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Efficiency Gains from the Relative Size of Information Technology Investments

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Abstract

The contribution of information technology (IT) to organizational performance has been investigated extensively in the MIS research recently. In this paper, the relationship between the relative size of IT investments by firms and the productive efficiency is examined using stochastic frontiers. We find evidence that the level of IT investments has a positive effect on the firm's productive efficiency, implying that the firms investing relatively more in IT are likely to be more efficient in their production processes than those that invest less.

Introduction

Information technology has changed the way the firm conducts its businesses nowadays, and the pace of change is expected to continue increasing in the future. Enormous resources have been allocated to invest in IT by managers to purchase state-of-the-art hardware equipments, to develop new application systems for re-engineering business processes, and to train the IS staff and end-users who may become more skilled in using IT.

The decisions to invest extensively in IT are made based on the benefits promised by IT such as enhanced capability, coordinated control, improved communication, lower cost, and competitive advantages (Senn 1989). Therefore, it has become necessary and imperative to find proof and evidence which can justify such expensive IT investments (Dos Santos 1991).

Researchers interested in the impacts of IT on organizational performance have reported their findings over the last two decades. The measures of organizational performance frequently studied for IT value include productivity, profitability, consumer welfare, quality, and variety. Some of them are able to confirm the contribution of IT, while some others obtain inconclusive results. The so-called productivity paradox of IT, for example, has puzzled both managers and researchers during the 1980s, and is claimed to disappear by 1991 (Brynjolfsson 1993 and 1996, Hitt and Brynjolfsson 1996).

Looking at a different performance measure called *efficiency*, which has been seldom studied for IT value (Mitra and Chaya 1996, and Brynjolfsson 1994), this paper investigates the influence of IT investment levels on the firm's performance in the production process. Empirical results provide evidence that the relative size of IT spending has positive effects on the firm's productive efficiency.

Production Theory and Stochastic Frontiers

Production theory in microeconomics suggests that firms utilize different production factors such as capital, labor, and others, and transform these inputs to output. Such a transformation process can be represented by a production function. The production function specifically identifies the *maximum* quantity of output attainable by employing a certain combination of inputs. Since the production function sets a ceiling limit on output, it implies a production frontier. The difference between the ideal and actual levels of output is defined as productive inefficiency in the production process.

From a producer's point of view, productive inefficiency should be made as little as possible. Many sources contribute to productive inefficiency. Natural causes include the obsolescence of equipment and attrition of the machinery. Artificial causes may arise from fatigue of workers, mismanagement of resources, or poor judgment by management. No matter what the sources are, the bottom line is the productive inefficiency, more or less, always exists in the production process, and the management should seek ways to minimize it.

Let Y_{it} be the actual output level produced by firm i at time t , \mathbf{X}_{it} be the set of inputs used for producing Y_{it} , and β be the vector of unknown coefficients to be estimated. Then a deterministic production function can be described by

$$Y_{it} = f(\mathbf{X}_{it}; \beta) - u_{it} \quad (1)$$

Deterministic frontiers treat the difference between the ideal output level $f(\mathbf{X}_{it}; \beta)$ and the actual output level Y_{it} as the measured inefficiency u_{it} , and do not distinguish a random error component from inefficiency. Such a negligence of a random error in the deterministic frontiers may cause statistical noise in estimation to be absorbed into inefficiency and, hence, make the measured inefficiency different from what it really is.

Stochastic frontiers, however, sets a stochastic upper bound on output, and can be expressed as

$$Y_{it} = f(\mathbf{X}_{it}; \beta) + v_{it} - u_{it} \quad (2)$$

They clearly acknowledge that the difference between the ideal and actual output levels is divided into two components: one for randomness or statistical noise v_{it} , and the other for true technical inefficiency u_{it} . The random error component represents those things not under control of the firm, like weather, luck, government regulations, and so on. The inefficiency component, however, reflects events under control of the firm, such as obsolescence of machines, poor resource allocation, and mismanagement of IT, and can be improved through continuous efforts. It is generally believed that stochastic frontiers are a better approach to investigating productive efficiency than deterministic frontiers (Schmidt 1985). The readers are requested to consult Lin and Chen (1998) for a more detailed survey of deterministic and stochastic frontiers.

Model and Data

The Cobb-Douglas functional form is one of the most frequently used specifications for production functions $f(\mathbf{X}_{it}; \boldsymbol{\beta})$ in (2). It meets the requirements for production functions such as quasi-concavity and monotonicity. It also has the virtue of simplicity and empirical validation (Hitt and Brynjolfsson 1996). Let Y_{it} , K_{it} , L_{it} , and T_{it} represent output, capital, labor, and IT spending for firm i at time t , respectively. Then the Cobb-Douglas stochastic frontier can be described as

$$Y_{it} = aK_{it}^{\beta_1} L_{it}^{\beta_2} T_{it}^{\beta_3} e^{v_{it} - u_{it}}, \quad (3)$$

or, after taking logarithm, we have

$$\ln Y_{it} = \beta_0 + \beta_1 \ln K_{it} + \beta_2 \ln L_{it} + \beta_3 \ln T_{it} + v_{it} - u_{it} \quad (4)$$

where $v_{it} \sim N(0, \sigma_v)$ and $u_{it} \sim |N(0, \sigma_u)|$. The one-sided distribution of u_{it} guarantees inefficiency to be positive only. Jondrow et al. (1982) have proposed a method to obtain the expected value of u_{it} , conditional on $v_{it} - u_{it}$. Efficiency is then equal to $e^{-u_{it}}$ and falls in the range between 0 and 1.

The data set used for our study on efficiency is the same as the one for Hitt and Brynjolfsson's (1996) research on productivity, profitability, and consumer surplus. The reason to adopt this data set is to extend the line of researches based on the same data set (Brynjolfsson and Hitt 1996, Hitt and Brynjolfsson 1996, and Brynjolfsson 1996), so as to rule out the possibility of confusion created by comparing different studies with different data sets. Therefore, our findings in this paper can be fairly compared with previous work on the same grounds.

The data set is comprised of firm-level data on 370 firms over the time span of 1988 through 1992, consisting of 1115 observations out of a total of 1850 possible data points due to missing values on some variables. Several inputs were measured in 1990 dollars: Non-Computer Capital (K), Non-IS Labor (L), and Computer Capital, and IS Labor. The single measurement of IT investments is calculated as IT Stock = Computer Capital + 3 × IS Labor (Brynjolfsson and Hitt 1996), and denoted by T. The Output (Y) represents the firm's value added, also in 1990 dollars.

The issue to be addressed is the relationship between the level of IT investments and productive efficiency. We ask (test) the following question (hypothesis): "Does the size of IT investments influence productive efficiency?" To examine this relationship, the data set is arranged in the order of the ratio of T to (Total Capital + 3 × Total Labor). Because the IT Stock is defined as (Computer Capital + 3 × IS Labor), this ratio indicates the level of IT spending in relation to a similar composite indicator of total capital and total labor. Then the data set is equally divided into three groups according to the level of IT investments: low, medium, and high. The low-level group of IT investments consists of observations 1 through 370, with the ratio ranging from 0.0010 to 0.0134 and an average of 0.0085. The medium-level group contains observations 371 through 740, with the ratio from 0.0135 to 0.0252 and an average of 0.0186. The high-level group consists of observations 741 through 1115, with the ratio from 0.0253 to 0.3427 and an average of 0.0487. Then the three groups are estimated separately using the Cobb-Douglas stochastic frontier described by (4).

Empirical Results and Discussion

The empirical results are presented in Table 1. For the low-level group of IT investments, the average efficiency is 0.792, the smallest among the three groups. The medium-level group has an average efficiency of 0.898, and the high-level group's average efficiency is 0.942. Such a finding on the size of IT investments and productive efficiency suggests that the firms spending comparatively more on IT are more efficient in their production processes than those investing less in IT. All coefficient estimates β_1 , β_2 , and β_3 for K, L, and T, respectively, are found to be significant at the .01 level.

The R^2 values increase with the level of IT investments and indicate that the IT investment at the high level can explain the output variability better than that at the low and medium levels. The sums of coefficients are all less than one, indicating a decreasing returns to scale between the output and inputs in the production process. The individual efficiency measures for each observation in the three groups are plotted consecutively in Figure 1.

Table 1. Estimation Results for the Cobb-Douglas Stochastic Frontier

Coefficient	β_1 (K)	β_2 (L)	β_3 (T)	Sum	E[e ^{-u}]	R ²
IT Level						
Low (1-370)	0.237*	0.673*	0.064*	0.974*	0.792	0.943
Medium (371-740)	0.129*	0.675*	0.180*	0.984*	0.898	0.971
High (741-1115)	0.200*	0.710*	0.066*	0.976*	0.942	0.981

(*significant at the .01 level)

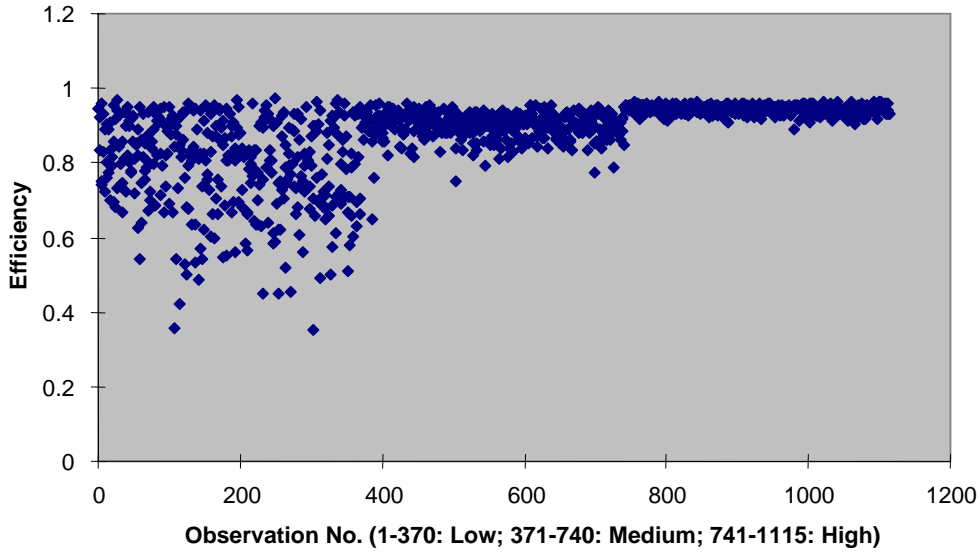


Figure 1. Efficiency Measures for Firms in Three Groups

We have found evidence to show that the size of IT investments has positive effects on organizational performance in terms of productive efficiency. For those firms investing relatively more in IT, it is likely that their production processes are more efficient than those who spend less on IT. The gap between the actual and ideal output levels is narrowed in the presence of more IT investments. In other words, IT spending has been justified in terms of this efficiency measure of organizational performance.

Our finding on the efficiency improvement by IT can be used

to explain, to some degree, the productivity enhancement by IT in Brynjolfsson and Hitt's (1996) study. Productivity is defined as the net effect of technical change and efficiency enhancement (Grasskopf 1993). Since IT is found here to favorably influence the efficiency component and regarded as a better technical change, productivity improvement can, therefore, be expected as a natural result.

Managerial implications for considering IT investments should be drawn carefully based on this finding. First, the fact that IT investments have a positive impact on efficiency does not directly imply that firms should spend aimlessly on IT. On the other hand, IT investments are perceived as riskier than other investments and, hence, IT spending should be taken care of in a more conscientious manner. Only when firms cautiously manage IT can such a benefit be realized. Also, with more companies exerting efforts to re-engineer business processes, IT as an enabler appears to pay off in their re-engineered production processes.

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