

THE PRODUCTIVITY OF INFORMATION
TECHNOLOGY:
Review and Assessment

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Abstract

Productivity is the bottom line for any investment. The quandary of information technology (IT) is that, despite astonishing improvements in the underlying capabilities of the computer, its productivity has proven almost impossible to assess. There is an increasing perception that IT has not lived up to its promise, fueled in part by the fact that the existing empirical literature on IT productivity generally has not identified significant productivity improvements. However, a careful review, whether at the level of the economy as a whole, among information workers, or in specific manufacturing and service industries, indicates that the evidence must still be considered inconclusive. It is premature to surmise that computers have been a paradoxically unwise investment. A puzzle remains in the inability of both academics and managers to document unambiguously the performance effects of IT. Four possible explanations are reviewed in turn: mismeasurement, lags, redistribution and mismanagement. The paper concludes with recommendations for investigating each of these explanations using traditional methodologies, while also proposing alternative, broader metrics of welfare that ultimately may be required to assess, and enhance, the benefits of IT.

Keywords: Productivity, Computers, Performance measurement, Economic value, Investment justification.

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

The relationship between information technology (IT) and productivity is widely discussed but little understood. On one hand, delivered computing-power in the US economy has increased by more than two orders of magnitude in the past two decades (figure 1). On the other hand, 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) and headlines like "Computer Data Overload Limits Productivity Gains" (Zachary, 1991) and "Computers Aren't Pulling Their Weight" (Berndt & Morrison, 1991a).

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 results are aptly characterized by Robert Solow's quip that "we see computers everywhere except in the productivity statistics," and Bakos and Kemerer's (1991) more recent summation that "These studies have fueled a controversial debate, primarily because they have failed to document substantial productivity improvements attributable to information technology investments." 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. Nonetheless, given the increasing significance of IT in the budgets of most businesses and in the nation as a whole, continued investment cannot be justified by blind faith alone.

This paper seeks to contribute to the research effort by summarizing what we know and don't know, by distinguishing the central issues from diversions, and by clarifying 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 at least as likely due to deficiencies in our measurement and methodological tool kit as to mismanagement by developers and users of IT. One can only conclude, as Attewell and Rule (1984) did in an earlier survey, that we still have much to learn about how to measure the effects of computers on organizations. While particular emphasis is placed on economic approaches to both theory and empirics in this review, it is hoped that the process of addressing the productivity mystery will prove to be a useful springboard for other methodologies as well and for examining the broader issues involved.

As a prelude to the literature survey, it is useful to define some of the terms used and to highlight some of the basic trends in the economics of IT.

Definitions:

- “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.
- “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.

- In productivity calculations, “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”, often using “hedonic” methods, that eliminate the effects of inflation without ignoring quality changes.

Trends:

- The price of computing has dropped by half every 2-3 years¹ (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.²
- There have been increasing levels of business investment in information technology equipment. These investments now account for over 10% of new investment in capital equipment by American firms³ (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. (figure 5).
- 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 6)

¹ In the last 35 years, the quality-adjusted costs of computing have decreased by over 6000-fold relative to equipment prices outside the computer sector [Gordon, 1987]. This relationship has been dubbed “Moore’s Law” after John Moore who first documented the trend in microprocessors. It is widely projected to continue at least into the next century.

² This comparison was inspired by the slightly exaggerated claim in Forbes, [, 1980 #279], 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.” The \$4.98 Cadillac is based on a price of \$30,890 for a 1991 *Sedan de Ville* divided by 6203, the relative deflator for computers. The grocery comparison is based on a wage of \$10 an hour and \$10,000 worth of groceries, each in actual 1991 dollars.

³ Some studies estimate that as much as 50% of recent equipment investment is in information technology [Kriebel, 1989 #417]. This higher figure seems to be partly due to a broader definition of IT. A discrepancy also arises when recent investments are expressed in 1982 dollars, when IT was relatively more expensive. This has the effect of boosting IT’s *real* share over time faster than its *nominal* share grows.

These facts suggest two central questions, which comprise the productivity paradox: 1) Why are companies investing so heavily in information technology if it doesn't add to productivity? 2) If information technology *is* contributing to productivity, why have we been unable to measure it?

In seeking to answer these questions, this paper builds on a number of previous literature surveys. Much of the material in section III is adapted from an earlier paper with Bruce Bimber (Brynjolfsson & Bimber, 1990) which also included an annotated bibliography of 104 related articles and a summary of six explanations for the productivity paradox from outside the economics literature. An earlier study by Crowston and Treacy (1986), identified 11 articles on the "impact of IT on enterprise level performance" by searching ten journals from 1975 to 1985. They conclude that there had been surprisingly little success in measuring the impact of IT and attribute this to the lack of clearly defined variables which in turn stems from an inadequacy of suitable reference disciplines and methodologies.

One natural reference discipline is economics and an excellent review of recent research combining information systems and economics, by Bakos and Kemerer (1991), includes particularly relevant work in sections on "macroeconomic impacts of information technology" and "information technology and organizational performance". Because statistical work is central to the majority of the approaches to assessing IT productivity, another very useful survey is Gurbaxani and Mendelson's (1989) paper on the use of data from secondary sources in MIS research. In addition to summarizing the work that has already been done, they make a convincing case that using pre-compiled data sets has significant advantages over starting *de novo* with original data, as has been the more common practice among MIS researchers. Finally, many of the papers that seek to directly

assess IT productivity begin with a literature survey. The reviews by Brooke (1991), Barua, Mukhopadhyay and Kriebel (1991), and Berndt and Morrison (1991b) were particularly useful.

Although over 150 articles were considered in this review, it cannot claim to be comprehensive. Rather, it aims to clarify for the reader the principal issues surrounding IT and productivity, reflecting the results of a computerized literature search of 30 of the leading journals in both information systems and economics,⁴ and more importantly, discussions with many of the leading researchers in this area, who helped identify recent research that has not yet been published.

The remainder of the paper is organized as follows. The next section summarizes the empirical research that has attempted to measure the productivity of information technology. Section III classifies the explanations for the "paradox" into four basic categories and assesses the components of each in turn. Section IV concludes with summaries of the key issues identified and some avenues for further research.

Dimensions of the Paradox

Productivity is the fundamental 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 (Loveman, 1988). While major success

⁴ The journals searched included *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*, *Journal of Business Finance*, *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*, and *Sloan Management Review*. 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.

stories exist, so do equally impressive failures (see, for example (Kemerer & Sosa, 1990; Schneider, 1987)). The lack of good quantitative measures for the output and value created by information technology 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 information technology 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
Correlations	(Jonscher, 1983; Jonscher, 1988)	(Berndt & Morrison, 1991b)	(Cron & Sobol, 1983)
	(Baily & Chakrabarti, 1988; Baily, 1986b; Baily & Gordon, 1988)	(Siegel & Griliches, 1991)	(Strassman, 1985)
	(Roach, 1987a; Roach, 1988; Roach, 1989b)		(Baily, 1986a)
	(Brooke, 1991)		(Roach, 1991; Roach, 1987b; Roach, 1989a)
			(Noyelle, 1990)
Models	(Osterman, 1986)	(Loveman, 1988)	(Brand & Duke, 1982)
	(Grove, 1990)	(Weill, 1988)	(Pulley & Braunstein, 1984)
	(Dos Santos, Peffers & Mauer, 1991)	(Dudley & Lasserre, 1989)	(Bender, 1986)
		(Morrison & Berndt, 1990)	(Bresnahan, 1986)
		(Barua, Kriebel & Mukhopadhyay, 1991)	(Franke, 1987)
			(Harris & Katz, 1988; Harris & Katz, 1989)
			(Parsons, Gotlieb & Denny, 1990)
			(Weitzendorf & Wigand, 1991)

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. There has been a drop in labor productivity growth from about 2.5% per year between 1953-1968 to about 0.7% per year from 1973-1979. Multi-factor productivity growth, which takes into account changes in capital, declined from 1.75% a year to 0.32% over the same periods (Baily, 1986b). Even after accounting for factors such as the oil price shocks, changes in labor quality and potential measurement errors, most researchers still 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 information technology (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 at the core of many of the arguments that information technology has not helped US productivity or even that information technology investments have been counter-productive (Baily, 1986b).

This link is made more explicit in research by Stephen Roach (1987a; 1988) focusing specifically on information workers, regardless of industry. While in the past, office work was not very capital intensive, recently the level of information technology capital per ("white collar") information worker has begun approaching that of ("blue collar") production capital per 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.⁵

A more sanguine explanation is put forth by Brooke (1991). Although he confirmed a broad-level correlation with declines in productivity, he hypothesized that this was due to increases in product variety which resulted in commensurate reductions in economies of scale. This hypothesis was supported by his finding of a positive correlation

⁵ 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.

between IT investment and the number of trademark applications. Because variety generally has positive value to consumers, but is ignored by conventional measures of productivity, this finding suggests a measurement problem, which is explored more fully in below in the section on mismeasurement.

Comment

Upon closer examination, the alarming correlation between IT and lower productivity at the level of the entire US economy is not compelling because so many other factors affect output and therefore 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, or total output. If, hypothetically, IT were being used efficiently and its marginal product were 20% (exceeding the return to most other capital investments), then current GNP would be directly increased about 2% ($10\% \times 20\%$) because of the existence of our current stock of IT. However, information technology capital stock did not jump to its current level in the past year alone. Instead, the increase must be spread over about 30 years, suggesting an average contribution to aggregate GNP growth of 0.06% in each year.⁶ This would be very difficult to isolate because so many other factors affected GNP, especially in the relatively turbulent 1970s and early 1980s. 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 and productivity growth by even less.⁷

⁶ In his comment on Baily and Gordon (1988), David Romer notes that a similar argument applies to almost any capital investment.

⁷ 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.

This is not to say that computers may not have had significant effects in specific areas, like transaction processing, or on other characteristics of the economy, like employment shares, organizational structure or product variety. Rather it suggests that very large changes in capital stock are needed to measurably change total output under conventional assumptions about typical rates of return. However, the growth in information technology stock is still strong and the share of the total economy accounted for by computers is becoming quite substantial. Presumably, if computers are productive, we should begin to notice changes at the level of aggregate GNP in the near future.

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 (1991b) confirm that information technology 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 (1984; 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.

Independent of its implications for productivity, growth in the white collar work force cannot be entirely blamed on information technology. Although over 38% of workers now use computers in their jobs⁸, the ranks of information workers began to

⁸ According to the US National Center for Education Statistics, 38.3% of persons in the 1989 Current Population Survey used computers at work, including nearly 60% of those with four or more years of college. Interestingly, Kreuger [, 1991 #411] finds that workers using computers are paid an average wage premium of 8%, even after controlling for education, computer literacy and other factors.

surge well before the advent of computers (Porat, 1977). Jonscher (1988) even goes so far as to argue that causality goes the other way: the increased demand for information enabled economies of scale and learning in the computer industry, thereby reducing costs.

These mitigating factors notwithstanding, the low measured productivity at the level of the whole economy and among white collar workers, especially in the face of huge increases in the accompanying capital stock, does call for closer scrutiny.

A more direct case for weakness in information technology's contribution comes from the explicit evaluation of information technology capital productivity, typically by estimating the coefficients of a production function. This has been done in both manufacturing and service industries, and we review each in turn.

The Productivity of Information Technology Capital in Manufacturing

The Issues

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

A study by Gary Loveman (1988) provided some of the first econometric evidence of a potential problem when he examined data from 60 business units.⁹ As is common in the productivity literature, he used ordinary least squares regression and assumed that production functions could be approximated by a Cobb-Douglas function. By taking the logarithm of all variables, he was able to estimate a linear relationship between changes in the log of output¹⁰ (q) and changes in the log of spending on key inputs, including

⁹ Namely, the Management Productivity of IT (MPIT) subset of the PIMS data set.

¹⁰ Where output was defined as (sales + net change in inventories)/ price index.

materials (m), purchased services (ps), labor (l), traditional capital (k), and information technology capital (c), while allowing for an exogenous time trend (λ), and an error term (ϵ):

$$q = \beta_1 m + \beta_2 ps + \beta_3 l + \beta_4 k + \beta_5 c + \lambda + \epsilon \quad (1)$$

Loveman estimated that the contribution of information technology capital to output (β_5) 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 suggest a paradox: while firms were demonstrating a voracious appetite for a technology experiencing radical improvements, measured productivity gains were insignificant.

While Loveman's dependent variable was final output, Barua, Kriebel and Mukhopadhyay (1991) traced Loveman's results 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 final output. Dudley and Lasserre (1989) also found econometric support for the hypothesis that better communication and information reduce the need for inventories, without explicitly relating this to bottom-line performance measures. Using a different data set, Weill (1988) was also able to disaggregate IT by use, and found that significant productivity could be attributed to transactional types of information technology (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 two papers using a broader data set from the US Bureau of Economic Analysis (BEA) that encompasses the whole U.S. manufacturing sector. The first (Morrison & Berndt, 1990), which 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. Their second paper (Berndt & Morrison, 1991b) took a less structured approach and examined broad correlations of IT with labor productivity and multifactor productivity, as well as other variables. This approach did not find a significant difference between the productivity of IT capital and other types of capital for a majority of the 20 industry categories examined. They did find that IT was correlated with significantly increased demand for skilled labor.

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, 1988)	Valve manufacturers	Contextual variables affect IT performance
(Dudley & Lasserre, 1989)		IT and communication reduces inventories
(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
(Berndt & Morrison, 1991b)	BEA, BLS	IT not correlated with higher multi-factor productivity in most industries, more labor use
(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 Loveman is careful to point out, his 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 results of both of these studies may also be unrepresentative to the extent that the relatively short period covered by the MPIT data, 1978- 83, was unusually turbulent.

The BEA data may be somewhat more dependable but are subject to subtle biases due to the unintuitive techniques used to aggregate and classify establishments. 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-information technology factors of production in each of the studies indicate that there may indeed be something worrisome, or at least special, about information technology. Additional

econometric work would go far toward establishing whether these results are an artifact of the data or a genuine puzzle in need of more thorough analysis.

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 (1991; Roach, 1987b; Schneider, 1987). Before about 1970, service productivity growth was comparable to that in manufacturing, but since then the trends have diverged significantly.¹¹ 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% information technology, this has been taken as indirect evidence of poor information technology 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

¹¹ According to government statistics, from 1953 to 1968, labor productivity growth in services averaged 2.56%, vs. 2.61% in manufacturing. For 1973 to 1979, the figures are 0.68% vs. 1.53%, respectively (Baily, 1986). However, a recent study (Gordon, 1989) suggests that measurement errors in US statistics systematically understate service productivity growth relative to manufacturing.

More recently, computers definitely have caused some divergence in the statistics on manufacturing and service productivity, but for a very different reason. Because of the enormous quality improvements attributed to the computers, the nonelectrical machinery category (containing the computer producing industry) has shown tremendous growth. As a result, while overall manufacturing productivity growth has rebounded from about 1.5% in the 1970s to 3.5% in the 1980s, about two thirds of this increase is simply attributable to the greater production (as opposed to use) of computers (see comment by William Nordhaus on Baily & Gordon, 1988 and section III.A of this paper)

approaches, helping well-organized firms succeed but only further confusing managers who haven't properly structured production in the first place.

Strassman (1985; 1990) 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 his most recent book (1990), he concludes that "there is no relation between spending for computers, profits and productivity".

Roach's widely cited research on white collar productivity, discussed above, focused principally on IT's dismal performance in the service sector (1991; 1987a; 1987b; 1988; 1989a; 1989b). 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. On the other

hand, Brand (1982), using BLS data and techniques, found that moderate productivity growth had already occurred in banking.

Harris and Katz (1988; 1989) and Bender (1986) 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.

Several case studies of IT's impact on performance have also been done, including one by Weitzendorf & Wigand (1991) which developed a model of information use in two service corporations, and a study of an information services firm by Pulley and Braunstein (1984), which found an association with increased economies of scope.

Table 3: Studies of IT in Services

Study	Data source	Findings
(Brand & Duke, 1982)	BLS	Productivity growth of 1.3%/yr in banking
(Cron & Sobol, 1983)	138 medical supply wholesalers	Bimodal distribution among high IT investors: either very good or very bad
(Pulley & Braunstein, 1984)	Monthly data from information service firm	Significant economies of scope
(Clarke, 1985)	Case study	Major business process redesign needed to reap benefits in investment firm
(Strassman, 1985; Strassman, 1990)]	Computerworld survey of 38 companies	No correlation between various IT ratios and performance measures
(Bender, 1986)	LOMA insurance data on 132 firms	Weak relationship between IT and various performance ratios
(Bresnahan, 1986)	Financial services firms	Large gains in imputed consumer welfare
(Franke, 1987)	Finance industry data	
(Roach, 1991; Roach, 1987b; Roach, 1989a)	Principally BLS, BEA	Vast increase in IT capital per information worker while measured output decreased
(Harris & Katz, 1988; 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
(Parsons, Gotlieb & Denny, 1990)	Internal operating data from 2 large banks	IT coefficient in translog production function small and often negative
(Weitzendorf & Wigand, 1991)	Interviews at 2 companies	Interactive model of information use

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 (Davenport & Short, 1990; Hammer, 1990). A frequently cited example is the success of the Batterymarch services firm, as documented by Clarke (1985). Batterymarch used information technology 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 "information technology productivity paradox" have been overstated, the question remains as to whether information technology is having the positive impact expected. In particular, better measures of information worker productivity are needed, as are explanations for why information technology capital hasn't clearly improved firm-level productivity in manufacturing and services. We now examine four basic approaches taken to answer these questions.

Leading 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 information technology. 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 information

technology: 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 in this section.

Measurement Errors

The Issues

The easiest explanation for the low measured productivity of information technology 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 information technology 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 information technology -- 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

As discussed in the introduction, 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, 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 information technology 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.¹² 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 (Banker & Kauffman, 1988).

¹² The same phenomenon suggests that much of the initial decline in "productivity" experienced by centrally-planned economies when they liberalize is spurious.

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! (Mark, 1982)

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 (Baily & 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.¹³

b. Information Technology Stock Mismeasurement

A related measurement issue is how to measure information technology 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 that the rapid decreases in the real costs of computer power are largely a function of general "advances in knowledge" and as a result, the government overstates the decline in the computer price deflator by attributing these advances to the producing industry. 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.

c. Input Mismeasurement

¹³ They also add 1.1% to productivity growth before 1973.

A third issue is the measurement of other inputs. 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 an artifact of unmeasured improvements in work life that are not accounted for in government statistics. Baily and Gordon (1988) conjecture that this may also be adding to the underestimation of productivity.

To the extent that complementary inputs, such as software, or training, are required to make investments in information technology 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.

d. Methodological Concerns

In addition to data problems, the methodology used to assess IT impacts can also significantly affect the results. Alpar and Kim (1990) 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.¹⁴ They found that the key ratios approach, which had been

¹⁴ An example of the key ratios approach is examining the correlation between the ratio of information processing expenses to total expenses and the ratio of total operating expenses to premium income, as Bender [, 1986 #295] did. An example of the cost function approach is to use duality theory to derive a cost function from a production function, such as the Cobb-Douglas function described above that was used by Loveman [, 1988 #58]. The exact function used by Alpar and Kim was the translog cost function, which is more general, but which requires the estimation of a large number of parameters.

previously used by Bender (1986) and Cron and Sobol (1983), among others, could be particularly misleading.

In an effort to model IT effects more rigorously, several papers have called for the use of approaches derived from microeconomics. Cooper and Mukhopadhyay (1990) advocate a production function approach while frontier methodologies such as data envelopment analysis (DEA) have been proposed by Chismar and Kriebel (1985) and Stabell (1982). A very different approach has been applied in an article by Tim Bresnahan (1986). Recognizing the inherent difficulties in measurement in the financial services sector, Bresnahan made no attempt to directly measure output. Instead, he inferred it from the level of spending on mainframes under the assumption that the unregulated parts of the financial services sector were competitive and were therefore acting as agents for consumers. He found that welfare gains were five times greater than expenditures through 1973. Bresnahan's findings serve to underscore the size of the gap between the benefits perceived by the consumers of IT and those measured by researchers using conventional techniques.

Comments

Output measurement is undoubtedly problematic. Rapid innovation has made information technology-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 information technology. Because

information is intangible, increases in the implicit information content of products and services are likely to be under-measured compared to increases in materials content.

Nonetheless, some analysts are skeptical that measurement problems can explain much of the slowdown. They point out that by many measures, service quality has gone down, not up.¹⁵ Furthermore, they question the value of variety when it takes the form of six dozen brands of breakfast cereal. Indeed, models from industrial organization theory suggest that while more variety will result from the flexible manufacturing and lower search costs enabled by IT, the new equilibrium can exhibit *excess* variety making consumers worse off (Tirole, 1988).

Denison is in the minority in his view that the government is overestimating the improvements in computing power per dollar. A study by Gordon (1987) found that, if anything, computer prices are declining slightly faster than government statistics show. More recently, a study by Triplett (1989) considered Denison's criticisms but in the end supported the BEA methods.¹⁶

Ultimately, a closer look at productivity statistics reminds researchers that the poor showing of information technology may not rest on an entirely solid foundation simply because the statistics are not as reliable as we would like.

Lags

The Issues

¹⁵ Nordhaus in a comment on Baily and Gordon (1988) recalls the doctor's house call, custom tailoring, and windshield wiping at gas stations, among other relics.

¹⁶ Most economists appear to be less concerned than Denison about this bias in the BEA statistics. For instance, a consensus of economists at the June, 1990 NBER conference on productivity concurred with Triplett's conclusions.

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

a. Evidence of Lags

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 information technology investments to pay-off (Nolan/Norton, 1988). This accords with a recent econometric study by Brynjolfsson et al. (1991a) which found lags of two to four years before the strongest organizational impacts of information technology were felt. Loveman (1988) also found slightly higher, albeit still very low, productivity when small lags were introduced. In general, while the benefits from investment in infrastructure can be large, they are indirect and often not immediate.

b. Theoretical Basis for Lags

The existence of lags has some basis in theory. Because of its unusual complexity and novelty, firms and individual users of information technology may require some experience before becoming proficient (Curley & Pyburn, 1982). According to dynamic 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 (Scherer, 1980). If only short-term costs and benefits are measured, then it might appear that the investment was inefficient. Viewed in this framework, there is nothing irrational about the "experimentation" phase firms are said to experience in which rigorous cost/benefit analysis is not undertaken (Nolan/Norton, 1988). Because future information technology investments tend to be large

relative to current investments, the learning effect could potentially be quite substantial. A similar pattern of costs and benefits is predicted by an emerging literature that treats investments in information technology as “options”, with short term costs, but with the potential for long-term benefits (Kambil, Henderson & Mohsenzadeh, 1991).

Comments

One way to address the measurement problem associated with complementary inputs (see section III.A.1.c) is to introduce appropriate lags in the estimation procedure. For instance, the purchase of a mainframe computer must generally precede the development of mainframe database software. Software, in turn, usually precedes data acquisition. Good decisions may depend on years of acquired data and may not instantaneously lead to profits.¹⁷ Optimally, a manager must take into account these long-term benefits when purchasing a computer and so must the researcher seeking to verify the benefits of computerization.

If managers are rationally accounting for lags, this explanation for low information technology 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. However, the credibility of this explanation is somewhat undermined by the fact that American managers have not been noted for their ability to postpone benefits to the future. On the contrary, the risk and uncertainty associated with new technologies can make risk-averse managers require higher, not lower, rates of return before they will invest. Increased familiarity, ease-of-use

¹⁷ It has been observation that firms that spend proportionately more money on software appear to be more profitable (Computer Economics Report, 1988) If firms go through a hardware buying phase followed by an applications phase, then this may have more to do with firms being in different stages of a multi-year process than with different technology strategies.

and end-user computing may lead to reduced lags between the costs and benefits of computerization in the future.

Redistribution

The Issues

A third possible explanation is that information technology 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.

a. The Private Value of Information Can Exceed its Social Value

There are several arguments for why redistribution may be more of a factor with IT investments than for other investments. For instance, information technology 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; Lasserre, 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. As Hirshleifer (1971) pointed out, 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.

In a similar spirit, "races" to be the first to apply an innovation can also lead to rent dissipation (Fudenberg & Tirole, 1985). The rapid-fire pace of innovation in the information technology industry might also encourage this form of wasteful investment.

b. Models of Redistribution

Baily and Chakrabarti (1988) run a simulation under the assumption that a major share of the private benefits of information technology result from redistribution. The results are broadly consistent with the stylized facts of increased amounts of information technology and workers without increases in total productivity.

2. Comments

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. It is interesting to note that most of the reasons for investing in information technology given by the articles in the business press involve taking profits from competitors rather than lowering costs.¹⁸

Mismanagement

The Issues

A fourth possibility is that, on the whole, information technology really is *not* productive at the firm level. The investments are made nevertheless because the decision-

¹⁸ Porter and Millar, 1985, is not atypical. They emphasize "competitive advantage" gained by changes in industry structure, product and service differentiation and spawning of new businesses while devoting about 5% of their space to cost savings enabled by IT. Others ignore cost reductions entirely.

makers aren't acting in the interests of the firm. Instead, they are a) increasing their slack, b) signalling their prowess or c) simply using outdated criteria for decision-making.

a. Increased scope for managerial slack

Many of the difficulties that researchers have in quantifying the benefits of information technology would also affect managers (Baily, 1986a; Gremillion & Pyburn, 1985). 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 (McKersie & Walton, 1988). The result is that information technology might increase organizational slack instead of output or profits. This is consistent with arguments by Roach (1989a) that manufacturing has made better use of information technology than has the service sector because manufacturing faces greater global competition, and thus tolerates less slack.

b. Information consumption as a signal

Feldman and March (1981) also point out that good decisions are generally correlated with significant consumption of information. If the amount of information requested is more easily observable than the quality of decisions, a signalling model will show that too much information will be consumed.

c. Use of outdated management heuristics

A related argument derives from evolutionary models (Nelson, 1981). The difficulties in measuring the benefits of information and information technology discussed above may also lead to the use of heuristics, rather than strict cost/benefit accounting to set

levels of information technology investments.¹⁹ Our current institutions, heuristics and management principles evolved largely in a world with little information technology. The radical changes enabled by information technology may make these institutions outdated (see e.g. (Clarke, 1985; Franke, 1987)). 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, Ayres (1989) argues that the rapid speed-up enabled by information technology creates unanticipated bottlenecks at each human in the information processing chain. More money spent on information technology won't help until these bottlenecks are addressed. Indeed, researchers have found that a successful IT implementation process must not simply overlay new technology on old processes (Davenport & Short, 1990).

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; Gay & Roach, 1986). 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 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

¹⁹ Indeed, a recent review of the techniques used by major companies to justify information technology investments [Yamamoto, 1991] revealed surprisingly little formal analysis. See Clemons [, 1991 #284] for an assessment of the IT justification process.

formally by models such as agency theory, employment signalling models 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.

For instance, a model of how IT enables managerial slack can be developed using agency theory. The standard result in this literature is that when managers' (agent) incentives are not aligned with shareholder (principal) interests, suboptimal investment decisions and effort can result. One little noted feature of most agency models is that the incentives for agents to acquire additional information generally exceed the social benefits. This is because agents can use the information to earn rents and to short-circuit the incentive scheme (Brynjolfsson, 1990a). Thus, information technology investments may be very attractive to managers even when they do little to boost productivity. To the extent that competition reduces the scope for managerial slack, the problem is alleviated.

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 information technology 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. Looking at the productivity of the US economy as a whole or of white collar information workers as a group is probably too blunt an approach. Estimating production and cost functions for specific sectors or industries can provide sharper insights, but even some of the authors applying this methodology express skepticism about their results (e.g. (Berndt & Morrison, 1991b)). When estimating production functions, heroic efforts are often required to get sensible coefficients for capital elasticities in even the best of circumstances. Poor data quality for IT outputs and inputs has exacerbated this problem.

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? Four hypotheses summarized below.

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 information technology 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 last of these explanations, mismanagement, 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?

Recommendations for Further Research

All four of the explanations are likely to be empirically important to some extent and future studies should test for them.

The first priority must be improving the data and measurement techniques. Government statistics, especially in services and for information workers, have not kept up with the growing importance and complexity of these sectors. Therefore, researchers may have to perform their own corrections on the data, turn to private sources of secondary data, or undertake original data gathering themselves. When the third option is pursued, it is important that the data be made available for use by other researchers so that a cumulative

tradition can be maintained. Adding to the plethora of uncorroborated studies that use idiosyncratic data sets is less helpful.

An effective strategy for identifying gaps in the data is to compare it with benefits that managers and customers expect from IT, such as quality, timeliness, customer-service, flexibility, innovation, customization and variety. In principal, many of these benefits are quantifiable. In fact, the capital budgeting and justification process is one place in which firms already attempt such an analysis. In addition, many companies have already developed elaborate measurement programs, for instance as part of "total quality management", that augment or even supersede financial accounting measures and can serve as a foundation for more refined metrics. Unfortunately, for many services, even basic output measures still need to be created, because government and accounting data records only inputs. Baily and Gordon (1988), and Noyelle (1990), among others, have done much to improve measurement in areas such as banking and retailing, while relatively good statistics can be compiled from private sources in areas such as package delivery (Dertouzos, 1991). Unfortunately, the individualized nature of many services defies aggregation. The output of a lawyer, manager or doctor cannot be extrapolated from the number of consultations, memoranda or medications provided. The complexity of the "Diagnostic Related Group" approach to valuing medical care is both a step in the right direction and a testament to these difficulties. A researcher who seeks to rigorously measure productivity of services generally must undertake this detailed work before jumping to conclusions based on input-based statistics. Similarly, disaggregating heterogeneous types of IT by use, as Weill (1988) did, can increase the resolution of standard statistical techniques.

Correcting for the potential lags in the impact of IT is conceptually easier. All that needs to be done is to be sure to include lagged values of IT in the regression. Of course,

because learning and adjustment may take five or more years (Brynjolfsson, Malone, Gurbaxani & Kambil, 1991a) this presupposes that a sufficiently long sample can be obtained. Depending on the assumptions made about the nature of adjustment costs, including lagged values of the dependent variable may also be appropriate, although this can introduce complications when serial correlation is present. In a structural model, there is some potential for examining adjustment costs even with only cross-sectional samples. For instance, if software spending generally peaks after hardware spending, then their ratio can be an indicator of the relative stage of the investment cycle of the firm, with implications for the timing and level of expected benefits. Because so many other factors affect firm performance, it will generally be impossible to distinguish the impact of IT from simple bivariate correlations. It is essential to include controls for other factors such as the macro-economic environment, input prices, demand schedules for output, and the nature of competition. Because many factors will be unobservable but will affect either the whole industry or one firm persistently, examining a panel consisting of both time series and cross-sectional data is the best approach, where feasible.

The redistribution hypothesis can be examined in two ways. If IT spending serves mainly to take market share from competitors, but the resulting profits²⁰ are quickly dissipated or transferred to the customer, then profitability or even revenues may not be a good indicator of IT's impact. Instead, a regression using market share as the dependent variable will be a better indicator. This is especially true when intangibles associated with the output of the firm (e.g. customer service and quality) are not easily captured in traditional measures but do influence the customer's purchase decision. A second technique is to compare various measures of a firm's performance with its *competitors'* IT spending. Under the above assumptions, the coefficient should be negative. The coefficient will also be negative when IT serves to increase the efficiency of the market, for

²⁰ Strictly speaking, "rents" is the more accurate economic term.

instance by reducing search costs, and thereby reducing the market power of suppliers and the potential for pricing above marginal cost. As Bakos (1987) has shown, competitors may be collectively better off if such systems are not introduced, but each has an individual incentive to pre-empt the others.²¹ There is evidence that this phenomenon may have been important in the financial services industry in the 1980s (Steiner & Teixeira, 1991).

To address the mismanagement hypothesis, what is most needed is the development of better theoretical models. While there is a great deal of anecdotal evidence for misuses of the technology in organizations, more rigorous explanations are needed to show how and why IT might be subject to systematic overinvestment or mistakes in implementation. Among the more promising approaches is the development of better principal-agent models that analyze the demand for information. Preliminary work suggests that under reasonable assumptions, agents may have an overincentive to acquire and process information (Brynjolfsson, 1989). Signalling models, that formalize use of IT as a non-productive, but individually valuable, symbol of managerial or technological prowess, also appear to be a natural next step. A better theoretical foundation for the mismanagement hypothesis will enable order-of-magnitude estimates that will help identify which explanations are likely to be empirically significant, and will facilitate the testing of these explanations by identifying the relevant variables and relationships.

Finally, even with these substantive improvements in our research on IT and productivity, we 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. The studies themselves are usually careful to spell out the limitations of the data and methods, because they are written for an academic audience, but sometimes only the surprising conclusions are reported by the media. Because significant investment

²¹ In this way, the pay-offs are like a prisoner's dilemma.

decisions are based on these conclusions²², 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 idea that information technology will not so much help us produce more of the same things as allow us to do entirely new things in new ways (Applegate, Cash & Mills, 1988; Benjamin, Rockart, Scott Morton & Wyman, 1984; Cecil & Hall, 1988; Hammer, 1990; Malone & Rockart, 1991; Porter & Miller, 1985; Watts, 1986). For instance, Watts (1986) finds that information technology investments cannot be justified by costs reductions alone, but that instead managers should look to increased flexibility and responsiveness, while 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 information technology 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. For instance, because consumers of a product are generally assumed to be the best positioned to assess the utility they gain from their purchases, one might naturally look to IT buyers for an estimate of IT value as Bresnahan did. A second alternative to

²² For instance, the stock prices of major IT vendors changed significantly in response to a recent *Wall Street Journal* article on IT productivity [Dos Santos, 1991 #419].

traditional productivity measures is to look at stock market data. If one assumes that rational investors will value both the tangible and intangible aspects of firms' revenue generating capacity, then changes in stock market value should approximate the true contribution of IT to the firm, not only in cost reductions, but also in increased variety, timeliness, and quality, and in principle, even the effectiveness of the firm in foreseeing and rapidly adapting to its changing environment.²³ In most industries, to many other factors are likely to affect stock value to be able to discern the impact of IT, but in some industries different strategies toward IT may make all the difference. While relying on consumer or stockholder valuations begs the question of actual IT productivity to some extent, at a minimum these measures provide two additional benchmarks that can help triangulate IT value.

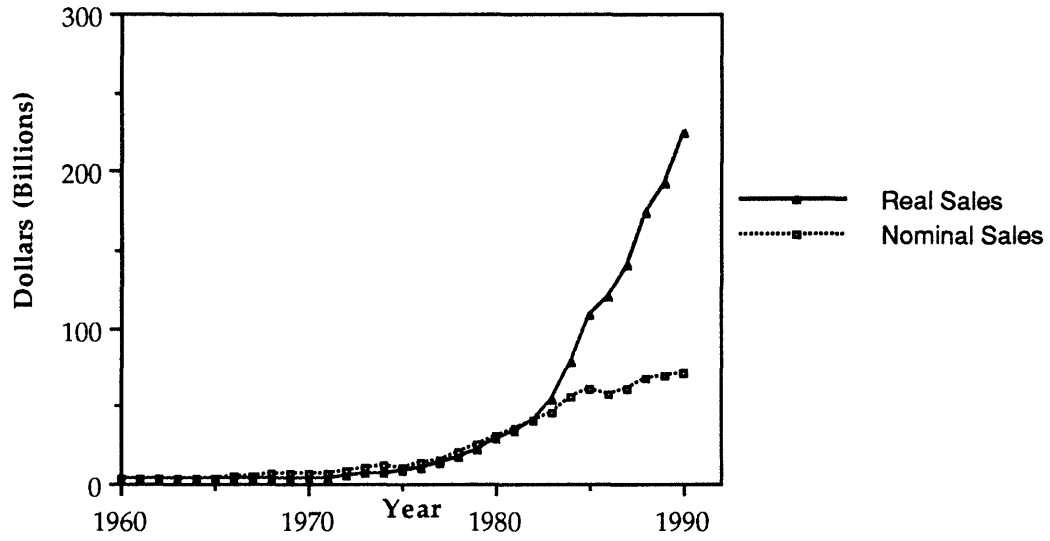
If the value of IT remains unproven, the one certainty is that the measurement problem is becoming more severe. Developed nations are devoting increasing shares of their economies to service- and information-intensive activities for which output measures are poor.²⁴ The comparison of the emerging "information age" to the industrial revolution has prompted a new approach to management accounting (Beniger, 1986; Kaplan, 1989). A review of the IT productivity research indicates an analogous opportunity to rethink the way we measure productivity and output.

²³ Unfortunately, stock market valuation also reflects the firm's relative market power, so where IT leads to more efficient markets or greater *customer* bargaining power, the relationship between IT and stock price is ambiguous.

²⁴ A look at the BEA's SIC codes quickly reveals that manufacturing is classified in relatively rich detail while only the broadest measures exist for services, which comprise over 80% of the economy.

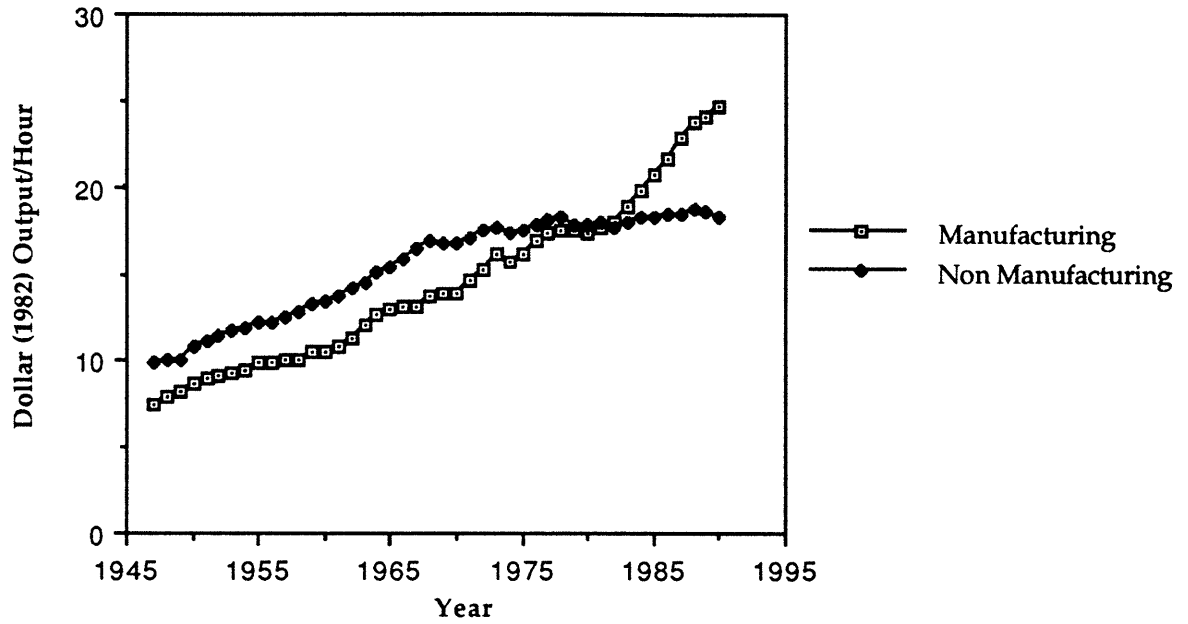
Tables and Graphs

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



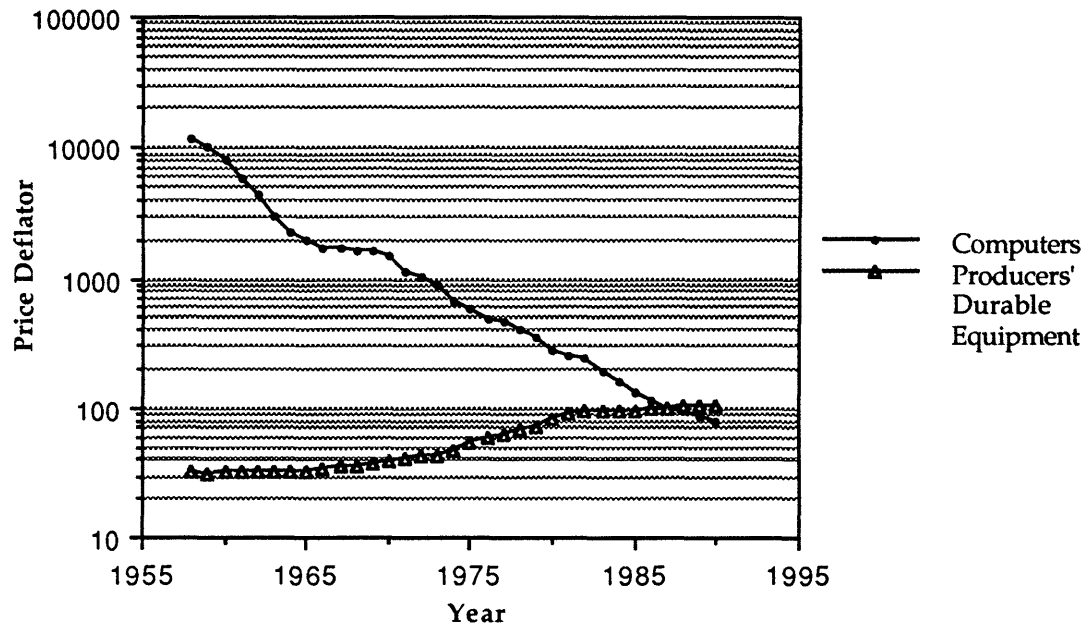
Source: Commerce Department Census of Shipments, Inventories, & Orders using BEA deflators. (Data for 1991 are estimates).

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}

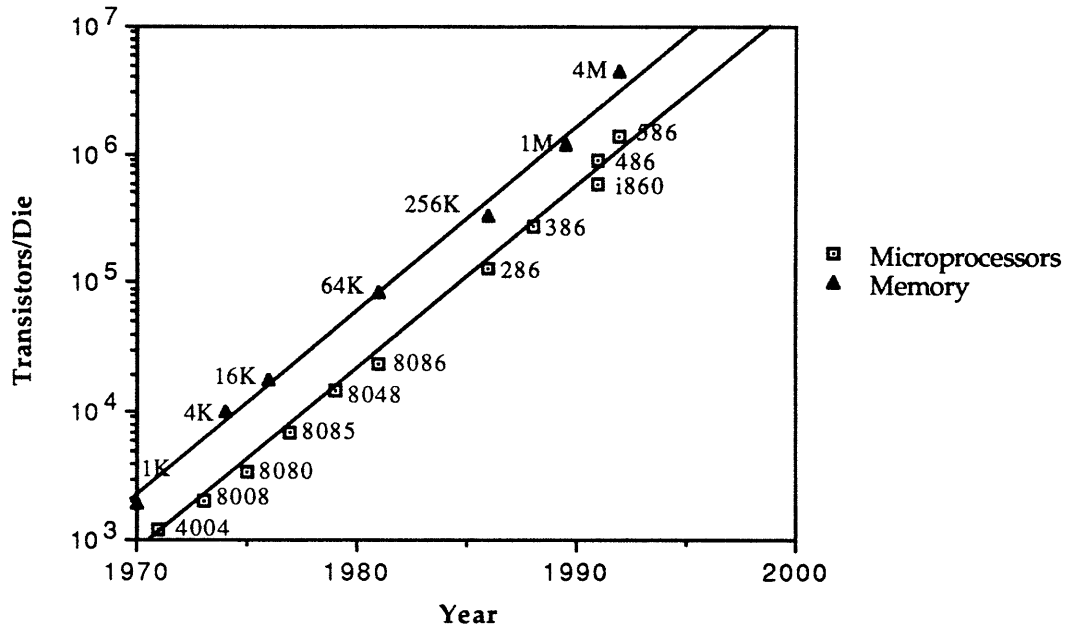
Figure 3a -- The cost of computing has declined substantially relative to other capital purchases.



Based on data from [U.S. Dept. of Commerce, Survey of Current Business]

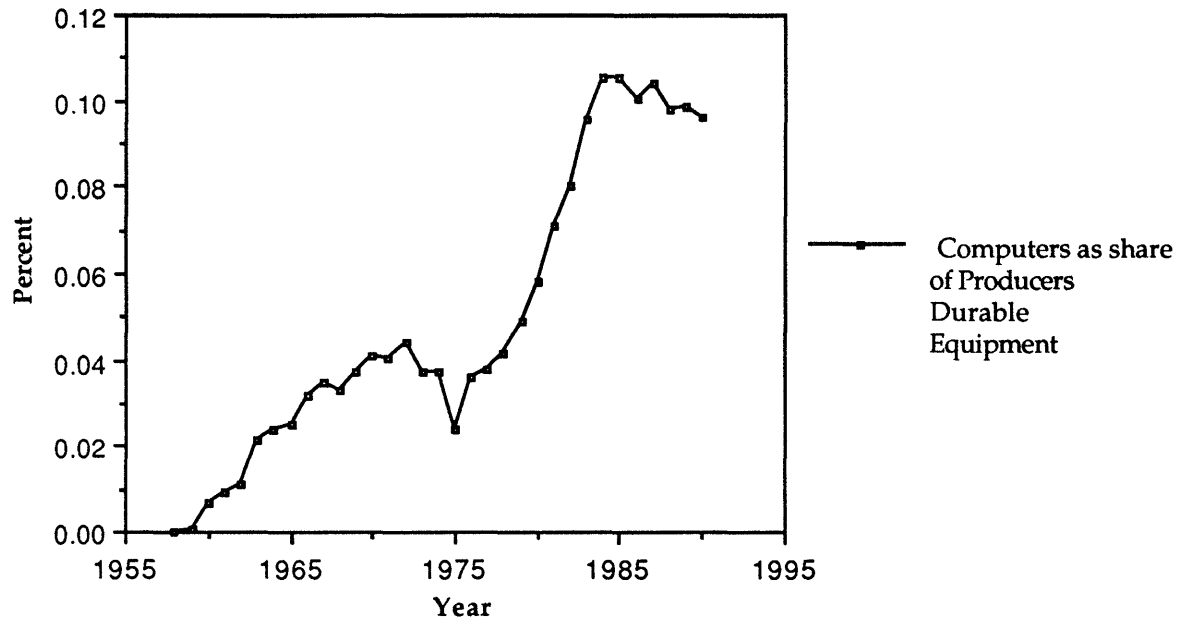
{1990 Data is prepublication}

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



Adapted from (Grove, 1990) and data provided by Intel

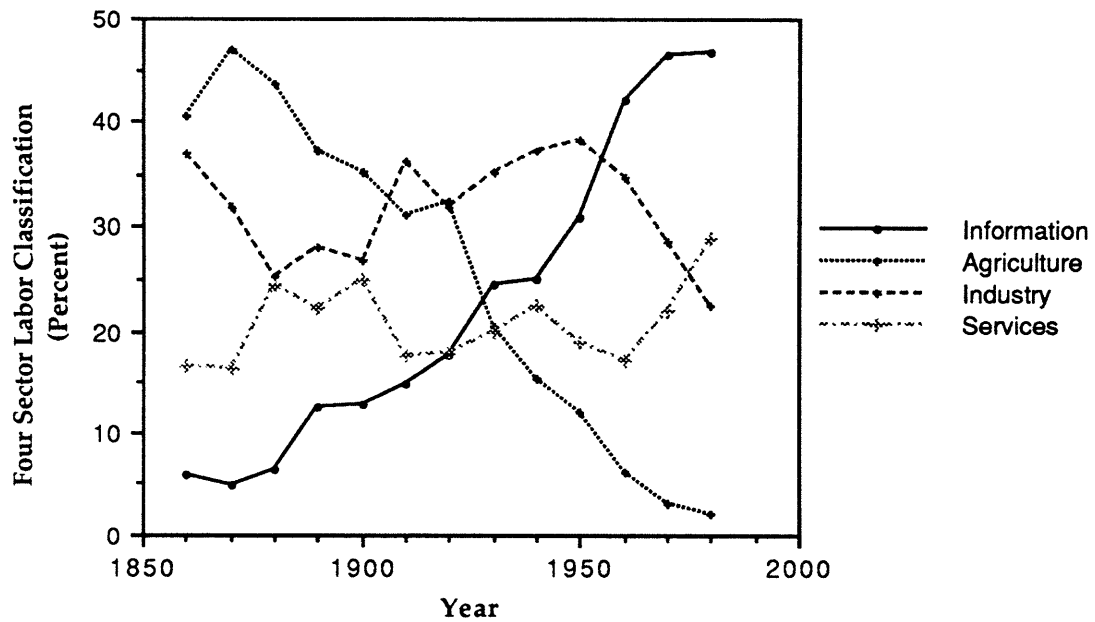
Figure 4 -- Computer hardware comprises about 10% of investment in Producers' Durable Equipment



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

{1990 Data is prepublication}

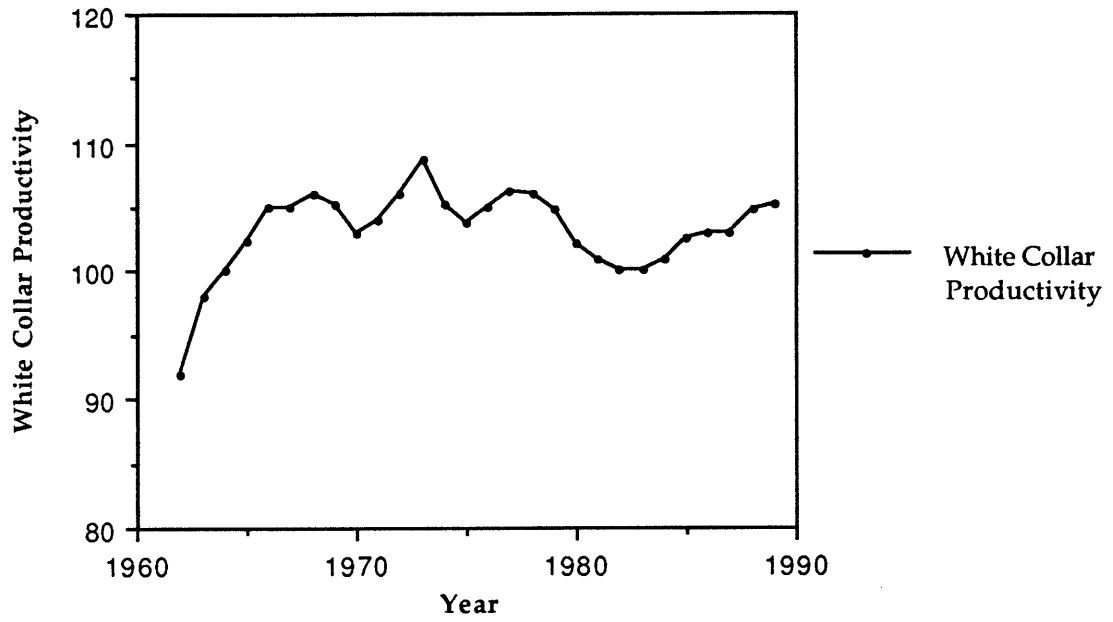
Figure 5 -- Information work is the largest category of employment.



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)

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