to enjoy a revival, even as its firms invested heavily in the same computer hardware and software as did their U.S. counterparts, suggests that the productivity gap across the Atlantic originates in something other than new economy investment. To understand the transatlantic gap, and indeed to make progress in trying to forecast whether future U.S. productivity growth will more closely resemble that of 1995–2001 or that of 1973–95, we need to move beyond the macroeconomic framework of the Nordhaus paper and much of the closely related recent research.

Daniel E. Sichel: William Nordhaus starts his paper by asking, rhetorically, why we need another paper on the new economy now, given the collapse of the technology sector and the bursting of the NASDAQ bubble. Indeed, analysts at Goldman Sachs recently started an issue of a newsletter with the headline "New Economy, Rest In Peace: It Was Fun While It Lasted."[1] However, given the uncertainty engendered by recent

1. Goldman Sachs (2002).

developments about the underlying pace of productivity growth, now is an especially appropriate time to take a fresh look at what accounted for the productivity revival in the mid-1990s. The Nordhaus paper does this in a careful and thoughtful way.

For the most part, I agree with the paper's conclusions and I like the style of the analysis. The decomposition of labor productivity growth in a chain-weighted world into a pure productivity effect, a Baumol effect, and a Denison effect is useful and insightful. Where I would interpret the numbers differently relates mainly to the extent to which the rebound in productivity growth is linked to information technology (IT). I will start with that issue, comment on some measurement issues raised by the paper, and then offer a few words about the big question on everyone's mind: how much of the productivity resurgence might be sustainable?

THE ROLE OF IT CAPITAL DEEPENING IN THE PRODUCTIVITY REVIVAL. Nordhaus's paper focuses on labor productivity and a decomposition of its growth by industry. As the section on "Qualifications" clearly notes, he explicitly chooses not to take account of the role of capital deepening. Although Nordhaus argues that the numbers on capital deepening are potentially problematic, I believe that taking account of capital deepening as best one can would give a clearer picture of the role played by IT in the productivity resurgence.

Table 1 below shows the results of Nordhaus's decomposition of labor productivity growth. According to his numbers for the nonfarm business sector, labor productivity increased at an average pace of 1.3 percent a year from 1989 to 1995 (first line of the table). This rate increased to 2.8 percent a year from 1995 to 2000, implying a step-up of 1.5 percentage points over the 1989–95 period.[2] (These figures are based on income-side data. Product-side figures are discussed below.) Using data on output by industry from the Bureau of Economic Analysis, Nordhaus essentially defines the new economy as those industries that produce new economy products. These include industrial machinery and equipment (which produces computer hardware), electronic and other electric equipment (which produces communications equipment and semiconductors), tele-

2. The step-up in productivity growth is smaller when data for 2001 are included. According to an unpublished update of Oliner and Sichel (2002), labor productivity growth—measured on the income side to maintain comparability with Nordhaus's figures—picked up about 1 percentage point when figures for 2001 are included.

Table 1. Contributors to Labor Productivity Growth in the Nonfarm Business Sector, 1978–2000[a]

Percentage points a year except where noted otherwise

Item	*1978–89*	*1989–95*	*1995–2000*	*Change from 1989-95 to 1995–2000*
Nordhaus decomposition				
Labor productivity growth (percent a year[b])	1.3	1.3	2.8	1.5
Contribution of:				
New economy industries[c]	0.5	0.5	0.8	0.3
Other	0.8	0.8	2.0	1.2
Oliner-Sichel decomposition				
Labor productivity growth (percent a year[b])	1.3	1.5	2.9	1.4
Contribution of:				
IT production	0.3	0.4	0.8	0.4
IT capital deepening	0.5	0.5	1.0	0.5
Other	0.5	0.6	1.1	0.5

Sources: Nordhaus, this volume; Oliner and Sichel (2002).

a. Both decompositions are based on income-side data.

b. Measured as the annual log difference for the indicated years, multiplied by 100.

c. Includes only the contribution from the production of goods by new economy industries, not the use of those goods in other industries.

phone and telegraph (which provides telecommunications services), and software. This new economy classification focuses primarily on the companies involved in the *production* of IT, but says little about the companies and industries that *use* IT. According to Nordhaus's definition, the contribution to productivity growth from new economy industries stepped up from an average of 0.5 percentage point a year during 1989–95 to 0.8 percentage point a year during 1995–2000 (second line of table 1). Thus, according to this classification scheme, the new economy accounted for 0.3 percentage point of the 1.5-percentage-point improvement in labor productivity growth in the mid-1990s. Nordhaus's interpretation of these numbers is that the new economy made a noticeable contribution to the resurgence in productivity growth after 1995, but that the bulk of the improvement in labor productivity growth owed to developments elsewhere in the economy.

In contrast, I believe that, to assess the role of IT on labor productivity growth, it is essential to consider the use of IT as well as its production.

Several authors have done this;[3] here I will draw on a recent study by Stephen Oliner and myself.[4] As the fifth line of table 1 shows, the Oliner-Sichel decomposition indicates that the *production* of IT contributed 0.4 percentage point to the step-up in labor productivity growth in the second half of the 1990s, a figure quite similar to Nordhaus's for the contribution of new economy industries to the pickup. The figures for the contribution of IT capital deepening (sixth line of the table) capture the impact on labor productivity growth of greater *use* of IT throughout all sectors. Under standard neoclassical assumptions, these numbers show the effect on labor productivity growth of rising amounts of IT capital available per worker-hour; that is, the growing use of IT. As shown, Oliner and Sichel report that IT capital deepening accounted for 0.5 percentage point of the pickup in labor productivity growth.

By these numbers, the use of IT was even more important to the productivity revival than was the production of IT. In this sense, Nordhaus's argument that much of the pickup in labor productivity growth occurred outside the new economy could mislead the casual reader. It is true that the industries he identifies as part of the new economy accounted for a relatively modest portion of the improvement in productivity growth, but the goods produced by those industries were very important contributors to productivity growth in the industries in which they were used. Indeed, of the 1.4-percentage-point pickup in labor productivity growth through 2000 identified by Oliner and Sichel, the use and the production of IT together accounted for nearly two-thirds.[5] Thus, once IT capital is accounted for, it appears that IT played a central role in the mid-1990s resurgence of labor productivity growth. This view contrasts with Nordhaus's narrower interpretation of the impact of the new economy.

In the "Qualifications" section of the paper, Nordhaus discusses the reasons behind his choice to explicitly exclude the role of capital deep-

3. They include Jorgenson and Stiroh (2000a), Jorgenson, Ho, and Stiroh (2002), and Oliner and Sichel (2000, 2002).

4. Oliner and Sichel (2002); that study presents product-side figures extending through 2001. The numbers presented in this comment are for the period ending in 2000 and are income-side numbers to ensure comparability with Nordhaus's. In addition, the numbers presented here incorporate the 2002 annual revision of the National Income and Product Accounts, which the numbers in the published version of Oliner and Sichel (2002) do not.

5. Jorgenson, Ho, and Stiroh (2002) and Stiroh (forthcoming) also show that, taken together, the use and production of IT account for a significant portion of the pickup in labor productivity growth after 1995.

ening (and therefore the use of IT) from his analysis. He highlights potential problems with measures of capital and suggests reasons to doubt the validity of the neoclassical assumptions that underlie conventional growth accounting. I would grant him some of the points raised here, but not all.[6] Wherever one comes down in that debate, the key question is how to paint the most accurate picture one can of the impact of new economy developments. Is it more useful to focus just on the contribution of the production of IT alone because that piece is, arguably, better measured? Or is it more useful to focus on the contribution of both the production and the use of IT, despite the long-standing challenges of correctly measuring capital? I believe that a clearer picture of the impact of IT on productivity growth emerges from evaluating the impact of both its production and its use.[7]

OTHER MATTERS. A few other measurement issues bear emphasis. First, as the paper explains clearly, the data on output by industry used in the paper are income-side measures, in contrast to the product-side measures that have been used in some aggregate growth accounting studies.[8] Although income-side and product-side measures of real output have typically shown similar patterns of growth—they did so in the first half of the 1990s, for example—during the late 1990s the income-side measure of real output increased noticeably more rapidly than the product-side measure. In terms of the Oliner-Sichel decomposition, during 1995–2000 the product-side measure increased at an average annual rate of 2.5 percent, implying a 1-percentage-point improvement in the pace of labor productivity growth, compared with the 1.4-percentage-point pickup in the income-side measure. No one knows whether the income-side or the product-side figures portray the economy more accurately. But the choice between income- and product-side data is not inconsequential for an analysis of the late 1990s.

Second, Nordhaus's decompositions use industry value-added data rather than industry gross output. There are, however, arguments for

6. Also recall that Nordhaus's measure of the output of new economy industries is less than ideal, because data limitations necessitate that industries be broadly defined and therefore include products that would not typically be associated with the new economy.

7. See Triplett and Bosworth (2002) for an industry-by-industry decomposition of labor productivity growth that breaks out the contribution of IT capital deepening within services industries.

8. Such as Jorgenson, Ho, and Stiroh (2002) and Oliner and Sichel (2002).

preferring a decomposition that uses industry gross output. (Gross output is the total value of an industry's production, and value added is gross output less the value of the intermediate inputs purchased by that industry.) As a practical matter, gross output may be preferable because an industry actually produces gross output, not value added.[9] For example, the motor vehicle industry produces motor vehicles; it does not produce motor vehicle value added. Thus, to assess the labor productivity of an industry, it may be more natural to use the actual output that the industry produces rather than value added. In some industries the distinction between gross output and value added can be important, because intermediate inputs can be large and can move around a lot. For example, I have reported elsewhere that in the communications industry—telecommunications and radio and television broadcasting—labor productivity *decelerated* considerably on a value-added basis in the mid-1990s but *accelerated* slightly on a gross output basis.[10]

Third, Nordhaus's paper highlights an important point about data availability. Although the objective of the paper was to focus on high-technology, new economy industries, Nordhaus was forced to look at broader industry classifications than would be ideal. For example, where he would have liked to examine just the industry that produces computers, data limitations forced him instead to look at the broader industry that produces industrial machinery. And where he would have liked to study just the semiconductor industry and just the telecommunications equipment industry, data limitations forced him to look at the broader industry that produces all electronic equipment. Nordhaus does the best he can with the available data, but in my view these data limitations represent a shortcoming in our national data system. The statistical agencies are working on this, but it still is not possible to track precisely the role of IT in the economy.

WHAT MIGHT THE FUTURE HOLD? Despite my concern about the importance of considering the use of IT capital, this paper lays out a very useful framework for thinking about the sources of labor productivity growth on an industry-by-industry basis. Stepping a bit beyond what is in the paper itself, I would like to offer a few words about an important ques-

9. In terms of econometrics, Basu and Fernald (1995) argue that gross output industry data are preferable because econometric analyses based on value-added data can, in certain circumstances, lead to spurious findings.

10. Sichel (2001).

tion implicit in the paper, namely, what portion of the productivity revival might be sustainable?

Robert Gordon, the other discussant of this paper, has tended to take a relatively pessimistic view on this. He has identified several reasons why the late 1990s were a unique period, with a confluence of events that are unlikely to be repeated: the World Wide Web could only be invented once, and efforts to counter the year-2000 (Y2K) bug compressed the replacement cycle. Perhaps most important, Gordon argues that the supply of greater computing power and falling prices may not generate new demand, and he therefore urges some caution in thinking about how much of the productivity revival might be sustainable.

We really do not know the answer to this question, but there are ways to examine the issue systematically. For example, the paper I wrote with Oliner analyzed the steady-state properties of a multisector growth model, to try to put some rough bounds on what might be reasonable numbers, or "structured guesses," for sustainable labor productivity growth over the next five to ten years.[11] Compared with the very interesting work done by Bill Martin and Karl Whelan,[12] the Oliner-Sichel model beefs up the high-technology portion of the model in order to focus on the impact of developments in that sector. We do not regard this exercise as a forecasting model, but rather as a way to translate alternative views about underlying fundamentals—such as total factor productivity growth in each industry and IT output shares—into the metric of labor productivity growth. We considered both more conservative and more optimistic scenarios for key parameters and found a plausible range for sustainable growth in labor productivity between 2 and 2¾ percent a year. Even at the bottom end of the range, productivity is performing quite a bit better than its pace during the sluggish period from the early 1970s to the mid-1990s. The reason is that, despite the downturn in IT shares in 2001, those shares had moved up enough so that there would now be a bigger weight on fast-growing IT sectors.

An assessment of whether or not this story is reasonable hinges on two key issues. First, what will be the pace of technological progress in key IT sectors? Second, as this progress unfolds and semiconductor and computer prices continue to fall on a quality-adjusted basis, how much of this

11. Oliner and Sichel (2002).
12. Martin (2001); Whelan (2001).

new technology will be absorbed? Put another way, will computing power in the economy reach a saturation point, or will new applications be found as prices continue to fall?

Dale Jorgenson has said a great deal about the first question, and I do not want to pursue that further here.[13] As for the second, Bradford DeLong has offered an interesting perspective based on a historical analogy.[14] Starting from the early days of computers in the 1950s, DeLong looks back at each successive generation of computers and falling prices of computers. He starts with large mainframes, which in the early days were primarily used for military applications, the U.S. Census, or very specialized business applications. Then computers became cheaper, smaller, and faster, and the use of computers expanded into back-office calculations in insurance companies and other large firms. As time passed, computers became still cheaper, smaller, and faster, and their use expanded to allow real-time manipulation of databases such as airline reservation systems. With further miniaturization and further price cuts, a whole additional set of applications opened up as the era of desktop computing unfolded and evolved into the network and Internet era.

The key question is, will this process continue? As prices fall further and miniaturization proceeds, will there be a next generation on DeLong's list? Or have we come to the end of the diffusion of microcomputing technology through the economy? Obviously, these are hard questions, and I do not think anyone can know for sure. Having said that, I put myself in the camp of the relatively more optimistic. Historically, as miniaturization proceeded and prices fell ever lower, firms did find new ways to use that power in entirely new and unforeseen ways that enhanced efficiency. And my best guess is that that process still has a significant way to run.

General discussion: Martin Baily observed that, in his 1972 Brookings paper, Nordhaus had concluded that shift effects were more important than within-industry effects in explaining the productivity slowdown then coming into view. But, in the years that followed, within-industry effects became important. Before 1973, productivity growth was recorded in both the manufacturing and the services sectors, but productivity growth

13. Jorgenson (2001).
14. DeLong (forthcoming).

in services came to a halt after that. Available data show that only since the mid-1990s has productivity growth in the services sector revived, but data problems cloud these observations. The revival in productivity growth in the services sector coincided with the application of new price deflators to industries in that sector. It is unclear how much of the observed growth is simply due to this data improvement, and whether this improvement would be detected in earlier years if one could backcast these deflators. Baily also raised the possibility that economists working on this data improvement might have looked too eagerly for ways to detect productivity gains in the services sector.

Addressing Nordhaus's focus on labor productivity rather than total factor productivity, Baily noted that capital input is poorly measured, particularly at the individual industry level, and so total factor productivity estimates are correspondingly mismeasured. Moreover, the timing and the causal link between information technology investment and productivity growth are uncertain. In the late 1990s productivity increased at the same time that firms were adding more computers. But firms may have been adding computers because profits were high and growth was rapid.

Looking ahead, Baily noted that much of the investment in information technology may not have yet paid off. If that is the case, it promises productivity growth in the coming years from technology already purchased in the late 1990s. Gregory Mankiw observed, on the other hand, that the serial correlation of productivity growth is low, and therefore one should have little confidence that the faster productivity growth of recent years can be projected into the future. Mankiw also noted that the pickup in U.S. productivity growth in the second half of the 1990s was not mirrored in other advanced economies. This contrasted with the preceding productivity slowdown, which appeared everywhere. He wondered why this time was different and what it implied about the United States and the other countries. Robert Gordon mentioned that comparisons of European and U.S. productivity performance in the late 1990s are hampered by inconsistent data. Most of the acceleration in total factor productivity in the United States achieved by the IT industry (evident in Sichel's decomposition) is dependent on the use of a hedonic price deflator for computers and semiconductors, but some of the large European countries, such as Germany, use inaccurate deflators that show little or no price decline for IT equipment. When U.S. deflators for this equipment are substituted for the inaccurate European deflators, the growth rate of European productivity in the late 1990s is boosted by 0.2 to 0.3 percentage point a year, but this is not nearly enough to close the puzzling gap between American and European performance.

Bradford DeLong noted some unusual features of the recent record. Capital deepening has been modest in 2001 and 2002 because of the high depreciation rates for IT capital acquired at the end of the 1990s. Yet measured total factor productivity and labor productivity have continued to grow rapidly. Unlike in typical previous recoveries, when rapid productivity gains were accompanied by rapid increases in hours worked, in the current recovery strong productivity growth has coincided with a substantial fall in hours worked. DeLong concluded that we need to better understand the behavior of productivity at the beginning of an economic expansion and how it is related to Okun's Law and to the behavior of labor hours.

Baily noted that Nordhaus's decomposition of productivity growth includes a shift effect, so that labor productivity growth in the economy as a whole is augmented if employment moves from industries with low to industries with high average labor productivity. He argued that although the algebra of the calculation is correct, the interpretation can be misleading. After adjusting for differences in worker quality, average labor productivity is maximized in an economy if the marginal product of labor is equalized in all activities. (In a market economy this requires perfect competition and the equalization of quality-adjusted wages.) An efficient economy will not be one in which average labor productivities are equalized across industries, because capital intensity and technology vary by industry. The movement of workers among industries is a fundamental cause of increased aggregate labor productivity only to the extent that it increases overall efficiency, and that in turn depends on marginal productivities, not average productivities. To sustain higher average productivity, capital must move along with the labor, and the additional capital can be seen as the source of the improved aggregate labor productivity.

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