# Are Some Firms Better at IT?
# Differing Relationships between Productivity and IT Spending

By

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*Abstract*

Although recent studies have found a positive relationship between spending on information technology and firm productivity, the magnitude of this relationship has not been as dramatic as one would expect given the anecdotal evidence. Data collected by the Bureau of the Census is analyzed to investigate the relationship between plant-level productivity and spending on IT. This relationship is investigated by separating the manufacturing plants in the sample along two dimensions, total factor productivity and IT spending. Analysis along these dimensions reveals that there are significant differences between the highest and lowest productivity plants. The highest productivity plants tend to spend less on IT while the lowest productivity plants tend to spend more on IT. Although there is support for the idea that lower productivity plants are spending more on IT to compensate for their productivity shortcomings, the results indicate that this is not the only difference. The robustness of this finding is strengthened by investigating changes in productivity and IT spending over time. High productivity plants with the lowest amounts of IT spending tend to remain high productivity plants with low IT spending while low productivity plants with high IT spending tend to remain low productivity plants with high IT spending. The results show that management skill, as measured by the overall productivity level of a firm, is an additional factor that must be taken into consideration when investigating the IT "productivity paradox."

AEA-JEL Classification: D24, L60, M21, O33
Keywords: Information Technology, Productivity Paradox, IS Investment, Total Factor Productivity

*****The research in this paper was conducted while the author was a research associate at the Carnegie Mellon Census Research Data Center. Research results and conclusions expressed are those of the author and do not necessarily indicate concurrence by the census Bureau, the Carnegie Mellon Census Research Data Center, or Carnegie Mellon University.

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# 1. Introduction

Among the possible explanations offered for the IT "productivity paradox" is the possibility of mismanagement. The idea is that not all firms make the most effective use of their IT spending. Earlier work by Strassmann (1990) found that there were differences among firms with some spending less on IT and achieving more while others spent more and had lower returns. If this is the case, investigating returns from IT spending should somehow take this factor into account. Although not a direct measure of management skill, total factor productivity provides an indication of the ability of a firm to effectively convert its inputs into outputs. In addition, total factor productivity provides a quantifiable measure that can be empirically analyzed. This research investigates the relationship between total factor productivity and IT spending in an effort to more fully understand the factors that influence the relationship between firm performance and IT spending in an effort to develop a better understanding of the "productivity paradox."

## 1.1 Previous Research

In evaluating firm "productivity" with respect to spending on information technology, three approaches have been used. The first, based on the economic assumption of profit maximization, involves investigating financial performance as the dependent variable. Examples include return on assets (Weill, 1992, Brynjolfsson and Hitt, 1996b, Barua, et al., 1995), return on equity and shareholder return (Brynjolfsson and Hitt, 1996b), and capital intensity and capital productivity (Franke, 1987). The second has been to identify specific productivity measures (employees per million dollars of sales (Weill, 1992)), output per labor expense (Franke, 1987), "value added" (Brynjolfsson and Hitt, 1996b)). The final approach has been to use a measure for "output" as the dependent variable. Output has been measured using total sales (Brynjolfsson and Hitt, 1993, 1996a, 1996b), market share (Barua et al., 1995), sales growth (Weill, 1992), and sales less inventory charges (Loveman, 1988). This study extends the work completed using the second approach and investigates the relationship between plant productivity and IT spending by measuring productivity using total factor productivity (TFP).

A second approach that has been taken in evaluating the impact of investment on information technology has been to look for impact at an economy-wide or sector-wide level. This approach has been used by Roach (1987, 1988, 1989), Franke (1987), Baily and Chakrabarti (1988), Baily and Gordon (1988), and Brynjolfsson (1996). Other than Brynjolfsson, who found increases to consumer surplus due to the decreasing costs and increasing functionality of computer hardware, increases in aggregate productivity have not been found to be associated with increases in spending on information technology. As this analysis is to be completed against plant level data, this research does not address the "IT productivity paradox" at this level of aggregation. The wide ranging research into the "productivity slowdown" and related topics (Baily and Chakrabarti, 1988; Griliches, 1994; and many others) has suggested a variety of explanations for the decline in the growth of U.S. productivity since the mid 1970's including labor composition changes, energy and material price changes, output measurement (mismeasurement), changes in the composition of output, management failures, government policies, technological decline, and convergence to the mean among nations. Without a clear understanding of the mechanisms behind the slowdown in growth of U.S. productivity, attempting to find direct benefit in the productivity numbers at an economy-wide measure is a tricky undertaking. It is possible that without the spending in computer technology that has occurred the productivity numbers could have been even worse. Attempting to analyze just the relationship between aggregate productivity and spending on computers without allowing for other factors that could be causing a decline in productivity growth fails to take other possible influences into consideration.

This research utilizes some Census data that has been analyzed in the past but represents a unique combination by investigating productivity and IT spending. Work on productivity includes Baily, Hulten, and Campbell (1992) and Dwyer (1995). Their results on the analysis of plant-level productivity will be incorporated into this research effort. Baily et al. empirically examined productivity of plants within industries, which plants accounted for industry productivity growth, and the impact of entries and exits on industry productivity growth. Using the Longitudinal Research Database, they found that entry and exits play a small role in changes to industry productivity and that the output share for high productivity plants increases over time while the output share for low productivity plants decrease over time. This change in the distribution of output share is an important factor in the overall growth in productivity for an industry. They also found that high productivity plants remain at the top over time and that plants that are part of high productivity or high productivity growth firms exhibit similar characteristics as the firm of which the plant is a part. Relative plant level productivity is found to remain stable over time. The most significant effort completed to date using the available data on IT spending is by Doms, Dunne, and Troske (1997). Their research found positive correlations between IT spending and worker type and IT spending and worker education. This research effort will combine and expand the analysis that has already been completed against the Census data as well as add knowledge to the field of information technology.

## 1.2 Possible Explanations for the Paradox

A variety of reasons have been suggested to explain the IS productivity paradox. (For a thorough review see Brynjolfsson, 1993.) Explanations include: mismeasurement of inputs and outputs, time lags between spending and realized benefits, redistribution of profits, and mismanagement. (Brynjolfsson, 1993). Griliches (1994) has suggested an additional confounding factor may be the lack of useful data. Brynjolfsson and Hitt's recent findings suggest that resolving the productivity paradox required a data sample larger than what had been used previously and more recent data in an attempt to overcome potential problems with lagged benefits. The issue of mismeasurement was overcome by limiting the analysis to the manufacturing sector for which input and output measurement concerns are not as great. Stolarick (1997) found that two situations were responsible for confounding earlier results. The first was sample size. When using an approach like Cobb-Douglas to model the relationship between IT spending and productivity, a relatively much smaller effect is all that is needed for IT to have a positive impact. However, finding a smaller effect requires a larger sample size to separate out the noise. The second confounding issue Stolarick identified was the inclusion of multiple industries in a sample. Using a data set from the U.S. Census that was orders of magnitude larger than what had been used previously, it was shown that the impact of IT on productivity varies across industries.

Paul Strassmann identified a concept called *Return-on-Management*™ which is a measure of management value-added per management costs (Strassmann, 1990). Using this measure along with the data collected by the MPIT (Management Productivity and Information Technology) project, firms were divided into five groups: *under-achievers*, *below average*, *average*, *above average*, and *over-achievers*. When investigating the relationship between the ratio of IT spending to business value-added and management productivity, Strassmann found that "[*o*]*ver-acheivers* show the lowest levels of spending for information technology" (ibid, p. 138). He concluded that "more technology does not necessarily deliver better results" and that "moderately lower spending levels are related to higher productivity for the participants in the *MPIT* study" (ibid, p. 138). Beyond these findings, it is clear from the chart (ibid, figure 7.6, p. 138) that *under-achievers* spend more and have lower management productivity. These results describe a situation under which trying to find an overall relationship between productivity and IT spending would be confounded by the variation in performance of the firms. In some ways this is a refinement of the "mismanagement" argument. While mismanagement of IT spending and IT resources may be an issue for some firms, it does not apply to all firms. Understanding the relationship between IT spending and productivity requires taking into consideration the performance of the firm. Firms can be divided into three groups: those that do well, those in the middle, and those that do poorly. If Strassmann's findings can be found to hold using another sample and a more general measure of productivity, a more complete picture of the relationship between IT spending and productivity is developed. By showing that individual firm performance can affect the relationship between IT spending and productivity, research can focus on identifying the differences between firms with high productivity, or *over-achievers*, and those with low productivity, or *under-achievers*. Understanding the differences can lead to prescriptive actions that could be taken by firms to increase the effectiveness of their IT spending.

This paper will use another data sample and a more general measure of productivity to replicate and extend the results found by Strassmann. Further, the nature of this relationship will be investigated to determine if the difference is simply one of relative spending or if there are also differences in the effectiveness and benefits achieved by higher productivity firms. The finding will be further supported by investigating the changes in productivity and IT spending over time and by analyzing the effect from industry mix. The paper will proceed with a discussion of the theoretical issues followed by the methods and data used. Results are presented next with a discussion of the implications of those results. Finally, concluding remarks are given.

## 2. Theoretical Issues

The primary emphasis of this paper is on understanding the relationship between productivity, measured using total factor productivity (TFP), and spending on information technology. However, prior to developing the explanation of TFP, understanding of the specification for a production function should be developed first. The specification for TFP and its alternatives will build on the production function.

### 2.1 Production Function

A neoclassical production function (F) for the *i*th plant in year *t* is assumed to have the following form:

$$Q_{it} = F(M_{it}, K_{it}, L_{it}) \quad (1)$$

where,

$Q_{it}$ = real gross output (in dollars) for plant *i* in year *t*

$M_{it}$ = input materials (in dollars) for plant *i* in year *t*

$K_{it}$ = capital stock for plant *i* in year *t*

$L_{it}$ = labor for plant *i* in year *t*

The simplest and most widely used function form used to relate inputs to outputs is the Cobb-Douglas specification. This form is typically used for studies such as this and is what has been used by other studies investigating the relationship between computer spending and productivity. The specification for a given industry and year is:

$$Q_{it} = e_{it}^{\beta 0} M_{it}^{\beta M} K_{it}^{\beta K} L_{it}^{\beta L} \qquad (2)$$

## 2.2 Total Factor Productivity

A variety of methods exist to measure total factor productivity. All attempt to incorporate two basic concepts. First, understanding productivity requires more than looking at output per unit of input for each input factor in isolation. Firms have tradeoffs between spending on input factors and may be equally productive while having dramatically different spending patterns on labor and capital assets, for example. Second, any measure of productivity must allow for comparison between firms. The three most common measures of total factor productivity are residual total factor productivity, relative total factor productivity, and factor share total factor productivity. Definitions for each of these will be given followed by an explanation of why factor share total factor productivity will be the measure of productivity primarily used in this study.

Residual Total Factor Productivity

Residual total factor productivity is the most straightforward approach. By taking the log of the Cobb-Douglas specification in equation (2), OLS can be used to estimate the following specification:

$$\ln Q = \beta_0 + \beta_M \ln M + \beta_K \ln K + \beta_L \ln L + \varepsilon \qquad (3)$$

Estimates for this equation are developed for each industry. Depending on the amount and granularity of the data, industries can be divided at the two, three, or four digit SIC code level. Once the $\beta$'s for each industry have been estimated, residual TFP for each observation (firm or plant) is calculated using the following:

$$RTFP_i = \ln Q_i - \beta_0 - \beta_M \ln M_i - \beta_K \ln K_i - \beta_L \ln L_i \qquad (4)$$

The $\beta$'s are the estimates developed for all observations in each industry while the input and output measurements are for a specific observation. Residual TFP is simply the error term, $\varepsilon$ from equation (3). By construction, OLS will estimate the $\beta$'s so that for the given data the expected value of $\varepsilon$ is zero. Each firm is assigned either a positive or negative residual TFP.

The basic idea behind using the residuals from the estimated logged Cobb-Douglas specification is that some firms are better than others at transforming their inputs into outputs. Since a single set of estimates is developed across all observations in an industry, any differences in the ability to produce more from less are, perforce, included in the residuals. By using the residuals as a measure of total factor productivity, all input factors are taken into consideration and individual differences are captured such that comparisons can be made. However, it is based on the assumption that a high correlation exists between the residuals and productivity and requires the use of a specific functional form, in this case Cobb-Douglas, for estimating the measure of productivity.

Relative Total Factor Productivity

Based on an approach suggested by Christensen, Cummings, and Jorgeson (1981), relative TFP for each observation is calculated using the following specification:

$$\ln TFP_i = \ln Q_i - \ln Q - \beta_M[\ln M_i - \ln M] - \beta_K[\ln K_i - \ln K] - \beta_L[\ln L_i - \ln L] \quad (5)$$

Q, M, K, and L are the industry average values for the output and factor inputs, $Q_i$, $M_i$, $K_i$ and $L_i$ are the output and input measurements for a specific observation, and the $\beta$'s are estimated using OLS on equation (3) for each industry. The relative TFP index is adjusted to have mean zero for each industry. By calculating relative TFP for each plant in each year, direct comparisons among plants in an industry can be completed, and changes in the relative performance of plants tracked over time. Since this approach calculates an index for TFP, specific plants can be ranked by productivity and also compared with each other.

This approach can be best understood by looking at the components of the specification in equation (5). The first part of the equation calculates the difference in output for a specific observation and the mean industry output:

$$\ln Q_i - \ln Q \quad (5a)$$

Next, the difference between the inputs for a specific observation and the mean industry factor inputs is calculated:

$$\ln M_i - \ln M$$

$$\ln K_i - \ln K \quad (5b)$$

$\ln L_i - \ln L$

The differences in these inputs are then adjusted by the estimated contribution of each as estimated by $\beta_M$, $\beta_K$, and $\beta_L$ for the given observation's industry. Total factor productivity is the difference in a particular plant or firm's output from the industry average output that cannot be explained by differences in the inputs. It is another way to attempt and capture the differences between the effectiveness with which firms transform their inputs into outputs. Like residual TFP, a specific functional form for the production function must be specified in order to calculate actual measures of productivity.

Factor Share Total Factor Productivity

A third approach to calculating total factor productivity is based on factor shares across an industry [I need to find the cite for this]. Unlike the previous two methods, factor share TFP can be calculated without resorting to a specific functional form for the production function. However, like Cobb-Douglas, the assumption of constant returns to scale (CRS) is still required.

Calculating factor share TFP begins by calculating the share of each input as it relates to the total output for an observation. Shares are calculated for input materials (MSHARE = M/Q) and labor (LSHARE = L/Q). By definition, capital share is what remains (KSHARE = 1 - MSHARE - LSHARE). Industry averages are then calculated for each of these three input factor shares, MMSHARE, MLSHARE, MKSHARE. Factor share total factor productivity for an observation can then be calculated using the following:

$$FSTFP_i = \ln Q_i - MMSHARE^* \ln M_i - MKSHARE^* \ln K_i - MLSHARE * \ln L_i \quad (6)$$

Once all the factor share TFP's have been calculated for an industry, it is adjusted to have mean zero across the industry.

Calculating total factor productivity using factor shares results in two primary benefits. First, the mean factor shares act as weights across a single industry. And, second, it results in a measure that is independent of any particular industry. Because the mean factor shares act as weights, the effect on TFP of a reduction in input costs is dependent on the importance of that particular input factor in the industry. For example, assume there are two similar firms in the same industry and that the mean factor shares for that industry are 0.55, 0.35, and 0.10 for materials, labor, and capital respectively. Further assume that each firm produces $1,000 worth of output. The first firm, A, produces its output using $500 of material costs and $350 in labor costs with $100 in capital. The second firm, B, produces its output using $550 of material costs and $350 in labor with $50 in capital. The factor share TFP for these two hypothetical firms would be as follows:

$$FSTFP_A = \ln 1000 - .55(\ln 500) - .35(\ln 350) - .10(\ln 100)$$

$$\cong 0.979$$

$$FSTFP_B = \ln 1000 - .55(\ln 550) - .35(\ln 350) - .10(\ln 50)$$

$$\cong 0.996$$

As can be seen from the example, although both firms spend the same total amount on their inputs, firm B is assigned a higher factor share TFP. Mathematically, this results from the reduction for that input with a low factor share (in this case capital) being smaller than the cost (increased reduction) for that input with a higher factor share (in this case materials). In effect, the calculation is awarding firm B a higher factor share TFP because it is spending 50% less on capital than firm A while only spending 10%

more on materials. By including mean industry factor shares in the calculation, more emphasis is placed on percentage differences from industry means instead of absolute dollar reductions.

The second benefit of using factor share TFP is that it results in a measure that is independent of any particular industry. Because the mean factor shares are calculated for each industry, specific industry differences in the "mix" of input factors are taken into consideration as part of the calculation. The resulting measure is an index that can be meaningfully compared across industries. The factor share TFP calculated for any individual plant or firm is an absolute measure of productivity that takes into consideration the mix of factor inputs specific to that plant or firm's industry. It should be noted that the typical approach in calculating factor share TFP is to "de-mean" the calculated values by industry. Once done, comparisons across industries are no longer meaningful. However, the relative performance and absolute performance differences of plants or firms within an industry are maintained. Also, setting the calculated factor share TFP's to have a mean of zero provides some support for analyzing the data in aggregate.

Given these benefits along with the need not to have to specify a specific functional form for the production function, factor share total factor productivity will be the measure of productivity that is used in this study. The robustness of the results will be enhanced by confirming that any results obtained also hold for residual total factor productivity and relative total factor productivity.

Factor share TFP is a measure of productivity that is independent of firm size. A similar measure of IT spending is needed if the relationship between the two is to be investigated. For this study, IT usage will be measured as IT intensity, which will be calculated as follows:

$$\text{IT intensity} = \frac{\text{IT spending (\$)}}{\text{Total Output (\$)}} \qquad (7)$$

By measuring IT spending in this way, firms of all sizes can be compared.

Given these measures and the earlier findings of Strassmann, the following hypothesis results:

**Hypothesis 1:** *The relationship between productivity, as measured by factor share total factor productivity, and IT spending is such that higher productivity firms will be shown to spend less on IT while lower productivity firms will be shown to spend more.*

The discussion of other measures of productivity results in this adjunct to the first hypothesis.

**Hypothesis 1A:** *Hypothesis 1 will hold regardless of the measure of productivity, residual total factor productivity, relative total factor productivity, or factor share total factor productivity, that is used.*

Based on the findings of Baily, Hulten, and Campbell (1992), it is expected that high productivity firms are likely to remain highly productive while low productivity firms will not improve over time. This results in the following hypothesis:

> **Hypothesis 2:** *The relationship between productivity and IT spending will not change over time. Higher productivity firms will remain higher productivity firms and continue spending less on IT while lower productivity firms will maintain lower productivity and continue to spend more. IT spending will not influence a plant's relative productivity.*

Because of the construction of factor share TFP, it is unlikely that differences in industry composition among the high and low productivity groups will emerge. However, it is possible that even after de-meaning the factor share TFP measures, the highest and lowest productivity plants could be from similar industries. If that is the case, the first hypothesis would only uncover differences within a few industries and not provide additional information towards an explanation for the "productivity paradox" as is its intention. Toward that end, the following hypothesis must also be tested.

> **Hypothesis 3:** *The industry composition of plants when divided into groups by productivity will be stable. The relationship between productivity levels and IT spending will be independent of industry.*

The measures of productivity to be used are constructed to remove any industry specific component. Separate estimates of the coefficients on the Cobb-Douglas production function are developed by industry in the case of residual TFP and relative TFP. In the case of factor share TFP, the factors are calculated separately for each industry. It is expected that similar results will be found whether all plants across all industries are separated by productivity levels or plants within an industry are separated by productivity levels and then aggregated.

## 2.3 Contribution versus Spending

Given that more recent studies (Brynjolfsson and Hitt, 1993, 1996a, 1996b and Stolarick 1997) have shown a positive relationship between output and IT spending, how does one explain the three hypotheses given above? The solution to this dilemma is in understanding the difference between contribution to output and spending. The hypotheses presented above relate productivity to IT spending. They do not relate productivity to the impact from that spending. Because they are, by definition, more productive, it is possible that those firms that are spending less on IT are achieving the same level of benefit as those less productive firms. In essence, a level positive benefit is being achieved with more productive firms able to "spend down" while less productive firms have to "spend up" to obtain the same benefits.

In order to investigate this possibility, the model presented in equation (1) in § 2.1 must be extended to include IT spending as an input. This results in the following specification for a production function for the *i*th plant in year *t*:

$$Q_{it} = F(M_{it}, K_{it}, L_{it}, C_{it}) \qquad (8)$$

where,

$Q_{it}$ = real gross output (in dollars) for plant *i* in year *t*

$M_{it}$ = input materials (in dollars) for plant *i* in year *t*

$K_{it}$ = capital stock for plant *i* in year *t*

$L_{it}$ = labor for plant *i* in year *t*

$C_{it}$ = spending on computers for plant *i* in year *t*

Again, a Cobb-Douglas specification can be used. This specification for a given industry and year is:

$$Q_{it} = e_{it}^{\beta 0} M_{it}^{\beta M} K_{it}^{\beta K} L_{it}^{\beta L} C_{it}^{\beta C} \qquad (9)$$

$\beta_C$ is the output elasticity of spending on computers and is the variable of interest for this portion of the study. If, as assumed, higher productivity plants spend less on IT than lower productivity plants but the relative contribution of IT to output is consistent, the following relationship should be expected to hold:

$$C_H^{\beta_{HC}} \cong C_L^{\beta_{LC}} \qquad (10)$$

where,

$C_H$ = average IT spending for high productivity plants

$C_L$ = average IT spending for low productivity plants

$\beta_{HC}$ = estimated elasticity of computers for high productivity plants

$\beta_{LC}$ = estimated elasticity of computers for low productivity plants

Based on earlier results (Stolarick, 1997), it will be necessary to include fixed effects for industry when estimating the $\beta$'s. Because the $\beta_{HC}$ are estimated for plants that are known to be more productive and $C_H < C_L$ and given positive results found previously, it is expected that $\beta_{HC} > \beta_{LC} > 0$. This results in the following hypotheses:

**Hypothesis 4:** *Although spending more on IT than higher productivity plants, the relationship between IT spending and output will be significant, positive, and smaller than the relationship between IT spending and output for high productivity plants.*

**Hypothesis 5:** *The contribution to total output from high productivity, low IT spending plants and low productivity, higher IT spending plants will be approximately equivalent.*

It also should be noted that although more recent studies have found a significant, positive correlation between IT spending and outputs, the effect found has not been as large as one would have expected from the anecdotal evidence. The hypotheses present above describe a situation under which such results would be achieved. The effect for more productive plants is larger and more in line with what would be expected. However, when productivity is not controlled for, the effect is "muddied" by the presence of lower productivity plants which spend more on IT. Some firms are better than others -

both overall and with respect to their use of information technology and the dollars required to obtain it. By comparing the *over-achievers* with the *under-achievers*, the potential impact of IT can be more clearly identified.

The paper will proceed as follows. The next section will describe the statistical methods to be used to estimate the relationship between productivity and IT spending and the methods used to estimate the output elasticity of computer spending and will describe the data to be analyzed. The results will be presented in §4 followed by a discussion of the implications of the results in §5. Concluding remarks are presented in §6.

# 3. Methods and Data

## 3.1 Estimating Procedures

To complete the initial analysis for this study, factor share total factor productivity (FSTFP) will be calculated across all observations and years. Separate mean factor shares will be calculated for each industry, at the 4 digit SIC code level, for each year. In order to avoid any potential bias in the FSTFP calculations, it will be calculated for the entire population of manufacturing plants included in the economic census. After FSTFP has been calculated, only those plants that reported spending for computers will be selected out.

In order to avoid potential disclosure problems and to follow an approach similar to the one used by Strassmann with the *MPIT* data, the plants will be divided into quartiles along two dimensions - productivity, measured as FSTFP, and IT spending, measured as IT intensity. Although composite results across all three years under investigation will be presented, the assignment is first completed separately for each year. This will result in a four by four matrix of plant counts which will provide the test for the hypothesis 1. Hypothesis 1A will be tested by replicating the matrix using residual TFP and then relative TFP instead of factor share TFP. Analysis will be completed both in aggregate and by year. Any significant differences will be reported.

The impact of time and IT spending over time can be estimated by using a ordinal probit estimation procedure where the productivity quartile at time $t$ is the discrete dependent variable to be estimated. The independent variables include the productivity quartile and IT spending quartile at time $t-1$. If as expected by hypothesis 2, the primary influence on a plant's productivity is its prior productivity, the estimated coefficient on productivity quartile at time $t-1$ will be significant while the estimated coefficients on IT spending at either time $t$ or time $t-1$ will not be significant.

Based on the earlier results of Stolarick (1997), it is known that the relationship between IT spending and productivity varies by industry. As the productivity quartiles are assigned without regard to industry, it is possible that the plants from the highest performing industries are being assigned to the highest productivity quartile while those plants from the lowest performing industries are being assigned to the lowest productivity quartiles. Since the measures of productivity being used reflect overall productivity levels without incorporating IT into the equation, it is unlikely that this will be the case as is predicted by hypothesis three above. To investigate this possibility, the procedure for assigning plants to productivity quartiles will be changed and the results compared with those from the former procedure. Rather than assigning all plants by productivity levels, plants will be assigned to the productivity quartiles *with a specific industry* (at the two digit SIC code level). Then all plants from each quartile will be aggregated. The analysis for hypotheses one and two will be repeated after this new assignment method has be used. Any significant differences in the results will be reported.

Testing of hypotheses four and five will be completed by estimating the elasticity of computer spending with regard to output. By taking logarithms of the Cobb-Douglas specification provided in equation (9), a linear specification is developed. By adding an error term, $\varepsilon$, to the linear equation, the elasticities can be estimated using standard linear regression techniques. The resulting equation to be estimated for a given industry and year is:

$$\text{Log } Q = \beta_0 + \beta_M \text{ Log } M + \beta_K \text{ Log } K + \beta_L \text{ Log } L + \beta_C \text{ Log } C + \varepsilon \qquad (11)$$

Ordinary Least Squares (OLS) estimation can be used provided the error terms are independently and identically distributed. Tests for hetroskedasticity will need to be performed to verify this assumption. Fixed effects for industry will be included, but the individual results will not be reported.

Separate estimates will be developed for two groups. The first is those plants in the highest productivity quartile. The second is those plants in the lowest productivity quartile. Separate estimates for each group by year will be developed as will an estimate across all years. Any significant differences will be reported.

## 3.2 Data Sources

The Longitudinal Research Database (LRD) has been developed by the Center for Economic Studies at the Bureau of the Census. The LRD consists of a time series of economic variables collected from manufacturing locations in the Census of Manufacturers (CM) and the Annual Survey of Manufacturers (ASM). The information in the LRD is collected at the establishment, or plant, level and includes detailed annual information on production factors such as capital stock, labor, input materials, and services and on the outputs produced. The LRD contains the same sample of manufacturers as the ASM. Approximately 55,000 of the population of 350,000 establishments are included in the sample. Information on all establishments for all companies with more than $500 million in shipments are included in the LRD with certainty. These 500 companies account for approximately 18,000 of the included establishments. The next 12,000 establishments are selected to include all those with 250 or more employees or "a very large value of shipments" (Census Bureau, ASM, 1986). These first 30,000 establishments selected account for approximately 80% of the total value of all manufacturing shipments included in the U.S. economy. The remaining 25,000 establishments are randomly selected based on measures of size. Although the LRD provides fairly continuous observations for large firms across all years since it's inception in the 80's, the smaller firms included in the sample are resampled every five years (following a Census of Manufactures, x2 and x7 years).

When a plant is first selected to be included in the ASM (or every five years for large plants or those that are part of the largest firms), more detailed information is collected in the first year and follow up information collected in the next four years. As part of the detailed data collection, firms are asked to provide a breakdown of new machinery and equipment expenditures. This breakdown request collects up to three pieces of information which are contained under a single item on the reporting form. The breakdown consists of: (1) automobiles, trucks, etc., (2) computer and peripheral data processing equipment, and (3) other. The instructions request that plants "[r]eport all purchases of computers and related equipment" ("Instructions for Completing the Annual Survey of Manufacturers Report", Bureau of the Census, 1982). Only information on new computer equipment (hardware) is requested. This information is collected for the prior year only and is not intended to provide a measure of capital stock invested in computer equipment. The response rate for the ASM typically ranges from 80% to 85% (Bureau of the Census).

Because the goal of the Census is to collect information that can be analyzed to reflect the state of the entire U.S. economy, if a response has not been received from a plant, the Census will generate an observation for the plant based on data from other U.S. government sources and/or will impute data values based on industry, plant size, geographic location, and other characteristics. Imputed observations are clearly marked and have been excluded from this analysis. Further, those plants for which all necessary information has not been provided have also been excluded. For the years analyzed in this study, the elimination of "imputed" observations and those will missing data resulted in a reduction of approximately 20% of the sample.

The sample is further reduced when plants failed to report on the detailed breakdown for new equipment and machinery expenditures. As mentioned above, three breakdown categories were requested under the same heading. Since the intent of this study is to understand the relationship between productivity and IT spending, some level of IT spending needed to be reported. All observations that reported any non-zero amount for new computer spending where retained. This elimination for non-response further reduced the sample size by approximately 65%.

Data on new computer and equipment spending was collected for the Annual Survey of Manufacturers in 1982, 1987, and 1992 which are the years included in this analysis. Table 2 (below) shows by year the summary statistics for those plants that have been included in the analysis. As expected given the sampling procedure, larger plants are overrepresented in the sample. (For a more detailed comparison of the ASM with a full Census of Manufacturers, see Doms, et al, 1997.) However, data is captured at the plant level and not the firm level which is in keeping with the findings of Barua, et al (1995).

Since separate estimates will be developed for each of the three years and a time series analysis is not being conducted, it is not necessary to apply any discounting factors to the data to bring all dollar amounts to "constant" levels.

| | | **Annual Averages** | | | | |
|---|---|---|---|---|---|---|
| **Year** | **N** (plants) | **Value of Shipments** ($1000's) | **Cost of Materials** ($1000's) | **Capital Stock** ($1000's) | **Employees** | **New Computer** ($1000's) |
| **1982** | 7468 | 79425 | 43149 | 31663 | 601 | 246 |
| **1987** | 14189 | 78879 | 40509 | 31850 | 435 | 235 |
| **1992** | 18831 | 81513 | 41959 | 36858 | 349 | 231 |

Table 2 - Annual Summary Statistics

## 4. **Results**

### 4.1 Productivity and IT Spending

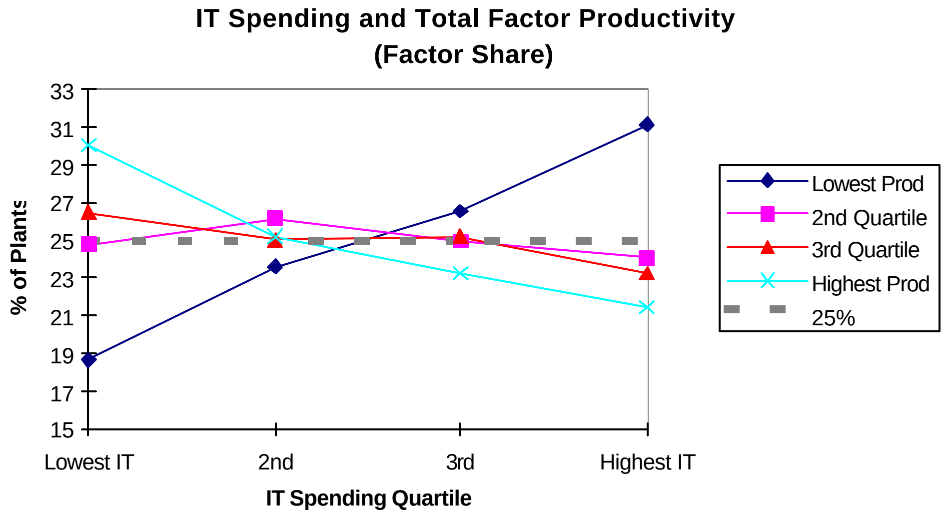


Figure 1 - Relationship between Productivity and IT Spending

Figure 1 shows the relationship between productivity and IT spending by quartiles. Each line represents all plants in a particular productivity quartile. The X axis gives the IT spending quartiles. The Y axis is the percentage of the total number of plants for each productivity quartile in each IT spending quartile. Each point represents the percentage of plants for a given productivity quartile that are in the given IT spending quartile. For example, among all plants in the lowest productivity quartile (represented by the diamonds in the figure above), 18.5%, 23.5%, 26.5% and 31.2% are in the lowest to highest IT spending quartiles respectively. The dashed line is at 25% which is what is expected if there is no relationship between productivity and IT spending quartiles. The figure above represents aggregated data from 1982, 1987, and 1992, and total factor productivity was measured using factor share total factor productivity. The results were also found to hold when each year was examined separately.

There are four significant ($p<0.05$, one-tailed t-test) points in this figure. They are:

1. Highest productivity plants in the lowest IT spending quartile, which are significantly *higher* than 25%.
2. Highest productivity plants in the highest IT spending quartile, which are significantly *lower* than 25%.
3. Lowest productivity plants in the lowest IT spending quartile, which are significantly *lower* than 25%.
4. Lowest productivity plants in the highest IT spending quartile, which are significantly *higher* than 25%.

Although there is a symmetry to these results, that symmetry is not imposed as a result of the method being used - it is a direct result from the data. Note also that although somewhat symmetric, the results do not show exact symmetry.

The figure, and accompanying statistical tests, support the first hypothesis, the relationship between productivity, as measured by factor share total factor productivity, and IT spending is such that higher productivity firms will be shown to spend less on IT while lower productivity firms will be shown to spend more. This replicates the earlier results found by Strassmann.

The adjunct to the first hypothesis, hypothesis 1A, that hypothesis 1 will hold regardless of the measure of productivity, residual total factor productivity, relative total factor productivity, or factor share total factor productivity, that is used, was also supported. Figures 2 and 3 below present the same results as figure 1 with residual total factor productivity and relative total factor productivity used respectively as the measure of productivity.  The results shown also represent and aggregation across all observations from the years 1982, 1987, and 1992.  However, as with factor share total factor productivity, the results are consistent when each year is considered individually.  The results for those plants in the lowest productivity quartile were consistent across the measures of total factor productivity.  The results for those plants in the highest productivity quartile were not as strong, especially with regard to finding number two above, that the highest productivity plants are less likely to be in the highest IT spending quartile.  However, the results at least provide an indication of the robustness of the findings with regard to the specific measure of productivity used.  As factor share productivity requires fewer restrictive assumptions than the other measures, the results found using factor share total factor productivity should be given greater weight.

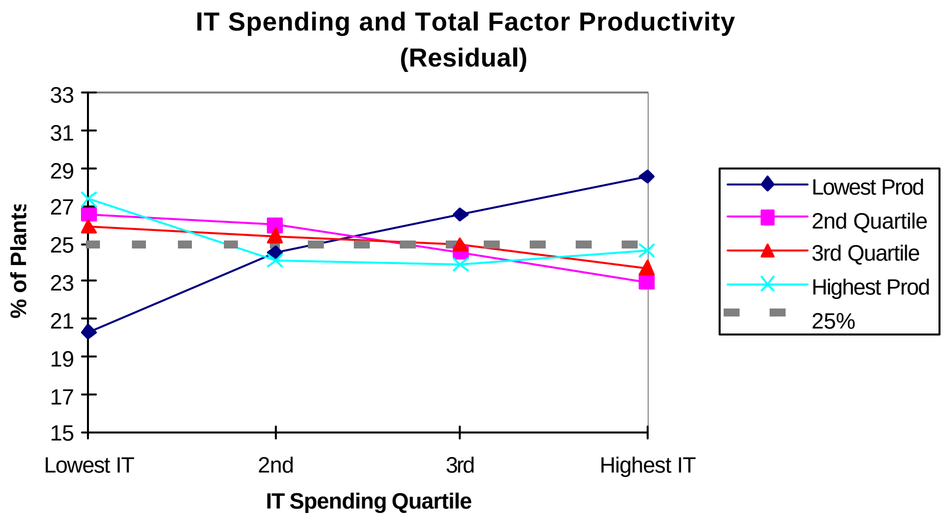


Figure 2 - Relationship between Residual TFP and IT Spending

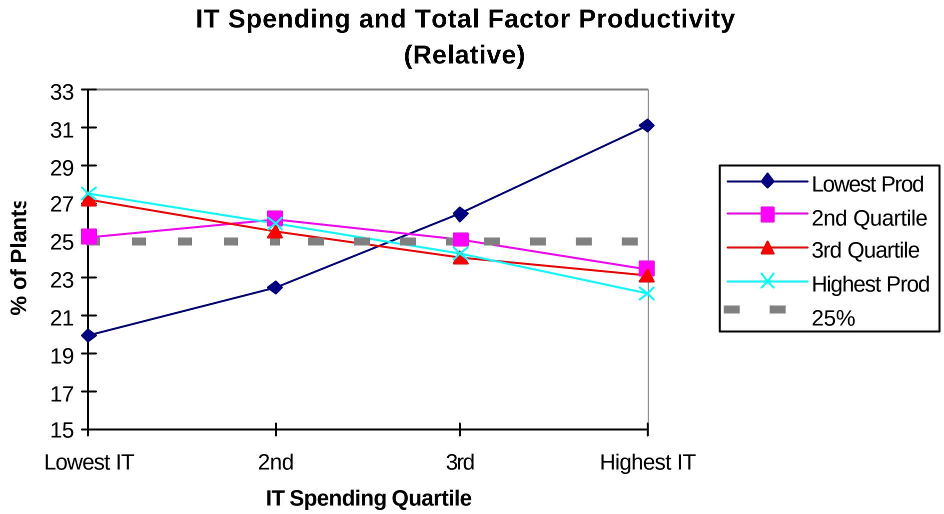


Figure 3 - Relationship between Relative TFP and IT Spending

## 4.2 Productivity over Time

Table 4 presents the results of completing the ordinal probit analysis with the current productivity quartile as dependent on prior productivity and current and prior IT spending. Given the available data, three separate analyses are supported: (1) the relationship between 1987 productivity and 1982 productivity, 1982 IT spending and 1987 IT spending; (2) the relationship between 1992 productivity and 1987 productivity, 1987 IT spending and 1992 IT spending; (3) the relationship between 1992 productivity and 1982 and 1987 productivity and 1982, 1987, and 1992 IT spending.

| | **Independent Variables** | | | | |
|---|---|---|---|---|---|
| Dependent Variable | 82 Prod | 87 Prod | 82 IT | 87 IT | 92 IT |
| 87 Productivity | 3.44** | 0.0000 | -0.0000 | | |
| 92 Productivity | | 4.42** | | -0.0000 | 0.0000 |
| 92 Productivity | 1.07** | 3.66** | -0.000097* | 0.0000 | -0.0000 |

** $p<0.0001$
* $p<0.05$

Table 4 - Impact on Productivity over Time

As expected, the second hypothesis, the relationship between productivity and IT spending will not change over time - higher productivity firms will remain higher productivity firms and continue spending less on IT while lower productivity firms will maintain lower productivity and continue to spend more - IT spending will not influence a plant's relative productivity, does hold. Time in this case is only available in five year increments. However, even when separated by 5 years, over 60% of the highest productivity plants, remain in the highest quartile and over 40% of the lowest productivity plants remain in the lowest IT spending quartile. The finding of stability in productivity is not new (Baily, Hulten, and Campbell, 1992), but it is news that the relative IT spending patterns also remain stable. Further, the ordinal probit findings confirm that the primary driver of productivity ranking is previous productivity and that IT spending does not significantly influence productivity - across all plants.

It should be noted that this analysis is being completed against all plants with a given productivity standing and that the really interesting situations are those that are going to be treated as outliers in this analysis. It is those plants that had low productivity, spent relatively more on IT, and reached higher productivity that can account for much of the anecdotal evidence and case studies. It's clear that such cases exist in the data. However, it doesn't happen very often (between 5% and 8%). Using only the data available from the Census, the specifics of these situations cannot be determined. Future research could include matching the Census data with data from other sources (Compustat and industry periodicals for example) for these cases (low productivity/high IT spending that got better) as well as their inverse (high productivity/low IT spending that got worse) to get a better sense of what was going on. The risk with this analysis is that the Census data will by necessity be cut pretty finely, and once outside data it matched with Census data, everything has to meet with disclosure requirements.

## 4.3 Industry Mix

Figure 5 shows the relationship between factor share total factor productivity quartiles and IT spending quartiles as in figure 1. However, in this case productivity quartile assignments were completed separately for each industry at the two digit SIC code level. The figure again shows the combined data for all three years under investigation, but the results are the same if each year is presented separately. In this case rather than consisting of the top productivity performers across all manufacturing, as is the case in § 4.1, the highest productivity quartile consists of the top 25% of the performers from each industry. IT spending quartile assignment has also been completed by industry.

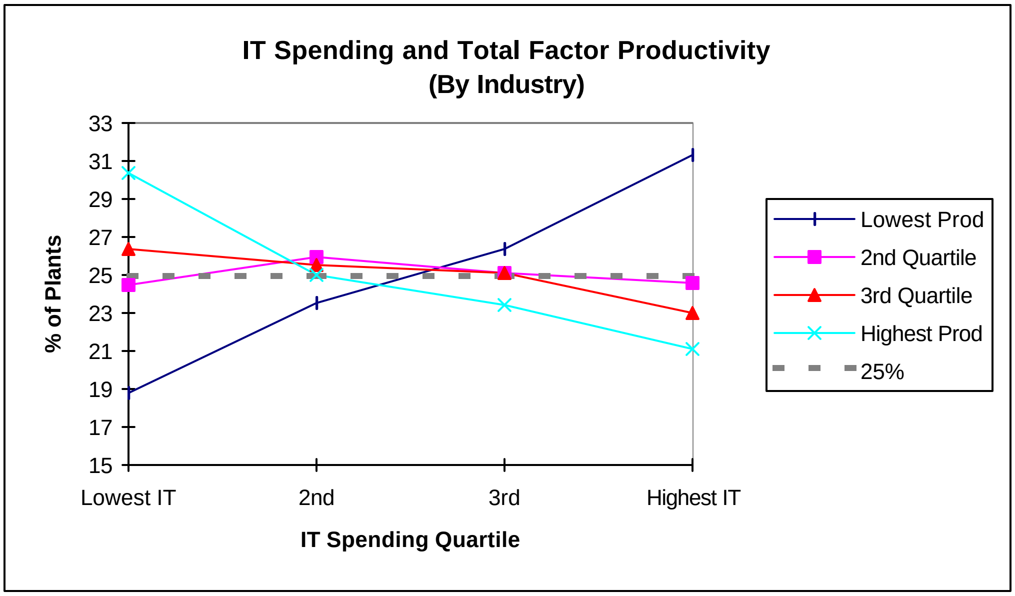


Figure 5 - Relationship between Factory Share TFP (by Industry) and IT Spending

The third hypothesis, the relationship between productivity levels and IT spending will be independent of industry, also holds.

As stated above, since the productivity quartile assignment is based on factor share TFP, which is relatively independent of industry, one would expect that the factor share TFP calculated for all plants across industries would have relatively the same values regardless of industry. This is what is happening. Within each industry, the factor share TFP's range from around -2.0 to 2.0. Since the calculated factor share TFP's are similar, the results of dividing the sample into productivity quartiles either on an overall basis or by industry achieve essential the same productivity quartile assignments,

## 4.4 Contribution versus Spending

Table 6, below, shows the estimates for the elasticity of IT, $\beta_C$ from equation 11, for both the highest and lowest productivity groups. Hypothesis 4, although spending more on IT than higher productivity plants, the relationship between IT spending and output will be significant, positive, and smaller than the relationship between IT spending and output for high productivity plants, is supported. As expected, higher productivity plants have larger returns to output from their IT spending and do spend less. Hypothesis 5, the contribution to total output from high productivity, low IT spending plants and low productivity, higher IT spending plants will be approximately equivalent, is based on the assumption that because they are lower productivity, lower productivity plants will "spend up" their IT investments to achieve the same benefit as higher productivity plants. As table 6 shows, lower productivity plants spend more on average than higher productivity plants. However, the additional spending is not sufficient to bring the total contribution to output from IT to the same level as is achieved by the higher productivity plants. It should be noted that this finding is based on an assumption of *ceteris paribus* with regard to the other factor inputs that clearly does not hold. By definition, the higher productivity plants are achieving similar results with the other inputs (material, labor, and capital) - they are spending less and getting more. Although the analysis suggests some support for hypothesis 5, it appears as if the difference in spending levels is not fully explained by the difference in productivity levels.

| | Elasticity of IT | Mean IT | Contribution to |
|---|---|---|---|

| | | N | ($\beta_C$) | Spending | Output |
|---|---|---|---|---|---|
| **Highest Productivity** | | | | | |
| | 1982 | 1867 | 0.0108* | 228.41 | 1.0604 |
| | 1987 | 3548 | 0.0221** | 235.43 | 1.1284 |
| | 1992 | 4708 | 0.0221** | 213.38 | 1.1260 |
| **Lowest Productivity** | | | | | |
| | 1982 | 1867 | 0.0100** | 304.10 | 1.0593 |
| | 1987 | 3547 | 0.0141** | 284.13 | 1.0830 |
| | 1992 | 4708 | 0.0165** | 288.62 | 1.0980 |

* $p<0.01$
** $p<0.0001$

Table 6 - Impact of IT Spending for Highest/Lowest Productivity Plants

In essence, the final two hypotheses resolve the dilemma posed by the earlier findings of this paper. It is clear from the data that higher productivity plants tend to spend less on IT while lower productivity plants tend to spend more. This is definitely a surprising finding. Given that a positive relationship has been found (elsewhere and even in this same data) between IT spending and output, these hypotheses help to explain what is going on. Higher productivity plants are spending less but are getting greater benefit from this smaller amount. Further knowledge is added to the "productivity paradox" question. It's another example of unaccounted for heterogeneity influencing prior results. Since some plants are more productive than others (call it management skill, Return-on-Management™, or whatever you'd like), they are able to achieve a greater level of benefit at less cost. Their returns are higher but their investment is lower. If the data is analyzed without taking this difference into account, the results would be much lower than anticipated, which they are. By showing not only are the returns are positive for both high productivity and low productivity plants but that their contributions to output are similar, a deeper understanding of the "productivity paradox" and the conflicting results is obtained.

## 4.5 Limitations

This analysis was completed against data compiled by the Bureau of the Census as part of the Annual Survey of Manufactures and the Census of Manufactures. As such, it consists of data provided to the federal government by each of the manufacturing locations included in the annual sample or all locations in the census. The accuracy of this information can easily be called into question. Following the approach taken by Doms, Dunne and Troske (1997) who used the Census provided data in their analysis, statistics for the sample analyzed have been calculated and compared against those from other available data sources. No significant differences were found. As the sample selection method is explicitly weighted toward including all large firms and plants, the sample is clearly biased toward large firms. However, the sample does account for approximately 80% of the total manufacturing economic activity in the U.S. Also, approximately 50% of the sample is randomly selected for all known manufacturing establishments so the sample averages are below those of Brynjolfsson and Hitt (1996) whose sample was selected from the Fortune 500. In addition when working with the LRD, Baily et al. (1992) noted problems with outliers and missing data. Their approach was to discard information on any plant in a given year that resulted in a productivity level outside of a range of ± 200% of the industry average. Given the significant impact to any statistical analysis that outliers may introduce, this may not represent the best approach to this problem. Given the large number of observations in the sample, it is not possible to investigate each outlier to determine if it is a legitimate data point or the result of inaccurate data. As no significant outliers were found in the data that may have positively biased the results, the analysis was completed without removing any of the observations as outliers.

A further limitation of the results presented by this analysis is that it was only completed against manufacturing industries. However, as part of this analysis is an attempt to replicate the results of Strassmann and his results where obtained by analyzing primarily manufacturing data from a different source, this does not present a severe limitation on the results. The results of Brynjolfsson and Hitt (1993, 1996a, 1996b), Loveman, Barua, et al. and others were also obtained from data that consisted primarily of manufacturing firms so ample precedent has been established in the study of the relationship between IT spending and productivity for a satisfactory degree of significance to be associated with these results. It should be noted that the results only reflect manufacturing firms and care should be taken in applying any result to other industries.

This study has only investigated the relationship between productivity and IT spending using three possible measures of productivity, factor share total factor productivity, residual total factor productivity, and relative total factor productivity. A more vigorous approach could include other measures of productivity. Other definitions of productivity are possible and available from the data source analyzed. As only manufacturing locations are represented in the data, the traditional measure of productivity, output per unit of input, could be useful but would not be as meaningful as measuring productivity using total factor productivity. Other methods for determining productivity should be investigated, and the impact of their use on the results analyzed.

The final limitations of this research result from the specific information on IT spending that is available. As the required data is only collected every five years, a longitudinal study of the impact of IT spending on productivity is not immediately available. This analysis reflects aggregate analysis and three separate cross-sectional results. Further, only spending information on "new computer equipment" has been collected. This spending does not represent the total required investment by a plant in computer technology which must include the support and labor costs. Total computer "stock" values would be more appropriate for the production function estimated. Given the fairly stable investment rate by firms in computer technology since the mid 1980's and the relatively rapid depreciation for computer equipment, the correlation between current year spending and total stock should be sufficiently high enough to allow current year spending to act as a proxy for total stock values.

A further limitation results from the way in which manufacturers may have been reporting new computer equipment spending (Troske, personal communication). The reported level of spending has increased over time while spending on "other" new technology has shown a corresponding decrease. It is not clear whether the numbers truly represent a change in spending or reporting. Additionally, some plants do not seem to have reported their computer investment, but the growth rates for the reported numbers correlate strongly across industries. Within specific industries there are large standard errors in computer investment. It is unclear whether these standard errors are the result of truly different spending patterns or poorly reported data.

# 5. Discussion

## 5.1 Managerial Implications

Beyond providing additional insights into the productivity paradox and the factors that must be taken into consideration, this research offers findings that have direct implications for management and the management of information technology resources. First, it offers support for the idea that management skill is an important factor that must be taken into consideration. Some firms are clearly better than others at effectively utilizing their IT investments. Although specific differences have not been identified in this analysis, it is important to realize that those differences exist. Firms would do well to recognize who the best performers are in their industry and develop and understanding of why they do so well. This research offers empirical evidence that IT is not a panacea. Firms that are not doing well relative to their competitors cannot spend their way "out of the hole." Lower productivity firms tend to spend more on IT than higher productivity firms but achieve mixed results. First, to a limited extent, the increased spending on IT does increase the contribution to output from IT. However, even with increased spending, lower productivity firms do not reach the same level as higher productivity firms. The management of a firm needs to recognize if it is a lower productivity firm and compensate to some extent with increased spending. Second, most firms have not successfully used IT spending to increase overall productivity. The primary driver of productivity levels is previous productivity - IT does not significantly enter into the relationship. However, a small minority of firms who did spend more on IT were successfully able to improve their productivity position. When combined with the result that higher productivity firms spend less on IT and achieve more, this strongly supports the need for strategic management of IT and the need for situational awareness. Since higher productivity firms, regardless of the industry, are able to achieve more from less, it suggests that IT usage can be specifically targeted within the firm. It is not sufficient to undertake the same IT projects as everyone else, the management of the firm needs to understand its internal and external environment and undertake those efforts that best fit the firm's unique situation.

## 5.2 Future Research

As stated above, the potentially most interesting cases have been treated as outliers in this analysis because the primary focus was on understanding the "big picture" of the relationship between productivity and IT spending. However, this analysis has identified two specific groups of plants that warrant additional attention. The first is those plants that were in the lowest productivity quartile and the highest IT spending quartile that were able to move to a higher, or even the highest, productivity quartile. This is strongly suggestive of an ability on the part of some to use IT to their strategic advantage and make dramatic improvements over the five and ten year periods analyzed. The second group of interest is those that were in the highest productivity quartile and lowest IT spending quartile that moved to a lower, or even the lowest, productivity quartile. As TFP was calculated relative to the performance of other plants in the same industry, this suggests that some plants were unable to keep pace with their peers. It provides support for the argument that, in some instances, IT is a necessity that must be maintained at a certain level simply to remain competitive. On its own, the data available from the Census Bureau will only support limited additional analysis into these situations. However, it is possible to match the Census data to data from other sources in an attempt to gain a better understanding of those plants that made dramatic moves in their relative productivity.

Although information on new computer equipment spending is only available in five year increments, the annual information that is available for the four following years will support longitudinal analysis of plant productivity.  It will be possible to complete three separate longitudinal analyses of productivity in five year blocks for the "small" plant portion of the sample and analysis over the duration of the time series for the large plants and firms.  This analysis would allow for identification of lagged effects from spending on computer technology in the years available.  Given the differential effects across industries and initial productivity, it is likely that the impact of lagged effects will be moderated by industry or firm characteristics.  There may be a relationship between *ex ante* productivity and the *ex post* impact from spending on computers.  Understanding this relationship and its moderators could lead to significant improvements in managerial decision making by firms with respect to spending on information systems.

Olley and Pakes (1996) have identified numerous concerns with the traditional methods of estimating production function parameters and have developed a method to overcome these concerns.  Their new method also impacts the calculation of TFP which uses estimates of the production function parameters. This work can be extended to use the latest in TFP "technology."

The results presented above have focused only on the manufacturing sector because that is the only information currently available in the LRD.  However, finance, insurance, and real estate (FIRE) data will be available soon as will other "service sector" Census data.  This will allow for a detailed analysis in the "service sector" of the economy and comparison with the results found for manufacturing.

## 6. Conclusion

Some firms are clearly more efficient than others. This effectiveness extends to IT as well. Not only do higher productivity firms get a greater benefit with less spending on IT, but lower productivity firms get a lower benefit with greater spending. Although the returns are different, they are still positive and significant when industry differences are allowed for and a large enough sample is used. Further, IT spending is not significantly related to subsequent productivity levels. Although the data did contain examples of low productivity plants that spent more on IT and increased their productivity and high productivity plants that spent less on IT and lost productivity, the overall finding is that previous productivity is significantly related to current productivity while IT spending is not.

Mismanagement was originally given as a possible explanation for the productivity paradox. It would be more clear to say that management skill effects the level of benefit that a firm can get from its IT spending. Even though the lowest productivity firms had a smaller benefit and greater spending than the other firms, the lowest productivity firms still had a positive return associated with their IT spending. The relationship between firm performance and IT spending is a complex one. By showing that management skill must also be taken into account, a deeper understanding of the earlier findings that led to the “productivity paradox” is developed.

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