

## *The Age of Optimism*

Just yesterday the *Wall Street Journal* reported on a random, presumably fair sample survey of the entire American population. The lead headlines were "Americans look to 21st Century with Optimism and Confidence," and "Optimism Outduels Pessimism." There was a brief detour into the failed predictions of 100 years ago — including the pessimistic that heavier-than-air flying machines are impossible, or that from IBM Chairman Thomas Watson in 1943 that "I think there's a world market for maybe five computers." Bill Gates, Watson's successor as computer quasi-monopolist, opined in 1981 that "640K of random-access memory ought to be enough for anyone."

Today, with 58.9 home computers in use in the United States having an average of 32 megabytes of RAM (or 50 times Gates adequate amount), we should be humble about pessimistic projections. But it goes both ways. Not so long ago there were overly optimistic forecasts that all diseases would be wiped out by the turn of the century, or that the automobile would be a relic by the turn of the century, since everyone would by then own one or more personal hovercraft able to maneuver in three dimensions.

Well, whatever the flaws of forecasting, Americans appear to have great confidence in the future. The one area where confidence seems most unanimous is in the future of medical technology, with advances in communications and education next in line. Computers themselves did not rate a mention. But about medical technology itself there are decidedly mixed views. When asked whether they wanted to live to be 100, 52 percent said yes but fully 42 percent said no, and this answer did not vary much by age. Everyone knows by now that aging allows us to enjoy more of the marvels of future technology, but with the possibility of a diminished quality of life and the overriding question as to who is going to pay for it. This survey response reveals indirectly the subtleties of trying to quantify the value of increasing life expectancy, an area which the Boskin commission on the U. S. CPI discussed without trying to quantify or value.

But our topic tonight is not medical technology, where everyone supports the conclusion of the Boskin Commission that this is the most important single source of

downward bias in the CPI. No one ascribes to medical care the label "new economy" or attributes to medical care the role of reviving American productivity growth from its long slumber, simply because unmeasured gains in the quality of medical care have been with us throughout the postwar era, are nothing new, and cannot be claimed to have emerged suddenly in the last few years.

Instead, the heart of the "new economy" is not medical care, it is computers. And this is where we turn to the meat of our topic.

### **The "Solow Paradox"**

It has been more than a decade since Robert M. Solow (1987) came up with his lovely quip, "You can see the computer age everywhere but in the productivity statistics." The prevailing reaction to Solow's paradox has been "well, the computers are indeed everywhere, so there must be something wrong with the productivity statistics." The idea that the contribution of computers to output is inherently difficult to measure and has been systematically understated can be classified as the first solution to the Solow paradox. In a minute, I'll show you some interesting statistics that lead me to doubt that we are missing the computers because of measurement errors.

A second possible solution to the Solow paradox has been suggested by the important work of Stephen Oliner and Dan Sichel (1994, Sichel 1997), who criticize Solow's basic premise by arguing that "the computers are *not* everywhere." Specifically, computers and related peripherals represent only about 2 percent of the nation's capital stock. Further, this tiny share is not likely to increase appreciably, as so much of investment in computers is chewed up by depreciation and obsolescence of relatively young hardware and software. Only if the return from computers were to increase dramatically in the future would their contribution to productivity growth accelerate.

The third explanation has been proposed by Paul David (1990) and others. David argues by analogy with the invention of the electric motor around 1880; the payoff of the electric motor in creating an acceleration of productivity growth in U. S. manufacturing did not become apparent in the statistics until the interval 1913-29. This analogy would seem to imply that it may take a full generation before systems of

production are changed to take full advantage of IT.

I prefer to make the case for a fourth possible solution to the Solow paradox. Computers may be pervasive, but they have not created a revival of productivity growth because something is wrong with the computers. Computers fail as a source of a productivity revolution because they pale in comparison with the great inventions earlier in this century that created the golden era of productivity growth; because many activities in the service sector are inherently immune to productivity improvements achieved by computers; because diminishing returns to increasing computer speed and memory has already set in; and because substantial activity created by computers has zero or negative productivity.

### **The Recent Productivity Revival in the United States**

Recently some doubt has been cast on the relevance of the Solow computer paradox, because productivity growth seems to be reviving in the United States. Maybe we *are* starting to see the computer age in the productivity statistics. I've recently written a paper that raises questions about this widespread belief that the "New Economy" is finally starting to emerge in the U. S. productivity statistics. Let's look at this evidence . .

[show color Figures]

Qualifications vs. 2nd quarter figures.

## Escaping "the Bad Old Days"

As the years go by without a productivity payoff from computers commensurate with their cost, journalists have become more frenetic in proclaiming that we are in the midst of a true revolution: "Computers may be the most profound technology since steam power ignited the Industrial Revolution." There is a "waiting for Godot" quality to the anticipation generated as productivity growth continues to languish while computer investment continues to surge. Those who wait for Godot appeal to Paul David's (1990) electricity analogy, arguing that since 25 years elapsed between the invention of electricity and the beginning of its transformation of farm, home, and factory, so it is reasonable to expect such a delayed impact of the computer. Yet if anything is clear, it is that however unimportant the computer is today in generating productivity growth, we can be sure that at the margin it was *more* important a decade ago and will be *less* important a decade hence, simply because continuing exponential declines in the cost of computer power reduce the marginal product of computer power, i.e., push incremental increases in computer power into lower and lower productivity uses.

To begin our investigation of why computers have not yielded a productivity revolution, it is useful to compare the contribution of computers to economic output and welfare with some of the more important inventions that had their main diffusion earlier in the twentieth century and help to explain the "one big wave" of MFP growth peaking in 1913-64 exhibited in Table 1. A useful context is to ask how the great inventions helped us to escape from the abysmal living conditions of the late nineteenth century.

## Living Conditions 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 Archive. Bettmann divides the horrors of the past into eleven categories, which for brevity will be greatly condensed here:

1. **Air, Food, Drink, and Health.** The urban streets of the 1870s and 1880s were full not just of horses but pigs, which roamed the streets and were tolerated because they ate garbage. In Kansas City, the confusion and stench of patrolling hogs

were so penetrating that Oscar Wilde observed, "They made granite eyes weep." The steadily increasing production of animal waste caused the more 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 stirred together in 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 unrefrigerated meat and poultry hung unrefrigerated for days, spoiled fruit, bacteria-infected milk, and virtually all types of food were suspected of adulteration. Epidemics included yellow fever, scarlet fever, and smallpox. The pain and lack of sanitation in surgery were endemic, and many hospitals were deathtraps.

**2. Motive Power.** Before the invention of electricity, urban streets were a chaotic jungle of horse trolleys, and 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 also no picnic; among its features were 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. Emigrants traveled west on wooden benches in worn-out filthy boxcars attached to freight or cattle trains.

**3. Housing.** In 1882 only two 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; families were shelved in layers, with no insulation from the neighbors' cooking smells or babies' squallings. In the slums as many as eight persons shared a single small room.

**4. Working Conditions.** Those who have seen the movie "Titanic" may have shared my momentary shock at the working conditions of the sweating laborers shoveling coal into the huge mouths of the ship's boilers. 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**

The transition from these often abysmal living conditions to today's much easier and more pleasant life resulted from the complex interaction of ideas, inventions, and the feedback from growing wealth that allowed poor families to live as well or better in many aspects of life than the wealthy of one hundred years earlier.

Here, however, I want to select five major inventions for comparison with the computer, or chip-based IT broadly conceived. These are:

(1) The first great invention in the "Group of Four" is electricity, including both electric light and electric motors. As shown by Nordhaus (1997), electricity drastically reduced the true price of light. Electric motors, after a developmental period of two or more decades emphasized by David (1990), 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, and through refrigeration virtually eliminated food spoilage and through air conditioning made summers enjoyable and opened the southern United States for modern economic development. In fact, I would venture to make the claim, perhaps strange to Canadian ears, that one single application of electricity — that is, air conditioning — was a more important invention than everything done by personal computers and the internet. Ask the population of the ex-Confederacy in the United States which they would choose if they could only have one — air conditioning or a computer — and you know what the answer will be.

(2) 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, interstate highway, and supermarket. Gradually eliminated or greatly reduced were many of the ills of the late nineteenth century, from manure to unplowed snow to putrid air to rural isolation.

(3) The third group of great inventions includes both petroleum and all the processes which "rearrange molecules," including petroleum, natural gas, petrochemicals, plastics, and pharmaceuticals. These are largely an independent invention, but some of the innovations 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 products, as well as conquering illness and prolonging life.

(4) The final member of the "Group of Four" is the complex of entertainment, communication, and information innovations that were developed before World War II. This set of inventions that made the world smaller can be traced back to the telegraph in 1844 and includes the telephone, radio, movies, television, recorded music, and mass-circulation newspapers and magazines. Television, which was invented in the 1920s and 1930s, is the only one of these innovations that was diffused after World War II. Otherwise, all the rest were well established before World War II and created a quantum leap in the standard of living when a year like, say, 1939 is compared with fifty years earlier.

(5) It used to be the four big inventions, but a bit of thought suggests that there was a fifth great invention that deserves to join the top rank. This is the invention of indoor plumbing and urban sanitation infrastructure. Shall we use the same mock public opinion poll as I suggested for southern Americans thinking about air conditioning — let me ask Canadians which they would choose if they could only chose one, indoor plumbing or the computer, and I think you know what the answer would be. I credit my colleague Joel Mokyr in drawing my attention to this fifth set of inventions, which starts with Pasteur's germ theory of disease, together with the development of clean urban waterworks, to which Mokyr gives credit for the great decline in mortality in the four decades prior to World War I.

The "Group of Five" inventions, in turn, created an increase in per-capita income and wealth 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 at the turn of the century.

## **Comparing Revolutions**

Has the information revolution spawned by the computer created as great a change in living conditions as any of the four major complexes of early twentieth-century inventions? While retrospective exercises are inevitably subjective, it is interesting to play an expanded version of what I like to call the "New Yorker game."

A few years ago the *New Yorker* commissioned a critic to sit in front a television set for an entire week and record his impressions. He had many reactions, but the one most relevant for us is that he was surprised from the reruns of 1950 TV shows how similar were the living conditions of the 1950s Ozzie and Harriet families in comparison to those of today. Clearly living conditions were far worse in the 1890s than in the 1950s, in large part because of the "Group of Five" inventions. We can surmise that a hypothetical critic revisiting the 1890s through a time machine would not have the same reaction as the *New Yorker* critic visiting the 1950s from the 1980s.

What does seem sure is that society had cured most of the ills of late nineteenth century living conditions by the 1950s and 1960s without any help from computers.

## **What the Great Inventions Achieved**

To understand at a deeper level why the computer revolution does not measure up to the earlier great inventions, it is useful to consider some of the ways in which the great inventions created productivity growth. Electric light was a unique invention that extended the length of the day for reading, entertainment, and other pursuits. Both the electric motor and internal combustion engine created faster and more flexible movement, directly raising the productivity of factory workers, housewives, truck drivers, and airline pilots as the machines they powered could rotate ever faster. Air conditioning put humans rather than Mother Nature in control of indoor climate, greatly expanded the area of comfortable habitation of the United States and other countries, and hugely increased productivity in hot and humid climates.



Petroleum refining, chemicals, plastics, and pharmaceuticals all involve the physical rearrangement of molecules in ways that change materials into more productive forms. The complex of electric and electronic entertainment and information industries arrived in a void in which nothing comparable existed and had, one may safely conjecture, a greater impact on everyday life of the average family than the second and third generation developments, e.g., VCRs, CDs, the first generation of color TV, and ever-larger TV screens, which provided merely better or more convenient ways of performing the same basic functions.

Some of the output of computers is, in principle, as productivity-enhancing as that of electric motors or motorized transport. From the earliest punch-card sorters, some applications of computer technology involved movement and speed. Numerically controlled machine tools, robots, and other computer-driven machinery has the same potential for productivity improvement as the earlier great inventions and doubtless accounts for the robust rate of productivity growth still apparent in some (but not all) manufacturing industries. The use of ever-faster computers and peripherals to churn out securities transactions, bank statements, and insurance policies should enhance productivity growth in the finance/insurance sector. And, just as the motor car enormously increased personal mobility and flexibility, so the computer has spawned inventions whose main output is convenience, most notably the ATM machine. But notice that the big advances in finance, insurance, ATM machines, airline reservations systems, and other primary uses of computer technology were achieved by the mainframe, not the personal computer, and are now 20 to 40 years in the past.

#### ***V. Where the Computer Falls Short***

With this historical background, we can now explore some of the reasons why the computer has not made more of a positive impact on productivity growth. We begin with several general limitations of computers and then discuss the pervasive role of diminishing returns in the diffusion of computer technology.

## Why Computers are Not Everywhere

In new results of Jorgenson and Stiroh (1995) and Stiroh (1998), the impact of computers on MFP growth come to a mere 0.07 percentage points for 1973-96 and only 0.13 points for 1990-96.

The Oliner-Sichel explanation of the Solow computer paradox focusses on the small share of computers in the capital stock. But we should go further by asking why computers have not appeared everywhere. An insightful study by McGuckin, Stiroh, and van Ark (1997) shows that more than 75 percent of all computer inputs are concentrated within three service sectors — trade, finance/insurance, and what they call "other services." Only these three sectors and five of 21 manufacturing sectors had more than 4 percent of total capital in the form of computers in 1991.

**Hand and Eye Coordination.** Computers are less pervasive than is generally thought, because there are real limitations to the replacement of human beings by computers. Commercial aircraft, large and small alike, will always need two human pilots, no matter how advanced the avionics in the cockpit. Trucks will always need drivers. 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. No matter how powerful the computer hardware and how user-friendly the software, most functions provided by personal computers, including word-processing, spreadsheets, and data-base management, still require hands-on contact through a keyboard and mouse to be productive.

**Face-to-face Contact in the Services.** 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, flight attendants, barbers, or beauticians. Many other services require in-person contact between the practitioner and an object, such as in auto repair, lawn maintenance, restaurant chefs, hotel housekeepers, and almost every type of maintenance of homes and 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.

### **Why Social Returns May be below Private Returns**

A critical challenge posed by the Solow paradox is to explain how computers could simultaneously be contributing relatively little to aggregate productivity growth while at the same time be purchased with great eagerness by millions of business firms and consumers, spawning whole new industries and creating vast wealth.

There are numerous reasons why computers may be purchased even if they have no visible payoff in measured aggregate productivity growth.

(1) There may be a temporary delay in the productivity benefits of computers as training takes place and managers reorganize production. Baily and I were skeptical of this hypothesis in 1988, and it seems considerably more implausible now, ten years later, despite David's (1990) intervening attempt to provide an analogy with the diffusion of the electric motor. Also, this explanation is incompatible with the Brynjolfsson-Hitt evidence.

(2) Computers may be purchased as a result of managerial error. Firms may underestimate the full costs of information technology, e.g., by focussing only on hardware cost and by failing to include the cost of labor needed to maintain computers and provide ongoing training. The only real distinction between (1) and (2) is that the first is temporary and the second is permanent. The second, like the first, is incompatible with the Brynjolfsson-Hitt evidence.

(3) 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 and the failure of computers to spark a productivity growth revival in the macro data; the high payoff to computers for individual firms may reflect redistributions to computer-using firms from firms that use computers less intensively.

(4) Computers may improve working conditions. Firms without adequate computer equipment may not be able to hire high-quality employees. These higher quality employees, in turn, may provide some of the payoff to computers that Brynjolfsson-Hitt have measured. However, to the extent that computers allow consumption on the job, in the form of personal e-mail, games, or web access for consumption purposes, they may create unmeasured declines in work hours and output together with unmeasured increases in consumption.

(5) Computers may produce valuable services that are not included in official measurements of output and productivity, e.g., the convenience services of automatic cash machines (ATMs) and faster check-out made possible by bar-code readers in supermarkets and other retail outlets.

Factors (1) and (2) should be expected to disappear as firms learn to avoid mistakes in the use of computers. It is hard to believe that pervasive and ongoing managerial error this is still a major factor, if it ever was such. Factors (3) and (4) would seem to be critical. There is a "keeping up with the Joneses" aspect of hardware and software purchase motivated by competition, employee satisfaction, and employee recruitment. Added software complexity creates hardware obsolescence and the need to buy newer, higher-powered computers. As someone quipped, "What Intel Giveth, Microsoft Taketh Away."

How much of the motivation for the private purchase of computers remains for output mismeasurement? While this question may seem impossible to answer, one overriding factor limits its importance. 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.

### **The Fundamental Limitation: Time**

Since Gary Becker's seminal article (1965) 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 the fundamental limitation on the ability of exponential growth in computer speed and memory to create commensurate increases in output and productivity. In performing the two 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 one-fiftieth of the memory and operated at one-thirtieth of the speed of my present model. The capital stock with which I work has increased by a factor of at least fifteen, according to the hedonic price methodology used by the BEA in the U. S. national accounts, 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. 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 Pervasiveness of Diminishing Returns**

There is nothing unique about the applicability of diminishing returns to the computer hardware and software industries. 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.

What makes diminishing returns particularly important in understanding the computer paradox is the sheer pace of cost reduction, and hence the rate of which computer users are sliding down the computer demand curve to ever-lower marginal utility uses. My way of illustrating this point is to take word-processing. The upper frame in Figure 6 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 PC 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 the final step to Windows contributed, beyond ease of training for novice users, escapes me.

The bottom frame replots the same relationship with marginal utility on the vertical axis. This is the demand curve for computers; a set of continuous improvements rather than discrete improvements would result in a continuous nonlinear demand curve instead of the piecewise function drawn in Figure 6. This demand curve is drawn on the simplified assumption that word processing is the only use of computers, but the point can be made in multiple dimensions. A steady decline in the cost of producing computer speed has allowed the user to slide down from point A (not shown in the bottom frame) to B to C to D. But clearly, as the diagram is drawn, a large part of the consumer surplus occurred in going from A to B to C, and further gains will be relatively small.

### **Continuity from Mainframes to Personal Computers**

The diminishing returns argument provides the definitive answer to the Paul David (1990) "delay" hypothesis. The reason that electric motors and consumer appliances took time to diffuse is that initially they were very expensive and didn't work very well. But the personal computer worked reliably from the beginning, provided its main benefits early on, and encountered relatively soon not just diminishing returns but the pervasiveness of face-to-face technology in the service sector that limits the ability of super-fast computers to replace labor input in a significant way.

The David (1990) "delay" hypothesis encounters another obstacle. Personal computers are only a secondary step in the evolution of computer technology that began with the first commercial mainframe computer (the UNIVAC I in 1951). Hedonic price indexes show that steady price declines at geometric rates of 25 to 35 percent have characterized both the mainframe and personal computer industries since the beginning. Many of the industries that are the heaviest users of computer technology, e.g., 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 PCs just as smart terminals to access the mainframe data base. In this sense computers have been around for more than 40 years, not just a decade or so, and the "waiting for Godot" hypothesis of David and others loses further credibility.

### **Is Some Computer Investment Producing Negative Social Returns?**

It is unusual to have a section of an academic paper suggested by a newspaper cartoon, but in this case the cartoon is so appropriate that it must be included (see Figure 7). It suggests some of the ways in which computer games and the internet have crept into the office environment in ways that may diminish productivity more surely than the traditional coffee break or trip to the water cooler. The explosion of the internet and the web in the last few years might seem to create a new function for personal computers that allow them to escape the merciless vice of diminishing returns, but this conclusion is open to doubt.

First, much personal web access, both from the office and from home, is a substitute for other forms of entertainment or information. Much information available on the web duplicates that already in print, as suggested by Figure 8, and many functions of on-line services were provided prior to the development of the web. Just as the productivity of a word processor is limited by the typing speed of the user, so the potential surplus provided by the web is limited by the leisure time of the consumer (even if extra leisure is taken on the job). Second, much investment in web sites by commercial firms falls under category (3) above, the use of the computer to redistribute wealth rather than create wealth. And the commercial use of the internet largely duplicates other forms of advertising, so from society's point of view extra employees have been hired to duplicate a pre-existing function, simply for offensive or defensive competitive purposes. And this competitive drive extends into the nonprofit sector. What economics department does not have its web site, designed to impress prospective students and faculty members? Yet in what sense do such web sites produce better students or faculty members, rather than just reallocating them among departments?

## ***V. Conclusion***

Profound issues are raised by the apparent failure of IT to boost the rate of multi-factor productivity (MFP) growth or of average labor productivity (ALP) growth in the United States in the past decade, beyond the sparkling productivity performance of the computer industry in making computer power faster and cheaper. Where is the payoff for the other 99% of the economy that uses these computers?

To advance our understanding of the failure of computers to revive productivity growth, we contrast the role of the computer with the great inventions of the early twentieth century, initially by asking how the greatest advances from the abysmal living standards of the late nineteenth century were achieved. These advances had nothing to do with computers, but rather were achieved by an advance in general knowledge, particularly regarding health, and five key groups of inventions, namely (1) electricity, (2) the internal combustion engine, (3) petroleum and chemicals, and (4) electric and electronic entertainment and information, and (5) indoor plumbing and sanitation infrastructure. By the 1950s these inventions had diffused throughout the economy and life bore little resemblance to that of the 1890s, while in contrast life today differs relatively less from that of the 1950s.

The failure of computers to have a productivity impact comparable to that of the earlier great inventions reflects the simple fact that computers have to interact with humans, and humans have a limited quantity of time to combine their unique talents (thinking, typing, planning) with the computational and information-gathering resources of computers. The productivity of computers is increasingly subject to diminishing returns and a dramatic decline in the ratio of computer output to computer capital, due to the increasing mismatch between the clock speed of computers and the finger speed of operators writing documents and creating spreadsheets. Further, the computer revolution encounters physical limits in replacing humans in such diverse occupations as airline pilots, truck drivers, flexible finger-sensitive manufacturing assembly, and surgery. Most basically, the output of most industries within the service sector requires some type of face-to-face contact between practitioner and client, or practitioner and an object.

Some uses of the computer provide a real convenience, like the ATM machine. But for other uses the investment is duplicative of existing resources, with only a small



prospective social payoff. Many computers are purchased by business firms in order to compete with other firms. The aim is redistribution of market share, not an improvement in aggregate productivity. This is the primary reason why computers may have a social return that is lower than their private returns, the opposite of the super-normal returns that have sometimes been suggested. While many earlier inventions have been subject to diminishing returns, the role of diminishing returns in computers is more important and pervasive, simply because the cost curve is shifting down the demand curve so rapidly.

The recent development of the internet and the World Wide Web may appear to shift the demand curve and delay the onset of diminishing returns, and to some extent this is true. But much commercial activity on the web simply duplicates existing forms of advertising, requiring more people to achieve the same purpose as previously, and hence reducing productivity. Much personal web access is a substitute for other forms of entertainment.

In the end our conclusion is that the productivity slowdown is real, and that diminishing returns places the most productive contribution of the computer behind us in the past. Our conclusion stands in sharp contrast to the widespread view that we have a "new economy" dominated by the revolutionary implications of the information age. The "bad old days" of the late nineteenth century may indeed have been terrible, but at least they witnessed the creation of truly important inventions that made possible a half-century of rapid growth in productivity (between roughly 1915 and 1965) that far exceeds what occurred before, what has occurred since, or what is likely to occur in the foreseeable future.