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Are Computers Boosting Productivity?: A Test of the Paradox in State Governments



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# ARE COMPUTERS BOOSTING PRODUCTIVITY?:

# A TEST OF THE PARADOX IN STATE GOVERNMENTS

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**ARE COMPUTERS BOOSTING PRODUCTIVITY?:**

**A TEST OF THE PARADOX IN STATE GOVERNMENTS**


Abstract

An issue long nagging scholars who study the effects of information technology (IT) investments is the so-called productivity paradox. Investments in IT have promised productivity improvements, but the benefits have often not materialized. This research seeks explicitly to study many of the explanations for null findings in previous research in a rarely studied context, state governments. The research employs several novel features, including innovative measures of productivity and the technology itself, and a formal measure of information technology management structure. IT investments by state governments have positive and significant affects on the measure of productivity, gross state product. Organizations that use chief information officer structures to manage the technology reap greater rewards from their investments. We conclude that research that eliminates shortcomings of previous studies is likely to find performance improvements from IT investments.

# ARE COMPUTERS BOOSTING PRODUCTIVITY?:

# A TEST OF THE PARADOX IN STATE GOVERNMENTS

During the last two decades, information technology (IT) investments have grown rapidly. U.S. business alone invested more than $1 trillion in the last decade (Twigg, 1995). Thus far, however, productivity improvements associated with IT investments have been questioned. Several reviews of major studies report that evidence of productivity improvement is hard to find in the private sector (e.g., Brynjolfsson, 1993; Wilson, 1993), but recent studies report evidence of positive gains from IT investment (e.g., Kraemer & Dedrick, 1994; Brynjolfsson & Hitt, 1993; Lichtenberg, 1993).

Although government spending on computers has increased tremendously, empirical studies about the impact of IT in public sector organizations are rare (Kraemer & Dedrick, 1997). Only a few studies have estimated the impact of IT investment and use on the performance of public organizations (e.g., Laudon & Marr, 1994; Lehr & Lichtenberg, 1996). Little is known regarding the impact of IT investment in public organizations. Given these circumstances, it is appropriate to investigate the impact of IT in public organizations while attending to issues raised from previous research in the private sector.

The specific focus of this study is the economic impacts of IT investment in state governments. In light of intrinsic differences between the public and private sectors (e.g., Bretschneider, 1990; Perry & Rainey, 1988), the results of private sector research cannot be generalized to government organizations. In addition, by clarifying the sources of the 'productivity paradox', this study will address the obstacles of realizing the potential of IT investment.

## THE PRODUCTIVITY PARADOX

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 the impact of IT investment and has generated heated discussion (e.g., Roach, 1988). Many reasons, substantive and methodological, have been offered for the IT 'productivity paradox,' among them redistribution, poor measurement, lagged effects, and mismanagement (e.g., Brynjolfsson, 1993; Wilson, 1993; Lee, 1999; Lucas, 1999).

The redistribution explanation for the productivity paradox contends that IT does not improve the productivity of the whole sector but only redistributes benefits within the sector. According to this explanation, IT does not contribute to overall productivity improvement. Like investments in advertising, IT investment only brings a firm more market share with little impact on the efficient operation of a firm.

Poor measurement is the most common reason given for null findings (e.g. Brynjolfsson, 1993; Due, 1994; Baily, 1996; National Research Council, 1993). Traditional measures of performance such as labor productivity are inappropriate for capturing non-traditional sources of value. IT increases not only efficiency, but also the quality of output, such as the variety and unrestricted availability of customer services, timeliness of service delivery, and responsiveness to customers' needs.

The lagged effect of investments is also used frequently to account for the productivity paradox. There are two potential sources of this lag. One is that redesigned workflows and organizational infrastructure may be needed for organizations to exploit the promised performance improvements. Existing infrastructure is not designed for the best use of IT and it takes time to modify to accommodate new technology (David, 1989). Another source of lagged effects arises among individual users. The unusual complexity and novelty of IT requires users to attain experience before they become proficient and reap its benefits. In particular, poor human-computer interfaces frequently make computer literacy hard to master. This sometimes results in underutilized IT (Straub & Wetherbe, 1989). If this is the case, the results based on cross-sectional data may not reveal real benefits and may even appear inefficient.

The mismanagement explanation for the productivity paradox asserts 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). Managers may be interested in maintaining higher levels of slack resources than necessary for the best interest of the whole organization (Brynjolfsson, 1993). The organization could make a higher level of investment in IT than necessary, leading to disappointing results (Perry & Kraemer, 1977). Lack of analysis and planning, and inability of monitoring could lead to misallocation of resources (Due, 1994). Organizations may vary in their ability and willingness to manage IT for diverse organizational goals (Pentland, 1989).

Several studies found productivity improvements from IT investment (e.g. Brynjolfsson & Hitt, 1993; Lichtenberg, 1993). Although this might be assumed to put the debate about IT and productivity to rest, these analyses do not explicitly address the specific explanations for the productivity paradox. For example, 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), preventing assessment of the redistribution explanation.

## HYPOTHESES

This study investigates the impacts of public sector IT investment and the role of IT management structure in realizing such imp acts. In doing so, it explicitly addresses some of the possible explanations of the productivity paradox, namely redistribution, mismanagement and lagged effects.

### The Impact of Information Technology

Examining the relationship between the performance of state governments and investments in IT is a difficult task. The difficulties come primarily from the lack of availability of performance measures. Most of the outputs public organizations produce are intangible and do not carry market value, which is a convenient proxy for performance in the private sector.

One way to get around some of these problems is to change the scope of analysis. The bottom line of the government's role is service to society. While the contents of service vary depending on society's demands, the basic role of state services is to help the private sector perform better. Improving the service quality provided by public entities is considered one of the major tools for improving society (Kim & Wolff, 1994; Sturgess, 1996). Investing in IT helps state government organizations improve the efficiency of internal operations through automation. In addition, IT can improve the quality of existing public services, create new types of service that were not previously available, and increase the accessibility of those services. Government IT investment and its associated improvements are geared toward increasing value to society. Improving statewide economic performance is one of results a state government is trying to achieve

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Figure 1 about here
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State government uses IT as one of the factors of production (or resources) along with labor and capital to provide public services and to produce statewide wealth. One of the critical roles of a state government is to help private firms do business well. With improved public sector support, private firms perform better. State government also directly contributes to the statewide economy by providing services that are not provided by the private sector. If state government is using IT as an important and effective factor of production, IT should have a positive impact on statewide economic performance.

To measure state economic performance, this study will use statewide GSP, an economic performance measure, as a dependent variable. Statewide economic performance is determined by contributions from the public and the private sector (see Figure 1). By regressing total GSP against state government's contribution along with private sector's inputs, the model can estimate the public sector's statewide economic contribution. Total GSP also allows us to make a comparison across the states by estimating the contribution of each state government. Because GSP is a value-added measure, it overcomes the problem inherent in using state expenditure levels.

Hypothesis 1: IT investment in state government increases the economic performance of the state as measured by GSP.

Relying on public sector data has one more advantage. It helps us bypass the redistribution explanation based on market competition. Public sector organizations do not have an equivalent to markets in the private sector. The argument that state governments compete with each other is not compelling, at least in the short run. Thus, the results of public sector analysis is less likely to be affected by the redistribution impact. The sample this study uses is the 50 U.S. state governments. This creates a situation in which redistribution is not a major obstacle to finding real impacts of IT investment.

**Management of Information Technology**

The level of IT investment does not automatically determine the level of performance of new technology. There are higher and lower performers within groups of firms that are known for extensive use of IT (Cron & Sobol, 1983). This implies the importance of the way each organization uses its IT resources, i.e., IT management.

Although the improper management of IT has been identified as one of the major sources of the productivity paradox (e.g., Cron & Sobol, 1983; Brynjolfsson & Hitt, 1995; Verstegen et al., 1995), little research has investigated the relationship directly. Previous studies pose more questions than answers. Those studies failed to identify which organizational characteristics make the difference due to the nature of the variables and research design they used. For example, Brynjolfsson and Hitt (1995) included dummy variables for each organization in an effort to capture the differences an organization may have from others. These differences, however, could be organizational characteristics, managerial differences, geographical location, or a host of other factors.

IT helps an organization improve overall performance by linking different information sources (Johnston & Vitale, 1988). Communicating and processing information across organizational units cannot be accomplished without well-coordinated networks (Cats-Baril & Thompson, 1995). To achieve this, it is necessary to have some person or organizational unit oversee organization-wide, or network-wide, IT resources and their management.

Information resources management (IRM) refers to the process of managing information resources to accomplish organizational missions (OMB, 1996). To manage information resources effectively, attention is directed to determining what is best for the organization as a whole. This involves various tasks, including planning, organizing, budgeting, directing, monitoring, and controlling the people, funding, technologies, and activities associated with acquiring, storing, processing, and distributing data (Lewis et al., 1995).

According to the National Association of State Information Resource Executives (NASAIRE) data, four different types of IT management can be identified: CIO only, IRM commission only, mixture of CIO and IRM commission, and no formal IT management structure. The Chief Information Officer (CIO) is a senior executive responsible for overseeing the entire IT operation and is usually a technical expert. The CIO facilitates information resources management from an organizationwide perspective (Roeber, 1991). While the CIO is the highest-ranking position in IT management, this managerial role requires effective communication with top management. The chief executive and other members of senior management are consulted by the CIO. This can ensure that IT is acquired and managed in such a way that it helps the organization achieve better results with fewer resources. Developing, maintaining, and facilitating the implementation of an integrated IT architecture is one of the major responsibilities of a CIO.

While a CIO is given individual responsibility for managing state government-wide IT resources, an IRM commission reflects a collective approach to managing IT resources. It may formally be a board, commission, or committee. The commission is usually composed of top managers in various state agencies who have a stake in IT (NASIRE, 1994). Under the commission arrangement, decision making and coordination differ from the CIO structure, while the scope of authority is similar. A commission, however, must reach agreement among members about technology management issues before it makes substantive decisions. This team approach may produce better decisions. It also creates the potential for delaying or politicizing decisions. If we consider that technology changes rapidly, delayed decisions could produce ineffective or inefficient choices. This means the effects of CIO and IRM commission structures could be quite different. Such differences should have differential impacts on performance. Thus, the second hypothesis will test different IT management structures and their impact on performance.

Hypothesis 2: Different IT management structures have differential performance effects.

**Lagged Effect of Information Technology Investment**

Lagged realization of the benefits of IT is one of the explanations for the IT productivity paradox. Two different sources of lags are discussed in the literature. The first type comes from the fundamental changes in the infrastructure and has a long lag structure (Scott Morton, 1991; David, 1989). New structures and processes based on new technology have to diffuse throughout the production system (Brynjolfsson & Hitt, 1998). In case of electronic dynamo, for example, it took more than 20 years for the new infrastructure to take hold (David, 1989).

Another source of the lagged effect of IT is individual and minor organizational adjustments. It has a shorter lag structure. Several studies reported a 1 or 2 year lag for individual users and organizational adjustments (Jurison, 1996; Brown et al., 1995). While the methodologies applied in these studies are different, they found that the effectiveness of the organization that adopted IT increased 1 year after the system installation. These results imply that it takes about a year for the individual users to familiarize themselves with the new system and for organizations to make minor adjustments. Only after organizations and their members can fully utilize the system will they reap the benefits IT can provide.

Due to the lack of sufficient longitudinal observations, this study will test only the 1-year lag. Six years of data are available for each state. This does not give us enough degrees of freedom to apply sophisticated distributed lag models. Thus, the hypothesis for the lagged effect focuses on the individual learning and minor organizational adjustments needed to take advantage of IT investment.

Hypothesis 3: IT investment has a one-year lagged effect on economic performance.

## METHODOLGY

The model for testing the hypotheses, data sources, and variable definitions are discussed next.

### The Model: Production Function Framework

While there are various ways of measuring and estimating productivity impacts (e.g., Forsund et al., 1980), this study will be based on a Cobb-Douglas production function as a base model and the ordinary least squares (OLS) approach as a way of estimating the model. The analysis does not enforce constant returns to scale. Doing so may contradict the nature of IT because IT is said to have transformational effects on the organizations that adopt it (Huber, 1990). By affecting the process and the structure of an organization, IT changes the way an organization produces its output. If this is the case, assuming constant return to scale is problematic.

The theory of production states that the inputs (e.g., *K* and *L*) an economic entity consumes can be related to output (*Q*) through a production function (*f*) (see Equation 1).

**Equation 1**

$$Q = f(K, L)$$

The basic model can be modified to accommodate the specific inputs, the scope of analysis, and the available data. For the public sector input, IT capital (*C*), labor (*L*), non-IT capital (*K*), and other expenditures (*E*) are included in the model. In addition to state government inputs, population of a state (*P*) is included to capture the private contribution to statewide economic performance.[1] Two sets of dummy variables are also included to control for year (*y*) specific and state (*s*) specific differences. These are included to control for the short-term economic shocks that may influence year-by-year data and for the embedded characteristics of each state. These parameters yield the following equations (see Equation 2):

**Equation 2**

$$Q = f(C, L, K, E, P; y, s)$$

Equation 3 expresses the general functional form of Equation 3 as a Cobb-Douglas production function to fit the data set.

**Equation 3**

$$Q_{ys} = b_0 \exp(\sum_{y=1}^{n-1} g_y Y_y + \sum_{s=1}^{n-1} d_s S_s) C_{ys}^{b_1} K_{ys}^{b_2} L_{ys}^{b_3} E_{ys}^{b_4} P_{ys}^{b_5}$$

To make the equation amenable for regression analysis, it is necessary to take the natural log of each side of the equation and add an error term so that the equation can be expressed in additive terms (see Equation 4).

**Equation 4**

$$\ln Q_{ys} = a + \sum_{y=1}^{n-1} g_y Y_y + \sum_{s=1}^{n-1} d_s S_s + b_1 \ln C_{ys} + b_2 \ln K_{ys} + b_3 \ln L_{ys} + b_4 \ln E_{ys} + b_5 \ln P_{ys} + e_{ys}$$

where $a = \ln b_0$

The impact of the IT management structure of a state government can be estimated by adding a management dummy variable into the equation (*M*). Three dummy variables are included (see Equation 5).

**Equation 5**

$$\ln Q_{ys} = a + \sum_{y=1}^{n-1} g_y Y_y + \sum_{s=1}^{n-1} d_s S_s + b_1 \ln C_{ys} + b_2 \ln K_{ys} + b_3 \ln L_{ys} + b_4 \ln E_{ys}$$

$$+ b_5 \ln P_{ys} + \sum_{i=1}^{3} f_i M_{iys} + e_{ys}$$

Equation 5 is the final model, where $a$, $g$ 's, $d$ 's, $b$ 's, and $f$ 's are parameters to be estimated. *Y* and *S* stand for year and state. Because the model is based on a production function in natural log form, each coefficient represents the output elasticity of the corresponding input.

Equation 5 assumes that management varies over the sample period and across the states. The subscript *y* attached to *M* in Equation 5 serves to incorporate the fact that some states changed their management structure during the sample period. The estimation of the parameters will be based on OLS. Because the number of parameters to be estimated is 62 and the sample size is 350 (50 states by 7 years), no linear transformation of variables is necessary to reduce the number of parameters to be estimated.

While Equation 5 estimates the contemporaneous impact of IT on performance, the time specific lag model is designed to estimate the lagged impact of IT on the economic performance of a state. This research will focus on a 1-year time specific lag. Due to individual learning and organizational adjustment, efficient IT capital is composed of current investment and previous investment. This relationship can be written as follows:

**Equation 6**

$$C^{eff} = f(C_t, C_{t-1})$$

With usual transformation, Equation 6 can be transformed into Equation 7.

**Equation 7**

$$\ln C^{eff} = b_1 \ln C_t + (1 - b_1) \ln C_{t-1}$$

If we replace C with $C^{eff}$ in Equation 5, our final model for 1-year time specific lag model is as follows:

**Equation 8**

$$\ln Q_{ys} = a + \sum_{y=1}^{n-1} g_y Y_y + \sum_{s=1}^{n-1} d_s S_s + b_1 \ln C_{ys} + b_2 \ln C_{y-1,s} + b_3 \ln K_{ys} + b_4 \ln L_{ys} + b_5 \ln E_{ys}$$

$$+ b_6 \ln P_{ys} + \sum_{i=1}^{3} f_i M_{iys} + e_{ys}$$

where $a = \ln b_0$ and $b_2 = (1 - b_1)$ .

**Endogenous independent variable problem**. One problem associated with the production function is that the direction of causality may be reversed. While changes in the level of inputs usually lead to changes in output, the opposite is also possible. There are two potential sources of simultaneous relationships. First, it is possible that state governments adjust their level of inputs based on the level of service demand. Increased economic activities are usually associated with an increased demand for public service. To meet increased demand, state governments need to hire personnel and invest in equipment. Second, the changes in revenue can also influence the level of a state government's investment. Better economic performance usually means more tax revenue. With increases in their resources, state governments can invest in capital equipment and hire more employees. Because of this simultaneity problem, the regressor (independent variable) is contemporaneously correlated with the error term. In the presence of the contemporaneous correlation between error and regressor, the OLS estimator is biased in small samples. Moreover, the bias does not disappear in the asymptotic situation, that is, it is inconsistent even when the sample gets larger (Greene, 1993).

To correct this problem, this study will rely on two-stage least square (2SLS), which is the standard choice due to the robustness of the result[2] (Kennedy, 1993). For the choice between OLS and 2SLS, the Hausman specification test can be applied (Hausman, 1978; Greene, 1993). The null hypothesis of the test is that there is no simultaneity. Thus, if the test statistic rejects the null hypothesis, we will rely on the 2SLS result and, if not, we will rely on the OLS result.

To compute the Hausman test statistic, all the variables in the equation except the year and state dummy variables will be tested together. It is possible that all types of a state government's inputs, such as labor, IT and non-IT capital, and other expenditures, can be influenced by the economic performance of the state. State and year dummies are excluded because some years and states are excluded from the 2SLS model to permit identification of the model. There is a strong reason for a grouped test. The simultaneity affects not only the coefficients of the problematic variables but also the whole set of coefficients. Thus, it is better to compare the whole model than to test the individual variables in question.

**Data**

The data for this study come from four different sources. IT capital, which is the key variable of the study, is from Computer Intelligence (CI). CI is a private consulting firm and surveys IT-related information from the 50 state governments annually (Kraemer & Gurbaxani, 1998). CI began collecting the information in 1989 and the data are available through 1995. State government employment, financial information, and state population are from the U.S. Bureau of the Census. The figures for recent years were downloaded from the U.S. Bureau of the Census' Web site[3]. Gross state product (GSP) is also obtained from the Web site of the U.S. Bureau of Economic Analysis (U.S. BEA).[4]

The IT management structure of each state government was obtained from National Association of State Information Resource Executives (NASIRE) (NASIRE, 1996). The data sources and variable definitions are summarized in Table 1.

**Variable Definitions**

The dependent variable of the model is economic performance of a state as measured by gross state product (GSP). It is the difference between a state's gross output (sales or receipts and other operating income, commodity taxes, and inventory changes) and its intermediate inputs (consumption of goods and services purchased from other U.S. industries or imported). It also includes a substantial volume of output shipped to other states or countries. Thus, GSP is the state counterpart of the nation's gross domestic product (Beemiller & Downey, 1998). Consequently, GSP does a good job of measuring real outputs of a state by capturing the differences across the states in the mix of goods and services that each state produces (Friedenberg & Beemiller, 1997). The current value of GSP was deflated by using the implicit price deflator as suggested by BEA (Beemiller & Downey, 1998).

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Table 1 about here
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The stock of IT is measured by the market value of computer systems. Computer Intelligence (CI) reports the "total purchase value of all systems in parent organizations" (Kraemer & Gurbaxani, 1998). The variable is calculated by CI and is based on the current value of the installed base. The definition of the IT stock variable has been changed several times (Kraemer & Gurbaxani, 1998). For 1994 and 1995, PCs are not included. To correct for this problem, the market value of the total PCs a state owns is added to the variable.[5] Because the variable reports the current market value of all the systems, the electrical machinery and equipment producer price index was used to convert it to constant 1992 dollars.

Although the market value approach is the most popular way of measuring the intensity of IT investment, it is not without problems. Financial measures alone may not fully capture some of the critical aspects of IT. When a new product is introduced, the market price of existing equipment drops rapidly. Often times, the prices of comparable existing products drop below their quality. Thus, the market price of used equipment may not represent the real quality of the equipment. A proper price deflator could adjust the problem but calculating one is a difficult task due to the rapid pace of technological change (e.g., Gurbaxani & Mendelson, 1990; Oliner, 1993; Berndt et al., 1995).

To overcome the limitations of the market value approach to IT stock estimation, this study employs a new measure based on system performance: IT performance index (IPI). IPI is based on information processing power. The speed of information processing is indicated by MIPS, million instructions per second, a performance measure for a processor. MIPS is a primary measure for systems capability. To measure the information-processing capacity of the whole system, total MIPS of mainframe and personal computers are added (see Equation 9).

**Equation 9**

$$IPI = (ctotmips + ctotpc*mips).$$

Where ctotmips is total MIPS for mainframes,
ctotpc is total number of PC,
mips is an average processor speed of a PC expressed in MIPS.

CI only reports total MIPS (ctotmips) for main frames (Kraemer & Gurbaxani, 1998). MIPS for PCs has to be calculated. MIPS for PC was estimated by the improvement in the computing power of Intel processors.[6] Each year's number of PCs is multiplied by the corresponding year's MIPS of a PC to estimate the total performance of PCs of a particular year. While the improvement of microprocessor performance is exponential, this study assumes linear improvement considering the fact that not all the PCs are new in a certain year.[7] A desirable property of performance-based IT measures is that they do not have to be adjusted for deflation. Because they are based on technological characteristics, direct comparisons can be made between different years' figures. In addition, to test the lag hypothesis, the lagged value of IT variables was also included in the model. Using the lag operator in SAS, the lag of IT stock and IPI were created.

For labor input, the number of full-time equivalent employees (FTE) was used (Bureau of the Census). Because IT-specific labor input was not available, FTE represents total state government employment. Consequently, the result of the analysis will not provide any details about the contributions that IT-related employees would make. Non-IT capital is measured using capital outlays of a state government. Non-IT capital was also converted to constant 1992 dollars.

Because other expenditures including outsourcing are a major component of state governments' expenditures, they are included in the model. To calculate the other expenditures, wages and total capital outlays are excluded from the state total expenditure. Other expenditures is also converted to constant 1992 dollars.

While this is not a perfect model specification, the model is acceptable because it has a dummy variable for each state to capture factors not explicitly included in the model.[8] These state dummy variables are expected to pick up any variances that are not explained by the variables.

Table 2 and Table 3 summarize the characteristics of the data used in the analysis. Due to missing information and mathematical operation for lagged variables, the final analysis will be based on 6 years of data from 1990 to 1995. As Table 3 indicates, almost all states have a formal IT management structure (88%). CIO is the most popular choice (82%), and more than half (58%) of the states have both CIO and IRM commission for their IT resource management. Only three states adopted an IRM commission as their sole choice for IT resource management and 6 states do not have any formal organization that manages their IT resources.

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Tables 2 and 3 about here
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**RESULTS**

Tables 4 and 5 report the results of the analysis. Table 4 is the result of the model using a financial measure of IT (IT stock), and Table 5 is the model using the IT performance measure (IPI). Each table contains the results of two regression analyses, OLS and 2SLS. For the two stage least squares (2SLS), the wages of state employees, the length of buried cable, the 1-year lag of other expenditures and capital outlay are selected as instrumental variables (IVs).[9,10] For estimation, the syslin 2sls procedure in SAS was used.

The model specification test developed by Hausman was applied (Hausman, 1978). For both the IT stock and the IPI model, the test statistics do not reject the null hypothesis that the OLS model has no simultaneity problem. The test statistics are $\chi^2$=4.2199, df=9 (see Table 4), and $\chi^2$=4.5066, df=9 (see Table 5), respectively. Thus, we will rely on the results of OLS for both of the models.

Other potential sources of violation of the Gauss-Markov theorem were considered. In the case of pooled data, serial correlation is usually not a problem because the data are both cross-sectional and time series.

Heteroskedasticity, on the other hand, could be a problem. While the direction is not clear, it is possible that the error term is proportional to the size of a state. More specifically, this could be a problem because the sample is aggregated. State government information is based on an aggregation of individual state agencies, and state economic data is the aggregation of individual economic activities. To check heteroskedasticity, the White test was applied. It showed no heteroskedasticity ( $c^2$ =0.4, df=11). This is reasonable because the variables are in log form.

**Performance Impact of Information Technology**

The results of the analysis support the first hypothesis: IT in state government increases the economic performance of the state as a whole as measured by gross state product (GSP). As shown in Tables 4 and 5, the stock of IT in state government, measured in both financial and technical performance terms, has made a positive and statistically significant contribution to statewide economic performance after controlling for the effect of other variables in the model. If a positive finding occurred only for the model using a financial measure of IT, it could be interpreted as the result of a financial relationship between government spending and GSP. We have the same result, however, from a model using an IT performance measure. The consistent results support the hypothesis that IT invested and used in state governments does contribute to statewide economic performance.

The coefficients for IPI and financial IT stock are 2.8 percent and 1.6 percent, respectively. They may seem small (OLS results in Tables 4 and 5), but if we consider that average IT investment by state governments during the sample period is about 1.5 percent of total capital outlays, the coefficients represent a substantial contribution. Although the relative contribution to statewide economic performance is small compared to other state government inputs, IT invested and used within state government does make a positive contribution to statewide economic performance.

In addition, other state expenditures and state population turned out to be positive and statistically significant contributors to statewide economic performance. The coefficient of state population is the largest, reflecting the importance of the private sector's contribution in generating statewide wealth. It is possible that the exclusion of private capital stock in the model caused an overstatement of the importance of population. The non-IT investment in state government and the number of state government employees were not significant. It may be that the imperfect measure used for non-IT capital is a reason for not finding any significant contribution of non-IT investment. The non-IT variable is not a stock of the whole state's public capital but an annual flow of investment. While highways and public schools, for example, are critical infrastructure items that the public sector should provide for economic growth, the associated depreciation schedules are so long that annual investment—marginal increments—may not capture their real contribution.

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Tables 4 and 5 about here
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Other expenditures have a positive and significant impact. This variable was originally included to capture the expenditures that are not included in the model as specific input factors. This variable is intended to capture the contracting out or outsourcing of state government services, which is not included in the model as labor or any type of investment. If contracting out of public service increases, the associated state employees and capital investments are expected to decrease. Though further investigation is necessary, the coefficient may indicate that contracting out or outsourcing of the public function could have a positive impact on statewide economic performance.

While there is no significant difference across years in the sample period, virtually all state dummy variables turned out to be statistically significant. This is a desirable result since the state dummies are expected to capture the differences across the states in terms of private capital and other state specific factors that are not included in the model. As Laudon and Marr (1994) have shown, a different macro culture could be a critical determinant of the level of organizational effort regarding the adoption and use of IT. The state dummy variable could also illustrate the political, social, and geographical variances in each state.

**Influence of Information Technology Management**

The analysis also provides support for hypothesis 2—IT management matters. The results show that different IT management structures have different impacts on the economic performance of a state. This indicates the importance of efficient IT resource management. States with a CIO who controls statewide IT resources performed better than those with different formal IT management arrangements (OLS results in Tables 4 and 5). Another interesting point is that states with only an IRM commission showed no performance differences from the states without any formal IT management functions. This indicates that a CIO, who usually has technical expertise, may play a critical role in managing IT resources.

These results also attest to the importance of centralized control of IT resources to assure the compatibility of the systems and data formats across state government agencies. Connectivity and compatibility in terms of information and data as well as hardware are critical issues. Without easy and timely exchange of information, the benefits of using IT are diminished. A centralized decision based on technical expertise can provide a platform on which each sub-unit can build its system to communicate with others.

**Lagged Effect of Information Technology**

Table 6 presents the results of 1-year time specific lag models using the two different IT measures. There is no evidence of a lagged effect of IT on the statewide economic performance in our data. The two models produced nearly identical results in that the coefficients of contemporaneous IT had positive and significant impacts while the time-specific lagged coefficients are not significant. In short, there is no support for the lagged impact of IT.

## DISCUSSION

This study is the first to report the positive impact of IT investments made in state governments. The results indicate that investment in IT by state governments has led to an increase in statewide economic performance as measured by gross state product (GSP). In addition, two different IT measures, financial and performance, were used. The nearly identical results from two different IT measures refute an interpretation that the IT investment-productivity relationship is based purely on a financial relationship between state government and GSP.

Other research during the 1990s has also reported a positive impact of IT investment in various contexts (e.g., Lehr & Lichtenberg, 1996; Brynjolfsson & Hitt, 1993; Dewan & Kraemer, 1998). Lehr & Lichtenberg (1996) used federal agencies, Brynjolfsson & Hitt's (1993) findings were based on manufacturing, and Dewan & Kraemer (1998) examined country-level data to report a positive impact of IT. The sole public sector study, Lehr & Lichtenberg (1996), reported a positive IT contribution to the productivity of federal agencies from 1987 to 1992. The present study, based on data collected from state government during the period 1989 to 1995, reinforces Lehr & Lichtenberg's (1996) finding.

A major finding is that IT investments in state government improve statewide economic performance. This confirms Jurison's argument (1996) that the benefits of IT investment made by a firm are reaped by a variety of participants and stakeholders including stockholders, employees, customers, suppliers, competitors, and the public. IT produces substantial value which is not limited to return on investment but multidimentional (Lucas, 1999) The statewide economy as well as the state bureaucracy benefits from IT investment.

Measurement of IT investment is another critical issue broached by this research. Financial measures based on the market price may be a less than accurate way to measure the amount of IT resources. Due to rapid technological advances, as Moore's law states, the price of IT related equipment drops very fast (Scott & Pisa, 1998). Thus, if we measure the IT stock based on its market value, we tend to underestimate its real contribution. In fact, the coefficient[11] for the financial IT measure ( $b_1$ =0.016) is smaller than that of IPI, the technical performance measure ( $b_1$ =0.028) (see Tables 4 and 5). It is possible that the coefficient of the financial IT measure could be downwardly biased because it is based on the market value of existing systems.

The positive and statistically significant coefficient of the IPI measure suggests that constructing IT measures in terms of its technological characteristics could be very effective. IPI is an index composed of computing power of both mainframe computers and PCs. While IPI may not be the perfect IT measure, it provides us with an estimate of the level of services IT resources can currently provide. An additional advantage of using IPI is that it can be compared without yearly adjustments using price deflators because IPI is based on core technical characteristics.

This study supports the idea that how IT is managed is important in realizing its benefits. Different IT management structures have differential impacts. States with centralized IT control perform better than those without it. Unlike tangible goods, information may not have intrinsic value. The value of information, and thus the contribution of IT, can only be realized when the organization is capable of exploiting IT. Organizations need appropriate structures and processes to manage IT and the information it generates.

The coefficients of the management variables indicate 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. While 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 operation and telecommunication operation (Caudle, 1990). In addition to day-to-day data processing operation, a CIO can play a decisive role in developing and implementing IT-related plans. The CIO's technical expertise seems to facilitate better decisions regarding the design, modernization, use, sharing, and performance of IT resources.

The redistribution explanation for null findings can be made when analysis is based on observations from private firms. The redistribution argument could explain the lack of positive and significant evidence in industry-level analyses. A few firm-level analyses that reported positive impacts of IT are also vulnerable to the redistribution argument because the analyses are usually based on samples of larger firms. This study provided an opportunity to overcome such interpretations. Using data collected from all 50 states—with little chance for a redistribution effect—this study showed that IT in state governments contributes to statewide economic performance.

The research did not support the hypothesis that there was a short-term lagged benefit effect. Lagged effect of IT investment is an issue that requires closer investigation using longer time series data with more sophisticated models.

Other than a methodological issue, data aggregation, there are substantive explanations for the results with regard to lagged benefit of IT. The proliferation of graphical user interfaces (GUI) could 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, a GUI eliminates the necessity of memorizing commands (Cardinali, 1994). Command-line interfaces (e.g., MS-DOS and Unix) are efficient, but they demand a greater amount of memorizing and learning before the command prompts are meaningful. The graphical user interface makes the information readily available to the users because it is easier for them to learn and use than the character-based interface. Although GUI-based operating system programs were first shipped in the 1980s,[12] it was not until the beginning of the 1990s that Windows was shipped with almost every PC, which coincides with the period of this study.

## CONCLUSION

Aside from the substantive findings about IT investment and gross state product, this study makes several contributions to research about the impacts of information technology investment. First, it extends IT productivity research for the first time to state governments. Second, it explicitly examined the effect of different information resources management structures. Unlike previous studies, which used organizational dummies that can be interpreted in several ways, this study used specific management structure variables that are easier to interpret. Third, the research illustrated that technology-based IT measures can overcome some of the shortcomings of financial IT measures. The development of IT measures based on the technical properties of IT has much promise. Such measures could provide more specific information regarding the technology-user interface that can be used for reorganizing existing structures and processes.

Two limitations of the study should be noted. The model did not include IT-related labor separately. Due to the lack of information, the model only included total labor. One potential consequence of this, while not serious, could be the overestimation of IT contribution. Another limitation is the exclusion of private capital information, due to lack of information. Because population and state dummy variables are included to control for such limitations, it is unlikely that the lack of private capital information makes the results less valid.

This study fills in small pieces of a larger puzzle. More public sector research needs to be conducted, particularly in light of the positive findings about the relationship between state government IT investments and gross state product. Future research should also be directed more broadly to identifying the scope of benefits from using IT, appropriate levels of IT investment, and appropriate IT management structures. Investigating these issues will not only help practitioners make informed decisions regarding IT investment and management but also enrich management and organization theory.

The potential for developing more accurate non-financial IT measures is substantial. IPI only includes information processing capacity (MIPS) of mainframes and PCs. IPI may be elaborated by including other aspects of IT such as network properties, actual use, and application areas. This information would reflect the specific attributes of IT in an organization. Research using such IT measures would tell us more about the effects of different configurations of computing environments.

Given the results of this research, future research about IT management structure is also promising. The level of centralization, scope of authority of IT resource managers, and relations to other top managers are some of the dimensions that should be explored in future studies. Understanding efficient IT resource management structures and processes would help top managers design proper IT management structures.

Finally, while this study showed that IT has a positive impact on economic performance, it did not show that IT is an efficient input factor. Future research should investigate whether IT is an efficient input. In addition, budget constraints were not explicitly considered. Cost of IT investments should be examined. Without this information, IT investment may not be a wise choice.

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**Figure 1: Basic Model**

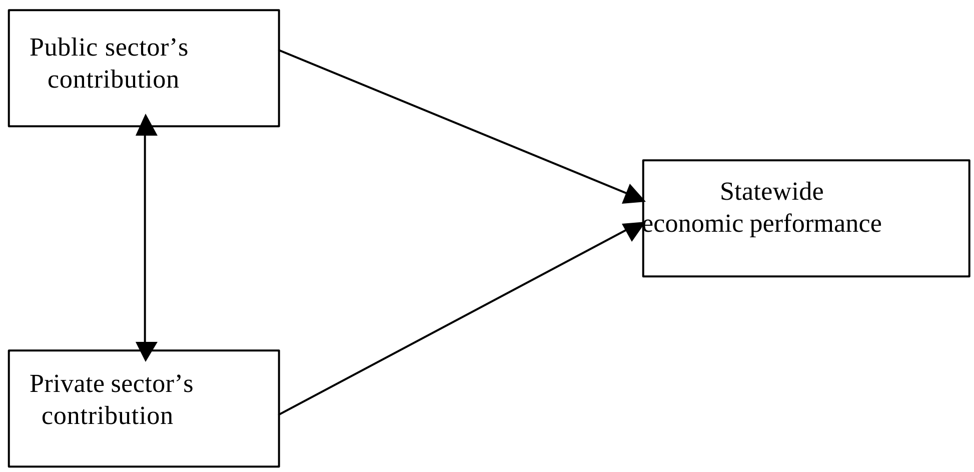

**Table 1: Source of the data and definitions of the variables**

| Variable | Source | Construction procedure | Coverage |
|---|---|---|---|
| Dependent variable | | | |
| Gross State Product | BEA | Gross State Product converted to constant 1992 dollars using implicit price deflator | 1989-1995 |
| Independent variables | | | |
| IT stock (Financial measure) | CI | "Purchase value of IT" converted to constant 1992 dollars using electrical machinery and equipment producer price index. For the 1994 and 1995 figure, the value of PCs were included to adjust for the changes in definition and assumed that the value of PC is a constant value of $2,835 in 1990 dollar (Brynolfsson & Hitt, 1995). | 1989-1995 |
| IPI (Performance measure) | | IPI is calculated by the following formula: ctotmips + ctotpc*mips | 1990-1995 |
| Labor | Census Bureau | Total state government employee, (FTE) | 1989-1995 |
| Non-IT | Census Bureau | Capital outlay – (IT stock increments) Converted to constant 1992 dollar using capital equipment producer price index. | 1990-1995 |
| Other expenditures | Census Bureau | Total expenditures,-((October payroll*12)+ Capital outlay), Converted to constant 1992 dollars using implicit price deflator | 1989-1995 |
| Management | NASIRE | 4 different management types CIO only, Commission only, CIO and Commission, None (reference) | 1989-1995 |
| Population | BEA | Total state population | 1989-1995 |
| Lag IT stock (Financial measure) | CI | Created using lag operator in SAS | 1990-1995 |
| Lag IPI (Performance measure) | CI | Created using lag operator in SAS | 1991-1995 |

**Table 2: Sample Characteristics**

| Variables | N | Mean | Std. Dev. | Minimum | Maximum |
|---|---|---|---|---|---|
| Gross State Product* | 350 | $123,416 | $147,831 | $11,581 | $845,105 |
| IT stock* | 349 | $63.1 | $70.5 | $3.8 | $574 |
| IPI** | 298 | 57 | 287 | .589 | 3,886,000 |
| Labor (FTE) | 350 | 77120 | 65242 | 10863 | 343781 |
| Non-IT* | 300 | $1013 | $953 | $104 | $5562 |
| Other expenditures* | 300 | $10970 | $14460 | $820 | $98430 |
| Population | 350 | 5085970 | 5553377 | 453398 | 31558406 |

Note: * : in million dollar.
** : in billion MIPS

**Table 3: IT Management type in state government (1993)**

| | | CIO | |
|---|---|---|---|
| | | Yes | No |
| IRM commission | Yes | 24 | 3 |
| | No | 17 | 6 |

**Table 4: OLS and 2SLS for IT stock: Financial IT measure**

| Dependent variable: Total Gross State Product | | |
|---|---|---|
| | OLS model | 2SLS model |
| Variables | Parameter estimates (standard error) | Parameter estimates (standard error) |
| Intercept | -8.4327$^{***}$ (1.6897) | -9.3700$^{***}$ (2.2764) |
| IT stock (financial measure) | 0.0166$^{*}$ (0.0088) | 0.0218 (0.0213) |
| Non-IT Capital | 0.0176 (0.0141) | 0.0214 (0.0595) |
| Number of State Employee (FTE) | 0.0488 (0.0537) | 0.1726$^{*}$ (0.0966) |
| Other state expenditure | 0.1076$^{***}$ (0.0391) | 0.0767 (0.1360) |
| State Population | 1.1199$^{***}$ (0.1332) | 1.1414$^{***}$ (0.2209) |
| Management | | |
| CIO only | 0.0307$^{*}$ (0.0185) | 0.0310 (0.0193) |
| IRM commission only | 0.0115 (0.0235) | 0.0071 (0.0261) |
| CIO and IRM commission | 0.0260 (0.0182) | 0.029$^{*}$ (0.0167) |
| Year dummies | No significant difference At Alpha = .1 | No significant difference at Alpha = .1 |
| State dummies | Most states are different[1] At Alpha = .1 | Most states are different[2] at Alpha = .1 |
| R-square | 0.9995 | 0.9996 |
| N | 248 | 242 |
| F-value | 6174.972 | 8039.626 |
| Hausman test | | $\chi^2$ =4.2199, df=9 |

$^{***}$ :Alpha = .01
$^{**}$ :Alpha = .05
$^{*}$ :Alpha = .1

Note 1. Exceptions are Alaska and Delaware.
2. Exception is Delaware.
3. Referent state is Wyoming and referent year is 1995.

**Table 5: OLS and 2SLS for IPI: Performance IT measure**

| Dependent variable: Total Gross State Product | OLS model | 2SLS model |
|---|---|---|
| Variables | Parameter estimates (standard error) | Parameter estimates (standard error) |
| Intercept | -9.0084*** (1.6656) | -9.6923*** (2.2240) |
| IPI (performance measure) | 0.0282*** (0.0082) | 0.04243* (0.0225) |
| Non-IT Capital | 0.0169 (0.0137) | 0.0410 (0.0576) |
| Number of State Employee (FTE) | 0.0447 (0.0528) | 0.1537 (0.0958) |
| Other state expenditure | 0.1165*** (0.0378) | 0.0070 (0.1354) |
| State Population | 1.1451*** (0.1307) | 1.2465*** (0.2198) |
| Management | | |
| CIO only | 0.0359** (0.0179) | 0.0359* (0.0189) |
| IRM commission only | 0.0141 (0.0235) | 0.0249 (0.0262) |
| CIO and IRM commission | 0.0259 (0.0178) | 0.0282* (0.0165) |
| Year dummies | No significant difference at Alpha = .1 | No significant difference at Alpha = .1 |
| State dummies | Most states are different [1] at Alpha = .1 | Most states are different [2] at Alpha = .1 |
| R-square | 0.9996 | 0.9996 |
| N | 247 | 242 |
| F-value | 6972.609 | 8180.081 |
| Hausman test | | $c^2$ = 4.5066, df =9 |

*** :Alpha = .01
** :Alpha = .05
* :Alpha = .1

Note 1. Exceptions are Alaska and Delaware.
2. Exception is Delaware.
3. Referent state is Wyoming and referent year is 1995.

**Table 6: 1-Year Time Specific Lag Model (OLS)**

| Dependent variable: Total State Gross Product | IT stock | IPI |
|---|---|---|
| Variables | Parameter estimates (standard error) | Parameter estimates (standard error) |
| Intercept | -6.4467*** | -6.1149*** |
| | (1.4428) | (1.5703) |
| Current IT | 0.0200** | 0.0198** |
| | (0.0099) | (0.0094) |
| Lagged IT (1-year lag) | 0.0040 | -0.0079 |
| | (0.0090) | (0.0076) |
| Non-IT capital | 0.0060 | 0.0009 |
| | (0.0143) | (0.0142) |
| Number of State Employee (FTE) | 0.0743 | 0.0831 |
| | (0.0582) | (0.0589) |
| Other state expenditure | 0.0873*** | 0.0891** |
| | (0.0252) | (0.0360) |
| State population | 0.9927*** | 0.9841*** |
| | (0.1300) | (0.1307) |
| Management | | |
| CIO only | 0.0203 | 0.0221 |
| | (0.0195) | (0.0195) |
| IRM commission only | 0.0083 | 0.0034 |
| | (0.0234) | (.0248) |
| CIO and IRM commission | 0.0208 | 0.0194 |
| | (0.0180) | (0.0181) |
| Year dummies | No significant difference at Alpha = 0.1 | Some years are different[1] at Alpha = 0.1 |
| State dummies | Most states are different[2] at alpha=.1 | Most states are different[3] at Alpha = 0.1 |
| R-square | 0.9992 | 0.9992 |
| N | 297 | 295 |
| F-value | 4933.022 | 4877.918 |

*** : Alpha>.01
** : Alpha>.05
* : Alpha>.1

Note 1. The year 1994 is no different from 1995. From year 1991 to 1993, coefficients are significantly lower than the year 1995, and they increase over time. Exceptions are Alaska, Connecticut, and Delaware.

2. Exceptions are Alaska, and Delaware.

3. Referent state is Wyoming and referent year is 1995.

[1] Private employment information could be used instead of population. However, this could be a problem because employment information may have a bias against agricultural states.
[2] The result of 2SLS is robust because its desirable properties are insensitive to the presence of other estimating problems such as multicollinearity and specification error (Kennedy, 1993, p. 160).
[3] http://www.census.gov/govs/www/index.html
[4] http://www.bea.doc.gov/bea/dr1.htm
[5] For the value of a PC, an estimate by Brynjolfsson & Hitt (1995) is used. They estimated that the price of a PC is $2835 (1990 constant dollar). It was converted to 1994 and 1995 constant dollar using implicit price deflator. The converted figures were multiplied by the number of PCs for the particular years and added to the variable.
[6] The Intel 80486, introduced in 1989, carries more than 1 million transistors and performs about 10 MIPS. A Pentium processor (66 Mhz) introduced in 1993 performs about 100 MIPS. Comparison based on MIPS, however, is not a perfect measure since MIPS is dependent on the instruction set. Computers with different instruction sets, 16 bits or 32 bits, perform differently even with similar MIPS.
[7] Microprocessor's MIPS for corresponding year.

| Year | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 |
|---|---|---|---|---|---|---|
| MIPS | 33 | 66 | 100 | 133 | 166 | 200 |

Source: Illustration, Britannica Online. <http://www.eb.com:180/cgi-in/g?DocF=macro/5001/46/28.html>
[8] It would be desirable to have information regarding private capital stock by state. The Bureau of Census reports private capital stock information by year and by industry, but the same information is not categorized by state.
[9] Listed IVs are selected from previous studies (e.g. Brynjolffson & Hitt 1993; Dewan & Kraemer, 1998).
[10] Financial measure—IT stock—was used as IV for IPI model and IPI was used as IV for IT stock model.
[11] The functional form of our model makes each coefficient somewhat comparable. Once the model is log transformed, coefficients are interpreted as elasticity, which is a ratio between changes in inputs and changes in outputs. Because it is a ratio, comparison of coefficients across independent variables provide us with meaningful information.
[12] 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).