THE PRODUCTIVITY PARADOX OF INFORMATION TECHNOLOGY

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The relationship between information technology (IT) and productivity is widely discussed but little understood. Delivered computing power in the U.S. 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" [29], 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" [13].

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. The Nobel Laureate economist Robert Solow has cleverly 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 overinterpret these findings; a shortfall of evidence is not necessarily evidence of a shortfall. Furthermore, recent work [7] suggests that the return to IT spending may in fact be much higher than previously estimated.

This article summarizes what we know and do not 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 article reflects the results of a computerized literature search of 30 of the leading journals in both information systems (IS) and economics (see sidebar for a comprehensive list of literature searched), as well as discussions with leading researchers in the field. In what follows, the key findings and essential research references are highlighted and discussed.

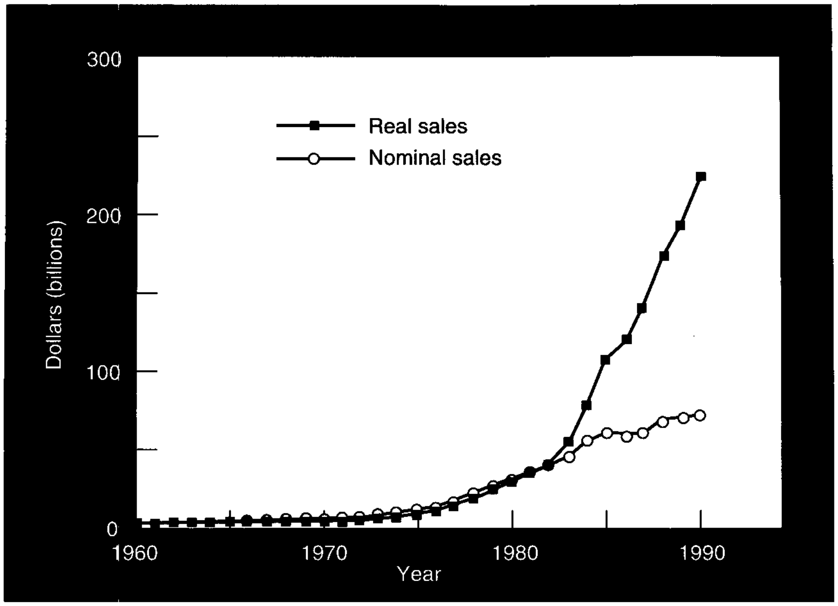
Dimensions of the Paradox

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 [18]). 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.

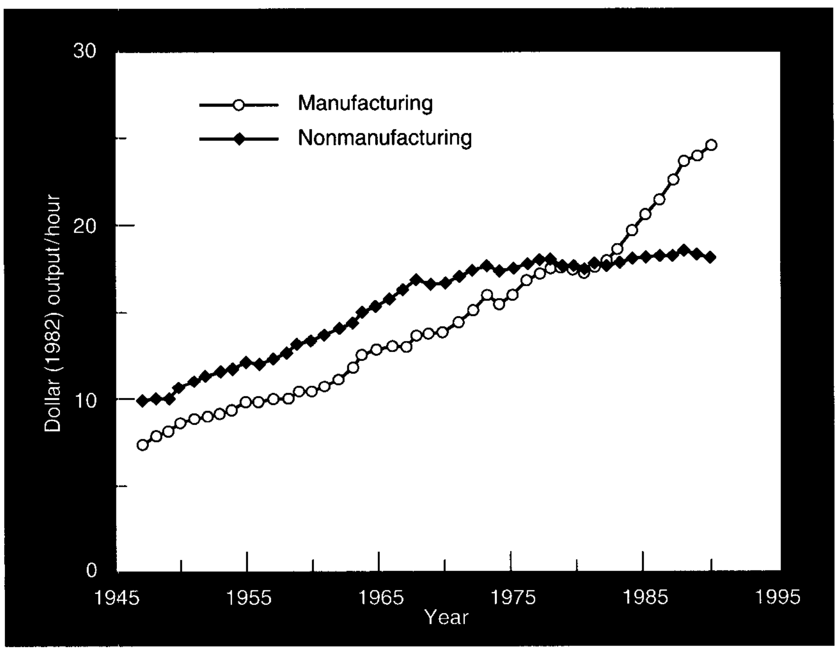
The disappointment in IT has been chronicled in articles disclosing broad negative correlations with economywide productivity and information worker productivity. Econometric estimates have also indicated low IT capital productivity in a variety of manufacturing and service industries. The principal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

Economywide Productivity and the Information Worker

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 changing oil prices, most researchers find there is an unexplained residual drop in productivity as compared with the first half of the postwar 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 econ-



Based on data from Bureau of Labor Statistics, Productivity and Testing (1990 Data is prepublication.)



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

Figure 1. Real purchases of computers continue to rise

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

omywide productivity and the advent of computers is the basis for many of the arguments that IT has not helped U.S. productivity or even that IT investments have been counterproductive.

This link is made more directly in research by Roach [27] 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.[1]

Comment. On closer examination, the alarming correlation between higher IT spending and lower productivity at the level of the entire U.S. 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. IT 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% × 20%) because of the existence of the current stock of IT. The 2% increase must be spread over about 30 years, since that is how long it took 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.[2]

This is not to say that computers may not have had significant effects in specific areas, such as transaction

[1]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.

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. The growth in IT stock, however, continues to be significant. At current growth rates, changes at the level of aggregate GNP should be apparent in the near future if computers increase productivity.

As for the apparent stagnation in white-collar productivity, one should keep 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 [23] suggests this is why clerical employment increased in the 1970s after the introduction of computers and Berndt and Morrison [5] 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 [24] 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 the contribution of IT 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 in the following subsections.

The Productivity of IT Capital in Manufacturing

The Issues. There have been at least six studies of IT productivity in the manufacturing sector, summarized in Table 2. A study by Loveman [19] 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 et al. [4] traced the causal chain back a step by looking at the effect of IT 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

List of Literature Searched

Literature 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, DSS, ES, or high technology combined with an emphasis on productivity. A longer version of this article, including a more comprehensive bibliography of articles in this area is available from the author—see "About the Author" for contact information.

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 U.S. 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.

[2] In dollar terms, each white-collar worker is endowed with about $10,000 in IT capital, which at a 20% return on investment (ROI), would increase his or her total output by about $2,000 per year as compared with precomputer 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.

small to measurably affect return on assets or market share.

Using a different data set, Weill [32] 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 U.S. Bureau of Economic Analysis (BEA) that encompasses the whole U.S. manufacturing sector [21]. They examined a series of highly parameterized models of production in their paper, 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 [28] 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.

Most recently, a study of 380 large firms between 1987 and 1991 (over 1,000 observations in all) was completed by Brynjolfsson and Hitt [7]. Using essentially the same methodology as used by Loveman and by Berndt and Morrison, they found the return on investment for IT capital was over 50% per year and the return to spending on IS labor was also very high.

Comment. All authors make a point of emphasizing the limitations of their respective data sets. The MPIT data, used by both [4] and [19], can be particularly unreliable.

The BEA data may be somewhat more dependable, but one of the principal conclusions of Siegel and Griliches [28] was that "after auditing the industry numbers, we found that a nonnegligible number of sectors were not consistently defined over time."

The importance of data quality is underscored by the fact that different estimates of the contribution of IT were obtained when different data sets were used. Indeed, Brynjolfsson and Hitt [7] attribute the statistical significance of their findings not only the more recent time period of their data, but also to larger size of their data set, which enable them to estimate returns for all factors with greater precision.

However, the generally reasonable estimates derived for the other, non-IT factors of production in all of the studies indicate that there may indeed be something worrisome, or at least special, about IT.

Table 1. Principal Empirical Studies of IT and Productivity

Economywide or Cross-sector	Manufacturing	Services
Osterman [23]	Loveman [19]	Cron and Sobol [10]
Baily and Chakrabarti [2]	Weill [32]	Strassman [30]
Roach [26]	Morrison and Berndt [21]	
Brooke [6]	Barua et al. [4]	Franke [14]
	Siegel and Griliches [28]	Harris and Katz [16]
	Brynjolfsson and Hitt [7]	Alpar and Kim [1]
		Parsons et al. [25]
		Noyelle [22]
		Roach [27]
		Brynjolfsson and Hitt [7]

The Productivity of IT Capital in Services

The Issues. It has been widely reported that most of the productivity slowdown is concentrated in the service sector [27]. 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 the impact of IT was performed by Cron and Sobol [10], 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 have not properly structured production in the first place.

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 previously and had similar results. He concludes that "there is no relation between spending for computers, profits and productivity" [30].

Roach's widely cited research on white-collar productivity, discussed previously, focused principally on the dismal performance of IT in the service sector [27]. 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 the impact of IT on the performance of various types of financial services firms. A recent study by Parsons, Gottlieb and Denny [25] 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 [14], 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 [16] 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 [1] 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.

Using a standard production function approach, Brynjolfsson and Hitt

Table 2. Studies of IT in Manufacturing

Study	Data source	Findings
Loveman [19]	PIMS/MPIT	IT investments added nothing to output
Weill [32]	Interviews and Surveys	Contextual variables affect IT performance
Morrison and Berndt [21]	BEA	IT marginal benefit is just 80 cents per dollar invested
Barua et al. [4]	PIMS/MPIT	IT improved intermediate outputs, if not necessarily final output
Siegal and Griliches [28]	Multiple gov't. sources	IT = using industries tend to be more productive; government data is unreliable
Brynjolfsson and Hitt [7]	IDG; Compustat; BEA	The return on investments in IT capital is over 50% per year in manufacturing

Table 3. Studies of IT in Services

Study	Data source	Findings
Cron and Sobol [10]	138 medical supply wholesalers	Bimodal distribution among high IT investors: either very good or very bad
Strassman [30]	Computerworld survey of 38 companies	No correlation between various IT ratios and performance measures
Roach [27]	Principally BLS, BEA	Vast increase in IT capital per information worker while measured output decreased
Harris and Katz [16]	LOMA insurance data for 40	Weak positive relationship between IT and various performance ratios
Noyelle [22]	U.S. and French industry	Severe measurement problems in services
Alpar and Kim [1]	Federal Reserve Data	Performance estimates sensitive to methodology
Parsons et al. [25]	Internal operating data from 2 large banks	IT coefficient in translog production function small and often negative
Brynjolfsson and Hitt [7]	IDG; Compustat; BEA	The return on IT investments is over 60% per year in services

[7] found that for the service firms in their sample, return on investment averaged over 60% per year.

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 et al. [25] 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 effects.

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 [10]. Furthermore, researchers and consultants have increasingly emphasized the theme of reengineering work when introducing major IT investments [15]. 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 has not clearly improved firm-level productivity in manufacturing and services. We now examine four basic approaches taken to answer these questions.

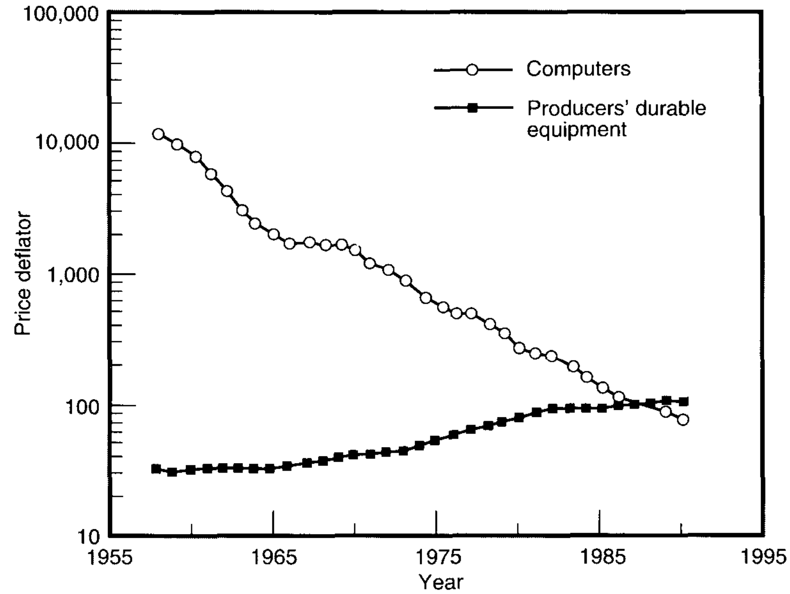
Four Explanations for the Paradox

Although it is too early to conclude that the productivity contribution of IT has been subpar, a paradox remains in the difficulty of unequivocally documenting any contribution,

Plotting the Paradox: Some Key Trends

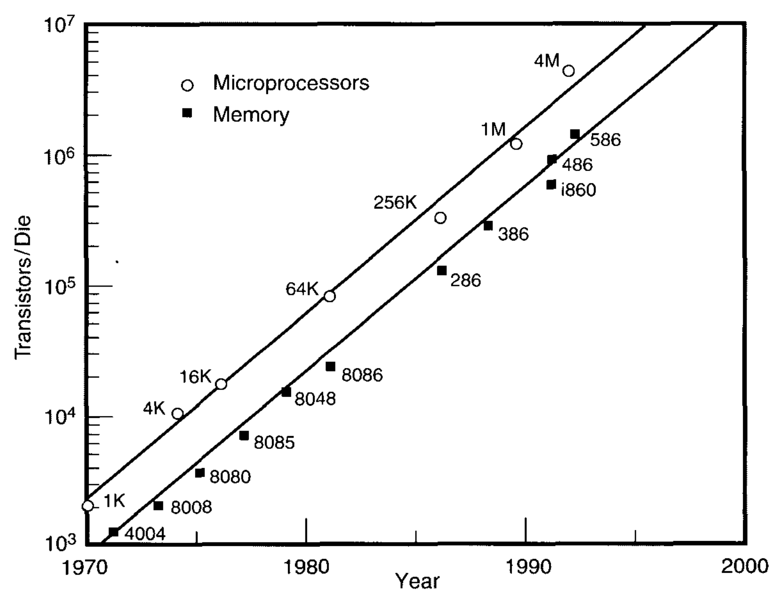
The price of computing has dropped by half every 2 to 3 years (Figure 3a and Figure 3b). If progress in the rest of the economy had matched progress in the computer sector, a Cadillac would cost $4.98, while 10 minutes' worth of labor would buy a year's worth of groceries.*

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 U.S. firms (Figure 4). Information processing continues to be the principal task undertaken by the U.S. work force. Over half the labor force is



Based on data from U.S. Department of Commerce, Survey of Current Business (1990 Data is prepublication.)

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



Data provided by Intel

Figure 3b. Microchip performance has shown uninterrupted exponential growth 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). White-collar productivity statistics have been essentially stagnant for 20 years (Figure 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 million miles to the gallon."

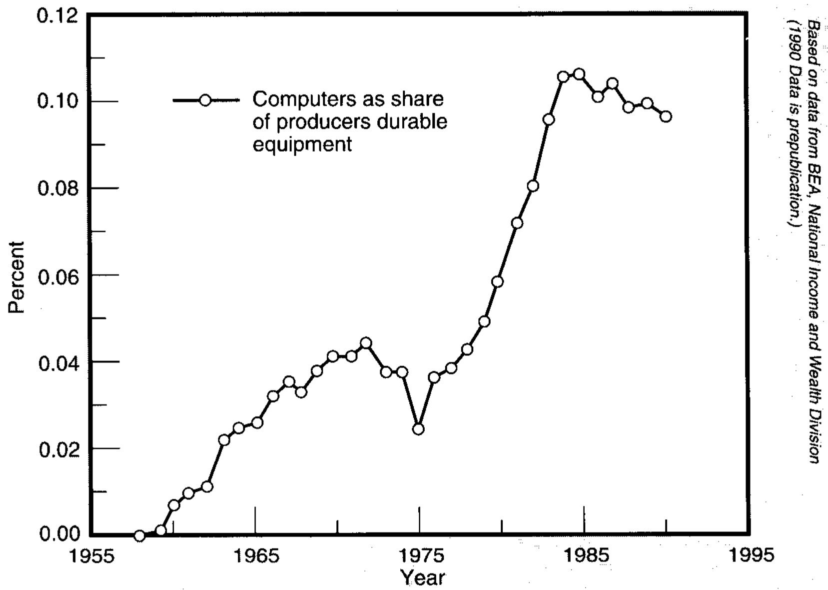


Figure 4. Computer hardware comprises about 10% of investment in producers' durable equipment

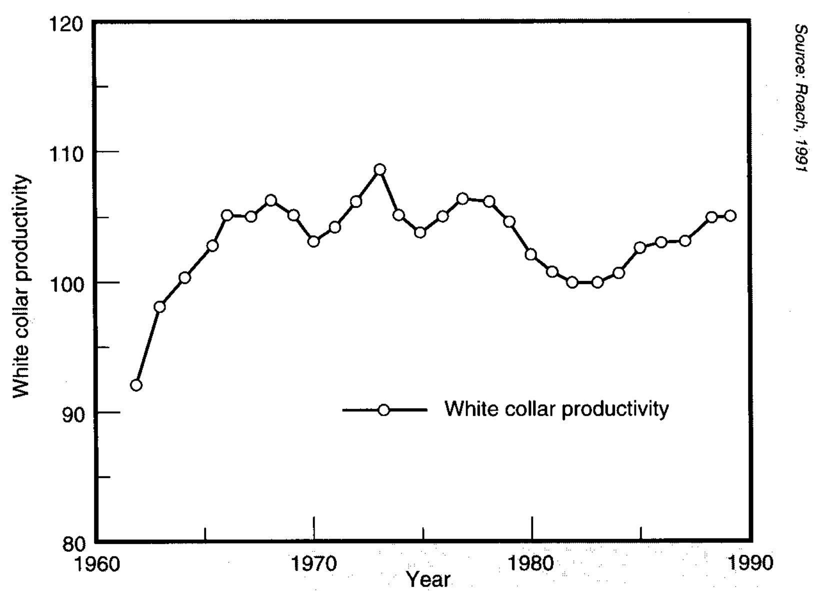


Figure 5. White collar productivity appears to have stagnated

even 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 *nontraditional* sources of value. Second, if significant lags between cost and benefit may exist, then short-term results look poor but ultimately the payoff 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 should not, to misallocate it, or to use it to create slack instead of productivity. Each of these four sets of hypotheses is assessed in the following subsections.

Measurement Errors

The Issues. The easiest explanation for the low measured productivity of IT is simply that output is not being measured correctly. Denison [12] makes a wide-ranging case that productivity and output statistics can be very unreliable. Most economists would agree with the evidence presented by [3], and [22] 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 types of benefits managers attribute 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 [7]. 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.

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 [6]. He argues that lower costs of information processing have enabled companies to handle more products and more variations of existing products. The increased scope has been purchased at the cost of reduced economies of scale, however, 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 24-hour automatic teller machines (ATMs) is a clear example of 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 [3] 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.

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 [12] 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 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 the impact of IT 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 underreported 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 results, 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. [8] 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 [2]. 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 electronic data processing (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 are not 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 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 [27] 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 previously may also lead to the use of heuristics, rather than strict cost/benefit accounting to set levels of IT investments.[3] 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 [31]. Indeed, the rapid speedup enabled by IT can create unanticipated bottlenecks at each human in the information processing chain. More money spent on IT will not 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" [11, 14]. For instance, David [11] makes an analogy to the electrification of factories at the turn of the century. Major productivity gains did not

[3] Indeed, a recent review of the techniques used by major companies to justify IT investments revealed surprisingly little formal analysis. See [9] for an assessment of the IT justification process.

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 payoffs to IT make analysis of current costs vs. current benefits misleading.
3. *Redistribution:* It is especially likely that IT is 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 makes it particularly vulnerable to misallocation and overconsumption by managers.

occur for 20 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 power-transmitting 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

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. Only by understanding the causes of the "productivity paradox" can we learn how to identify and remove the obstacles to higher productivity growth.

The section "Dimensions of the Paradox" 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 the productivity impact of IT has actually been unusually low. The section "Four Explanations for the Paradox" focused on identifying explanations for a slightly redefined "paradox": Why has it been so difficult to unambiguously document productivity gains from IT thus far? The four principal hypotheses are summarized in the sidebar "Why Haven't Computers Measurably Improved Productivity?" 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. Indeed, the study with the largest and most detailed data set [7] found *no* productivity shortfall.

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 emphasis 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.

While the focus of this article has been on the productivity literature, in business-oriented publications 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 [15, 20]. For instance, [6] 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 has not yet been widely documented—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 [17]. A review of the IT productivity research indicates an analogous opportunity to rethink the way productivity and output are measured.

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