The Productivity Paradox Revisited: Its Implications and Research Issues

Geunjoo Lee*

Abstract: Information technology (IT) investments in the public and private sector are made with an expectation that productivity improvement will follow. We do have a bunch of theories to expect this. However, a review of the literature shows that the empirical evidence of productivity gain is scant, especially in the public sector. Understanding the nature of the relationship between IT investment in the public sector and its impact will help us to make better investment decisions and better use of the technology. This paper investigates the reasons for the productivity paradox in terms of redistribution, poor performance measure, lagged effect, and management issues. Four sources of productivity paradox are discussed to understand the characteristics of each problem. The use of larger and representative samples, creation of new performance measures to capture the diverse effects of IT, and explicit consideration of lagged effect of IT in the research design are suggested as future research issues.

INTRODUCTION

As Robert Solow (1987) aptly quipped, "You can see the computer age everywhere but in the productivity statistics." This so-called productivity paradox questions the extent and impact of IT investment and has generated heated discussion (e.g., Roach, 1988). During the last two decades, information technology (IT) investment has been made with the belief that it would bring about productivity improvement. IT promised to have enormous impacts on economic efficiency and effectiveness because of its direct impact on important factors of production, namely, information and knowledge (Laudon & Marr, 1994 Pelsak, 2003).

Thus far, however, the IT investment and productivity numbers do not add up. The evidence of IT-induced productivity improvement is still scant, especially in the service and public sectors. Some reviews of major studies have reported that evidence of productivity improvement is hard to find (e.g., Brynjolfsson, 1993; Wilson, 1993). The lack of positive results attributable to IT investment has turned the attention of managers in both the private and public sectors to more tractable issues such as system design and development. Without information about performance improvement, however, those activities cannot be evaluated properly. Identifying and understanding the ITperformance relationship can provide overall guidelines for other critical and strategic aspects of IT related activities.

When it comes to empirical studies about the impact of IT on the performance of public organizations, the situation is worse than it is for private-sector

* Assistant Professor: Ewha Womans University

counterparts (Kraemer & Dedrick, 1997). Because of intrinsic difficulties such as measuring the performance of public organizations, not much research has been performed that focuses on the public sector (e.g., Lee,2002). The major focus of the literature on IT in public organizations has shifted away from the impact and management of IT to the promotion of IT uses such as the National Information Infrastructure and the Internet (Kraemer & Dedrick, 1997). However, this does not necessarily mean that productivity improvement is an unimportant issue in the public sector. On the contrary, it is critical for both practitioners and scholars to have such information. IT productivity research can be used to enhance accountability and program improvement by matching results with plans (Hatry & Fisk, 1992). To understand the relationship between IT investment in the public sector and its impact will also help us to make better investment decisions and better use of the technology. This study reviews the IT productivity-related research to evaluate the status of the field. The analysis will enumerate the reasons for elusive findings and draw implications for future research.

THE IMPACT OF INFORMATION TECHNOLOGY

The impact of IT on organizations in general and their performance in specific settings is believed to be enormous in terms of scope and depth (e.g., Eason, 1988). The automation of routine work is the least of the computer's impacts. It is much more than that. The use of computer-based communications not only has changed the mode of communication but also has created new information that previously had not been available. With the help of IT, organizations gather and process information in an accurate and timely fashion so that they can make better-informed and more timely decisions (Huber, 1990). IT collects, processes, and shares huge amounts of information at a rate that has never before been experienced or imagined. Faster information processing and information-rich communication help decision makers at all levels increase their ability to cope with contingencies. It allows more people to have easy and direct access to information that otherwise would be unavailable.

Electronically stored data are easier to analyze and transform into formats that can be used for other purposes to create new value. The "informated" value activity creates information that provides whole new perspectives about organizational activity (Zuboff, 1988). This newly available information through informated value activities allows organizations to understand new aspects of activities that have not been recognized. This ultimately helps organizations to respond in ways that increase the efficiency and effectiveness of organizational and managerial processes.

This new technology also has the power to change the structure of organizations and markets. IT is said to affect the boundary between organization and market by influencing the costs of coordination and transaction (Gurbaxani &

Hwang, 1991 Malone et al., 1987). The very nature of IT the rapid and accurate gathering and processing of information modifies the choice mechanism between market and hierarchy (or organization) by reducing the cost of collecting and exchanging information. Internet and networked computers such as those found in the electronic marketplace reduce coordination costs, including search and transaction costs in the market (e.g., Bakos, 1991). This could result in more frequent use of market transactions because market transactions are less costly and more efficient compared to internalizing such activities. Within hierarchies, new organizational structures based on electronic communication sand databases are possible. Intranet and computerized organizational processes make it easier to monitor and coordinate within hierarchies. Because IT makes monitoring easier and less costly, the span of control can be enlarged. Matrix and flat organizations are feasible alternatives to hierarchical organizations as a result of the development of IT (Lucas, 1996).

In addition, IT creates a competitive advantage rather than simply reducing costs (e.g., Porter & Millar, 1985). IT creates strategic opportunities such as new products and services so that organizations can increase their outputs in terms of quantity, quality, and variety. The public sector can take advantage of IT to create new services for new segments of the public, as well as to provide existing services better and cheaper. For example, a networked database can provide the public with service when they need it and where they need it. Electronically delivered public services can help to prevent fraud, so the overall cost of implementation can be kept low. Compared to traditional paper vouchers, electronic vouchers can be easily tracked so that suspicious transactions can be detected.

IT has contributed to transformational changes in such industries as airlines, autos, hospitals, and banking. IT not only transforms and improves the way organizational activities are performed, but at the same time, improves the links among the participants (Espejo, 1994; Schuhmann, 1990). Time and geographical locations are no longer barriers to communication and coordination. With the introduction of computer-mediated communications, new forms of data transmission are reshaping the way people and organizations communicate and share information. Computer-based communications such as e-mail and FTP (file transfer protocol) are convenient ways of transferring large amounts of information almost instantaneously among a group of people.

INFORMATION TECHNOLOGY IN THE PUBLIC SECTOR

Interest in the impact of IT on public organizations can be traced back to the late 1960s (Laudon, 1974, p. ixxi). The initial focus was on the impact of computers on various aspects of public organizations, such as decision making, structure, and resistance to adoption. Recently, studies about the relationship between organizational performance and the use of IT reflect the extensive diffusion and adoption of personal computers. Managers and professionals are applying IT in their work and expect productivity and performance improvement (Perry et al., 1993).

Although there are a number of qualitative evaluations of IT in public-sector settings, many of these provide only anecdotal evidence about productivity impacts (e.g., Northrop et al., 1990). Only a few quantitative analyses were identified that employed large samples and objective measures from public-sector organizations (e.g., Lehr & Lichtenberg, 1996). Like private-sector service organizations, public-sector organizations suffer from the lack of agreed-upon performance measures. This limits many public-sector studies to evaluating the impact of IT based on user satisfaction or perceptions(e.g., Kraemer et al., 1981; Pentland, 1989; Northrop et al., 1990).

Several public-sector IT studies were conducted using panel data from the Urban Information Systems (URBIS) study carried out from 1976 to 1988[1] (e.g., Danziger et al., 1982; Kraemer et al., 1981, 1993; Northrop et al., 1990). The information about computer service was collected from 42 cities in the United States. The data contain six policy variables: automation, centralization, data integration, technical sophistication, user involvement, and charges for service (Northrop et al., 1990). Using this data set, Kraemer et al. (1981) and Danziger et al. (1982) both studied the impact of computer use on local municipalities. Their qualitative evaluation, largely based on managers' perception, concluded that there are overall positive impacts of computing, such as more control, better information, and improved work environment.

In further analysis of the panel data, the authors also concluded that maximum efficiency gains requires organizational reform and that the way managers use IT affects its perceived effectiveness (Kraemer et al., 1993). Northrop et al. (1990) reported the payoffs perceived by city managers over 12 years of computer use. The perception of city managers was disappointing according to the URBIS data. The study was able to identify minimal payoffs in the area of fiscal control, cost avoidance, and better interaction with the public. City managers were not convinced that computerization had helped them to get more and better information for management control and planning.

Laudon and Marr (1994) investigated IT use in three federal agencies the Social Security Administration (SSA), Internal Revenue Service (IRS), and Federal Bureau of Investigation (FBI). The analysis tried to explain different levels of performance by examining each agency's macro culture. Using longitudinal data, the authors showed that the IRS's experience with IT was disappointing, whereas the SSA and FBI showed strong productivity gains from IT investment. The authors illustrated that the differential productivity payoffs from IT resulted from differences in the political and internal environment of each agency. Strong external political control in the SSA and commitment from in-

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1) The first URBIS survey, URBIS I, was conducted in 1976, and the second wave of the survey, URBIS II, was administered in 1988 (Northrop et al., 1990).

ternal FBI management yielded positive gains from IT investment. Without such internal and external enforcing factors, the IRS remained unmotivated to improve its performance and gained little from its huge investment in IT.

Another study using data from the IRS investigated the link between voluntary and direct computer use and efficiency and effectiveness (Pentland, 1989). A survey of accounting professionals in the IRS and a review of completed audits showed that accounting professionals perceived an improvement in efficiency and effectiveness from using IT, in contrast to objective data, which did not correspond with individual perceptions. The accounting professionals enjoyed a sense of professionalism and self-esteem, but little evidence emerged to suggest overall organizational benefits. It is possible that managerial policy intended to promote computer use actually hurt organizational productivity when encouragement was provided for tasks for which the computer is only marginally useful. The uncritical support of IT and innovation could lead to "unnecessary, counter productive, or overly-expensive innovations" (Perry & Kraemer, 1977, p. 129).

Some researchers have examined the impacts of IT at the process level. Using U.S. Postal Service data, Mukhopadhyay et al. (1997) found that IT had a positive impact on both the quantity and quality of process output. Closely examining individual applications, they concluded that (1) IT produced high-quality outputs in terms of timeliness, and (2) the improved quality led to higher quantity in sorting mail. The new technology, however, did not translate into performance improvement unless other processes were redesigned or renovated to assure proper use of IT.

A study by Lehr & Lichtenberg (1996) indicates increased performance from IT investment. They examined trends in computer usage and the effects on productivity growth using a sample of federal government agencies over the period 198792. The authors combined data from the U.S. Bureau of Labor Statistics on the growth in real output per employee with another set of data from Computer Intelligence, a private consulting firm, on the growth in per capita computer assets for a sample of 44 federal agencies. The analysis reported that computer usage in federal agencies increased dramatically during the sample period. The Cobb-Douglas production function analysis also demonstrated the positive impact of IT on the performance of federal agencies. This is the first report to use public-sector data with a Cobb-Douglas production function model specification.

Lee (2002) analyzed the relationship between IT investment and performance improvement using public-sector data. The study used state-level data and included management and lagged effects in addition to IT investment. The result showed that there is a positive relation between IT investment and performance improvement and that IT management structure is a critical factor in realizing the potential of new IT.

KEY FINDINGS FROM THE LITERATURE : STILL A PRODUCTIVITY PARADOX

Although previous research has contributed to our understanding of the nature of IT and its impacts, the mixed results regarding productivity improvement lead us to no clear conclusion. Many factors are said to account for the varied results. This section will recap the paradox of IT performance identified in the previous research to identify the nature of persistent problems.

Explanations for the productivity paradox abound. Given the inconclusive research results, we have three possibilities. First, there may be no real productivity gain from IT investment at the industry or sector level. Our perception that IT investment results in performance enhancement may be based only on the redistribution effect, namely, that firms equipped with IT take benefits away from firms without IT. Second, there may be productivity gains that we fail to measure because we lack an appropriate performance measure. Improper performance measures may prevent us from capturing the benefits of new technology. The third possibility is that the expected productivity improvement may not have been realized yet, either because of an exceptionally long gestation period or because of poor management.

Redistribution

Many of the recent firm-level analyses of the manufacturing sector reported positive impacts on economic performance from IT investment. These results do not necessarily mean that IT has helped to increase industry-wide or society-wide performance or that of individual firms. We do not yet have decisive evidence that IT has increased the performance of the whole economy. The studies used either large U.S. firms (e.g., Brynjolfsson & Hitt, 1993) or firms that are known to be the best performers in the industry (e.g., Mahmood & Mann, 1993). IT may have given such firms a bigger share without enlarging the size of the whole pie. Thus, the results of the analysis based on such samples do not rule out the possibility of the so-called redistribution effect of IT. The improved performance of firms included in those analyses could be the result of large firms getting a bigger share at the expense of small firms or poor performers in the industry.

These research designs and samples may fail to control for the spurious relationship among IT investment, performance, and size (see Figure 1). What we want to know is the impact of IT investment on performance. As Figure 1 shows, it is possible that the findings of these studies are based on the spurious relationship (left plane in Figure 1) in which performance is the function of size rather than IT. If this is the case, IT investment and performance seem to covary, though in fact, they are not related to each other at all. We need research design and data that can distinguish the direct relationship between IT and performance (right plane in Figure 1) from the spurious relationship.

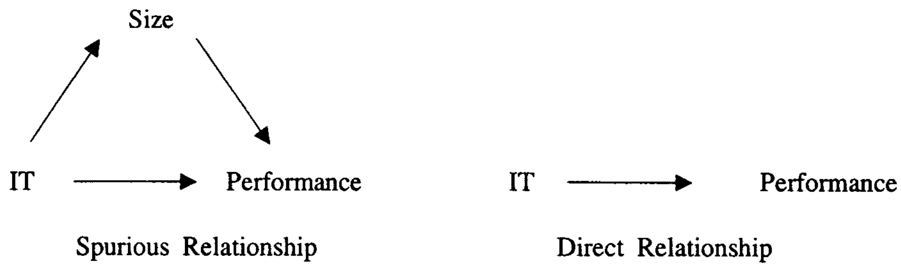

Figure 1. Spurious Relationship and Direct Relationship

Another possibility is that the impact of IT may be closely related to temporary competitive advantage rather than productivity improvement (Loveman, 1991). Loveman speculated that many of the capabilities of IT were used to gain or maintain competitive advantage rather than improve organizational efficiency. The case of the airline industry provides an example in which IT resources were utilized to support frequent flier programs, with little discernible impact on productivity. It is possible that computerized databases help each airline to provide individualized service to its customers. Such a use could help each airline to gain advantage over other competitors. However, the advantage disappears as soon as other companies adopt the same technology.2) Such uses do not necessarily improve operational efficiency, which could reduce cost and increase performance.

Poor Measurement

Poor measurement seems to be the most popular excuse for null findings (e.g., Baily, 1996; Brynjolfsson, 1993; Due, 1994; National Research Council, 1993). The traditional measures of performance are said to be inappropriate for capturing nontraditional sources of value. IT is said to increase not only efficiency but also the quality of output, such as the variety and unrestricted availability of customer services, increased customer satisfaction, timeliness of service delivery, and responsiveness to customers' needs. Current statistical procedures to measure productivity were established when the service sector represented a much smaller fraction of the whole economy, not the 70% it makes up today.

Productivity measures based on traditional accounting practices present problems even in manufacturing industries. Productivity is frequently measured by counting units used and produced or, when counting units is problematic, by using the market price adjusted by a price index. These measures may capture only a part of the quality improvements. Traditional measurement techniques could

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2) If that is the case, why do firms adopt IT? Many firms try to adopt a new technology before their competitors do. In many cases, first movers are favored in the market and can take a strategic position in the market (Bakos, 1991).

be an even more serious problem in the service sector, where output is hard to define and measure (Quinn & Baily, 1994). For service industries such as banking, education, and government, productivity is sometimes measured by inputs. Difficulty in defining service outputs frequently leads to the use of other proxy measures for productivity, such as revenue, sales, or satisfaction. These could be good candidates but do not solve all of the problems associated with the traditional measurement techniques. For example, market conditions, such as severe competition resulting from deregulation, influence revenue along with the internal operations of a firm (Ives, 1994). Subjective evaluation from those who choose to use a certain technology could also present some problems (Laudon & Marr, 1994). In many cases, people made choices based on preference. If that is the case, a study is unlikely to obtain the "real" impact of IT from users who made a voluntary choice based on their preference. Organizational adoption of IT may have the same problem because the decision may reflect the member's preference. These reasons may keep researchers from documenting the increase in service-sector productivity that is actually achieved by means of IT investment.

Some recent studies reported the positive contribution of IT on productivity in the traditional sense (e.g., Brynjolfsson & Hitt, 1993; Lehr & Lichtenberg, 1996). This implies that it may not be necessary to have unique and separate performance measures for the impact of IT. Nevertheless, given the distinctiveness of the new technology, developing diverse performance measures is crucial (e.g., Delone & McLean, 1992). Such measures would reveal unexpected contributions of IT so that users of IT could understand and realize its full potential. The diverse performance measures also could tell us which technology works and which does not to achieve a given goal. However, developing new performance measures could be costly. Although it is possible to develop such performance measures and use them nationwide, developing new measures could require more resources than are affordable because of the intrinsic characteristics of the technology and the sector.

Lagged Effects

Although the benefits from investing in infrastructure can be large, they tend to be indirect and often not immediate. The quality of service may not be known until long after it is delivered, as in dentistry or insurance. The case of the dynamo, the primary electromechanical conversion device, makes this point clear: Edison invented electricity in 1879. Nevertheless, it took nearly 40 years for U.S. manufacturing factories to witness productivity growth from using electricity (David, 1989). Between 1900 and 1920, the percentage of U.S. factories equipped with electric motors jumped from 5% to 55%. Despite the obvious advantage of electric power over steam power, labor productivity showed no measurable increase during the two decades. Because the existing infrastructure had evolved around expensive steam power (so called group drive), it was extremely costly and inefficient to use electric motors, which are ideal for "unit drive."To take advantage of the promised benefits of electricity, factories had to take radical steps to rearrange their machines and flow of materials. It was only after changes in infrastructure were made that productivity growth took off. Such changes take time to be realized. Completely new work flows and organizational infrastructure may be needed for organizations to exploit the promised performance improvement of IT.

For individual users, the unusual complexity and novelty of IT may require them to have some experience before they become proficient and reap benefits from using it. In particular, poor humancomputer interfaces frequently make computer literacy hard to master. This sometimes results in under utilized IT (Straub & Wetherbe, 1989). In the case of public organizations, their political nature may delay the realization of performance improvements resulting from IT (Northrop et al., 1990). Because of this learning and adjustment, the optimal investment strategy may be to set marginal costs greater than marginal benefits in the short term. This would allow each firm to follow the learning curve and secure benefits analogous to economies of scale. If this is the case, results based on short-term IT investment and productivity data may not reveal real benefits or may even appear inefficient.

Lagged effects fit quite well with the results of previous studies. Most of the studies using data from the 1970s or 1980s showed few performance returns to IT investment, whereas studies done during the 1990s showed improved performance from IT investment (Cohen, 1995). This also implies that productivity gains could become muchlarger as individual users become accustomed to the new technology and as new investment in infrastructure allows better use of IT as it matures (e.g., Kelley, 1994).

Management of Information Technology

The management hypothesis for the productivity paradox assumes that investing in IT is not enough to improve productivity. The link between the use of IT and productivity improvement should not be taken for granted (Trice & Treacy, 1988). Economists tend to treat the firm as a black box. Thus, the process of transforming IT investment into changes in output is frequently ignored in their research designs. That is why most econometric studies do not include a management variable in their research models.

There are several reasons to believe that management is a critical factor in achieving the benefits of IT investment. Managers may be interested in maintaining higher level of slack resources than is necessary for the best interest of the whole organization (Brynjolfsson, 1993). To maintain slack resources, organizations have to pay additional costs. In theory, slack resources can help organizations to cope with contingencies, they also can be used for personal purposes. In particular, this is a problem because it is difficult to measure the benefits of IT and monitor managers' behavior. Managers, thus, tend to rely on intuition, hunches, and heuristics that are vulnerable to self-interest. Asymmetric information between principal and owner or among the organization, agent, and manager makes the principal vulnerable to the agent's hidden behavior. This problem is known as moral hazard: Once the contract between the principal and the agent is made, the principal is put into a relatively weak position in controlling and monitoring the agent's behavior. Only the agent knows the state realization and the level of effort he expends. Moral hazard occurs because the agent is self-interested and the information is asymmetric (Williamson, 1985, 1986). These types of managerial behaviors could prevent IT from achieving its expected potential.

The organization could make a higher level of investment in IT than is necessary, leading to disappointing results (Perry & Kraemer, 1977). If the investment decision is made based on top managers' personal experiences and personal benefits, it is possible that the investment is not being made for the benefit of organization. Decision makers may not pay much attention to the broader benefits and costs of IT investment. If there is an unrealistically high level of performance expectation when the IT investment is made, overinvestment is likely. The unrealistic performance expectation could also lead to disappointment, even if there is an indication of improved performance.

Lack of analysis and planning and an inability to monitor could lead to misallocation of resources. Without proper project management, systems that were intended to increase the efficiency of the organization may build in inefficiencies and waste resources during implementation, resulting in a maintenance nightmare (Due, 1994). Organizations may vary in their ability to harness and use IT for diverse organizational goals. Pentland (1989) found that when managerial policy promotes computer use in areas where it is only marginally useful, organizational productivity falls rather than increases because of IT use. This implies that for an organization to get the most our of IT investment, it should be able to analyze its IT needs and develop a plan based on this analysis for proper IT investment and implementation.

IMPLICATIONS FOR FUTURE RESEARCH

Redistribution

The redistribution argument for the productivity paradox can be made when the analysis is based on observations from private firms. The argument is that efficient firms equipped with IT take the market shares of small, inefficient firms without proper IT equipment.[3] The redistribution argument could explain the lack of positive and significant evidence in industry-level analyses. A few firm-level analyses that reported the positive impacts of IT are also vulnerable to the redistribution argument because the analyses were based on samples of

3) According to the redistribution explanation, IT investment is like advertisement in that it does not improve productivity or efficiency. It only increases the sales of the advertiser by taking the shares of non-advertisers.

larger firms. This study provides an opportunity to overcome such vulnerability. Using data collected from all 50 states with no chance for a redistribution effect this study showed that IT in state governments contributes to statewide economic performance.

Redistribution can be avoided in a number of ways. First, appropriate research designs are required to rule out the possibility of redistribution. Sample selection must be made in such a way that inference to the intended population is less problematic. The selection bias may make the results of previous studies difficult to generalize because firms may not reveal their real behavior if it would hurt their reputation or stock performance. Thus, we are not sure yet that any firms benefit from investing in IT. To avoid this problem, the impact of IT investment should be estimated using a representative sample or in a context in which the redistribution effect is not a factor. Random sampling is the most desirable choice, but data availability often prevents researchers from making the best choice.

Using national level data is another possibility. At the aggregate level, all the numbers are averaged and the redistribution effect may be cancelled out. For instance, Kraemer and Dedrick (1997) examined the productivity impact of IT using data from developing Asian countries. They found a positive and significant correlation between growth in IT investment and growth in both gross domestic product and productivity. However, there is a potential problem in using national-level data when comparisons across countries are made. The data may not be comparable because countries sometimes use different methods of estimating certain measures. In particular, the way each country estimates its computer price could make the data less comparable across countries (Wyckoff, 1995).

Another option is to estimate the impact of IT using data from the public sector. Because there is no market equivalent in the public sector and competition for customers is unlikely, the redistribution argument rarely survives. For instance, new IT investment in one state is unlikely to induce more people or industries to move into the state from other states, at least in the short run. Estimating the impact of IT investment in a context in which performance is not affected by market competition may help to mitigate the redistribution effect of IT.

Performance Measurement

Inadequate performance measurement has been cited most frequently as an excuse for not finding a significant positive impact of IT investment (Brynjolfsson, 1993 Due, 1994; National Research Council, 1993). Traditional performance measures have been criticized for being insensitive to quality improvement. The null findings in quantity-oriented productivity research were attributed to the inability of quantity measures to monitor quality changes. Developing new measures is no easy matter which may be why no consensus exists on which IT performance measure to use, especially in the public sector. Cost and the uncertainty of developing legitimate performance measures are valid concerns, too

(Thurow, 1998).

This does not mean that we do not need new IT performance measures. Jurison (1996) suggested that the benefits of firms' IT investments are reaped by a variety of participants and stakeholders, including stockholders, employees, customers, suppliers, competitors, and the public. The impact of IT is so diverse and wide, we do not have to stick to the traditional ways of measuring performance. New and diverse ways of measuring performance that can capture the real impact of IT should be developed and used. Not only will this help us to measure the real impact of IT, but also it will guide us in using IT in more productive and effective ways.

Though some of the traditional performance measures picked up IT's positive contribution, this does not necessarily mean that traditional performance measures can monitor all the benefits IT provides. Researchers still need to develop performance measures that will allow us to understand the true value of IT and to critically reevaluate existing performance measures (e.g., Alpar & Kim, 1990; Cardinali, 1998). The new measures should be able to capture the impact of IT on individuals, organizations, and society. Even at the same level, aspects of IT impact should be explicitly considered. Quality improvement as well as quantity increases are two major areas. Adequate performance measures would allow us to monitor the real impact of IT, identify benefits that have been overlooked, and design ways to maximize such benefits.

Along with the inadequacy of performance measures, measurement of IT itself is another critical issue. Because of rapid development in technology, calculating an adequate price deflator and market-value estimates is a daunting task (e.g., Berndt et al., 1995; Gurbaxani & Mendelson, 1990; Oliner, 1993; Wyckoff 1995). There are two major methods of estimating the market value of computer equipment: the matched model and the hedonic model(Wyckoff, 1995). The matched model keeps a record of a predetermined set of models (e.g., IBM 8088) and estimates the computer price based on this record. When a product in the set is discontinued, only the remaining products are used, assuming that they would approximate the discontinued product. On the other hand, the hedonic index is based on the comparison of price changes and product characteristics, such as MIPS and disk space in the case of computer equipment. Thus, the hedonic index allows us to compare a variety of products based on their specific characteristics.

However, these two market-value-based estimation methods have a weakness in measuring the real contribution of existing IT equipment. The major shortcoming of these market-price-based approaches is that they generally fail to capture system capacity. This is a critical problem given the rapid improvement in IT-related equipment. As Moore's law states, the price of IT-related equipment drops very fast (Scott & Pisa,1998). In particular, whenever a new product is introduced to the market, the price of comparable existing products declines rapidly. The lower price, however, does not mean that existing products do not perform at the level at which they are supposed to perform. Their price is reduced only because there is a new product in the market. That is why the depreciation schedule for computer equipment is shorter than for other capital equipment (Oliner, 1993).

Even with some corrections using price deflators and shorter depreciation rates, a market-value-based IT measure has an intrinsic limitation in measuring the true amount of IT. Using the market-value-based approach, it is hard to reflect the technical characteristics that largely determine system performance but are not correctly captured by market prices. For example, in most cases, the market prices of comparable CPUs produced by different manufacturers are different not because of technical characteristics, but because of brand recognition. If we focus on market price, we may underestimate investments that are not based on brand recognition, but on technical characteristics.

A full understanding of the things that IT influences and how it does so will provide us with a better chance of making the most of IT investment. To do so, we want to have measures that capture the real amount and performance effects of IT. The new measures do not have to be applied nationwide at once. Diverse organizational-level and sector-level measures can be tested and employed so that we have a single, widely agreed-upon scale that can be used to understand national-level IT input and performance.

The public sector suffers from a lack of well-defined performance measures. Services that public organizations deliver are hard to count. It is also difficult to assign monetary value because there is no market for such public services. Consequently, some studies have relied on user perceptions to evaluate the performance effects of IT. However, as Pentland (1989) showed, individual perceptions do not necessarily correspond with objective organizational performance measures. It is critical to use objective or structural measurements where applicable to investigate the impact of public-sector IT investment.

The Lagged Effect of IT

There are two major reasons for the lagged delivery of IT benefits: individual and organizational adjustments and changes in overall infrastructure. The first source tends to work in the short term, whereas the second source has a long lag structure. As the literature review shows, null findings mainly occurred in studies using data prior to the 1990s. Using recent data, this study, and a few others, indicates there could be a long lag structure in the realization of benefits from IT investment. The lagged effect of IT investment is an issue that requires closer investigation using longer time-series data with more sophisticated models.

Other than methodological issues, such as data aggregation, there are substantive explanations for the results with regard to the lagged benefit of IT. The proliferation of graphical user interfaces (GUI) may explain the null finding for the short-term lag. One of the obvious benefits of a GUI is that it shortens the learning period. Because the user interface is based on graphics and pull-down menus, GUI eliminates the necessity of memorizing the commands (Cardinali, 1994). Command-line interfaces (e.g., MS-DOS and UNIX) are efficient, but they demand a greater amount of memorization and learning before the blinking command prompts are meaningful. The GUI makes the information readily available to users because it is easier for them to learn and use than the character-based interface. Although GUI-based operating systems were first shipped during the 1980s,[4] it was not until the beginning of the 1990s that Windows was shipped with almost every PC, which coincides with the sample period of this study.

Although some scholars have suggested the importance of the lagged effect, only a few have included lagged effects in their models (e.g., Brown et al., 1995; Lee 2002 Loveman, 1994; Verstegen et al., 1995). Not all theories can be empirically tested, for practical reasons. For the case of testing a lagged effect, the unavailability of time-series data to which lagged models can be applied is one of the practical obstacles. To test the lagged effect using a formal model, we need a lengthy time series to understand the underlying pattern.

Management of IT Resources

How IT is managed and used is as important as how much IT equipment organizations have. IT is different from other input factors in that it produces something intangible: information. Unlike tangible goods, information may not have intrinsic value. The value of information, and thus the contribution of IT, can be realized only when the organization is capable of exploiting IT. Organizations need appropriate structures and processes to manage IT and the information it generates.

A positive and statistically significant regression coefficient of IT capital does not guarantee that investment in IT always will be followed by performance improvement. The organization and management literature indicates that the link between the use of IT and performance improvement should not be taken for granted (Pentland, 1989 Perry & Kraemer, 1977; Trice & Treacy, 1988). Some empirical studies even suggest that organizational differences may be a critical factor in the IT performance relationship (Bryjnolfsson & Hitt, 1995 Verstegan et al., 1995). Despite its importance in the literature, few empirical researchers have directly studied the management issue.

By including management variables in the research model, Lee (2002) found that the way IT resources are managed makes a difference in the economic performance of a state. State governments have two major choices in effective IT management structures: the chief information officer (CIO) and the information resources management (IRM) commission. The CIO is an executive located at the top of the state government hierarchy who direct IT developments. On the other hand, the IRM commission relies on group decisions representing each department's interests. The analysis of the full sample (all states) shows that states with CIOs have better statewide economic performance than those with different

4) While the first GUI based operating system started in 1982 (VisiOn by VisiCorp), Microsoft and IBM first shipped the initial version of Windows and OS/2, respectively., in the middle of the 1980s (Elgan, 1995).

IT resource-management structures. This implies the importance of centralized and efficient management of IT resources and standardization. The results also support states' efforts to mandate strong management control of information resources (Caudle, 1990).

The significance of the management variable implies that, although the amount of IT investment is an important factor in improving performance, the way the information resources are managed also affects the level of performance. IT should be tied to the structures and processes of the organizations that it serves. Characteristics such as the level of shared information through networks, the stream of information, and the level of acceptance from the members of the organization are critical factors. For these factors to be properly managed, there must be a centralized effort to set a standard and to consistently enforce it throughout the organization so that systems can communicate with each other.

This also implies that performance improvement cannot be achieved when technical expertise is not properly involved in IT-related decision making. State governments with a CIO perform better than states without a CIO. Although an IRM commission is usually composed of managers representing individual organizations, a CIO in state governments is usually a technology-oriented person who is responsible for data-processing and telecommunications operations (Caudle, 1990). In addition to day-to-day data-processing operations, the CIO plays a decisive role in developing and implementing IT-related plans. Management of IT resources inevitably involves technical decisions regarding the content and processes of technological changes. It includes developing recommendations for IT management policy, procedures, and standards, as well as identifying opportunities to share information resources. The CIO's technical expertise seems to facilitate better decisions regarding the design, modernization, use, sharing, and performance of resources.

Despite its stated importance in the literature (e.g., Brynjolfsson & Hitt, 1995; Kelley, 1994 Mukhopadhyay et al., 1995; Sproull & Kiesler, 1991), only a few empirical studies have actually included the management variable in their research. Some included dummy variables for each organization to control for the heterogeneity of management and other characteristics that vary across firms. In those cases, it is difficult to interpret the results because the dummy variables incorporate too many factors (e.g., Verstegen et al., 1995). Given the importance of managerial intervention in realizing the potential of IT investment, its effects should be tested formally.

CONCLUSION

Technology has long been considered a major source of performance improvement. As the history of economic development reveals, the introduction of new technologies has been followed by remarkable economic growth and social change. IT is considered one of the most influential technologies humankind has invented. Unfortunately, despite the high level of expectation, it has been difficult to demonstrate a significant positive relationship between IT and performance measures.

Based on a review of the field, some implications for future research can be identified. Future research should be able to provide information regarding the scope of benefits from using IT, the appropriate amount of IT investment, the proper IT management structure, and the impacts of IT in organizations. Virtually every aspect of IT in organizations needs proper answers derived from further research. Answering these questions will not only help practitioners make informed decisions regarding IT investment and management but also enrich management and organization theory.

First, the use of diverse performance measures would allow us to investigate the scope and depth of IT's contribution. This could be critical information for policymakers to maximize investment through appropriate IT investment plans and to manage IT resources properly. The impact of IT investment is not limited to the organizations that adopt IT. By using diverse performance measures, we can understand the nature and scope of the benefits IT can deliver. This will help us to make better IT investments and to provide better management.

Second, future research should put more focus on IT management structure. The level of centralization, scope of authority of IT resource managers, and relation to other top managers are some of the critical questions that require answers. Understanding efficient IT resource-management structures and processes, along with their relationship to other parts of the organization, will help top managers to design proper IT management structures.

Third, there are some methodological and modeling issues that could be addressed in future research. Changes in technology and in the level of its demand usually result in continuous disequilibrium. In addition, allocative efficiency cannot be estimated because of technological change. Thus, analysis based on an equilibrium assumption may not describe the situation fully and correctly. The possibility of disequilibrium should be explicitly modeled. Less restrictive forms, such as a translog model, may provide us information that is more useful. The translog model is said to be more flexible than the Cobb-Douglas production function. However, some empirical studies show that the result of using the translog model does not give us new information on the impact of IT (e.g., Brynjolfsson & Hitt, 1995). However, Brynjolfsson and Hitt's study was based on private-sector data it needs to be replicated using public-sector data.

Finally, although some studies have shown that IT has a positive impact, no studies have shown that IT is an efficient input factor. Further research should address the fact that IT is in fact an efficient input.[5] To know whether the gains from IT should be substantially larger than its input is a critical piece of information for additional IT investment. Without this information, we have no idea whether IT investment is a wise choice.

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5) For example, the relationship between p_1 / p_2 and $(\Delta Q / \Delta x_2)/(\Delta Q / \Delta x_1)$, where p is the rental price of each input (x) and Qis output.

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