Computers and Productivity in the Information Economy

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THE TERM "INFORMATION ECONOMY" has rapidly made inroads into academic and popular discourse, reflecting the growing importance of computers, telecommunications equipment and other information technology (IT) tools in virtually all aspects of modern economic life. Producers of goods and services, by having ever more information at their fingertips, are able to manage their resources more efficiently, market products better suited to the tastes of their customers, and reduce costs—or so say those who stress the importance of the information economy. So powerful is the potential of IT, the popular business press has asserted, that the acceleration of productivity growth in the past several years represents a fundamental shift as companies begin to reap the payoff from investment in IT equipment, particularly computers. Some observers go so far as to predict that computers will end the business cycle as we know it and usher in unprecedented and uninterrupted prosperity.

If such beliefs about computers' profound effect on the economy are true, then we should have long since seen a marked improvement in productivity—the amount and quality of output that can be produced from a given amount of inputs. However, over the last 25 years economists generally agree that the industrial economies have all suffered a secular *slowdown* in the rate of productivity growth relative to long-run historical averages. This fundamental paradox of rapid growth in supposedly productivity-enhancing IT equipment and slower growth in standard measures of productivity led the noted MIT economist and Nobel Laureate Robert Solow to quip in the late 1980s that "You can see the computer age everywhere but in the productivity statistics."

This striking coincidence of huge investments in IT equipment and relatively low rates of productivity growth raises some troubling questions. Is it really possible that businesses have blindly invested billions of dollars in equipment that has had little or no positive effect on productivity? Have computers been contributing intangible benefits that are not captured in standard measures of productivity? If so, what are they? And given the conflicting evidence so far available, can the information economy yield more rapid increases in prosperity as we enter the 21st century, or will it simply increase the circulation of less and less useful information?

I try to answer these questions by taking a closer look at the computer revolution and the rise of the information economy in the United States over the last quarter century and examining how it has affected business productivity. During that period, the computer industry not only grew dramatically in size, but the role of computers in the economy changed significantly from labour substitution to labour complementarity, particularly since the onset of the PC era in the early 1980s. Rather than simply replacing employees through office automation, computers have evolved to become the indispensable companion of employees across the corporate spectrum. This evolution has altered the potential impact that computers are likely to have on business production and presented new challenges and opportunities.

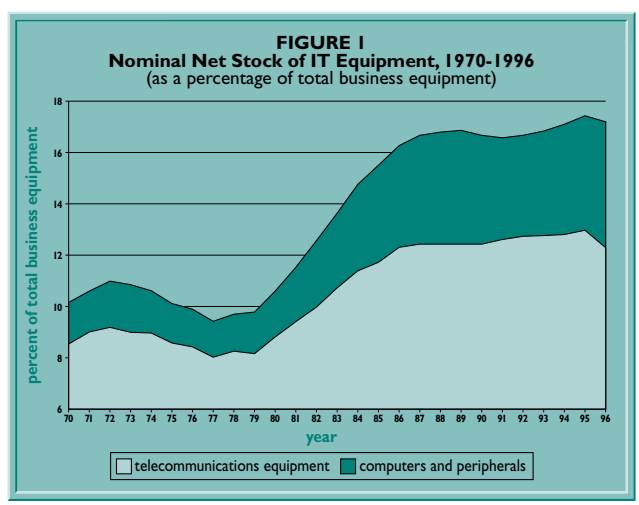

FIGURE 1
Nominal Net Stock of IT Equipment, 1970-1996
(as a percentage of total business equipment)

Trends in Computer Investment

The growth of investment in IT equipment—defined here as business purchases of computer and peripheral equipment as well as telecommunications equipment—since 1970 is staggering. Figure 1 shows, in nominal terms, the stock of IT equipment (broken down into its two major components) as a proportion of the total stock of business equipment. In 1970, IT equipment amounted to 10.1% of the total, the vast majority of which was accounted for by telecommunications equipment. Computers and peripheral equipment made up a scant 1.6%. By 1996, IT equipment was 17.3% of the total stock of equipment, and the share of computers and peripheral equipment had trebled to 4.8%. (Figure 1 may not look that dramatic, but keep in mind that the figure shows the changing fraction of the *stock* of business equipment made up by IT and computer equipment. The total stock of business equipment is many hundreds of billions of dollars, and so even a change from 1.6% to 4.8% of this total represents an enormous *flow* of investment into computer equipment.) It is interesting (and perhaps not surprising) to note that appreciable growth in

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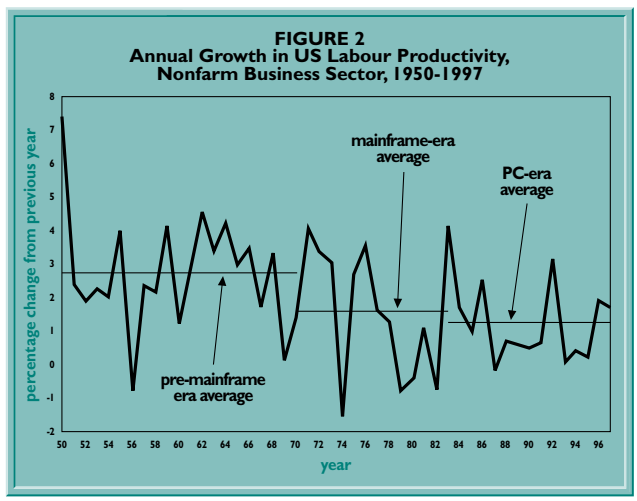
the computer capital stock did not begin until the late 1970s. Its share has continued to grow since 1996. Although capital stock data are not available after 1996, later investment data imply continued rapid growth in the stock of computers and peripheral equipment—it accounts for over 40% of the $230 billion currently invested annually in IT equipment.

The affordability, quality and usability of computer investment have improved markedly since 1970. During the early part of this period, the cost of computer memory and processing power was about twenty times higher than it is today. Thus precious processing power had to be reserved for calculations, necessarily sacrificing user-friendly interfaces. Punch-card input and programming languages that bore virtually no resemblance to English were commonplace until the late 1970s. During this first phase of the computer revolution, mainframe computers dominated, and they were generally used for specific calculation-intensive tasks such as accounting and precision control of machines and processes. Explicitly or implicitly, computer technology was designed to substitute for labour in tasks for which the human brain is less capable than a microprocessor.

By the early 1980s, the cost of memory and processing power had dropped sufficiently to make computers affordable on a wide scale and also to permit the evolution of more user-friendly interfaces. The beginning of this second phase of the revolution is symbolised by the introduction of the IBM Personal Computer in 1983 (and, to a lesser extent in business, the Apple Macintosh in 1984). The onset of the PC and networking era since the early 1980s has transformed the computer into an access point for a wide variety of previously unavailable information rather than a task-oriented information processor. Rapid growth in commercial use of the Internet (and, more recently, Intranets) has accelerated this transformation. Operating systems have become more intuitive and user-friendly at the same time that employees have become more skilled at navigating computer systems. The convergence of these trends has transformed the computer from a task-oriented labour-saving device to an integral part of a firm's organisational structure. It is only in the PC era that computers are capable of enabling true information exchange throughout the value-adding process. Management innovations such as just-in-time manufacturing and decentralised management of operations, widely credited with improving the competitive position of firms, were infeasible before the PC era.



Where is the Productivity Boost?

How has aggregate labour productivity growth fared during the computer revolution? As Figure 2 shows, the answer is fairly poorly relative to the previous quarter century. Annual growth in US labour productivity in the non-farm business sector (which includes all sectors of the economy except agriculture, government, and household production) averaged approximately 2.8% from 1950 to 1970. It then slowed to 1.6% in the mainframe era (1970-83) and slowed further to 1.3% in the PC era (1983-present). Such small differences compounded over time result in huge differences in economic welfare, as measured by real per capita GDP. Sustained annual productivity growth of 2.8% allows real per capita GDP to double every 25 years, compared to about 55 years at a 1.3% growth rate.

Computers do not contribute to final output in the same way that machinery does.

Because the early phase of the computer revolution primarily involved substitution of computers for labour (and hence a reduction in the labour intensity of production), one might expect to see the largest effect of computer investment on labour productivity in the 1970s. However, labour productivity growth slowed considerably relative to the mid-1960s and then slowed further at the beginning of the 1980s. Economists generally agree that the oil shocks of 1973 and 1979, a slowdown in the rate of R&D performance, and a large influx of younger workers into the labour force all put downward pressure on the growth of labour productivity. But the fact that computers appear to have had little impact in counterbalancing these forces is still remarkable. (Labour productivity growth has recently shown considerable strength, rising from 0.2% in 1994 to nearly 2% in 1997, though part of this is almost certainly due to the fact that productivity growth generally increases during economic expansions.)

Even within the quarter century of low productivity growth since 1970, the link between computer investment and productivity is tenuous at best. Figure 3 plots the annual growth of labour productivity against the annual growth in the capital stock of computers for the years 1970-1996. If computers are really spurring measured productivity growth, then we should see a positive relationship in the scatter plot. There is not even a hint of such a relationship in the data.

An exception to the overall trend of slowing labour productivity growth is the manufacturing sector, which avoided much of the damage of the 1970s' productivity growth slowdown and actually underwent a renaissance after several difficult years in the late 1970s and early 1980s. Figure 4 shows the same information as Chart 2 for the US manufacturing sector, and clearly illustrates that the paradox of declining average labour productivity growth in an era of rapid

computer investment does not apply to US manufacturers—but nor is the productivity boost particularly large.

It is important to caution that measuring output in certain industries—particularly service industries—is notoriously difficult, especially when the quality of the output is changing. This makes gauging productivity growth extremely difficult. For example, automatic teller machines represent an extremely common form of computer investment which improved the quality of banking "output"—customers can do most of their routine banking 24 hours a day, seven days a week, without waiting in line. Internet and telephone banking now permit customers to do the same thing from the comfort of their own home. However, these obvious quality improvements provided by computer investment are not picked up in productivity data, because official measures of the banking industry's "output" cannot quantify them. If the quality of service-sector output is increasing more rapidly now than in the past, service-sector productivity growth may be faster than we think it is.

An alternative way to examine the impact of computer investment on the overall economy is to estimate its direct contribution to GDP growth. This can be done with the help of "growth accounting," which is based on the notion that growth in output is a weighted average of growth in labour and capital inputs. A recent analysis by Daniel Sichel and Stephen Oliner of the US Federal Reserve Board demonstrates that computer investment has contributed a relatively small share to overall GDP growth since 1970. A decomposition of US economic growth from 1970 to 1992 shows that accumulation of computers and peripheral equipment only contributed an average of 0.09 percentage points to the 3.42% annual GDP growth from 1970 to 1979 and 0.21 percentage points to the 2.27% annual growth from 1980 to 1992.

While this result might not be surprising given the small (but rapidly growing) share of computer equipment in the total capital stock, it must be interpreted carefully. The result overlooks the fact that investment in computer equipment is fundamentally different from other types of equipment investment. Computers do not contribute directly to final output in the same way that machinery does. They gather and manipulate information—an intermediate input that may enhance the efficient use of existing labour and capital resources. Thus, in a growth accounting analysis, some of labour and capital's contribution to overall growth may in fact be due to the effect of such information, which will understate the measured contribution of computer investment. Nevertheless, analysis of neither labour productivity growth nor GDP growth reveals the vaunted benefits of computer investment.

FIGURE 3
US Growth in Labour Productivity vs. Growth in Computer Capital Stock, 1970-1996

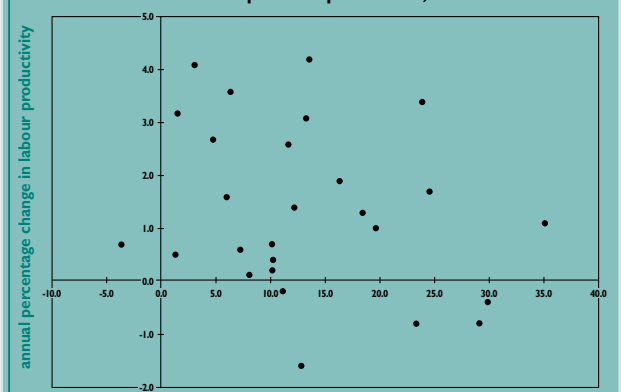
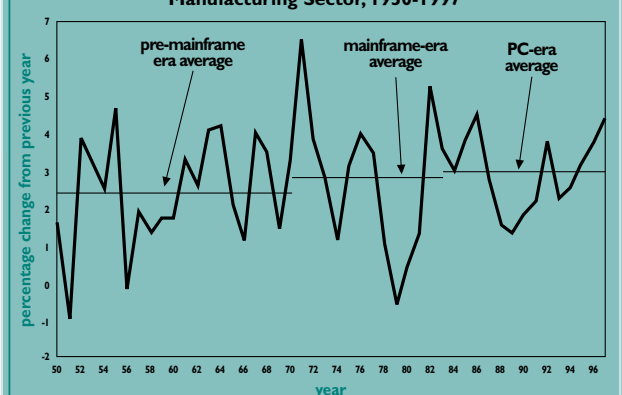


FIGURE 4
Annual Growth in US Labour Productivity, Manufacturing Sector, 1950-1997



Where Are the Benefits from Computers?

The paradox of computer investment's apparently negligible effect on labour productivity growth and GDP growth has baffled and troubled academic researchers. Thus, a very large research literature has blossomed, using a variety of approaches to measure the payoff to investment in computer technologies. The simplest way to approach this question is to compare various business tasks before and after computer systems are implemented. Numerous studies have examined the effectiveness of word processing relative to typing and computerised databases relative to paper card catalogues.

For word processing, a number of controlled experiments were done in the early 1980s to compare the cost of composing documents on word processors relative to the traditional method of writing a longhand draft to be typed by a secretary. The results were not encouraging: the total cost of the word processing was not appreciably lower than the traditional method. The primary reason was that relatively expensive professionals spent more time composing the letters using word processors, and more revisions were made with no appreciable increase in quality. These results do not indicate that word processors are not significant improvements over older technologies, only that the "wrong" people are using them. Studies of typing pools show that having professional typists switch from typewriters to word processors produces very large increases in efficiency.

On-line retrieval of bibliographic and reference information is another common task where computerisation holds considerable promise. Even though computers lack the selective intelligence of humans and have only crude contex-

tual-recognition capacity, they can retrieve information with tremendous speed and accuracy. A number of studies in the 1980s compared computerised database searches with the tried-and-true method of paging through reference books, and they suggest that on-line searches took anywhere from one-seventh to two-thirds as long as similar searches via traditional means. These studies generally ignore the fixed costs of the equipment and time required to create and maintain on-line databases, which would offset to some extent the time saving. These costs have likely dropped since the time the studies were undertaken.

Despite these payoffs from substituting on-line searches for hard-copy manual searches, few organisations have completely substituted one for the other. Most libraries have extensive on-line databases, but they also continue to maintain hard-copy reference materials, which is costly in terms of both subscription costs and distribution and storage costs. Furthermore, there is ample evidence that employees who perform on-line searches are more expensive than their card-catalogue predecessors, because of the additional computer skills required to do the work. Thus, the potential productivity gains from computerisation of text searches are currently much smaller than they could be. Of course, this is as much a function of peoples' willingness to adopt new ways of doing things as it is an "incomplete" exploitation of computer technology. But it is another illustration of why some commonly assumed benefits of computerisation have apparently not materialised.

These examples serve to illustrate that computers are powerful tools, but they can very easily be used in a less-than-optimal manner. By facilitating tasks such as document composition and layout and bibliographic searching for non-specialists, they can undermine the economic efficiencies that result from the pure specialisation of labour. It seems clear that workers whose tasks are aided by computers (such as secretaries and librarians) can and have exploited computer-based efficiency. But as computers become easier and easier to use, it also becomes possible for non-specialists to accomplish a large number of tasks once done by specialists. This possibility need not lead to improved efficiency and productivity.

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Cost-Effectiveness Studies

One way to examine more directly the impact of computer investment on business efficiency is by analysing its cost effectiveness. Economic theory predicts that a cost-minimising firm will continue investing up to the point at which the benefit from additional investment no longer exceeds its cost. As long as the benefits of additional computer investment exceed the benefits from investing such resources elsewhere, firms should continue to invest in computers. Beyond a certain threshold, benefits will diminish to the point that further computer investment is a losing proposition. As relative prices of inputs change, firms will substitute among different kinds of capital to keep costs minimised. This cost effectiveness can be encapsulated in a marginal benefit-cost ratio, which should equal one if firms are minimising costs.

A recent study by Catherine Morrison of the University of California at Davis examined this issue for 20 US manufacturing industries from 1972 to 1991. According to her results, the marginal costs of computer investment actually exceeded estimated marginal benefits between 1982 and 1987 (particularly in durable-goods industries), implying an over-investment in computer equipment. The pattern of over-investment continued into the 1987-91 period for durable-goods industries but disappeared in non-durable industries. In contrast, the data suggest that computer investment opportunities were so numerous in the 1972-76 period that manufacturers did not take advantage of all profitable projects—the benefit-cost ratios are greater than one. Benefit-cost ratios were very close to one during the 1977-81 period, suggesting close to optimal levels of computer investment.

Two primary observations are worth noting from these results. First, the decline in benefit-cost ratios over time suggests that the rapid growth in computer investment may have been too rapid from an economic perspective. Manufacturers appear to have exhausted the cost-saving potential of substituting away from traditional investment in machinery toward computers by the early 1980s—the end of the mainframe era. The PC era may have initially promised more than it could deliver, to the detriment of computer investment strategies. Second, the data end in 1991, thus omitting the many changes that have occurred in computing since then. The rise of the Internet, wide implementation of more intuitive graphical user interfaces, and continued declines in the cost of computer processing power are all believed to have increased the potential for computers to reduce business costs and increase efficiency, but their effects are not included in this analysis.

Quantifying the "Intangible" Benefits

A more comprehensive approach to examining the computer-productivity paradox is to estimate the impact of computer investment on productivity brought about by management innovations, corporate restructuring, and a host of other difficult-to-quantify factors. This measure of productivity is known in economic jargon as "total factor productivity" (TFP). TFP quantifies the growth in output that cannot be accounted for by physical increases in inputs. It is essentially the difference between actual observed growth in output less a weighted average of physical increases in inputs. Provided that physical inputs are measured relatively well, this catch-all residual variable should reflect intangible improvements in the quality of existing inputs and better use and management of those inputs—exactly the sorts of improvements that PC-era computer investments are intended to provide. Researchers have thus investigated the statistical relationship between TFP and computer investment.

The link between computer investment and total factor productivity varies depending on the time period studied. Most firm-level studies of the 1970s and

early 1980s show negligible, or even negative, relationships between computer investment and TFP growth. This holds true for just about every sector of the economy, with the notable exceptions of computer equipment manufacturing and telecommunications services. Some have argued that mismeasurement of productivity (particularly in the service sector) is hiding a strong positive effect, but there is scant evidence to support this claim. Mismeasured or not, TFP should increase if computer investment really does have a positive impact. Furthermore, the link between computer investment and TFP was weak during this period in the large majority of manufacturing industries, for which productivity and associated data are fairly reliable.

Firm-level studies of later periods, however, reveal a strong positive relationship between computer investment and TFP. The most recent is by Erik Brynjolfsson of the Sloan School of Management and Lorin Hitt of the Wharton School of Business. Their 1997 study examines a diverse group of 600 large US manufacturing and service companies from 1987 to 1994 and finds that a given amount of computer investment generates firm-level productivity gains from two to eight times greater than other kinds of investment. At current rates of investment, this implies that investment in computer equipment has probably added 0.25 to 0.5 percentage points to firm-level total factor productivity growth—a substantial amount considering that TFP growth of 2% per year is extremely high. Most of these gains arise from increased information flow that enables reorganisation of production in new and more efficient ways. This result corroborates considerable anecdotal evidence of the role of computers in improving inventory management, streamlining the supply chain, and a host of other business re-engineering initiatives. By examining computer investment over several years, Brynjolfsson and Hitt's work accounts for the fact that it may take companies several years to fully implement and take advantage of new computer systems. Indeed, the effect of computer investment in any given year on TFP strengthens as time goes by.

My own analysis of industry-level data for US manufacturers reveals a much less robust link between growth in TFP and computer investment. For many US manufacturing industries, I find a positive relationship between the level of computer intensity and total factor productivity (particularly in durable-goods industries such as fabricated metal products and industrial machinery) over the period 1970-1994. However, systematic links between year-to-year changes in the stock of computing equipment and changes in total factor productivity are not evident in the data. The contrast between my results and those of Brynjolfsson and Hitt strongly suggests that company-specific characteristics not captured by industry-level data—such as corporate willingness to adapt to new business processes and the ability to plan and implement computer systems effectively—are as important to the timing and magnitude of productivity gains as the investments themselves.

It appears that the benefits of business computerisation have at last begun to spread throughout the US economy, though there is much progress still to be made.

Conclusion

Based on the available evidence, it appears that the benefits of business computerisation have at last begun to spread throughout the US economy, though there is much progress still to be made. In the mainframe era, computers were especially well-suited for automating calculation-intensive tasks. However, the number of completely automatable tasks in a business enterprise is fairly limited—most important decisions regarding the structure of production require human judgement, for which computers of the time offered little assistance. The evidence suggests that many companies may have gone too far in automating processes during the 1970s.

The transition to desktop PCs and client-server-based environments ushered in an era in which computers gradually became capable of complementing rather than substituting for other inputs. By filtering information and disseminating it more widely across corporations and their suppliers and customers, computers began adding value both in terms of improved business processes and management and better product quality. Both anecdotal and quantitative evidence indicate that these benefits have strengthened in recent years.

Two favourable trends in computing have come together to help make the promised benefits of computers a reality. First, the price of computing power continues to drop rapidly, restraining end-user equipment costs even as the capabilities of the equipment multiply. Second, operating systems continue their evolution toward simpler, more intuitive interfaces at the same time that employees are becoming more accustomed to computerised environments. Computers that "think" more and more like humans, and humans that better understand the potential of computers, is what fundamentally underlies the computer-driven productivity gains seen in recent years. These benefits will continue as this mutual understanding evolves further.

Whether these trends herald a "new era of unprecedented prosperity" or the "end of the business cycle" is a much more difficult question to answer, largely because it is not yet possible to extrapolate a shift in trend productivity growth from the data of recent years. Many factors other than computer investment can affect productivity, and some of them, such as input prices and the degree of international competition, are currently favourable to strong productivity growth, but there is no reason that such a situation will persist indefinitely. Most careful studies of recent data in the United States suggest that computer investment has added at most 0.5 percentage points to annual productivity growth in recent years. This is a large amount to be sure, and there are strong reasons to believe that this benefit will persist. Nevertheless, it is not large enough or durable enough to support the contention that computer investment is the magic bullet which by itself will return us to growth rates experienced during the golden age of prosperity in the 25 years following the Second World War. ◆