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Does the "New Economy" Measure up to the Great Inventions of the Past?

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A widespread belief seems to be emerging, at least in the popular press, that the U.S. economy is in the throes of a fundamental transformation, one which is wiping out the 1972–95 productivity slowdown, along with inflation, the budget deficit, and the business cycle. A typical recent comment, in a *Wall Street Journal* article, claimed that "when it comes to technology, even the most bearish analysts agree the microchip and Internet are changing almost everything in the economy" (Ip, 2000). Or as an article in *Fortune* (June 8, 1998, pp. 86–87) magazine put it, "The [computer] chip has transformed us at least as pervasively as the internal combustion engine or electric motor." Alan Greenspan (1999) appears to be among the technological enthusiasts. He recently stated: "A perceptible quickening in the pace at which technological innovations are applied argues for the hypothesis that the recent acceleration in labor productivity is not just a cyclical phenomenon or a statistical aberration, but reflects, at least in part, a more deep-seated, still developing, shift in our economic landscape." The true enthusiasts treat the New Economy as a fundamental industrial revolution as great or greater in importance than the concurrence of inventions, particularly electricity and the internal combustion engine, which transformed the world at the turn of the last century.

There is no dispute that the U.S. economy is awash in computer investment, that productivity has revived, and that the late 1990s were extremely good years for the U.S. economy. Indeed, Robert M. Solow has now declared obsolete his 1987 paradox that "we can see the computer age everywhere but in the productivity statistics" (Uchitelle, 2000). However, room remains for a degree of skepticism.

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Does the "New Economy" really merit treatment as a basic industrial revolution of a magnitude and importance equivalent to the great inventions of the late nineteenth and early twentieth century? These earlier changes, particularly electricity and the internal combustion engine, but also including chemicals, movies, radio, and indoor plumbing, set off 60 years between roughly 1913 and 1972 during which multifactor productivity growth was more rapid than ever before or since, and during which everyday life was transformed.

The skeptic's case begins with a close examination of the recent productivity revival. While the aggregate numbers are impressive, the productivity revival appears to have occurred primarily within the production of computer hardware, peripherals, and telecommunications equipment, with substantial spillover to the 12 percent of the economy involved in manufacturing durable goods.[1] However, in the remaining 88 percent of the economy, the New Economy's effects on productivity growth are surprisingly absent, and capital deepening has been remarkably unproductive. Moreover, it is quite plausible that the greatest benefits of computers lie a decade or more in the past, not in the future. The paper then explores some of the intrinsic limitations of the computer in general and the Internet in particular for affecting productivity and the quality of life when evaluated in comparison with the great inventions of the past.

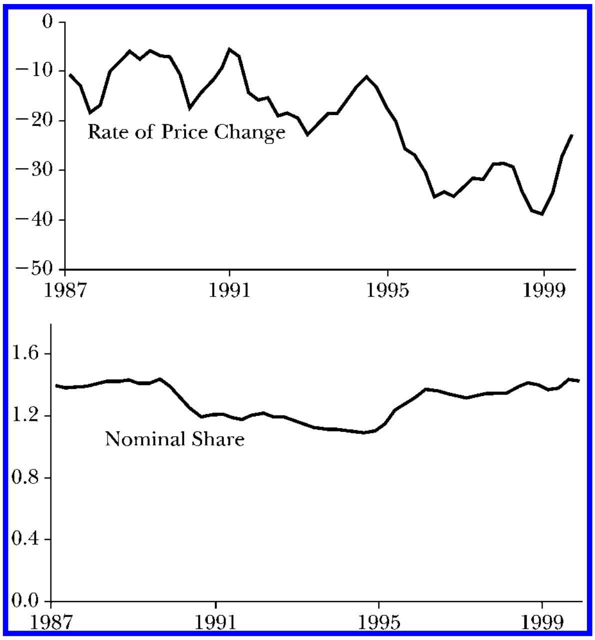
Dissecting the Revival in U.S. Productivity Growth

Since computer prices have been declining at rapid rates for the last 50 years, the phrase "New Economy" must mean that something more and different has happened in the last few years. Indeed, as shown in the top frame of Figure 1, at the end of 1995 there was an acceleration of the rate of price change in computer hardware (including peripherals) from an average rate of −14.7 percent during 1987–95 to an average rate of −31.2 percent during 1996–99. These growth rates do not mean that the prices of computers as listed on store shelves and websites literally fell by this amount. In the U.S. national accounts, computer prices since 1986 have been measured by the "hedonic" regression technique, in which the prices of a variety of models of computers are explained by the quantity of computer characteristics and by the passage of time. Thus, "decline in computer prices" actually means "a decline in the prices of computer attributes like a given level of speed, memory, disk drive access speed and capacity, presence and speed of a CD-ROM, and so on." Indeed, computers have seemed perhaps the ideal application for the hedonic regression technique since the work of Chow (1967).

One way to get a feel for the dramatic impact of this price decline is to consider the ratio of performance-to-price that is implicit in the BEA's calculations. From the fourth quarter of 1993 to the fourth quarter of 1999, the performance of a

[1] In 1996, current dollar value-added in durable manufacturing was 11.6 percent of current dollar output in the nonfarm private business sector. See *Economic Report of the President*, February 1999, Tables B-10 and B-12.

Figure 1
Final Sales of Computers and Peripherals, Four-quarter Rate of Price Change and Nominal Share in Nonfarm Nonhousing Business GDP, 1987–99



computer at a given price rose by a factor of 5.2. Improvements in performance-price ratios for individual computer components are substantially larger, by a factor of 16.2 for computer processors, 75.5 for RAM, and 176.0 for hard disk capacity.[2] The driving force behind the greater rate of price decline was an acceleration in the rate of technological progress; apparently, the time cycle of Moore's Law, which has historically held that the price of computing power falls by half every 18 months, shortened from 18 months to about 12 months at this time.[3]

Most of the discussion in this paper will follow the lead of Figure 1 by focusing on computer hardware, rather than the universe of computer hardware, software, and telecommunications equipment, because the government deflators for software and telecommunications equipment exhibit implausibly low rates of price decline (Jorgenson and Stiroh, 2000). These adjustments for the "true" price of computer performance are essential, since over the period since 1987, spending on computers stagnated at around 1.3 percent of the nonfarm private business economy, as shown in the bottom frame of Figure 1. Within the computer industry, the productivity gains involve greater amounts of computer speed and other capabilities from the same amount of total spending.

[2] See "Computers, then and now," *Consumer Reports*, May 2000, p. 10, where the published reported comparisons in 1999 dollars have been converted to nominal dollars using the Consumer Price Index.
[3] This judgement is based on a conversation between Gordon Moore and Dale W. Jorgenson, related to the author by the latter.

This acceleration in the price decline of computers since 1995 has been accompanied by a revival of productivity growth in the aggregate economy which is impressive in comparison with the American historical record dating back more than a century. Table 1 compares rates of output, input, and productivity growth achieved in the American economy during the four years 1995–99 as compared with three long earlier intervals: 1870–1913, 1913–1972, and 1972–1995.[4] The top line of the table shows the real growth rate of (nonfarm, nonhousing) output over these time periods.

Lines 2–6 show growth rates of inputs and productivity. Lines 2–3 show the growth rate of output for labor and capital, respectively. Line 4 is the growth rate of capital per hour worked. Line 5 shows the growth rate of output per hour or labor productivity, which can be calculated in the table by subtracting the growth rate of labor hours in line 2 from the growth rate of output in line 1. Line 6 is multifactor productivity growth, which is productivity growth based on a weighted average of several inputs, in this case labor and capital, with weights based on the share of each input in total income. The growth in output per hour (line 5) can be split up into multifactor productivity growth (line 6) and the contribution of capital deepening, which in turn is the growth in capital per hour (line 4) multiplied by capital's share of income, which is roughly one-third. Thus, the growth rate of output per hour minus one-third the growth rate of capital per hour equals multifactor productivity.[5]

Lines 6–9 repeat this exercise, but are based on alternative input concepts which are adjusted for changes in composition of the inputs. For example, the growth in labor input is adjusted for changes in the dimensions of age, sex, and educational attainment. The shift in capital input is adjusted for the change in capital spending from structures to equipment, and from longer-lived equipment

[4] The record compiled for 1870–1996 in Table 1 is based on Gordon (2000b), which merges data from Kendrick (1961) with BEA and BLS data for the postwar period and develops estimates for labor and capital composition to carry the postwar BLS composition adjustments back from 1948 to 1870.

[5] The concepts can be related by considering a production function:

$$y = m + bh + (1 - b)k,$$

where y is the growth rate of output, m is the growth rate of multifactor productivity growth, b is the elasticity of output with respect to labor input, h is the growth rate of labor input, $1 - b$ is the elasticity of output with respect to capital input (implicity invoking constant returns to scale), and k is the growth rate of capital input. Thus, output growth is the sum of productivity growth and of the separate contributions of labor and capital input, weighted by the elasticity of output growth to each input. Now rewrite the equation as

$$y - h = m + (1 - b)(k - h).$$

Growth in output per hour $(y - h)$ is now equal to growth in multifactor productivity plus the contribution of "capital deepening," which is the elasticity of output with respect to capital $(1 - b)$ times the growth rate of the capital-labor ratio $(k - h)$.

Table 1
Growth Rates of Output, Inputs, and Multifactor Productivity, Selected Intervals, 1870–1999

	1870–1913	*1913–1972*	*1972–1995*	*1995–1999*
1. Output (y)	4.42	3.14	2.75	4.90
Without Composition Adjustment to Inputs				
2. Labor Hours (h)	3.24	1.28	1.71	2.25
3. Capital (k)	4.16	2.07	2.98	4.87
4. Capital per Hour (k-h)	0.92	0.79	1.27	2.62
5. Output per Hour (y-h)	1.18	1.86	1.04	2.65
6. Multifactor productivity growth (m)	0.77	1.60	0.62	1.79
With Composition Adjustment to Inputs				
7. Labor Hours (h)	3.73	1.72	2.09	2.71
8. Capital (k)	4.22	2.76	4.04	5.58
9. Capital per hour (k-h)	0.49	1.04	1.95	2.87
10. Output per Hour (y-n)	0.69	1.42	0.66	2.19
11. Multifactor productivity growth (m)	0.47	1.08	0.02	1.25

Sources: 1870–1995. Lines 1–6 from Gordon (2000b), Table 1. Lines 7–11 from Gordon (2000b), Table 6. 1995–1999. All data are taken from Oliner and Sichel (2000) and are transformed as follows. Output (line 1): Table 1, line 1. Labor hours (line 2): Table 1, line 7, divided by 0.67, the implicit share of labor. Capital (line 3): Composition-adjusted capital (see below for source of line 7) minus 0.71, which is the difference between the growth of capital services and capital stock in Jorgenson and Stiroh (2000, Tables 1 and 2, column 1). MFP (line 6): Output growth minus input growth, using weights of 0.67 and 0.33 on labor and capital, respectively. Labor hours (line 7): Table 1, line 7 plus line 8, divided by 0.67, the implicit share of labor. Capital (line 8): Table 1, line 2 plus line 6, divided by 0.33, the implicit share of capital. MFP (line 11): Table 2, line 9.

like railroad locomotives to shorter-lived equipment like computers.[6] These composition-adjusted estimates should be viewed as the preferred measures of the growth rates of labor and capital input. However, the estimates in lines 2–6 that exclude the composition adjustments are useful for comparability with other unadjusted quarterly data, some of which will be explored later in this paper.

In past writing, I have pointed to the historical patterns summarized through 1995 in the first three columns and have suggested that the basic question about historical productivity growth should not be "Why was growth was so slow after 1972?" but rather "Why was growth was so fast during the golden years 1913–72?" I have attributed the outstanding performance of the golden years to the role of the great inventions of the late nineteenth and early twentieth century mentioned in the introduction and discussed further below.

Upon first examination, the data for 1995–99 are consistent with the beginning of a new golden age of productivity growth. Either with or without composition

[6] Likewise, housing is excluded to retain comparability with Table 2 below. Adjustments for labor composition were pioneered by Griliches (1960) and Denison (1962), and for capital composition by Jorgenson and Griliches (1967). Similar adjustments are incorporated in the official BLS series on multifactor productivity that currently covers 1948–97, and detailed annual data are available through 1998 in Jorgenson and Stiroh (2000).

adjustments, multifactor productivity growth during 1995–99 exceeded that in the golden age from 1913–1972. Capital deepening during 1995–99 proceeded at an extraordinary rate. The overall acceleration in output per hour, combining multifactor productivity growth and the impact of capital deepening, is more than a full percentage point per year when 1995–99 is compared to the 1972–95 slowdown period.

This performance is undeniably impressive. Yet there are two skeptical questions to be raised. First, when examined closely, it turns out that a major fraction of the revival in multifactor productivity growth has occurred within the part of the economy engaged in producing computers and peripherals, and within the rest of the durable manufacturing sector, which together comprise only about 12 percent of the private business economy. This raises the question of how far the New Economy actually reaches into the remaining 88 percent of economic activity. Second, the period from 1995 to 1999 is much shorter than the earlier three time periods and during at least part of that time, it seemed clear even to many of the New Economy optimists that output growth was running at a faster pace than the sustainable long-term growth trend. The idea that productivity varies procyclically dates back to Hultgren (1960) and "Okun's Law" (Okun, 1962) and was first interpreted by Oi (1962), who described labor as a "quasi-fixed factor" that adjusts only partially during cyclical swings of output. If output was growing faster than trend, then productivity was also growing faster than trend, and some part of the productivity revival recorded in Table 1 was transitory rather than permanent.

My recent research on the cyclical analysis of labor productivity in Gordon (2000c) updates the earlier results of Gordon (1993). In my econometric specification, the change in the growth of actual hours relative to the hours trend is explained by changes in its own lagged values and by changes in the growth of output relative to trend. Hours growth lags behind output growth and responds by roughly 0.75 of the output change; thus growth in output per hour exhibits a temporary acceleration when hours are lagging behind output changes, and in addition increases by roughly 0.25 of any excess in output growth relative to trend.[7]

Several decompositions between trend and cyclical productivity growth are displayed in Table 2. The first column refers to the aggregate economy, which in this case means the nonfarm private business sector including computers. Of the actual 2.75 percent annual growth of output per hour between 1995:Q4 and 1999:Q4, 0.50 percentage point are attributed to a cyclical effect and the remaining 2.25 points to trend growth. This is 0.83 points faster than the 1972–95 trend, as shown in lines 4 and 5. How can this acceleration be explained? A small part on

[7] I set the hours trend at a rate consistent with a nonaccelerating inflation rate of unemployment (NAIRU) in the fourth quarter of 1999 of 5.0 percent. Moreover, it is assumed that actual and trend output were equal in the later stages of upswings in 1954:Q1, 1963:Q3, 1972:Q2, 1978:Q2, 1987:Q3 and 1995:Q4. The task is to determine the optimal output trend after 1995:Q4. The decomposition of the recent productivity acceleration between cycle and trend is accomplished by specifying a value for the hours growth trend and then conducting a grid search to find the output growth trend that optimizes the fit of the equation. The regression equation is estimated for the period 1954:Q1–1999:Q4, and the growth in trend output is varied to minimize the root-mean-squared error over 1996:Q1–1999:Q4.

Table 2
Decomposition of Growth in Output Per Hour, 1995:4–1999:4, into Contributions of Cyclical Effects and Structural Change in Trend Growth
(*percentage growth rates at annual rate*)

	Nonfarm Private Business	*NFPB Excluding Computer Hardware Manufacturing*	*NFPB Excluding Durable Manufacturing*
1. Actual Growth	2.75	2.30	1.99
2. Contribution of Cyclical Effect	0.50	0.51	0.63
3. Growth in Trend (line 1–line 2)	2.25	1.79	1.36
4. Trend, 1972:2–1995:4	1.42	1.18	1.13
5. Acceleration of Trend (line 3–line 4)	0.83	0.61	0.23
6. Contribution of Price Measurement	0.14	0.14	0.14
7. Contribution of Labor Quality	0.05	0.05	0.05
8. Structural Acceleration in Labor Productivity (line 5–line 6)	0.64	0.42	0.04
9. Contribution of Capital Deepening	0.33	0.33	0.33
10. Contribution of MFP Growth in Computer and Computer-Related Semiconductor Manufacturing	0.29	0.19	—
11. Structural Acceleration in MFP (line 7–lines 8 through 10)	0.02	−0.10	−0.29

Sources and notes: Actual and trend growth and contribution of price measurement (lines 1–6): Gordon (2000c), Tables 1 and 2. Lines 6, 9, and 10 are from Oliner and Sichel (2000), in each case comparing their growth rates for 1995–99 with a weighted average of 1973–90 and 1990–95. The table and line sources from Oliner and Sichel are as follows: Labor quality (line 7): Table 2, line 8. Capital deepening (line 9): Table 2, line 2. MFP growth in computers and computer-related semiconductors (line 10): Table 4, line 5. Comparing Table 4, lines 2 and 5, of the total effect of 0.29, 0.10 is due to computers (and hence is omitted from column 2 in our Table 2) and the remaining 0.19 is due to computer-related semiconductor manufacture.

lines 6 and 7 is attributed to changes in price measurement methods and to a slight acceleration in the growth of labor quality.[8] The remaining 0.64 points can be directly attributed to computers. The capital-deepening effect of faster growth in capital relative to labor in the aggregate economy accounts for 0.33 percentage points of the acceleration (all due to computers), and an acceleration of multifac-

[8] The price measurement effect consists of two components. While most changes in price measurement methods in the CPI have been backcast in the national accounts to 1978, one remaining change—the 1993–94 shift in medical care deflation from the CPI to the slower-growing PPI—creates a measurement discontinuity of 0.09 percent. The fact that other measurement changes were carried back to 1978 rather than 1972 creates a further discontinuity of 0.05 when the full 1972–95 period is compared to 1995–99. The acceleration in labor quality growth is taken from Oliner and Sichel (2000, Table 2) and reflects the same compositional changes discussed in connection with Table 1 above; labor quality growth during 1972–95 was held down by a compositional shift toward female and teenage workers during the first half of that period.

tor productivity growth in computer and computer-related semiconductor manufacturing account for almost all of the rest.[9]

A different way of assessing the role of computers is displayed in the second column of Table 2. Here we carry out the same set of calculations, but in this case we subtract output and hours in computer hardware manufacturing (but not computer-related semiconductor manufacturing) from the nonfarm private business economy. In this calculation, the structural acceleration of labor productivity on line 8 is 0.42 percentage points, compared to 0.64 for the first column. Again, the impact of capital deepening has created a genuine revival in growth in output per hour in the non-computer economy, and the contribution of the computer sector is reduced. But in either case, spillover effects on multifactor productivity in the noncomputer economy are absent (column 1) or slightly negative (column 2).

The third column of Table 2 carries out these calculations yet again, but this time excludes all durable goods manufacturing from hours worked and output. The starting growth rate in the first line is a much lower 1.99 percent. A slightly larger cyclical effect is subtracted, leaving an acceleration in trend on line 5 of only 0.23 percent. The cyclical effect is slightly larger here because between 1995 and 1999, there is no increase in the capacity utilization rate in manufacturing nor any acceleration in hours of growth in manufacturing. The cyclical effects in the economy over this time occur entirely outside of manufacturing, which accounts for the higher cyclical effect in this column. Almost all of the acceleration in productivity trend can be explained by price measurement and labor quality, leaving a structural acceleration in output per hour growth of only 0.04 percent. As a result, after taking capital deepening into account, line 11 shows a *substantial structural deceleration* in multifactor productivity growth in the economy outside of the durable goods manufacturing sector.

From the fourth quarter of 1995 to the fourth quarter of 1999, the annual growth of output per hour was 1.33 percentage points faster than from 1972:Q2 to 1995:Q4 (as shown in Table 2, column 1, lines 1 and 4). The analysis here argues that .50 percentage points of that increase is a cyclical effect (column 1, line 2); .19 points of that increase results from changes in measurement of prices and labor quality; .33 points is the capital deepening from greater investment in computers; .29 points is the acceleration of multifactor productivity growth in manufacturing computers; .27 points is the acceleration in multifactor productivity growth in manufacturing other types of durable goods; and −.29 percent is a *deceleration* in trend productivity growth in the economy outside of durable goods manufacturing.

How credible is this decomposition? It depends on the accuracy of the cyclical adjustment; it would take a reduction in the cyclical effect in the right-hand column of Table 2 by .29 points (from .63 to .34) to eliminate the basic conclusion that trend productivity growth outside of durables has decelerated. Yet a cyclical effect

[9] In the Oliner-Sichel decomposition on which line 9 is based, computers account for all of the acceleration in the capital-deepening effect, and the additional acceleration attributable to semiconductors and telecommunications is exactly canceled out by a *deceleration* of capital deepening for all other types of equipment and structures (Oliner and Sichel, 2000, Table 2, lines 2 through 7).

of the magnitude estimated here is not unprecedented or unusual. Labor hiring always lags behind surges in output, and we would expect productivity to exhibit temporary growth in response to the astonishing 7.3 percent growth rate of nonfarm business output in the last half of 1999. At the end of 1999 the level of nonfarm business output per hour was 2.0 percent above trend, a smaller cyclical deviation than occurred in 1966, 1973, and 1992.[10]

These results imply that computer investment has had a near-zero rate of return outside of durable manufacturing. This is surprising, because 76.6 percent of all computers are used in the industries of wholesale and retail trade, finance, insurance, real estate, and other services, while just 11.9 percent of computers are used in five computer-intensive industries within manufacturing, and only 11.5 percent in the rest of the economy (McGuckin and Stiroh, 1998, Table 1, p. 42). Thus, three-quarters of all computer investment has been in industries with no perceptible trend increase in productivity. In this sense the Solow computer paradox survives intact for most of the economy, and the need to explain it motivates the rest of this paper.

How the Great Inventions Helped Us Escape from the Bad Old Days

The First Industrial Revolution began largely in Britain and extended from about 1760 to 1830. But despite the list of innovations of this time period—the steam engine, the power loom, and so on—multifactor productivity grew at a snail's pace in the nineteenth century. As Brad De Long (2000) has observed: "Compared to the pace of economic growth in the 20th century, all other centuries—even the 19th . . . —were standing still."[11] The Second Industrial Revolution took place simultaneously in Europe and the United States and can be dated roughly 1860 to 1900. This is the revolution of electricity, the internal combustion engine, and so on, and it led to the golden age of productivity growth from 1913 to 1972.

The question at hand is whether the role of the computer and Internet are likely to constitute a Third Industrial Revolution, with lasting productivity gains comparable to the second one. One might object that this comparison does not include the entirety of technological advance of the 1990s; for example, a broader perspective that included biology, pharmaceuticals, and medical technology might lead to a more sympathetic comparison of recent progress with the Second Industrial Revolution. But in common discourse, the New Economy is certainly more about computers than pharmaceuticals. Moreover, if one starts down the road of comparing changes in life expectancy, the yearly rate of increase in life expectancy at birth during 1900–50, resulting in substantial part from the inventions of the

[10] Compared to the 2.0 percent ratio in 1999:Q4, larger log ratios of actual to trend productivity in the nonfarm business sector occurred in 1966:Q1 (3.0 percent), 1973:Q1 (2.3 percent), and 1992:Q4 (2.2 percent).

[11] Quoted in "A Century of Progress," *Economist*, April 15, 2000, p. 86.

Second Industrial Revolution, was 0.72 percent per year, *triple* the 0.24 percent annual rate during 1950–95 (Nordhaus, 1999, Figure 3). Thus, it seems unlikely that taking gains in life expectancy into account will elevate the possible Third Industrial Revolution relative to the second one.

Life in the "Bad Old Days"

To understand the profound sense in which the great inventions of the Second Industrial Revolution altered the standard of living of the average American resident, we begin with a brief tour of some of the less desirable aspects of living in the late nineteenth century. An eye-opening introduction to the conditions of that era is provided in a little-known book by Otto Bettman (1974), the founder of the famed Bettman photographic archive, and I paraphrase and quote from that book in the next four paragraphs.

The urban streets of the 1870s and 1880s were full not just of horses but pigs, which were tolerated because they ate garbage. In Kansas City, the stench of patrolling hogs was so penetrating that Oscar Wilde observed, "They made granite eyes weep." The increasing production of animal waste caused pessimistic observers to fear that American cities would disappear like Pompeii—but not under ashes. Added to that was acrid industrial smog, sidewalks piled high with kitchen slops, coal dust, and dumped merchandise, which became a liquid slime after a rain. All of this was made worse in the summer, which was almost as unbearable outdoors as inside, especially with the heavy clothes of the day. Rudyard Kipling said of Chicago, "Having seen it, I desire urgently never to see it again. Its air is dirt." Added to putrid air was the danger of spoiled food—imagine meat and poultry hung unrefrigerated for days, spoiled fruit, bacteria-infected milk, and so on. Epidemics included yellow fever, scarlet fever, and smallpox. Many hospitals were deathtraps.

Before the invention of electricity, urban streets were a chaotic jungle of horse-drawn conveyances of all types, made even more congested in winter by horse-drawn snowplows that did little more than move the snow out of the way of the trolleys by dumping it on the sidewalks. Rural life was marked by isolation, loneliness, and the drudgery of fireplace cooking and laundry done by muscle-power. Travel between cities on railroads was surprisingly dangerous; in 1890, railroad-connected accidents caused 10,000 deaths.

In 1882, only 2 percent of New York City's houses had water connections. Urban apartments were crowded, damp, airless, and often firetraps. Even middle-class apartment buildings were little more than glorified tenements. In the slums as many as eight persons shared a single small room.

Coal miners, steel workers, and many others worked 60-hour weeks in dirty and dangerous conditions, exposed to suffocating gas and smoke. Danger was not confined to mines or mills; in 1890 one railroad employee was killed for every 300 employed. Sewing in a sweatshop might have been the most oppressive occupation for women, but was not as dangerous as soap-packing plants or the manual stripping of tobacco leaves.

The Great Inventions

Into this world of the late nineteenth and early twentieth century came a set of great inventions which can be usefully grouped into five "clusters." Each of these clusters had a primary breakthrough invention that occurred during the period 1860–1900. For specific chronologies of these inventions as they developed, see Bunch and Hellemans (1993) or the website of the "Greatest Engineering Achievements of the 20th Century" recently released by the National Academic of Engineering at ⟨http://www.greatachievements.org⟩.

The first great invention in the "Group of Five" is electricity, including both electric light and electric motors. In the opening decades of the twentieth century, electric motors revolutionized manufacturing by decentralizing the source of power and making possible flexible and portable tools and machines. After a somewhat longer lag, electric motors embodied in consumer appliances eliminated the greatest source of drudgery of all, manual laundry; refrigeration virtually eliminated food spoilage; and air conditioning made summers enjoyable and opened the southern United States for modern economic development (David, 1990).[12]

Sharing the title with electricity for the most important invention that had its main diffusion in the twentieth century is the internal combustion engine, which made possible personal autos, motor transport, and air transport. Grouped in this category are such derivative inventions as the suburb, highway, and supermarket. Gradually eliminated or greatly reduced were many of the ills of the late nineteenth century, from manure to unplowed snow to rural isolation.

The third group of great inventions includes petroleum, natural gas, and various processes which "rearrange molecules," including chemicals, plastics, and pharmaceuticals. Some of these inventions were spontaneous and others were induced by the demands of motor and air transport. They helped to reduce air pollution created by industrial and heating uses of coal, and they made possible many new and improved materials and products, as well as conquering illness and prolonging life.

The fourth cluster consists of the complex of entertainment, communication, and information innovations. This set of inventions that made the world smaller can be traced back to the telegraph (1844) and includes the telephone (1876), phonograph (1877), popular photography (1880s and 1890s), radio (1899), motion pictures (1881 to 1888), and television (1911). Television is the only one of these innovations that was diffused into the popular marketplace after World War II.

Perhaps the most tangible improvement in the everyday standard of living, besides electric light, came through the rapid spread after 1880 of running water, indoor plumbing, and urban sanitation infrastructure. Mokyr and Stein (1997, p. 146) credit Louis Pasteur's germ theory of disease for the great decline in mortality in the four decades prior to World War I, long before the invention of

[12] See Oi (1997) for an insightful analysis of the effect of air conditioning on productivity.

antibiotics, although in part the development of indoor plumbing was independent of the germ theory and dates to the invention of the indoor flush toilet.

These five clusters of inventions, in turn, created an increase in per capita income and wealth during the golden years of productivity growth from 1913–72 that allowed an improvement in living standards even in those aspects of consumption where inventions did not play a major role, particularly the ability of families to afford many more square feet of shelter (and in the suburbs more land surrounding that shelter) than in 1880.

Will the information revolution spawned by the computer create as great a change in living conditions as the major inventions of the late nineteenth and early twentieth century? At an intuitive level, it seems unlikely. For instance, we might gather together a group of Houston residents and ask: "If you could choose only one of the following two inventions, air conditioning or the Internet, which would you choose?" Or we might ask a group of Minneapolis residents, "If you could choose only one of the following two inventions, indoor plumbing or the Internet, which would you choose?" But there are deeper reasons, rooted in basic principles of economics like diminishing returns, as to why, half a century from now, it is unlikely that historians and economists will look back at the present surge in computer investment as the harbinger of a Third Industrial Revolution.

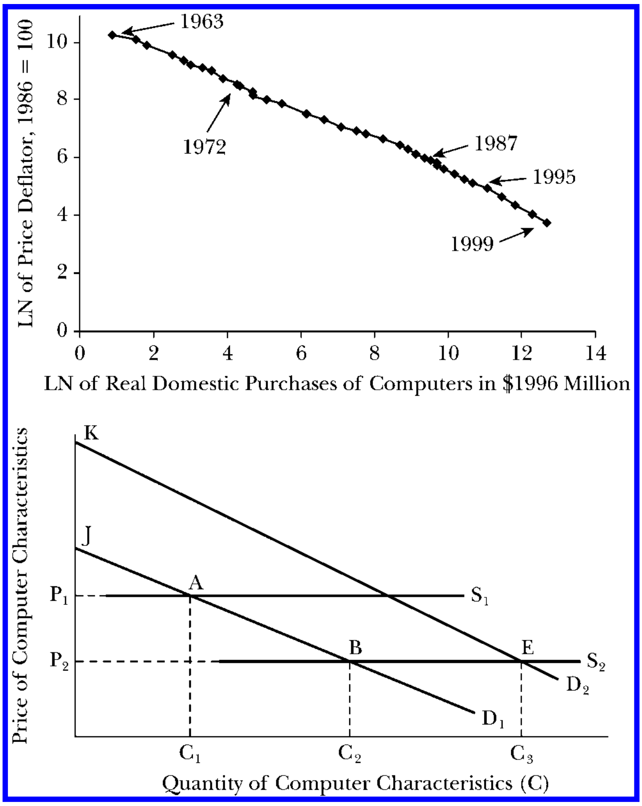
The Declining Cost of Computer Power and the Pervasiveness of Diminishing Returns

There are a number of differences between the computer and the great inventions of the Second Industrial Revolution, but perhaps the largest difference is the unprecedented rate of decline in the price of computer power. Although the price decline of computing power has accelerated from 1995–99 as opposed to the period from 1987–94, as shown earlier in Figure 1, over the last five decades these rapid rates of price decline are standard. The rate of price change has varied over time, but rapid price declines also occurred during the 1950–80 interval dominated by the mainframe computer and the 1980–95 interval dominated by the transition from mainframe to personal computer applications prior to the invention of the Internet. Indeed, existing computer price deflators fail to take account of the radical decline in the price per calculation that occurred in the transition from mainframes to personal computers, which have been studied only separately, not together. Gordon (1990, p. 239) calculates that the annual rate of price decline between 1972 and 1987 would have been 35 percent per annum, rather than 20 percent per annum, if this transitional benefit had been taken into account. From this perspective, the technological advance created by the New Economy of the last five years may be less significant than it at first appears.

The top frame of Figure 2 shows the implicit price deflator for computers on the vertical axis, and real expenditures for computers and peripherals on the

Figure 2

Real Gross Domestic Purchases of Computers and Peripherals and its Price Deflator, 1963–99



Source: Unpublished series provided by Christian Ehemann of the Bureau of Economic Analysis.

horizontal axis.[13] This set of points of price and quantity for given years has an intuitive supply and demand interpretation: there has been an outward shift of the supply curve for computers, driven by technological advance, happening at a rate much faster than the upward shift in the demand for computer services. In fact, the story is often told with a theoretical diagram like the bottom frame of Figure 2, in which the supply curve slides steadily downwards from S_1 to S_2 with no shift in the demand curve at all, as in Brynjolfsson (1996, p. 290), Gordon (1990, p. 46) and Sichel (1997, p. 17). The supply curves in this graph have been drawn as horizontal lines, both to simplify the subsequent discussion of consumer surplus and because

[13] Domestic purchases in Figure 2 includes consumption, investment, and government expenditures on computers and peripherals. This differs from final sales of computers (the subject of Figure 1 and the middle column of Table 2) by excluding net exports (which are strongly negative). Final sales are relevant to issues involving domestic output and productivity in the computer sector, while domestic purchases are relevant for issues involving the domestic demand for computers.

there is no evidence of a rising marginal cost of producing additional computer speed, memory, and other characteristics at a given level of technology.

The shape of the graph offers evidence that the demand curve has not shifted much or at all. If there had been a discontinuous rightward shift in the demand curve for computer hardware, the slope of the price-quantity relationship in the top frame of Figure 2 should flatten noticeably, as the rate of increase of quantity accelerates relative to the rate of decline in price, but it does not. The rate of change of price and quantity both accelerate after 1995 (as indicated by the greater price declines and quantity increases between annual observations) but the slope becomes steeper rather than flatter. This pattern suggests that while the pace of technological change has speeded up in the last few years, the relationship between supply and demand is not qualitatively different than earlier advances in the computer industry.

The data on the price and quantity of computer characteristics have previously been used to "map out" the demand curve (Brynjolfsson, 1996, p. 290). In fact, the slope of the price-quantity relationship was appreciably flatter during 1960–72 and 1972–87 than during 1987–95 or 1995–99. If the demand curve has not shifted, the inverse of these slopes is the price elasticity of demand, namely −2.03, −1.97, −1.64, and −1.36 in these four intervals, which can be compared with Brynjolfsson's (1996, p. 292) estimated price elasticity of −1.33 over the period 1970–89. The apparent decline in the price elasticity is the counterpart of the fact that the nominal share of computer hardware expenditures in the total economy (which implicitly holds income constant) rose rapidly before 1987 but barely increased at all after that year, and this shift in the price-quantity slope is consistent with the view that the most important uses of computers were developed more than a decade into the past, not currently.

A second distinguishing feature of the development of the computer industry, after the decline in price, is the unprecedented speed with which diminishing returns set in. While computer users steadily enjoy an increasing amount of consumer surplus as the price falls, the declining point of intersection of the supply curve with the fixed demand curve implies a rapid decline in the marginal utility or benefit of computer power. Since Gary Becker's (1965) seminal article on the economics of time, household production has been viewed as an activity which combines market goods and time. The fixed supply of time to any individual creates a fundamental limitation on the ability of exponential growth in computer speed and memory to create commensurate increases in output and productivity. As Zvi Griliches once said, "The cost of computing has dropped exponentially, but the cost of thinking is what it always was."[14]

In performing two of the activities that were revolutionized by the personal computer, namely word processing and spreadsheets, I cannot type or think any faster than I did with my first 1983 personal computer that contained 1/100th of the memory and operated at 1/60th of the speed of my present model. The capital

[14] The full remark continued, "That's why we see so many articles with so many regressions and so little thought." This comment was passed on to me by Jack Triplett.

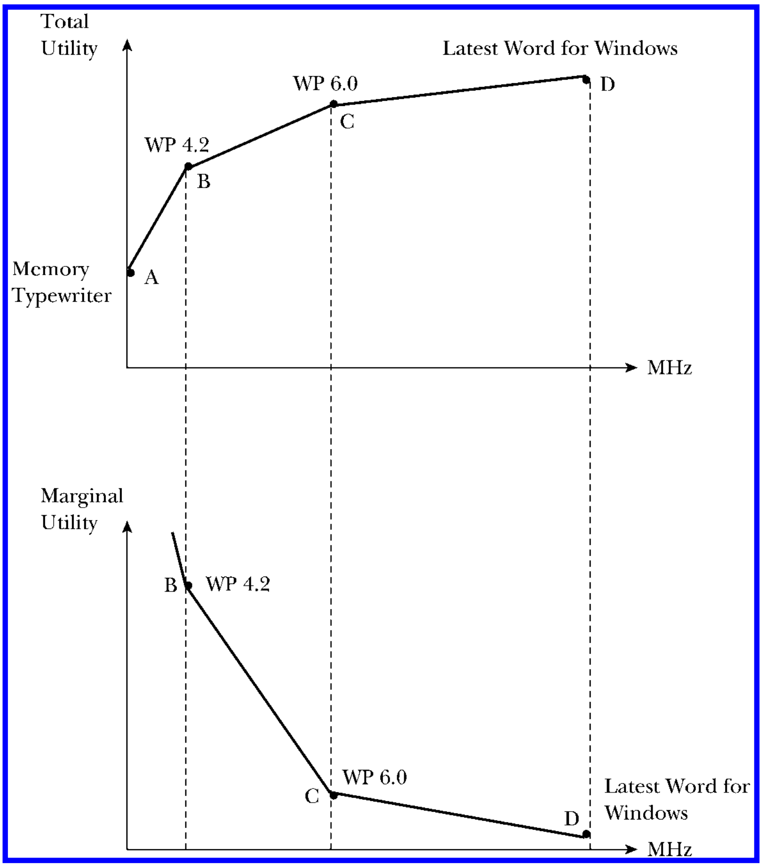
stock with which I work has increased by a factor of almost 30, according to the hedonic price methodology, yet my productivity has hardly budged, occasionally benefitting for a few seconds when I can jump from the beginning to the end of a 50-page paper much faster than in 1983. A price index that declines at 25 percent per year for 17 years reaches a level of 1.4 in 2000 on a base of 1983 equals 100. This implies that my present $1000 computer represents $70,100 in 1983 prices, or 28 times the $2500 that I spent in 1983 on my first computer net of peripherals. As a result, there has been an exponential rate of decline in my output-to-capital ratio, and an equally sharp decline in the marginal productivity of computer capital.

The computer hardware and software industries are certainly not unique in running into some form of diminishing returns. Numerous industries have run into barriers to steady growth in productivity, most notably the airline industry when jet aircraft reached natural barriers of size and speed, and the electric utility industry when turbogenerator/boiler sets reached natural barriers of temperature and pressure. The apparent dearth of productivity growth in the construction and home maintenance industry reflects that electric portable power tools could only be invented once and have been subject to only marginal improvements in recent decades.

What makes diminishing returns particularly important in understanding the computer paradox is the sheer pace at which computer users are sliding down the computer demand curve to ever-lower marginal utility uses. Word processing offers an example of this point. The upper frame in Figure 3 conjectures a total utility curve for word processing, plotted against the speed of the computer measured in mHz. Plotted are successive improvements starting at point A with the memory typewriter, which eliminated much repetitive retyping. At point B comes the early slow DOS personal computer with WordPerfect 4.2. Much faster computer speeds allowed the development of WordPerfect 6.0 for DOS, with a fully graphical WYSIWYG interface, as at point C. Further order-of-magnitude increases in speed bring us today's state of the art at point D, Windows 98 with the latest version of Microsoft Word. Yet look at how the curve flattens out. The real revolution in word processing came at the beginning, by ending repetitive retyping and by allowing revisions to be inserted while the rest of the document would automatically reformat itself. The productivity enhancement of WYSIWYG was minor in comparison, and what was contributed by the final step to the latest version of Word for Windows, beyond some ease of training for novice users, escapes me. As the computer industry has developed, the steady decline in the prices of computer characteristics has fueled the development of increasingly complex software with high requirements for speed and memory required by graphical point-and-click interfaces that yield increasingly small increments of true functionality. The race between hardware capability and software requirements has been aptly summed up in the phrase, "What Intel giveth, Microsoft taketh away."

The bottom frame of Figure 3 replots the same relationship with marginal utility on the vertical axis. This is the demand curve for computers which is drawn on the simplified assumption that word processing is the only use of computers, but the point can be made in multiple dimensions. As the diagram is drawn, a large part

Figure 3
A Total and Marginal Utility Curve for Word Processing



of the consumer surplus occurred in going from A to B to C, and further gains are relatively small.[15]

When investment in computers was failing to provide much (or any) measurable increase in productivity from the 1970s up into the early 1990s, one response from economists was that the productivity gains would arrive eventually. Perhaps the most noteworthy formulation of this argument was by David (1990), who argued that it had taken electric light and electric motors some decades to diffuse after their invention in the 1870s, so that their productivity benefits did not arrive until the opening decades of the 21st century. Perhaps, David argued, the productivity gains from computers would follow a similar pattern.

But the fact of extreme diminishing returns in computers argues against the David (1990) delay hypothesis. The reason that electric light and electric motors

[15] Even *Business Week*, normally enthusiastic about the benefits of the New Economy, admits that the latest increments in chip speed offer "a lot of speed you can't really use. . . a speedier chip won't make you type faster or think faster." See Wildstrom (1999, p. 23).

took time to diffuse is that initially they were very expensive and didn't work very well. But computers provided powerful benefits early on. Many of the industries that are the heaviest users of computer technology—like airlines, banks, and insurance companies—began in the 1960s and 1970s with mainframe technology and still perform the most computation-intensive activities on mainframes, often using personal computers as smart terminals to access the mainframe database. Personal computers are a secondary step in the evolution of computer technology, made practical by decreasing costs of computer power. The Internet is yet another step in the evolution of computer technology, also made possible by decreasing costs of computer power. In this sense, computers have been around for almost 50 years. Instead of waiting for the productivity boost to arrive, it is more plausible that the main productivity gains of computers have already been achieved.

A final reason that computers run into diminishing returns is that there are real limitations to the replacement of human beings by computers. To be sure, some of the output of computers is, in principle, as productivity-enhancing as that of electric motors or motorized transport. Numerically controlled machine tools, robots, and other computer-driven machinery have some of the same potential for productivity improvement as the earlier great inventions and doubtless account for the robust rate of productivity growth apparent in much of the durable manufacturing sector. The use of ever-faster computers and peripherals to churn out securities transactions, bank statements, and insurance policies has enhanced productivity growth in the finance/insurance sector. Just as the motor car enormously increased personal mobility and flexibility, so the computer has spawned inventions whose main output is convenience, perhaps most notably the automatic teller machine in the banking industry, but now also beginning to include various Internet-based services.

However, computers are actually less pervasive in the economy than is generally thought, because some tasks are resistant to replacement of human beings by computers. Commercial aircraft will always need two human pilots, no matter how advanced the avionics in the cockpit. Trucks will always need at least one driver. In manufacturing, some critical functions have proven to be resistant to automation, such as the connecting of tubes and wires when an auto chassis is "married" to the body.[16] By their nature, many services involve in-person contact between clients and practitioners, whether doctors, nurses, dentists, lawyers, professors, investment bankers, management consultants, bartenders, wait staff, bus boys, flight attendants, barbers, or beauticians. Many other services require in-person contact between an object and the practitioner, such as grocery cashiers, grocery baggers, parking lot attendants, valet parkers, auto repair, lawn maintenance, restaurant chefs, hotel housekeepers, and almost every type of maintenance of homes and

[16] Ford engineers explained to a group of National Bureau of Economic Research economists (including this author) touring a plant in Lakewood, Ohio, on November 1, 1996, that the "marriage" would be the last operation in automobile assembly to be fully automated. In another tour with some of the same economists at the Toyota plant in Georgetown, Kentucky, on April 3, 1998, officials explained their aversion to automation and replacing humans with robots: "Our philosophy is *kaizan* (continuous self-improvement), and machines cannot *kaizan*."

machines. Computers are a relatively large share of capital in business, health, legal, and educational services, but in each of these the contribution of capital to productivity growth is relatively small. No matter how powerful the computer hardware and how user-friendly the software, most functions provided by personal computers, including word processing, spreadsheets, and database management, still require hands-on human contact to be productive, and that need for human contact creates diminishing returns for the productivity impact of the computer.

The Positive and Negative Sides of the Internet

The accelerated rate of price decline in computer attributes has been accompanied since 1995 by the invention of the Internet, by which I really mean the widespread public use of the web using web browsers. In perhaps the most rapid diffusion of any invention since television in the late 1940s and early 1950s, by the end of the year 2000 the percentage of American households hooked up to the Internet will have reached 50 percent.[17] Although the New Economy was defined at the beginning of this paper as the apparent acceleration around 1995 in the rate of technical progress in information technology broadly conceived, most of the optimistic interpretations of this development point to the Internet, or more specifically the invention of web browsers, as the central development that warrants calling the present era a new Industrial Revolution. In terms of the supply and demand diagram in Figure 2, it might seem that the Internet represents an expansion of possibilities that should shift the demand curve rightwards and raise consumer surplus substantially in exactly the same way that supermarkets and superhighways raised the consumer surplus associated with the invention of the automobile. But as noted earlier in the discussion of Figure 2, there is little evidence that the demand curve has shifted in this way. Why have the productivity effects of the Internet been so moderate?

A useful starting point is the way in which Barua et al. (1999) divide the "Internet economy" into four "layers:" 1) the Internet infrastructure layer; 2) the Internet applications layer; 3) the Internet intermediary layer; and 4) the Internet commerce layer. The first layer consists of hardware manufacturers, including IBM, Dell, HP, Cisco, Lucent, Sun, and many others, all included in either the computer hardware or telecommunications hardware industries. As we have seen above in Table 2, this sector accounts for the largest single component of the post-1995 productivity growth acceleration, both the direct effect of faster multifactor growth in computer hardware (including computer-related semiconductors) and the indirect capital-deepening effect of the investment boom in information technology.

[17] This projection is made by Henry Harteveldt, Senior Analyst at Forrester Research, in communications with the author. The misleading data of Cox and Alm (1999, Figure 8.1, p. 162) suggests that it took more than 25 years for television to reach 50 percent household penetration, but dating from the first commercial TV station in 1947 this penetration rate was reached in only seven years. See Kurian (1994, series R105 divided by A335).

There is little debate about the dynamism of this sector, but rather about the uses to which this exponentially exploding quantity of computer power is being put.

The second layer consists of software, consulting, and training, and includes such companies as Microsoft and its competitors. The impact of this sector is potentially substantial, since producers' durable equipment investment in software in 1999 was $143.3 billion, almost 50 percent larger than such investment in computer and peripheral hardware. The main debate concerning the productivity of this layer is whether the BEA software deflators decline too slowly to capture the increased capability of the software being produced as part of this massive investment effort. However, as shown by Jorgenson and Stiroh (2000), the outcome of the debate over the software deflators has almost no impact on the question of how this sector of the Internet economy affects productivity in the rest of the economy. The reason is that using alternative software deflators with radically faster rates of price decline has two offsetting effects from the point of view of productivity calculations: capital inputs grow faster, but total output grows faster, too. Overall, there is more capital deepening and a higher share of the productivity acceleration accounted for by the software industry, but no change in any conclusions about spillovers from software to the rest of the economy.

The third and fourth layers of the Internet economy consist of providers of intermediate goods and consumption goods. Many aggregators, portals, and content providers, like Yahoo and Travelocity, sell information and services both to business firms and to consumers. To the extent that e-commerce is provided by one business to another, it is an intermediate good and not directly relevant for computing the productivity of final output in the noncomputer economy. In this sense, we do not need to debate whether business-to-business e-commerce is a fruitful invention. If the development of more efficient links in the supply chain reduces costs and allows the elimination of people and paper in the chain of intermediate transactions, then we should see the payoff in faster productivity growth in the noncomputer economy. So far this payoff has appeared in other parts of durable manufacturing, but not in rest of the economy. Thus our primary remaining question concerns the benefits of the Internet economy in the provision of final goods.

The consumer benefits of the Internet are familiar. Perhaps the most important single consumer benefit at present, also now used universally within business firms, is e-mail. The use of the Internet for e-mail long predated the invention of web browsers, and the hardware and software requirements for straight e-mail, as opposed to e-commerce, are very small. The benefits of e-commerce also include the provision of vast amounts of free information that was formerly expensive or inconvenient to obtain, including travel and sports schedules, hotel descriptions, maps, directions, news, security prices, and even entire encyclopedias. When items are purchased over the web rather than obtained for free, selection is often much better than at traditional bricks and mortar stores, and prices even net of shipping costs are often lower. Auctions on sites like e-Bay provide a new mechanism that allows the flea market to spread from local communities and neighborhoods to a worldwide community of potential buyers and sellers. According to Smith, Bailey and Brynjolfsson (1999), "[E]arly research suggests that electronic markets are more efficient than conventional markets with respect to price levels, menu costs, and price elasticity . . . although several studies find significant price dispersion in Internet markets."

If e-commerce contributes to holding down prices of goods traded in the noncomputer part of the economy, then this will provide an additional factor holding down inflation in addition to the direct impact of the falling prices of computer hardware discussed earlier. However, the low prices of many consumer web vendors have resulted in unsustainable financial losses financed temporarily—but surely not permanently!—by venture capitalists and stockholders. In 1999, it was common for well-known e-commerce companies to have losses that were 20 percent, 50 percent, or even more than 100 percent of sales revenues (Bulkeley and Carlton, 2000, p. A4). It remains to be seen how much the web reduces consumer prices once stockholders begin to require that e-commerce vendors actually earn profits (Byron, 2000).

The enormous variety of products and services available on the Internet, both for free and for pay, might seem to be an invention worthy of comparison with the great inventions of the past. Yet the mere fact that new products and services are being developed is not sufficient for an Industrial Revolution, which requires that the extent of improvements must be greater than in the past. In Triplett's insightful critique (1999, pp. 326–27), the enthusiastic retelling of anecdotes about the New Economy ignores the distinction between arithmetic numbers and logarithmic growth rates. If an economy has 10 products and invents a new one, the growth rate is 10 percent. If many years later the economy has 100 products, it must invent 10 new ones to grow at the same rate and invent 12 or 13 to register a significant increase in the growth rate. Today's U.S. real GDP is more than 40 times greater than in 1880, but does anyone think that today we are inventing 40 times as many important products as in the few decades that yielded the invention of electricity, the telephone, motion pictures, the phonograph, the indoor toilet, and the many others discussed above? No current development in communications has achieved a change in communication speed comparable to the telegraph, which between 1840 and 1850 reduced elapsed time per word transmitted by a factor of 3000 (from 10 days to 5 minutes for a one-page message between New York and Chicago), and the cost by a factor of 100 (Sichel, 1997, p. 127). The excitement of today's web access, taken in historical perspective, does not measure up to the first live electronic contact with the outside world achieved as radio spread in the early 1920s and television in the late 1940s.

The contribution of the Internet to productivity is not the same as its contribution to consumer welfare. For consumers, the new combination of home personal computers and web access provides a valuable invention: Why else would Internet access reach a 50 percent household penetration rate only six years after the invention of web browsers? But here again, as for computers in general, the vast variety of Internet products collides with the fixed quantity of time available to each household member. Inevitably, much Internet use represents a substitution from other forms of entertainment. Internet games replace hand-held games. Downloaded Internet music replaces purchased CDs. Internet pornography replaces purchased or rented adult videos. Other forms of Internet entertainment and surfing for information replace hours previously spent watching television, reading books, or shopping. New evidence of diminishing returns is now emerging. Use of personal computers and of the Internet is declining among newer purchasers who paid less for their machines and appear to value them less, and apparently only two-thirds of computer owners who subscribe to Internet services actually use them (Clark, 1999). As Herbert Simon once said: "A wealth of information creates a poverty of attention."[18]

The essential question raised by the earlier productivity decomposition is to explain why the New Economy in general and the Internet in particular have failed to boost multifactor productivity growth outside of the durable manufacturing sector. What explains the apparent contradiction between this unimpressive productivity performance and the eagerness with which millions of business firms and consumers have purchased business and home computers, as well as Internet infrastructure, spawning whole new industries and creating vast wealth? This conflict is highlighted by findings in microeconomic cross-section studies, discussed by Brynjolfsson and Hitt in this symposium, that the gross rate of return on investment in computers substantially exceeds investments in other areas.

At least four factors may play a role in resolving the conflict: market-share protection, recreation of old activities rather than creation of new activities, duplicative activity, and consumption on the job.

First, the need to protect market share against competitors explains much of the investment and maintenance expense of websites. Barnes and Noble and Borders would have been content to play a dominant role in the retailing of books, but were forced by competition from Amazon to become "clicks and mortar" organizations by developing their own websites that duplicated much of their previous retail activity and most of what Amazon had already pioneered. More generally, computers are used extensively to provide information aimed at taking customers, profits, or capital gains away from other companies. This is a zero-sum game involving redistribution of wealth rather than the increase of wealth, yet each individual firm has a strong incentive to make computer investments that, if they do not snatch wealth away from someone else, at least act as a defensive blockade against a hostile attack. This may be at the heart of the apparent contradiction between the Brynjolfsson-Hitt micro evidence on the high returns to computer investment and the failure of computers to spark a productivity growth revival outside of durable manufacturing; the high payoff to computers for individual firms may reflect redistributions to computer-using firms from firms that use computers less intensively. There is a "keeping up with the Joneses" aspect of

[18] This quotation was related to me by Hal Varian.

hardware and software purchase motivated by competition, employee satisfaction, and employee recruitment.[19]

Second, much Internet content is not truly new, but rather consists of preexisting forms of information now made available more cheaply and conveniently. Internet surfing of airline schedules provides a lower cost, although not necessarily faster, method of obtaining information already available in airline timetables, from the printed Official Airline Guide, and from travel agents. Obtaining stock quotes and performing trades on the web does not represent the invention of a new activity but rather a reduction in cost of performing an old activity. In contrast, the great inventions of the late nineteenth century created truly new products and activities.

A third factor subtracting from productivity is the duplicative aspect of the Internet. Much e-commerce is an alternative to mail-order catalog shopping (another invention of the 1870s, whose development is summarized in Gordon, 1990, pp. 419–23). Just as Wanamaker's and Macy's department stores began to issue catalogs to supplement their existing retail operations in the early 1870s, so currently Land's End, Spiegel's, and many other catalog operators have supplemented their existing operations with websites in the late 1990s. Yet the catalogs have not disappeared; the full cost of printing and mailing the catalogs is still incurred, but on top of that must be expended many millions on developing and maintaining duplicative websites. While it is cheaper to take an order from a web customer than with a human worker answering a phone, much of the rest of the transaction involves the same physical input of labor in building and stocking warehouses, selecting items from warehouse shelves, packing them, and shipping them. The brown UPS trucks are thriving with e-commerce, but each truck still requires one driver. In fact, far from reducing or eliminating the use of paper, the electronic age seems to multiply paper. As the president of one dot-com recently said: "For getting attention in a professional way, paper still matters. Nobody even asks anymore if paper is going away."[20]

An example closer to home for economists is the added cost to academic societies of developing websites to provide information already available in their printed journals. The Econometric Society now provides duplicate announcements of most of its activities through the back pages of its journal and through its website, and it like other societies is under increasing pressure to provide the contents of its journal and even papers given at its regional meetings to its members on the web without any additional fee. It costs money to develop and maintain these websites. Economists gain a consumer surplus in having more convenient access to research, but convenience for professors is not a final

[19] There seems to be a deeper contradiction between the macro and micro evidence that has not yet been resolved. For instance, in a study of multifactor productivity growth and computer capital across a number of industries, Stiroh (1998) finds: "For all computer-using sectors . . . the average growth rate of multifactor productivity fell while [computer] capital grew."

[20] The speaker is the president of NowDocs.com, as quoted by Doan (2000, p. 140). On the growth in paper usage, see also "Bad News for Trees" (1998).

good. The final product, education and research, is affected little if at all by the ease of access of references.[21]

Finally, productivity on the job may be impaired by the growing use of business computers with continuous fast web access for consumption purposes. One research service found that people spend more than twice as much time online at the office as they do at home, and that web users at the office take advantage of high-speed connections to access entertainment sites more frequently at work than at home. In fact the most-visited site from the office is eBay, and three financial trading sites are not far behind (Farrell, 2000, p. A1). The media have gleefully reported that a large fraction of on-line equity trading is happening at the office, not at home (for instance, Bennett, 2000; "Workers Leaving Water Cooler for Internet," 1999). Employers are so disturbed by the continuing use of office computers for personal e-mail that the number of companies using "surveillance software" to monitor their employees' e-mail usage is "soaring" (Guernsey, 2000, p. C1).

A final response from the New Economy optimists to the skeptics is that computers have added greatly to output, but that many of the benefits of computers have been mismeasured. While it is doubtless true that certain benefits of the current technology are not fully captured in national income accounts, a great many of the benefits should be captured. The heaviest uses of computers are in industries that provide mainly or entirely intermediate goods, especially wholesale trade, finance, many parts of the insurance industry, business services, and legal services. If computers truly raised the output of these intermediate industries in unmeasured ways, then the benefits should show up in the output of final goods industries that exhibit higher output in relation to their undermeasured inputs. Yet this spillover from intermediate to final goods industries is just what cannot be found in the official data on output and productivity growth, at least outside of the durable manufacturing sector.

Moreover, the presence of unmeasured outputs is certainly not new. Personal computers and the Internet have doubtless created consumer surplus, but so did most of the great inventions of the past. Indeed, it is quite plausible that the additional consumer surplus from present technologies is less than the amount from diffusion of the great inventions during the golden age of productivity growth from about 1913 to 1972.

Conclusion

The New Economy, defined as the post-1995 acceleration in the rate of technical change in information technology together with the development of the

[21] In a related investigation of the payoff for academic research of information technology, Hamermesh and Oster (1997) find that articles with co-authors working at long distance from each other actually have fewer citations than other articles; that is, "a greater ease of overcoming distance does not enhance productivity" (p. 18). They interpret the rise in long-distance co-authorship as mainly a consumption good as academic friends find it easier to work together.

Internet, has been both a great success and a profound disappointment. The New Economy has created a dynamic explosion of productivity growth in the durable manufacturing sector, both in the manufacturing of computers and semiconductors and of other types of durables. This productivity explosion has boosted the economy's rate of productivity growth and created enormous wealth in the stock market. Also, by helping to hold down inflationary pressures in the last few years, the New Economy allowed the Federal Reserve to postpone the tightening of monetary policy for several years in the face of a steadily declining unemployment rate. However, the New Economy has meant little to the 88 percent of the economy outside of durable manufacturing; in that part of the economy, trend growth in multifactor productivity has actually *decelerated,* despite a massive investment boom in computers and related equipment.

The fundamental limitation on the contribution to productivity of computers in general and the Internet in particular occurs because of the tension between rapid exponential growth in computer speed and memory on the one hand and the fixed endowment of human time. Most of the initial applications of mainframe and personal computers have encountered the rapid onset of diminishing returns. Much of the use of the Internet represents a substitution from one type of entertainment or information-gathering for another.

In assessing the importance of the New Economy and the Internet as an invention, we have applied a tough test. To measure up, the New Economy had to equal the great inventions that constitute what has been called the Second Industrial Revolution. Internet surfing may be fun and even informational, but it represents a far smaller increment in the standard of living than achieved by the extension of day into night achieved by electric light, the revolution in factory efficiency achieved by the electric motor, the flexibility and freedom achieved by the automobile, the saving of time and shrinking of the globe achieved by the airplane, the new materials achieved by the chemical industry, the first sense of live two-way communication achieved by the telephone, the arrival of live news and entertainment into the family parlor achieved by radio and then television, and the enormous improvements in life expectancy, health, and comfort achieved by urban sanitation and indoor plumbing.

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