

December 2002

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## Recommended Citation

Hu, Qing and Quan, Jim, "EVALUATING THE IMPACT OF IT ASSETS ON PRODUCTIVITY: AN INDUSTRY LEVEL PERSPECTIVE" (2002). *AMCIS 2002 Proceedings*. 169.  
<http://aisel.aisnet.org/amcis2002/169>

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# EVALUATING THE IMPACT OF IT ASSETS ON PRODUCTIVITY: AN INDUSTRY LEVEL PERSPECTIVE

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## Abstract

*Does it pay to invest in IT? Research over the last two decades has resulted in mixed findings. In this study, we examine the issue of IT investment impact on productivity from an industry level perspective. With IT and productivity data of eight industries over 30 year, we first use the classic economic production function models to test the relationship between IT assets and productivity. Then we employ the Granger causality model to determine the exact nature of this relationship. Our results suggest that there is indeed a significantly positive relationship between IT assets and productivity, but it is more likely that the change in productivity causes the change in IT assets than vice versa. This finding, however, by no means implies that IT does not have impact on productivity. It merely shows that if IT investments have any impact on firm performance or productivity, it is unlikely that such impact can be directly determined statistically from the IT investment data and productivity or performance data in most industries. Research on the impact of IT on intermediate business processes may yield much more meaningful results.*

## Introduction

Does it pay to invest in information technology? What is the ROI of the proposed IT projects? These are some of the questions CIOs and IT managers often find themselves having to answer whenever a budgetary decision on competing capital projects has to be made. In the period of economic down turn, managers are even more pressed to justify capital spending on IT. Unfortunately, there are few places the managers can turn to get help. Although there have been numerous attempts in academic research over the last two decades, the findings are largely mixed. More questions have been raised than perhaps answered. Some researchers (Hu and Plant 2001) argue that the conflicting findings are the result of mixing correlations with causality in the statistical tests used in some of the studies; others believe the impact of IT investment may not necessarily be reflected in firm productivity measures (Thatcher and Oliver 2001; Brynjolsson 1996); and some have shown that inaccurate performance metrics and model misspecifications may have contributed to the conflicting results in published studies (Barua and Lee 1997; Barua et al. 1995).

On the other hand, theoretical literatures and case studies on IT and organization impact over the last decades are overwhelmingly positive. The overall consensus is that IT provides competitive advantages to firms by adding value across all aspects of the value chain: improving operational performance, reducing costs, increasing decision quality, and enhancing product and service innovation and differentiation (Applegate et al. 1996; Porter and Millar 1985), etc. More recent literature suggests that sustained competitive advantages can be achieved through building and leveraging key IT assets such as human resources, reusable technology and partnership between IT and business management (Ross et al. 1996). Why, then, have so many empirical studies failed to provide consistent support for the theoretical conjectures? In this study, we posit that the impact of IT investments on productivity cannot be reliably assessed directly using aggregated statistical measures and the production function based analysis. Using the industry level IT and productivity data, we show that at the aggregated level, there is a strong evidence that IT assets is positively related to productivity, however, the hypothesis that the increase in IT investments causes increasing productivity cannot be reliably inferred from the data and statistical tests. Rather, it is more likely that the productivity change impacts firms' IT investment decisions.

## Data and Method

Industry level IT and productivity data are collected from the Bureau of Economic Analysis (BEA, 2001). Three separated data sets are gathered from the BEA and the Bureau of Labor Statistics (BLS) web sites. The first data set contains nonresidential net stock, real-cost valuation of more than 60 categories of equipment and structural assets in nine industry groups from 1947 to 1999. Out of these asset categories, 15 are identified as IT assets and 46 are non-IT assets. The second data set contains the Gross Domestic Product (GDP) of 9 industries. All statistics are aggregated accordingly. The third data set contains non-farm employment statistics for all 9 industries but Agriculture, Forestry and Fishing from BLS. See Table 1 for details of the main characteristics of the two data sets.

**Table 1. Characteristics of the BEA Data Set**

Industries in the Data Set	It Asset Categories
Agriculture, Forestry and Fishing (SIC 01-09)	Mainframe computers
Mining (SIC 10-14)	Personal computers
Construction (SIC 15-17)	Direct access storage devices
Manufacturing (SIC 24-25, 32-39)	Computer printers
Transportation and Public Utilities (SIC 40-42, 44-49)	Computer terminals
Wholesale trade (SIC 50-51)	Computer tape drives
Retail trade (SIC 52-59)	Computer storage devices
Finance, Insurance and Real Estate (SIC 60-67)	Integrated systems
Services (SIC 70-89)	Prepackaged software
	Custom software
	Own-account software
	Other office equipment
	Communication equipment
	Instruments
	Photocopy and related equipment

In this study we employ a two-phase approach to examine the impact of IT investments on the aggregated productivity of all firms in each of the industries in our data sets. The first phase involves the use of production functions to estimate the correlation between IT assets and productivity, and the second phase involves the use of Granger causality model (Granger, 1969) to determine the exact nature of the relationship between productivity and IT investments identified in phase 1.

The production function approach has been widely used in previous studies of IT impact on firm performance (Alpar and Kim 1990; Loveman 1994; Brynjolfsson and Hitt 1996; Barua and Lee 1997; Rai et al. 1997; Lee and Barua 1999). The foundation of this approach is the classic economic production theory that the output level ( $y$ ) of a firm using a combination of resources ( $x_1, x_2, \dots, x_n$ ) can be expressed as:

$$y = f(x_1, x_2, \dots, x_n) \tag{1}$$

Assuming that only three type of resources are used in the production processes: IT capital ( $x_1$ ), Non-IT capital ( $x_2$ ), and Labor ( $x_3$ ), and using the Cobb-Douglas form of the production function, we get:

$$y = Ax_1^{\beta_1} x_2^{\beta_2} x_3^{\beta_3} \tag{2}$$

where  $A$  is the production technology level, and  $\beta_1, \beta_2$ , and  $\beta_3$  are the elasticities of the production resources. The economic meaning of the  $\beta_i$ 's is marginal product of resource  $x_i$ , that is the increase of output for every unit increase in resource  $x_i$ , holding other factors constant, as expressed in the following equation:

$$\frac{\partial y}{\partial x_i} = A\beta_i x_i^{\beta_i-1} \prod_{j \neq i} x_j^{\beta_j} \Rightarrow \beta_i = \frac{\partial y / y}{\partial x_i / x_i} \tag{3}$$

In order to estimate this function, it is usually converted into its log-linear form:

$$\ln y_t = \ln A + \beta_1 \ln x_{1t} + \beta_2 \ln x_{2t} + \beta_3 \ln x_{3t} \quad t=1, 2, \dots, n \tag{4}$$

where  $\ln A$  becomes the ordinary regression intercept term, which is usually not of great interest.

One of the fundamental assumptions of the economic production functions is the unambiguous causal relationship between production resources ( $x_1, x_2, \dots, x_n$ ) and production output ( $y$ ),

$$(x_1, x_2, \dots, x_n) \longrightarrow y \tag{5}$$

However, when the production output is measured in financial terms such as sales, profits, and ROI, and input resources are in terms of IT budget and spending, the implicit causal relationship between output and resources may no longer hold true: one can logically argue that firms determine their IT resource allocation based on their past or forecasted financial results. Empirical evidence of such practices has been reported (Hu and Plant 2001). If this is the case, then production functions alone, such as equation (2), cannot reliably determine the true relationship between the production output and IT investments. At best, it can show that there is a relationship between the variables on the two sides. Different model specifications are needed to determine the exact causal relationship between the variables.

Although there exist quite a few statistical models for testing causal relationship (see, e.g., Asher 1983 and Blalock 1985), the Granger causality model (Granger 1969) is especially interesting to us. The major strength of the Granger model is that it can simultaneously test all possible causal relationships between two variables or vectors of variables without any predetermined causal assumptions. In addition, even though causal relationship in general requires time precedence between the two sets of variables, Granger causality model is flexible enough to accommodate the case of instantaneous causality.

Let  $x_t$  and  $y_t$  be two time series data, the general Granger causal model with consideration of possible instantaneous causality can be written as:

$$\begin{aligned} x_t &= b_0 + \sum_{j=1}^n a_j x_{t-j} + \sum_{j=1}^n b_j y_{t-j} + \varepsilon_t \\ y_t &= c_0 + \sum_{j=1}^n c_j x_{t-j} + \sum_{j=1}^n d_j y_{t-j} + \eta_t \end{aligned} \tag{6}$$

where  $\varepsilon_t$  and  $\eta_t$  are two uncorrelated white noise error terms with zero means.

According to the definition of causality,  $y$  causes  $x$  if at least one of the  $b_j$ 's is not zero and  $x$  causes  $y$  if at least one of the  $c_j$ 's is not zero. If both of these events occur, there is said to be a feedback relationship between  $x$  and  $y$ . Notice that the instantaneous causality (e.g.,  $x_t \rightarrow y_t$  vice versa) is not considered in this formulation.

## Results and Discussions

The original BEA data covers nine industries and over a time span of 50 years, before it can be used in the statistical models, some preprocessing must be done to eliminate or reduce statistical problems such as multicollinearity. In this study, we made some significant decisions on the data sets. First, the Agriculture, Forestry and Fishing (SIC 01-09) industry group is dropped due to missing employment data for this group. Second, only the data points from 1970 to 1999 are used. This is because that although the BEA data starts in 1947, significant use of computers and data processing technologies in business really began in late 1960's. If IT investments had any measurable impact on productivity, it should be reflected in the statistics of 1970 and later. Third, preliminary tests showed sever degrees of multicollinearity between IT assets and Non-IT assets in the panel data. Thus the ratio of IT asset to Non-IT asset is used in replace of the IT asset and Non-IT asset in estimating the production functions and Granger causality models to solves this problem yet still preserve the fundamental meaning of the statistical models. Sher and Pinola (1986, p221) also suggested the use of input ratio in production functions when considering production expansion. And finally, GDP per employee is used as the measure of productivity of each industry. This way it scales the outputs all industries in the data sets to the same comparable level. The annual GDP data for each industry in the data sets are all converted to the 1996 real dollar value using the GDP price deflators published in BEA web site. As a result, the production function model (4) becomes:

$$\ln\left(\frac{GDP_{it}}{EMP_{it}}\right) = \ln A_{it} + \beta_{it} \ln\left(\frac{IT_{it}}{NIT_{it}}\right) \quad i=1, 2, \dots, 8; t=1, 2, \dots, 30 \tag{7}$$

**Estimation of Production Function**

To estimate the production models, we use the SUR (Seemingly Unrelated Regression) procedure with the industry level panel data from 1970 to 1999. The main reason for using SUR procedure is that it produces more efficient estimated by utilizing the covariance information among the eight industries when performing industry level regressions. It is logical to assume that these industries operate in the same general economic environment and thus have non-zero covariance in their economic production functions. In cases where the covariance is indeed zero, SUR collapses to OLS (Ordinary Least Square) procedure.

The results are shown in Table 2. It is clear that the production models fit well with the data sets for all industries (significant at  $p < 0.01$  level), with the exception of retail trade where the estimated elasticity is insignificant, indicating that the increases in IT/NIT ratio does not contribute to the changes in productivity, at least not in this data set.

**Table 2. SUR Estimates of the Production Function Models ( $R^2 = 0.9428$ )**

Industry	Intercept	t-stat	$\beta$	t-stat
Mining	3.0851	46.983***	0.1049	8.128***
Construction	1.7416	50.678***	0.0499	6.686***
Manufacturing	2.2380	60.218***	0.2290	18.612***
Transportation and Public Utilities	2.7504	87.800***	0.3041	23.387***
Wholesale trade	1.9703	60.524***	0.0940	6.394***
Retail trade	1.0072	26.083***	0.0168	1.617
Finance, Insurance and Real Estate	3.7924	126.281***	0.4393	40.326***
Services	1.6814	142.555***	0.2140	40.274***

The overall significantly positive estimates of the elasticities ( $\beta$ 's) seem to suggest that over the last three decades, IT assets have contributed positively to the productivities of these industries, especially in Finance, ( $\beta = 0.44$ ), Transportation and Utilities ( $\beta = 0.30$ ), Manufacturing ( $\beta = 0.23$ ), and Services ( $\beta = 0.21$ ), which is consistent with the findings of many previous studies. However, the use of production function requires the explicit assumption that the input variables to be exogenous and the output variable to be endogenous (Barua and Mukhopadhyay 2000). Unfortunately, when production functions are used in the studies of IT assets and their contributions to the productivity, this assumption does not often hold true. It is conceivable that management allocates IT budget for year t based on the output of their firm (e.g., sales or profit) at year t-1 or projected output numbers for year t. Lee and Barua (1999) and Hu and Plant (2001) have provided empirical evidence at the firm level for this conjecture. In addition, the production function approach has the risk of "spurious regressions" when the two time series on both sides of equation (4) are not cointegrated.

If we cannot be sure of the nature of causal relationship between the presumed output variable (GDP/EMP as a proxy for productivity) and the input variable (IT/NIT asset ratio as a proxy of IT assets), then the only conclusion we can draw from the estimation of production function is that at the industry level, productivity and IT assets are significantly positively related and that this relationship is much stronger in the industries such as finance, transportation and utility, manufacturing, and services than in other industries such as mining, construction, wholesale, and retail.

**Testing for Causality**

In order to determine the exact nature of the relationship, we estimate the Granger causality model as specified in equation (6) where x and y are defined as follows:

$$\begin{aligned} x_{it} &= (IT / NIT)_{it} \\ y_{it} &= \frac{GDP_{it}}{E_{it}} \quad i=1, 2, \dots, 8; t=1, 2, \dots, 30 \end{aligned} \tag{8}$$

Due to the tendency of autocorrelation among the lagged series, only one time lag ( $j = 1$ ) is used in the causality model (6). Once again the SUR procedure is used to estimate the models simultaneously. The results are presented in Tables 3 and 4.

Overall, the results suggest that the relationship between IT assets and productivity are mixed. Table 3 shows that in some industries such as transportation and services IT assets in the prior year is strongly related to the change of productivity in the subsequent year, indicating a casual relationship that is the change of IT assets that causes the change of productivity. On the other hand Table 4 demonstrates that in other industries such as construction, wholesale, retail and finance, productivity in the prior year is strongly related to the change of IT assets in the subsequent year, indicating a causal relationship that it is the change in productivity that causes the change in IT assets.

**Table 3. SUR Estimates of Causality: GDP/EMP as Dependent Variable ( $R^2 = 0.9673$ )**

Industry	$d_1$	$c_0$	$c_1$
Mining	0.6053***	1.1989***	0.0330*
Construction	0.8543***	0.2634*	0.0076
Manufacturing	0.9493***	0.1357	0.0127
Transportation and Public Utilities	0.6199***	1.0246***	0.0997***
Wholesale trade	1.0082***	0.0050	0.0034
Retail trade	1.0114***	0.3887	0.0099*
Finance, Insurance and Real Estate	0.9248***	0.3738	0.0587
Services	0.3189**	1.1824***	0.1578***

**Table 4. SUR Estimates of Causality: IT/NIT as Dependent Variable ( $R^2 = 0.9963$ )**

Industry	$a_1$	$b_0$	$b_1$
Mining	0.9128***	-0.4362	0.0651
Construction	1.0264***	-1.4020***	1.0652***
Manufacturing	0.9488***	-0.2925	-0.0945
Transportation and Public Utilities	1.0216***	0.2939	0.0003
Wholesale trade	0.9470***	-0.4565**	0.2476**
Retail trade	0.9662***	-0.5097***	0.5143***
Finance, Insurance and Real Estate	0.9564***	-0.8585*	0.3039**
Services	1.3058***	2.0413***	-1.0869***

Even though the results are mixed, it should be noted that the results in Table 4 are stronger than the results in Table 3 in terms of system  $R^2$  and number of significant regression coefficients, indicating that the SUR model based on the proposition that the change in productivity causes the change in IT investments is stronger than the SUR model based on the proposition that the change in IT investments causes the change in productivity.

## Conclusions

The so called IT Productivity Paradox has supposedly disappeared by 1991 (Brynjolfsson and Hitt 1996), but the debate in academic research has continued over the last decade. Although majority of the studies published recently seem to confirm a positive impact of IT investments on productivity (e.g., Lee and Burua 1999; Bharadwaj et al. 1999; Menon, Lee, and Eldenburg 2000), we argue that research based on production function models merely established a positive correlation, not necessarily a causal relationship, between IT investments and productivity or other performance measures. In this study, we first use the production function model to test the relationship between IT assets and productivity and we confirm that this relationship is strongly positive in most of the industries in our sample. Following the same approach as Hu and Plant (2001), we then use the Granger causality model to test the exact nature of this “strongly positive relationship” between the two variables with industry level data from 1970 to 1999. Our results suggest that there is indeed a causal relationship between IT investments and productivity, but that *the change in productivity causes the change in IT investments is more likely than that the change in IT investments causes the change of productivity* in most industries. This is not surprising in the real world. Many top executives of organizations and firms consider IT as a necessary evil and a cost center. One of the consequences of such belief is that IT spending is often tied to the overall firm performance. If a firm is doing well or is projected to be doing well financially, an increase in IT spending becomes more likely. On the other hand, if a firm is experience financial difficulties due to poor performance or overall adverse economic conditions, IT budgets are usually among the first to be cut.

However, it must be noted this conclusion by no means suggests that investing in IT does not improve productivity. Firms allocating IT budgets based on performance do not exclude the potential of IT investments impacting firm performance. It merely shows that if IT investments have any impact on firm performance or productivity, it is unlikely that such impact can be directly determined statistically from IT investment data and productivity or performance data in most industries. With the exception of certain industries where IT directly produces and delivers products and services, such as software, media and publishing, the main contribution of IT is to improve the efficiency of intermediate processes, which may or may not be reflected in the final statistics of a firm's performance due to various operational, strategic and macroeconomic factors. Unfortunately, very few studies (e.g., Barua et al. 1995 and Mitra and Chaya 1996) have taken the approach. It is our hope that this study will stimulate more interest in research of IT impacts on intermediate business processes.

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