

The Productivity Paradox of Information Technology: Review and Assessment

Erik Brynjolfsson

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Center for Coordination Science
MIT Sloan School of Management
Cambridge, Massachusetts

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Table of Contents

[The "Productivity Paradox" -- A Clash of Expectations and Statistics](#)

[Dimensions of the Paradox](#)

[Economy-wide Productivity and Information Worker Productivity](#)

[The Productivity of Information Technology Capital in Manufacturing](#)

[The Productivity of Information Technology Capital in Services](#)

[Four Explanations for the Paradox](#)

[Measurement Errors](#)

[Lags](#)

[Redistribution](#)

[Mismanagement](#)

[Conclusion](#)

[Summary](#)

[Where Do We Go From Here?](#)

[Acknowledgments](#)

[Tables and Graphs](#)

[Bibliography](#)

[Footnotes](#)

The "Productivity Paradox" -- A Clash of Expectations and Statistics

The relationship between information technology (IT) and productivity is widely discussed but little understood. Delivered computing-power in the US economy has increased by more than two orders of magnitude since 1970 (figure 1) yet productivity, especially in the service sector, seems to have stagnated (figure 2). Given the enormous promise of IT to usher in "the biggest technological revolution men have known" (Snow, 1966), disillusionment and even frustration with the technology is increasingly evident in statements like "No, computers do not boost productivity, at least not most of the time" (Economist, 1990).

The increased interest in the "productivity paradox," as it has become known, has engendered a significant amount of research, but, thus far, this has only deepened the mystery. Robert Solow, the Nobel Laureate economist, has aptly characterized the results: "we see computers everywhere except in the productivity statistics." Although similar conclusions are repeated by an alarming number of researchers in this area, we must be careful not to over interpret these findings; a shortfall of evidence is not necessarily evidence of a shortfall. In fact, many of the most widely cited aspects of the "paradox" do not stand up to closer scrutiny.

This article summarizes what we know and don't know, distinguishes the central issues from diversions, and clarifies the questions that can be profitably explored in future research. After reviewing and assessing the research to date, it appears that the shortfall of IT productivity is as much due to deficiencies in our measurement and methodological tool kit as to mismanagement by developers and users of IT.

The research considered in this review reflects the results of a computerized literature search of 30 of the leading journals in both information systems and economics^[1], as well as discussions with leading researchers in the field. In what follows, I have highlighted the key findings and essential research references.

Dimensions of the Paradox

Productivity is the fundamental economic measure of a technology's contribution. With this in mind, CEOs and line managers have increasingly begun to question their huge investments in computers and related technologies. While major success stories exist, so do equally impressive failures (see, for example (Kemerer & Sosa, 1990)). The lack of good quantitative measures for the output and value created by IT has made the MIS manager's job of justifying investments particularly difficult. Academics have had similar problems assessing the contributions of this critical new technology, and this has been generally interpreted as a negative signal of its value.

The disappointment in IT has been chronicled in articles disclosing broad negative correlations with economy-wide productivity and information worker productivity. Econometric estimates have also indicated low IT capital productivity in a variety of manufacturing and service industries. The principal empirical research studies of IT and productivity are listed in table 1.

Table 1: Principal Empirical Studies of IT and Productivity

Economy-wide -- or Cross-sector	Manufacturing	Services
(Osterman, 1986)	(Loveman, 1988)	(Cron & Sobol, 1983)
(Baily & Chakrabarti, 1988)	(Weill, 1990)	(Strassmann, 1990)
(Roach, 1989b)	(Morrison & Berndt, 1990)	(Baily, 1986a)
	(Barua, Kriebel & Mukhopadhyay, 1991)	(Franke, 1987)
	(Siegel & Griliches, 1991)	(Harris & Katz, 1989)
		(Alpar & Kim, 1990)
		(Parsons, Gotlieb & Denny, 1990)
		(Noyelle, 1990)
		(Roach, 1990)

Economy-wide Productivity and Information Worker Productivity

The Issue

One of the core issues for economists in the past decade has been the productivity slowdown that began in the early 1970s. Even after accounting for factors such as the oil price shocks, most researchers find that there is an unexplained residual drop in productivity as compared with the first half of the post-war period. The sharp drop in productivity roughly coincided with the rapid increase in the use of IT (figure 1). Although recent productivity growth has rebounded somewhat, especially in manufacturing, the overall negative correlation between economy-wide productivity and the advent of computers is behind many of the arguments that IT has not helped US productivity or even that IT investments have been counter-productive.

This link is made more directly in research by Roach (1991) focusing specifically on information workers, regardless of industry. While in the past, office work was not very capital intensive, recently the level of IT capital per ("white collar") information worker has begun approaching that of production capital per ("blue collar") production worker. Concurrently, the ranks of information workers have ballooned and the ranks of production workers have shrunk. Roach cites statistics indicating that output per production worker grew by 16.9% between the mid-1970s and 1986, while output per information worker decreased by 6.6%. He concludes: "We have in essence isolated America's productivity shortfall and shown it to be concentrated in that portion of the economy that is the largest employer of white-collar workers and the most heavily endowed with high-tech capital." Roach's analysis provides quantitative support for widespread reports of low office productivity.[\[2\]](#)

Comment

Upon closer examination, the alarming correlation between higher IT spending and lower productivity at the level of the entire US economy is not compelling because so many other factors affect productivity. Until recently, computers were not a major share of the economy. Consider the following order-of-magnitude estimates. Information technology capital stock is currently equal to about 10% of GNP. If, hypothetically, the return on IT investment were 20%, then current GNP would be directly increased about 2% ($10\% \times 20\%$) because of the existence of our current stock of IT. The 2% increase must be spread over about 30 years since that is how long it took us to reach the current level of IT stock. This works out to an average contribution to aggregate GNP growth of 0.06% in each year. Although this amounts to billions of dollars, it is very difficult to isolate in our five trillion dollar economy because so many other factors affect GNP. Indeed, if the marginal product of IT capital were anywhere from -20% to +40%, it would still not have affected aggregate GNP growth by more than about 0.1% per year.[\[3\]](#)

This is not to say that computers may not have had significant effects in specific areas, such as transaction processing, or on other characteristics of the economy, such as employment shares, organizational structure or product variety. Rather it suggests that very large changes in capital stock are needed to measurably affect total output under conventional

assumptions about typical rates of return. However, the growth in IT stock continues to be significant. At current growth rates, we should begin to notice changes at the level of aggregate GNP in the near future if computers are productive.

As for the apparent stagnation in white collar productivity, one should bear in mind that relative productivity cannot be directly inferred from the number of information workers per unit output. For instance, if a new delivery schedule optimizer allows a firm to substitute a clerk for two truckers, the increase in the number of white collar workers is evidence of an increase, not a decrease, in their relative productivity and in the firm's productivity as well. Osterman (1986) suggests that this is why clerical employment often increases after the introduction of computers and Berndt and Morrison (1991) confirm that IT capital is, on average, a complement for white collar labor even as it leads to fewer blue collar workers. Unfortunately, more direct measures of office worker productivity are exceedingly difficult. Because of the lack of hard evidence, Panko (1991) has gone so far as to call the idea of stagnant office worker productivity a myth, although he cites no evidence to the contrary.

A more direct case for weakness in IT's contribution comes from the explicit evaluation of IT capital productivity, typically by estimating the coefficients of a production function. This has been done in both manufacturing and service industries, as reviewed below.

The Productivity of Information Technology Capital in Manufacturing

The Issues

There have been at least five studies of IT productivity in the manufacturing sector, summarized in table 2.

A study by Loveman (1988) provided some of the first econometric evidence of a potential problem when he examined data from 60 business units. As is common in the productivity literature, he used ordinary least squares regression to estimate the parameters of a production function. Loveman estimated that the contribution of IT capital to output was approximately zero over the five year period studied in almost every subsample he examined. His findings were fairly robust to a number of variations on his basic formulation and underscore the paradox: while firms were demonstrating a voracious appetite for a rapidly-improving technology, measured productivity gains were insignificant.

Barua, Kriebel and Mukhopadhyay (1991) traced the causal chain back a step by looking at IT's effect on intermediate variables such as capacity utilization, inventory turnover, quality, relative price and new product introduction. Using the same data set, they found that IT was positively related to three of these five intermediate measures of performance, although the magnitude of the effect was generally too small to measurably affect return on assets or market share.

Using a different data set, Weill (1990) was also able to disaggregate IT by use, and found that significant productivity could be attributed to transactional types of IT (e.g. data

processing), but was unable to identify gains associated with strategic systems (e.g. sales support) or informational investments (e.g. email infrastructure).

Morrison and Berndt have written a paper using a broader data set from the US Bureau of Economic Analysis (BEA) that encompasses the whole U.S. manufacturing sector (Morrison & Berndt, 1990). It examined a series of highly parameterized models of production, found evidence that every dollar spent on IT delivered, on average, only about \$0.80 of value on the margin, indicating a general overinvestment in IT.

Finally, Siegel and Griliches (1991) used industry and establishment data from a variety of sources to examine several possible biases in conventional productivity estimates. Among their findings was a positive simple correlation between an industry's level of investment in computers and its multifactor productivity growth in the 1980s. They did not examine more structural approaches, in part because of troubling concerns they raised regarding the reliability of the data and government measurement techniques.

Table 2: Studies of IT in Manufacturing

Study	Data Source	Findings
(Loveman, 1988)	PIMS/MPIT	IT investments added nothing to output
(Weill, 1990)	Interviews and Surveys	Contextual variables affect IT performance
(Morrison & Berndt, 1990)	BEA	IT marginal benefit is 80 cents per dollar invested
(Barua, Kriebel & Mukhopadhyay, 1991)	PIMS/MPIT	IT improved intermediate outputs, if not necessarily final output
(Siegel & Griliches, 1991)	Multiple gov't sources	IT using industries tend to be more productive; government data is unreliable

Comment

All authors make a point of emphasizing the limitations of their respective data sets. The MPIT data, which both Loveman and Barua, Kriebel and Mukhopadhyay use, can be particularly unreliable. As the authors are careful to point out, the results are based on dollar denominated outputs and inputs, and therefore depend on price indices which may not accurately account for changes in quality or the competitive structure of the industry.

The BEA data may be somewhat more dependable but one of Siegel and Griliches' principal conclusions was that "after auditing the industry numbers, we found that a non-negligible number of sectors were not consistently defined over time." However, the generally reasonable estimates derived for the other, non-IT factors of production in each of the studies indicate that there may indeed be something worrisome, or at least special, about IT.

The Productivity of Information Technology Capital in Services

The Issues

It has been widely reported that most of the productivity slowdown is concentrated in the service sector (Roach, 1991). Before about 1970, service productivity growth was comparable to that in manufacturing, but since then the trends have diverged significantly. Meanwhile services have dramatically increased as a share of total employment and to a lesser extent, as a share of total output. Because services use over 80% IT, this has been taken as indirect evidence of poor IT productivity. The studies that have tried to assess IT productivity in the service sector are summarized in table 3.

One of the first studies of IT's impact was by Cron and Sobol (1983), who looked at a sample of wholesalers. They found that on average, IT's impact was not significant, but that it seemed to be associated with both very high and very low performers. This finding has engendered the hypothesis that IT tends to reinforce existing management approaches, helping well-organized firms succeed but only further confusing managers who haven't properly structured production in the first place.

Paul Strassmann also reports disappointing evidence in several studies. In particular, he found that there was no correlation between IT and return on investment in a sample of 38 service sector firms: some top performers invest heavily in IT, while some do not. In many of his studies, he used the same MPIT data set discussed above and had similar results. He concludes that "there is no relation between spending for computers, profits and productivity" (Strassmann, 1990).

Roach's widely cited research on white collar productivity, discussed above, focused principally on IT's dismal performance in the service sector (1991; 1989a). Roach argues that IT is an effectively used substitute for labor in most manufacturing industries, but has paradoxically been associated with bloating white-collar employment in services, especially finance. He attributes this to relatively keener competitive pressures in manufacturing and foresees a period of belt-tightening and restructuring in services as they also become subject to international competition.

There have been several studies of IT's impact on the performance of various types of financial services firms. A recent study by Parsons, Gottlieb and Denny (1990) estimated a production function for banking services in Canada and found that overall, the impact of IT on multifactor productivity was quite low between 1974 and 1987. They speculate that IT has positioned the industry for greater growth in the future. Similar conclusions are reached by Franke (1987), who found that IT was associated with a sharp drop in capital

productivity and stagnation in labor productivity, but remained optimistic about the future potential of IT, citing the long time lags associated with previous "technological transformations" such as the conversion to steam power.

Harris and Katz (1989) looked at data on the insurance industry from the Life Office Management Association Information Processing Database. They found a positive relationship between IT expense ratios and various performance ratios although at times the relationship was quite weak.

Alpar and Kim (1990) note that the methodology used to assess IT impacts can also significantly affect the results. They applied two approaches to the same data set. One approach was based on key ratios and the other used a cost function derived from microeconomic theory. They concluded that key ratios could be particularly misleading.

Table 3: Studies of IT in Services

Study	Data Source	Findings
(Cron & Sobol, 1983)	138 medical supply wholesalers	Bimodal distribution among high IT investors: either very good or very bad
(Strassmann, 1990)	Computerworld survey of 38 companies	No correlation between various IT ratios and performance measures
(Roach, 1991; Roach, 1989a)	Principally BLS, BEA	Vast increase in IT capital per information worker while measured output decreased
(Harris & Katz, 1989)	LOMA insurance data for 40	Weak positive relationship between IT and various performance ratios
(Noyelle, 1990)	US and French industry	Severe measurement Problems in services
(Alpar & Kim, 1990)	Federal Reserve Data	Performance estimates sensitive to methodology
(Parsons, Gotlieb & Denny, 1990)	Internal operating data from 2 large banks	IT coefficient in translog production function small and often negative

Comment

Measurement problems are even more acute in services than in manufacturing. In part, this arises because many service transactions are idiosyncratic, and therefore not subject to statistical aggregation. Unfortunately, even when abundant data exist, classifications sometimes seem arbitrary. For instance, in accordance with a fairly standard approach, Parsons, Gottlieb and Denny (1990) treated *time* deposits as inputs into the banking production function and *demand* deposits as outputs. The logic for such decisions is often difficult to fathom and subtle changes in deposit patterns or classification standards can have disproportionate impacts.

The importance of variables other than IT also becomes particularly apparent in some of the service sector studies. Cron and Sobol's finding of a bimodal distribution suggests that some variable was left out of the equation. Furthermore, researchers and consultants have increasingly emphasized the theme of re-engineering work when introducing major IT investments (Hammer, 1990). A frequently cited example is the success of the Batterymarch services firm. Batterymarch used IT to radically restructure the investment management process, rather than simply overlaying IT on existing processes.

In sum, while a number of the dimensions of the "IT productivity paradox" have been overstated, the question remains as to whether IT is having the positive impact expected. In particular, better measures of information worker productivity are needed, as are explanations for why IT capital hasn't clearly improved firm-level productivity in manufacturing and services. We now examine four basic approaches taken to answer these questions.

Four Explanations for the Paradox

Although it is too early to conclude that IT's productivity contribution has been subpar, a paradox remains in our inability to unequivocally document any contribution after so much effort. The various explanations that have been proposed can be grouped into four categories:

- 1) **Mismeasurement** of outputs and inputs,
- 2) **Lags** due to learning and adjustment,
- 3) **Redistribution** and dissipation of profits,
- 4) **Mismanagement** of information and technology.

The first two explanations point to shortcomings in research, not practice, as the root of the productivity paradox. It is possible that the benefits of IT investment are quite large, but that a proper index of its true impact has yet to be analyzed. *Traditional* measures of the relationship between inputs and outputs fail to account for *non-traditional* sources of value. Second, if significant lags between cost and benefit may exist, then short-term results look

poor but ultimately the pay-off will be proportionately larger. This would be the case if extensive learning, by both individuals and organizations, were needed to fully exploit IT, as it is for most radically new technologies.

A more pessimistic view is embodied in the other two explanations. They propose that there really are no major benefits, now or in the future, and seek to explain why managers would systematically continue to invest in IT. The redistribution argument suggests that those investing in the technology benefit privately but at the expense of others, so no net benefits show up at the aggregate level. The final type of explanation examined is that we have systematically mismanaged IT: there is something in its nature that leads firms or industries to invest in it when they shouldn't, to misallocate it, or to use it to create slack instead of productivity. Each of these four sets of hypotheses is assessed in turn below.

Measurement Errors

The Issues

The easiest explanation for the low measured productivity of IT is simply that we're not properly measuring output. Denison (1989) makes a wide-ranging case that productivity and output statistics can be very unreliable. Most economists would agree with the evidence presented by Gordon and Baily (1989), and Noyelle (1990) that the problems are particularly bad in service industries, which happen to own the majority of IT capital. It is important to note that measurement errors need not necessarily bias IT productivity if they exist in comparable magnitudes both before and after IT investments. However, the sorts of benefits ascribed by managers to IT -- increased quality, variety, customer service, speed and responsiveness -- are precisely the aspects of output measurement that are poorly accounted for in productivity statistics as well as in most firms' accounting numbers. This can lead to systematic underestimates of IT productivity.

The measurement problems are particularly acute for IT use in the service sector and among white collar workers. Since the null hypothesis that no improvement occurred wins by default when no *measured* improvement is found, it probably is not coincidental that service sector and information worker productivity is considered more of a problem than manufacturing and blue collar productivity, where measures are better.

a. Output Mismeasurement

When comparing two output levels, it is important to deflate the prices so they are in comparable "real" dollars. Accurate price adjustment should remove not only the effects of inflation but also adjust for any quality changes. Much of the measurement problem arises from the difficulty of developing accurate, quality-adjusted price deflators. Additional problems arise when new products or features are introduced. This is not only because they have no predecessors for direct comparison, but also because variety itself has value, and that can be nearly impossible to measure.

The positive impact of IT on variety and the negative impact of variety on measured productivity has been econometrically and theoretically supported by Brooke (1991). He

argues that lower costs of information processing have enabled companies to handle more products and more variations of existing products. However, the increased scope has been purchased at the cost of reduced economies of scale and has therefore resulted in higher unit costs of output. For example, if a clothing manufacturer chooses to produce more colors and sizes of shirts, which may have value to consumers, existing productivity measures rarely account for such value and will typically show higher "productivity" in a firm that produces a single color and size. Higher prices in industries with increasing product diversity is likely to be attributed to inflation, despite the real increase in value provided to consumers.

In services, the problem of unmeasured improvements can be even worse than in manufacturing. For instance, the convenience afforded by twenty-four hour ATMs is frequently cited as an unmeasured quality improvement. How much value has this contributed to banking customers? Government statistics implicitly assume it is all captured in the number of transactions, or worse, that output is a constant multiple of labor input!

In a case study of the finance, insurance and real estate sector, where computer usage and the numbers of information workers are particularly high, Baily and Gordon (1988) identified a number of practices by the Bureau of Economic Analysis (BEA) which tend to understate productivity growth. Their revisions add 2.3% per year to productivity between 1973 and 1987 in this sector.

b. Input Mismeasurement

If the quality of work life is improved by computer usage (less repetitive retyping, tedious tabulation and messy mimeos), then theory suggests that proportionately lower wages can be paid. Thus the slow growth in clerical wages may be compensated for by unmeasured improvements in work life that are not accounted for in government statistics.

A related measurement issue is how to measure IT stock itself. For any given amount of output, if the level of IT stock used is overestimated, then its unit productivity will appear to be less than it really is. Denison (1989) argues the government overstates the decline in the computer price deflator. If this is true, the "real" quantity of computers purchased recently is not as great as statistics show, while the "real" quantity purchased 20 years ago is higher. The net result is that much of the productivity improvement that the government attributes to the computer-producing industry, should be allocated to computer-using industries. Effectively, computer users have been "overcharged" for their recent computer investments in the government productivity calculations.

To the extent that complementary inputs, such as software, or training, are required to make investments in IT worthwhile, labor input may also be overestimated. Although spending on software and training yields benefits for several years, it is generally expensed in the same year that computers are purchased, artificially raising the short-term costs associated with computerization. In an era of annually rising investments, the subsequent benefits would be masked by the subsequent expensing of the next, larger, round of complementary inputs. On the other hand, IT purchases may also create long-term liabilities in software and

hardware maintenance that are not fully accounted for, leading to an underestimate of IT's impact on costs.

Comments

The closer one examines the data behind the studies of IT performance, the more it looks like mismeasurement is at the core of the "productivity paradox". Rapid innovation has made IT intensive industries particularly susceptible to the problems associated with measuring quality changes and valuing new products. The way productivity statistics are currently kept can lead to bizarre anomalies: to the extent that ATMs lead to fewer checks being written, they can actually lower productivity statistics. Increased variety, improved timeliness of delivery and personalized customer service are additional benefits that are poorly represented in productivity statistics. These are all qualities that are particularly likely to be enhanced by IT. Because information is intangible, increases in the implicit information content of products and services are likely to be under-reported compared to increases in materials content.

Nonetheless, some analysts remain skeptical that measurement problems can explain much of the slowdown. They point out that by many measures, service quality has gone down, not up. Furthermore, they question the value of variety when it takes the form of six dozen brands of breakfast cereal.

Lags

The Issues

A second explanation for the paradox is that the benefits from IT can take several years to show up on the bottom line.

The idea that new technologies may not have an immediate impact is a common one in business. For instance, a survey of executives suggested that many expected it to take at much as five years for IT investments to pay-off. This accords with a recent econometric study by Brynjolfsson et al. (1991a) which found lags of two to three years before the strongest organizational impacts of IT were felt. In general, while the benefits from investment in infrastructure can be large, they are indirect and often not immediate.

The existence of lags has some basis in theory. Because of its unusual complexity and novelty, firms and individual users of IT may require some experience before becoming proficient. According to models of learning-by-using, the optimal investment strategy sets short term marginal costs greater than short-term marginal benefits. This allows the firm to "ride" the learning curve and reap benefits analogous to economies of scale. If only short-term costs and benefits are measured, then it might appear that the investment was inefficient.

Comment

If managers are rationally accounting for lags, this explanation for low IT productivity growth is particularly optimistic. In the future, not only should we reap the then-current benefits of the technology, but also enough additional benefits to make up for the extra costs we are currently incurring.

Redistribution

The Issues

A third possible explanation is that IT may be beneficial to individual firms, but unproductive from the standpoint of the industry as a whole or the economy as a whole: IT rearranges the shares of the pie without making it any bigger.

There are several arguments for why redistribution may be more of a factor with IT investments than for other investments. For instance, IT may be used disproportionately for market research and marketing, activities which can be very beneficial to the firm while adding nothing to total output (Baily & Chakrabarti, 1988). Furthermore, economists have recognized for some time that, compared to other goods, information is particularly vulnerable to rent dissipation, in which one firm's gain comes entirely at the expense of others, instead of by creating new wealth. Advance knowledge of demand, supply, weather or other conditions that affect asset prices can be very profitable privately even without increasing total output. This will lead to excessive incentives for information gathering.

Comment

Unlike the other possible explanations, the redistribution hypothesis would not explain any shortfall in IT productivity at the firm-level: firms with inadequate IT budgets would lose market share and profits to high IT spenders. In this way, an analogy could be made to models of the costs and benefits of advertising. The recent popularity of "strategic information systems" designed to take profits from competitors rather than to lower costs may be illustrative of this thinking. On the other hand, the original impetus for much of the spending on EDP was administrative cost reduction. This is still the principal justification used in many firms.

Mismanagement

The Issues

A fourth possibility is that, on the whole, IT really is not productive at the firm level. The investments are made nevertheless because the decision-makers aren't acting in the interests of the firm. Instead, they are increasing their slack, building inefficient systems, or simply using outdated criteria for decision-making.

Many of the difficulties that researchers have in quantifying the benefits of IT would also affect managers. As a result, they may have difficulty in bringing the benefits to the bottom line if output targets, work organization and incentives are not appropriately adjusted. The

result is that IT might increase organizational slack instead of output or profits. This is consistent with arguments by Roach (1989a) that manufacturing has made better use of IT than has the service sector because manufacturing faces greater international competition, and thus tolerates less slack.

Sometimes the benefits do not even appear in the most direct measures of IT effectiveness. This stems not only from the intrinsic difficulty of system design and software engineering, but also because the rapidly-evolving technology leaves little time for time-tested principles to diffuse before being supplanted.

A related argument derives from evolutionary models of organizations. The difficulties in measuring the benefits of information and IT discussed above may also lead to the use of heuristics, rather than strict cost/benefit accounting to set levels of IT investments.^[4] Our current institutions, heuristics and management principles evolved largely in a world with little IT. The radical changes enabled by IT may make these institutions outdated. For instance, a valuable heuristic in 1960 might have been "get all readily available information before making a decision." The same heuristic today could lead to information overload and chaos (Thurow, 1987). Indeed, the rapid speed-up enabled by IT can create unanticipated bottlenecks at each human in the information processing chain. More money spent on IT won't help until these bottlenecks are addressed. Successful IT implementation process must not simply overlay new technology on old processes.

At a broader level, several researchers suggest that our currently low productivity levels are symptomatic of an economy in transition, in this case to the "information era" (David, 1989; Franke, 1987). For instance, David makes an analogy to the electrification of factories at the turn of the century. Major productivity gains did not occur for twenty years, when new factories were designed and built to take advantage of electricity's flexibility which enabled machines to be located based on work-flow efficiency, instead of proximity to waterwheels, steam-engines and powertransmitting shafts and rods.

Comments

While the idea of firms consistently making inefficient investments in IT is anathema to the neoclassical view of the firm as a profit-maximizer, it can be explained formally by models such as agency theory and evolutionary economics, which treat the firm as a more complex entity. The fact that firms continue to invest large sums in the technology suggests that the individuals within the firm that make investment decisions are getting some benefit or at least believe they are getting some benefit from IT.

In general, however, we do not yet have comprehensive models of the internal organization of the firm and researchers, at least in economics, are mostly silent on the sorts of inefficiency discussed in this section.

Conclusion

Summary

Research on IT and productivity has been disappointing, not only because it has only exacerbated apprehension about the ultimate value of billions of dollars of IT investment, but also because it has raised frustrating concerns with the measures and methods commonly used for productivity assessment. However, only by understanding the causes of the "productivity paradox", we can learn how to identify and remove the obstacles to higher productivity growth.

Section II presented a review of the principal empirical literature that engendered the term "productivity paradox" regarding poor IT performance. While a number of dimensions of the paradox are disturbing and provoking, we still do not have a definitive answer to the question of whether IT's productivity impact actually has been unusually low.

Section III focused on identifying explanations for a slightly redefined "paradox": Why have we been unable to document any productivity gains from IT thus far? The four principal hypotheses summarized in the adjoining sidebar.

- {Sidebar:} **Why Haven't Computers Measurably Improved Productivity?**
1. Measurement Error: Outputs (and inputs) of information-using industries are not being properly measured by conventional approaches.
 2. Lags: Time lags in the pay-offs to IT make analysis of current costs versus current benefits misleading.
 3. Redistribution: Information technology is especially likely to be used in redistributive activities among firms, making it privately beneficial without adding to total output.
 4. Mismanagement: The lack of explicit measures of the value of information make it particularly vulnerable to misallocation and overconsumption by managers.

It is common to focus only on the mismanagement explanation, but a closer examination of the principal studies and the underlying data underscores the possibility that measurement difficulties may account for the lion's share of the gap between our expectations for the technology and its apparent performance.

Where Do We Go From Here?

Even with substantive improvements in our research on IT and productivity, researchers must not overlook that fact that our tools are still blunt. Managers do not always recognize this and tend to give a great deal of weight to studies of IT and productivity. Because they are written for an academic audience, the studies themselves are usually careful to spell out the limitations of the data and methods, but sometimes only the surprising conclusions are

reported by the media. Because significant investment decisions are based on these conditions, researchers must be doubly careful to communicate the limitations as well.

Beyond Productivity and Productivity Measurement

While the focus of this paper has been on the productivity literature, in business-oriented journals a recurrent theme is the ideas that IT will not so much help us produce more of the same things as allow us to do entirely new things in new ways (Hammer, 1990; Malone & Rockart, 1991). For instance, Brooke (1991) makes a connection to greater variety but lower productivity as traditionally measured. The business transformation literature highlights how difficult and perhaps inappropriate it would be to try to translate the benefits of IT usage into quantifiable productivity measures of output. Intangibles such as better responsiveness to customers and increased coordination with suppliers do not always increase the amount or even intrinsic quality of output, but they do help make sure it arrives at the right time, at the right place, with the right attributes for each customer. Just as managers look beyond "productivity" for some of the benefits of IT, so must researchers be prepared to look beyond conventional productivity measurement techniques.

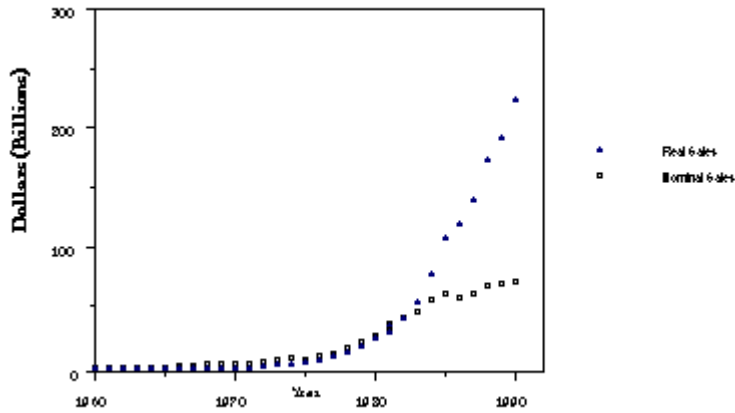
If the value of IT remains unproved, the one certainty is that the measurement problem is becoming more severe. Developed nations are devoting increasing shares of their economies to service- and information-intensive activities for which output measures are poor. The comparison of the emerging "information age" to the industrial revolution has prompted a new approach to management accounting (Kaplan, 1989). A review of the IT productivity research indicates an analogous opportunity to rethink the way we measure productivity and output.

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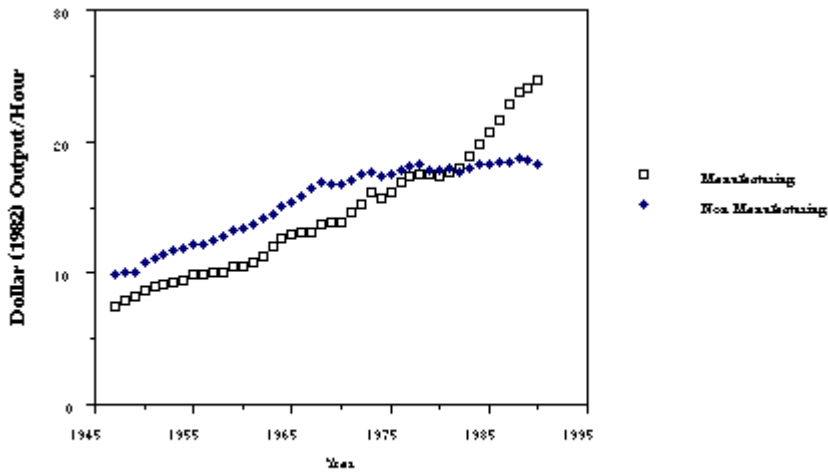
Tables and Graphs

Figure 1 -- Real Purchases of Computers Continue to Rise.



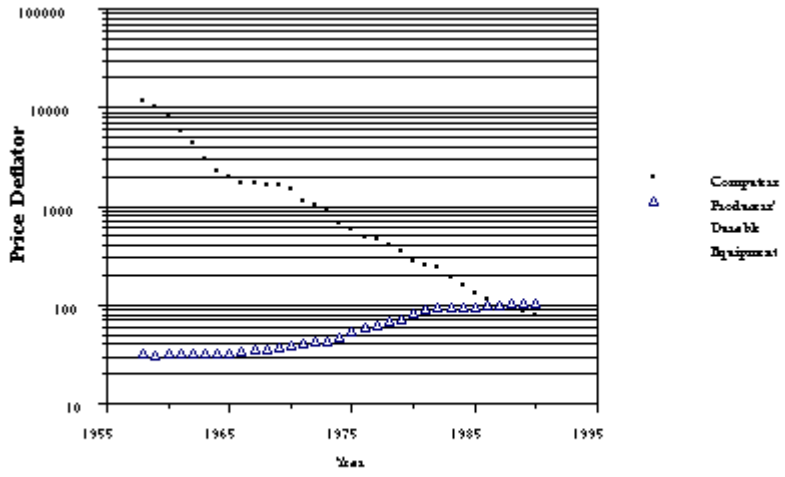
Source: Commerce Department Census of Shipments, Inventories, & Orders using BEA deflators. (Data for 1991 are estimates).

Figure 2 -- Productivity in the service sector has not kept pace with that in manufacturing.



Based on data from [Bureau of Labor Statistics, Productivity & Testing]
 { 1990 Data is prepublication }

Figure 3a -- The cost of computing has declined substantially relative to other capital purchases.

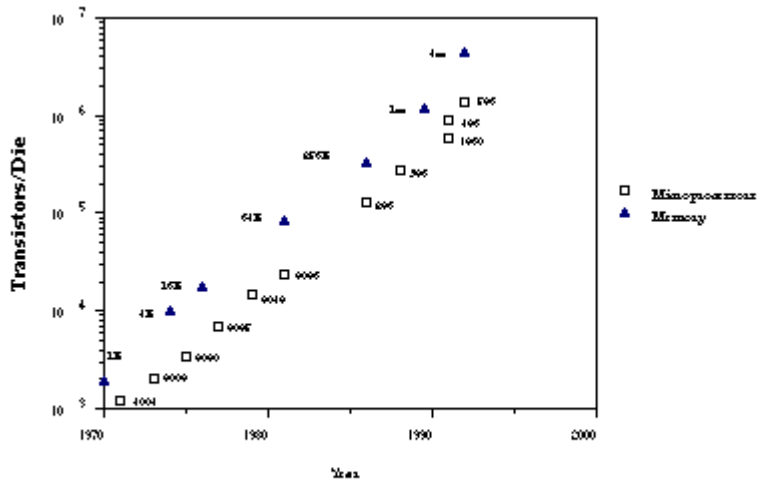


Based on data from [U.S.]

]

{1990 Data is prepublication}

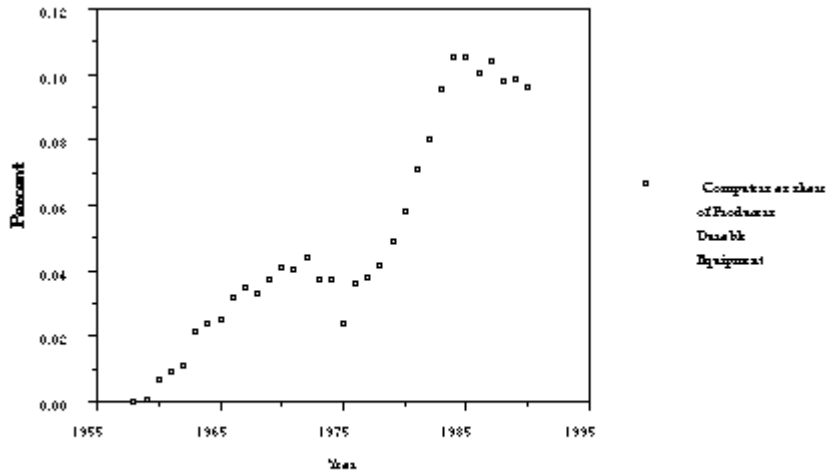
Figure 3b -- Microchip performance has shown uninterrupted exponential growth.



and data provided by Intel

Adapted from [Grove, 1990]

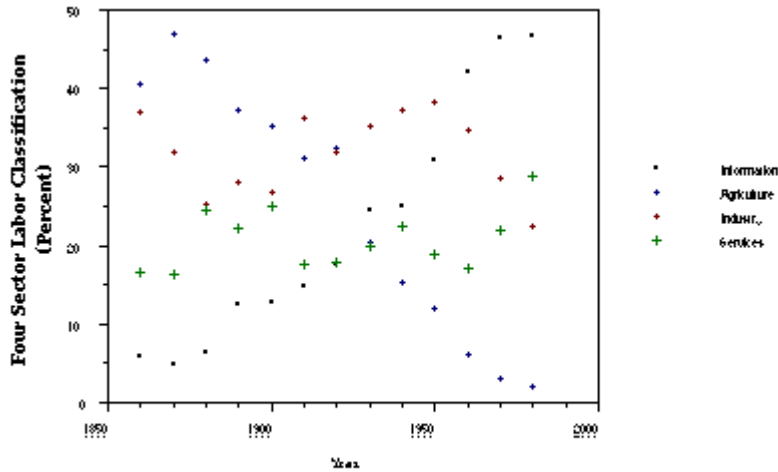
Figure 4 -- Computer hardware comprises about 10% of investment in Producers' Durable Equipment



Based on data from [BEA, National Income and Wealth Division]

{ 1990 Data is prepublication }

Figure 5 -- Information work is the largest category of employment.



Source: [Porat, 1977]

The defining criterion for information workers is whether the primary activity is knowledge creation, warehousing, or dissemination.

Figure 6 -- White collar productivity appears to have stagnated.



Source: [Roach, 1991]

{Sidebar} Defining the Paradox: Some Key Terms

- *Information Technology* can be defined in various ways. Among the most common is the category "Office, Computing and Accounting Machinery" of the US Bureau of Economic Analysis (BEA) which consists primarily of computers. Some researchers use definitions that also include communications equipment, instruments, photocopiers and related equipment, and software and related services.
- *Output* is defined as the number of units produced times their unit value, proxied by their "real" price. Establishing the real price of a good or service requires the calculation of individual price "deflators" that eliminate the effects of inflation without ignoring quality changes.
- *Labor productivity* is calculated as the level of output divided by a given level of labor input.
- *Multifactor productivity* (sometimes more ambitiously called "total factor productivity") is calculated as the level of output for a given level of several inputs, typically labor, capital and materials. In principle, multifactor productivity is a better guide to the efficiency of a firm or industry because it adjusts for shifts among inputs, such as an increase in capital intensity, but lack of data can make this consideration moot.

{Sidebar} Plotting the Paradox: Some Key Trends

- The price of computing has dropped by half every 2-3 years (figure 3a and figure 3b). If progress in the rest of the economy had matched progress in the computer sector, a Cadillac would cost \$4.98, while ten minutes' labor would buy a year's worth of groceries.¹
- There have been increasing levels of business investment in IT equipment. These investments now account for over 10% of new investment in capital equipment by American firms (figure 4).
- Information processing continues to be the principal task undertaken by America's work force. Over half the labor force is employed in information-handling activities.
- Overall productivity growth has slowed significantly since the early 1970s and measured productivity growth has fallen especially sharply in the service sector, which consumes over 80% of IT (figure 2).
- Information work is the largest category of employment (figure 5), yet white collar productivity statistics have been essentially stagnant for 20 years. (figure 6)

[5](After first point of "{Sidebar} Plotting the Paradox: Some Key Trends.")

Bibliography

- Alpar, P. and Kim, M. A Comparison of Approaches to the Measurement of IT Value. *In Proceedings of the Twenty-Second Hawaii International Conference on System Science* (1990, Honolulu, HI).
- Baily, M. and Chakrabarti, A. Electronics and White-Collar Productivity in *Innovation and the Productivity Crisis*, Brookings, Washington, 1988.
- Baily, M.N. Taming the Information Monster. *Bell Atlantic Quarterly*, Summer (1986a).
- Baily, M.N. and Gordon, R.J. The Productivity Slowdown, Measurement Issues, and the Explosion of Computer Power in *Brookings Papers on Economic Activity*, W. C. Brainard, & G. L. Perry. The Brookings Institution, Washington, DC, 1988.
- Barua, A., Kriebel, C. and Mukhopadhyay, T. *Information Technology and Business Value: An Analytic and Empirical Investigation*. Univ. of Texas, Austin Working Paper, (May 1991).
- Berndt, E.R. and Morrison, C.J. *High-Tech Capital, Economic and Labor Composition in U.S. Manufacturing Industries: an Exploratory Analysis*. National Bureau of Economic Research Manuscript, (April 24, 1991).
- Brooke, G. *Information Technology and Productivity: An Economic Analysis of the Effects of Product Differentiation*, PhD Thesis, University of Minnesota, 1991.
- Brynjolfsson, E., Malone, T., Gurbaxani, V., et al. *Does Information Technology Lead to Smaller Firms?* MIT, Center Coordination Science Technical Report #123, (September, 1991a).
- Clemons, E.K. Evaluation of Strategic Investments in Information Technology. *Communications of the ACM* Vol. 34, No. 1 (1991), pp. 22-36.
- Cron, W.L. and Sobol, M.G. The Relationship Between Computerization and Performance: A Strategy for Maximizing the Economic Benefits of Computerization. *Journal of Information and Management* Vol. 6, (1983), pp. 171-181.
- David, P.A. *Computer and Dynamo: The Modern Productivity Paradox in a Not-Too-Distant Mirror*. Center for Economic Policy Research, Stanford, CA, (1989).
- Denison, E.F. *Estimates of Productivity Change by Industry, an Evaluation and an Alternative*. The Brookings Institution, Washington, DC, 1989.
- Economist*. (1990) "Working Harder, Doing Less", p. 17.

Franke, R.H. Technological Revolution and Productivity Decline: Computer Introduction in the Financial Industry. *Technological Forecasting and Social Change*, Vol. 31, (1987).

Gordon, R.J. and Baily, M.N. Measurement Issues and the Productivity Slowdown in Five Major Industrial Countries. *International Seminar on Science, Technology, and Economic Growth* (1989, Paris).

Hammer, M. Reengineering Work: Don't Automate, Obliterate. *Harvard Business Review*, July August (1990), pp. 104-112.

Harris, S.E. and Katz, J.L. Predicting Organizational Performance Using Information Technology Managerial Control Ratios. *In Proceedings of the Twenty-Second Hawaii International Conference on System Science* (1989, Honolulu, HI).

Kaplan, R. Management Accounting for Advanced Technological Environments. *Science*, Vol. 245, September (1989), pp. 819-823.

Kemerer, C.F. and Sosa, G.L. *Systems Development Risks in Strategic Information Systems* . CISR/Sloan Working Paper, (May, 1990).

Loveman, G.W. *An Assessment of the Productivity Impact on Information Technologies* . MIT Management in the 1990s Working Paper #88-054, (July, 1988).

Malone, T. and Rockart, J. Computers, Networks and the Corporation. *Scientific American*, Vol. 265, No. 3 (1991), pp. 128-136.

Morrison, C.J. and Berndt, E.R. *Assessing the Productivity of Information Technology Equipment in the U.S. Manufacturing Industries* . National Bureau of Economic Research Working Paper #3582, (January, 1990).

Noyelle, T. (Ed.), *Skills, Wages, and Productivity in the Service Sector.*, Boulder, Colorado: Westview Press, 1990.

Osterman, P. The Impact of Computers on the Employment of Clerks and Managers. *Industrial and Labor Relations Review*, Vol. 39, (1986), pp. 175-186.

Panko, R.R. Is Office Productivity Stagnant? *MIS Quarterly*, June (1991), 190-203.

Parsons, D.J., Gotlieb, C.C. and Denny, M. *Productivity and Computers in Canadian Banking* . University of Toronto Dept. of Economics Working Paper #9012, (June, 1990).

Roach, S.S. Services Under Siege - The Restructuring Imperative. *Harvard Business Review*, September-October (1991), pp. 82-92.

Roach, S.S. *Pitfalls of the 'New' Assembly Line: Can Services Learn From Manufacturing?* Morgan Stanley Special Economic Study, New York, (June 22, 1989a).

Roach, S.S. America's White-collar Productivity Dilemma. *Manufacturing Engineering*, August (1989b), pp. 104.

Siegel, D. and Griliches, Z. *Purchased Services, Outsourcing, Computers and Productivity in Manufacturing*. National Bureau of Economic Research WP#3678, (April, 1991).

Snow, C.P. Government Science and Public Policy. *Science*, Vol. 151, (1966), pp. 650-653.

Strassmann, P.A. *The Business Value of Computers*. Information Economics Press, New Canaan, Conn, 1990.

Thurow, L. Economic Paradigms and Slow American Productivity Growth. *Eastern Economic Journal*, Vol. 13, (1987), pp. 333-343.

Weill, P. *Do Computers Pay Off?* ICIT Press, Washington, D.C., 1990.

Footnotes

[1] The journals searched included *Communications of the ACM, Database, Datamation, Decision Sciences, Harvard Business Review, IEEE Spectrum, IEEE Transactions on Engineering Management, IEEE Transactions on Software Engineering, Information & Management, Interfaces, Journal of Systems Management, Management Science, MIS Quarterly, Operations Research, Sloan Management Review, American Economic Review, Bell (Rand) Journal of Economics, Brookings Papers on Economics and Accounting, Econometrica, Economic Development Review, Economica, Economics Journal, Economist (Netherlands), Information Economics & Policy, International Economics Review, and the Journal of Business Finance*. Articles were selected if they indicated an emphasis on computers, information systems, information technology, decision support systems, expert systems, or high technology combined with an emphasis on productivity. A longer version of this paper, including comprehensive bibliography of articles in this area is available from the author.

[2] For instance, Lester Thurow has noted that "the American factory works, the American office doesn't", citing examples from the auto industry indicating that Japanese managers are able to get more output from blue collar workers (even in American plants) with up to 40% fewer managers.

[3] In dollar terms, each white collar worker is endowed with about \$10,000 in IT capital, which at a 20% ROI, would increase his or her total output about by about \$2000 per year as compared with pre-computer levels of output. Compare to the \$100,000 or so in salary and overhead that it costs to employ this worker and the expectations for a technological "silver bullet" seem rather ambitious.

[4] Indeed, a recent review of the techniques used by major companies to justify IT investments revealed surprisingly little formal analysis. See Clemons (1991) for an assessment of the IT justification process.

[5] This comparison was inspired by the slightly exaggerated claim in Forbes, (1980), that "If the auto industry had done what the computer industry has done, ... a Rolls-Royce would cost \$2.50 and get 2,000,000 miles to the gallon."