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IT Spending and Firm Productivity: Additional Evidence from the Manufacturing Sector

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Abstract

The information systems (IS) "productivity paradox" is based on those studies that found little or no positive relationship between firm productivity and spending on IS. However, some earlier studies and one more recent study have found a positive relationship. Given the large amounts spent by organizations on information systems, it is important to understand the relationship between spending on IS and productivity. Beyond replicating positive results, an explanation is needed for the conflicting conclusions reached by these earlier studies. Data collected by the Bureau of the Census is analyzed to investigate the relationship between plant-level productivity and spending on IS. The relationship between productivity and spending on IS is investigated using assumptions and models similar to both studies with positive findings and studies with negative findings. First, the overall relationship is investigated across all manufacturing industries. Next, the relationship is investigated industry by industry. The analysis finds a positive relationship between plant-level productivity and spending on IS. The relationship is also shown to vary across industries. The conflicting results from earlier studies are explained by understanding the characteristics of the data analyzed in each study. A large enough sample size is needed to find the relatively smaller effect from IS spending as compared to other input spending included in the models. Because the relationship between productivity and IS spending varies across industries, industry mix is shown to be an important data characteristic that may have influenced prior results.

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1. Introduction

The question of why so much is being spent on information technology while little (if any) measurable gain can be shown has been an outstanding once since William Bowen's cover story "The Puny Payoff for Office Computers" in the May 1986 issue of Fortune. While early studies found little, if any, positive relationship between firm productivity and spending on information technology, a more recent study (Brynjolfsson and Hitt, 1993) found significant contributions to firm output, when measured as a marginal product of the inputs, associated with spending on IT. They also found that the gross marginal product for computer spending is at least as large as the marginal product associated with other capital investments. Brynjolfsson and Hitt, applying a more recent, larger data sample to models like those used in previous studies that did not find a significant relationship, attributed their "different results to the recency and larger size of [their] dataset" (Brynjolfsson and Hitt (1993) p. 47). This study will replicate their results and explain why positive results have been found in some situations and not in others.

The significance of this paper is that it provides an explanation for *why* the IS productivity paradox was apparently found and then resolved. By developing an understanding of the process and assumptions that have been used in previous work, it is shown that only a relatively small effect needs to be identified for there to be a significant relationship between spending on information technology, firm output, and the average product associated with the computer investment. This paper also replicates the results found by Brynjolfsson and Hitt, it adds support to their argument that the "productivity paradox" was an artifact of the data used in previous analyses. The results show not that the "IT productivity paradox" has "disappeared" but that it "never was."

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 uses this third approach and investigates the relationship between plant output and IT spending.

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). Brynjolfsson found increases to consumer surplus due to the decreasing costs and increasing functionality of computer hardware. This approach was based on social welfare theory and found benefits have been realized from a user's point of view. However, in looking from the producer's viewpoint, the other studies did not find increases in aggregate productivity 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. 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.

Although learning by doing is a factor in realizing productivity benefits from the implementation of an information system and some time lag before benefits are realized should be expected, the decades during which computers have been used by businesses lead one to expect to find a high correlation between expenses and benefits in the current year even if the benefit was from spending made in previous years. Although a thorough understanding of the relationship between spending on IT and productivity changes requires a careful matching of costs and benefits, the assumption of rational expectations leads to the conclusion that spending in the current year will correlate strongly with the benefits obtained from spending in prior years. Therefore, increases in firm productivity should be expected starting right after the widespread adoption of the mainframe computer. With a strong correlation between prior benefits and current spending, firms that are spending more in the current year should also show greater benefits in the current year. Although the full benefits for the current year may not be realized in the same year, benefits from prior years' spending should be realized in the current year. The relationship between current year spending and productivity would be moderated by time lag effects if spending was not at relatively stable levels. For example, assuming a positive relationship between spending on information technology and productivity and growing levels of spending, failure to account for time lags properly would result in underestimating the impact of IT on productivity. However, since the mid 1980's computer spending as a percentage of durable equipment has remained at around ten percent. (Brynjolfsson, 1993). Given the relative stability of spending on computers, time lags, although necessary to accurately reflect the true underlying relationship between spending on IT and productivity, should not be necessary to find a fairly accurate estimate of the effect of spending on IT and productivity. The result is that finding productivity benefits from information technology may only require a sufficiently large enough data sample.

1.3 Theoretical Issues

Given the assumption of rational expectations and relatively stable spending on computers over the past fifteen years, finding a positive relationship between spending on computers and productivity in a given year is likely to rely solely on obtaining sufficiently large enough data sample. A large enough sample will allow for more accurate estimation of the output elasticity for computer spending. Since a fairly small elasticity can result in a significant average product when spending on the given input factor is also small relative to output and a larger data set can allow for a more accurate estimate of the small elasticity, finding a positive result may only require a sample large enough for the elasticity of computer spending to rise above the "noise." Below is outlined the specification for the production function to be modeled, examples of anticipated elasticities associated with various average product levels, and the hypotheses concerning the relationship between spending on information technology and productivity.

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

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

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*

C_{it} = spending on computers 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:

$$Q = e^{\beta 0} M^{\beta 1} K^{\beta 2} L^{\beta 3} C^{\beta 4} \tag{2}$$

β_4 is the output elasticity of spending on computers and is the variable of interest for this study. The average product for computers (AP_C) can be found by multiplying the output elasticity for computers by the ratio of total output to computer spending. The average product can be thought of the return on the investment for an input factor. Provided the average product is positive, productivity is being enhanced by the input factor.

The average product for computers is calculated using the following:

$$AP_C = \beta_4 \frac{Q}{C} \tag{3}$$

Solving for β_4 yields,

$$\beta_4 = AP_C \frac{C}{Q} \tag{4}$$

The table below shows the output elasticity, β_4, required in order to reach the given average product value for various levels of computer spending (as a percentage of total output).

Average	Computer Spending (% of Total Output)					
Product	0.5	1	1.5	2	2.5	3
1	0.005	0.01	0.015	0.02	0.025	0.03
0.8	0.004	0.008	0.012	0.016	0.02	0.024
0.6	0.003	0.006	0.009	0.012	0.015	0.018
0.4	0.002	0.004	0.006	0.008	0.01	0.012
0.2	0.001	0.002	0.003	0.004	0.005	0.006
0.1	0.0005	0.001	0.0015	0.002	0.0025	0.003
0.05	0.00025	0.0005	0.00075	0.001	0.00125	0.0015
0.01	0.00005	0.0001	0.00015	0.0002	0.00025	0.0003
0.005	0.000025	0.00005	0.000075	0.0001	0.000125	0.00015

Table 1 - Output Elasticities for given average products and spending

As can be seen in the table, the output elasticity for computer spending need not be large for there to be a significant positive return to output from spending on computers. Given the relatively much larger elasticities that are found for the other input factors (input materials spending, capital, and labor), which typically are in the 0.25 to 0.50 range and are even higher when the input factors are not analyzed separately, the effect associated with spending on computers can be several orders of magnitude smaller than the others analyzed.

Given that a relatively small effect must be found, a much larger sample size than most of those previously used to investigate the IS productivity paradox would be needed in order to be able to separate the effect of spending on computers from the noise. However, if a small effect can be clearly identified, given the large amount of output and relatively small amount of spending on computers, fairly significant average product can be obtained (equation 3). More formally, this paper investigates the following hypothesis:

Hypothesis 1: *Analysis of a large enough sample will show a positive output elasticity and positive average product for spending on computers.*

Following the discussion on the impact, or lack thereof, contained in §1.2, results in the second hypothesis:

Hypothesis 2: *Finding a positive result using data from the mid 1980's on will not require allowance for lagged impacts from computer spending.*

Although the Cobb-Douglas specification requires constant returns to scale (CRS), which means the elasticities must sum to one, there is no requirement that the elasticities be the same across industries or years. For the data analyzed, constant returns to scale does seem to apply across industries (see Baily, et al, 1992, table 12, p. 234). However, it is likely that different industries will have different output elasticities with respect to computer spending. Although understanding these differences is an important endeavor (see §4.2), the focus of this paper is explaining *why* the IS productivity paradox was found and *why* it was apparently resolved. Accordingly, showing that there are differences across industries is sufficient at this time. By finding differences across industries, previous results could be shown to be confounded by the mix of industries included in their samples. Since only a relatively small effect is expected, searching for that effect in sample comprised of many industries, which could have different values for the elasticity, would generate additional, unnecessary noise which could not be controlled for given the small sample sizes without significantly impairing the available degrees of freedom. Subsequently, the final hypothesis is:

> **Hypothesis 3:** *The output elasticity for spending on computers will differ between industries when measured at the 2 digit SIC code level.*

Taken together, these hypotheses present an explanation for the IS productivity paradox and its resolution. Since the traditional approach to this question has been to model the data using a standard production function, finding a positive result has relied on estimating a relatively much smaller elasticity in comparison to the others being estimated. Once a significant positive elasticity could be identified, a significant average product could also be found given the simple mathematics of the situation. The difficulty has been with obtaining a large enough sample to be able to clearly identify the effect of computer spending on output. Estimation techniques when a small effect needs to be identified require a significantly larger sample size in order to be able to isolate the desired effect from the noise. This is further confounded by differences across industries. One of the earlier studies that did find some positive results focused exclusively on one industry (Weill, 1992). Although necessary for developing a more complete understanding of the relationship between IS spending and productivity, lagged effects should not play an important role when spending levels remain fairly stable as they have.

As Zvi Griliches put it: "[O]ur understanding of what is happening in our economy (and in the world economy) is constrained by the extent and quality of the available data." (Griliches, 1994). The IS productivity paradox is an artifact of the availability of data. Once a large enough sample was used (Brynjolfsson and Hitt, 1993a, 1993b, 1996), there was no paradox. This study will also use a sufficiently larger sample of manufacturers to show there is no paradox and explain what led to it be being found and resolved.

The paper will proceed as follows. The next section will describe the statistical methods to be used to estimate the output elasticity of computer spending and will describe the data to be analyzed. The results will be presented in §3 followed by a discussion of the implications of the results in §4. Concluding remarks are presented in §5.

2. Methods and Data

2.1 Estimating Procedures

By taking logarithms of the Cobb-Douglas specification provided in equation (2), a linear specification is developed. By adding an error term, ε, 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:

$$\text{Log } Q = \beta_0 + \beta_1 \text{ Log } M + \beta_2 \text{ Log } K + \beta_3 \text{ Log } L + \beta_4 \text{ Log } C + \varepsilon \qquad (5)$$

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.

The estimates for the equation will be developed in two ways. Under both procedures, separate estimates will be developed for each year to allow comparison of the effect across years. For the first method, the equation will be estimated with "fixed effects" by industry with industry determined at the four digit SIC code level. By including the industry fixed effects dummy variables in the equation, the overall effect can be estimated while allowing for differences across industries. With fixed effects by industry the constant, β_0, will not be estimated as the inclusion of dummy variables for all industries eliminates the need for a constant in the regression equation. Only the coefficient estimates included in equation (5) will be reported as will the results of a joint hypothesis test on the significance of the inclusion of industry fixed effects. The second method will also estimate equation (5) by year but will involve developing separate estimates of the coefficients for each industry. For this analysis, industries will only be separated at the two digit SIC code level.

The first approach will allow for the development of an overall impact of computer spending for all manufacturing plants included in the sample and allow for testing of differing impacts by industry. These estimates will provide an indication of the impact of computer spending for the entire manufacturing sector. The second approach will investigate the possibility of different effects for each industry.

2.2 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 requested 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. In order to provide the most conservative estimates while still attempting to eliminate non-responses, observations were retained when *at least one* of the detailed breakdown categories was provided. This allows for the analysis to include firms with zero dollars spent on new computer equipment. This elimination for non-response further reduced the sample size by approximately 50%.

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).

Tables 2A, 2B and 2C present the summary statistics for the sample by year broken down by industry at the two digit SIC code level. Summary statistics for SIC 21, Tobacco, have been excluded to preserve Census Bureau disclosure integrity.

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	25131	46900	25324	17346	348.85	73.21
1987	26570	58815	30067	22962	327.35	125.47
1992	29433	66193	33400	29372	287.78	147.66

Table 2 - Annual Summary Statistics

1982		Annual Averages					
SIC	**Description**	**N** (plants)	**Value of Shipments** ($1000's)	**Cost of Materials** ($1000's)	**Capital Stock** ($1000's)	**Employees**	**New Computer** ($1000's)
20	Food	2927	54400	34540	12153	251.04	18.10
22	Textiles	1038	29077	16705	11912	405.38	15.12
23	Apparel	1021	16587	8107	2511	288.03	16.39
24	Lumber and wood	1112	12286	7323	5475	128.76	7.16
25	Furniture	553	17496	7484	5199	296.55	23.33
26	Paper	1143	45975	22839	33702	288.07	39.05
27	Printing and publishing	1288	22566	7551	8581	305.44	122.28
28	Chemicals	1694	62179	28306	34589	277.40	55.54
29	Petroleum refining	333	442663	380511	102225	250.27	34.12
30	Rubber and plastics	1336	22060	10057	10542	233.71	15.67
31	Leather	282	16491	7805	2360	301.19	7.62
32	Stone, clay, glass and concrete	949	20948	7261	15081	223.88	17.08
33	Primary metals	1199	49839	26335	36419	392.08	53.10
34	Fabricated metals	2803	20817	9925	7829	217.69	23.18
35	Industrial and commercial machinery (including computers)	3248	38263	16772	13872	376.16	172.30
36	Electronics (excluding computers)	1825	42761	18068	15178	490.52	126.94
37	Transportation equipment	984	166535	92239	45682	1190.67	220.00
38	Measuring instruments; photographic, medical, watches, & clocks	910	56829	18155	17349	654.26	252.55
39	Miscellaneous manufacturing	440	21594	9165	5973	250.65	24.52

Table 2A - Industry Summary Statistics (1982)

1987		**Annual Averages**					
SIC	**Description**	**N** (plants)	**Value of Shipments** ($1000’s)	**Cost of Materials** ($1000’s)	**Capital Stock** ($1000’s)	**Employees**	**New Computer** ($1000’s)
20	Food	3753	59245	34396	15150	223.21	40.16
22	Textiles	982	40515	22538	15033	391.77	29.25
23	Apparel	1078	22645	11326	3001	294.09	17.81
24	Lumber and wood	1252	21411	12384	7893	156.08	13.90
25	Furniture	655	26567	11589	7194	322.78	39.54
26	Paper	1465	54826	26005	41106	261.39	57.17
27	Printing and publishing	1538	29871	9463	12588	291.47	162.44
28	Chemicals	2003	76981	32700	42622	225.68	127.62
29	Petroleum refining	384	259615	217476	98895	191.43	77.31
30	Rubber and plastics	1309	30487	13699	13321	241.19	35.12
31	Leather	286	17859	9080	2883	232.80	22.31
32	Stone, clay, glass and concrete	1151	26507	9001	17651	191.64	65.48
33	Primary metals	1124	76376	40839	49424	389.59	75.12
34	Fabricated metals	2582	26471	12757	10107	209.86	46.44
35	Industrial and commercial machinery (including computers)	2661	48018	21816	17864	317.02	237.52
36	Electronics (excluding computers)	1736	62058	25676	24611	489.92	245.97
37	Transportation equipment	1092	258711	151046	67122	1251.50	585.90
38	Measuring instruments; photographic, medical, watches, & clocks	975	74833	23441	25375	620.82	387.41
39	Miscellaneous manufacturing	500	25034	10236	6896	216.61	61.99

Table 2B - Industry Summary Statistics (1987)

1992		**Annual Averages**					
SIC	**Description**	**N** (plants)	**Value of Shipments** ($1000’s)	**Cost of Materials** ($1000’s)	**Capital Stock** ($1000’s)	**Employees**	**New Computer** ($1000’s)
20	Food	3570	77340	45037	22221	243.99	53.70
22	Textiles	1030	48231	26414	20029	375.61	50.39
23	Apparel	934	27437	13231	4010	290.96	41.62
24	Lumber and wood	1489	22533	13158	8959	133.55	14.75
25	Furniture	705	28837	12999	8982	278.55	44.24
26	Paper	1608	62888	30984	62731	253.31	84.53
27	Printing and publishing	2038	30236	9017	15534	241.99	186.20
28	Chemicals	2393	96639	40550	59034	217.28	210.55
29	Petroleum refining	425	281068	228546	114199	181.96	155.74
30	Rubber and plastics	2156	29113	13195	14966	194.72	47.57
31	Leather	111	34201	16876	5523	315.43	39.93
32	Stone, clay, glass and concrete	1507	21504	7216	16359	141.79	29.87
33	Primary metals	1193	82936	45110	56667	350.33	78.92
34	Fabricated metals	2772	27713	13307	11607	180.07	48.22
35	Industrial and commercial machinery (including computers)	2908	49103	23321	18802	260.46	306.31
36	Electronics (excluding computers)	1789	79909	33433	35155	456.60	355.69
37	Transportation equipment	1288	257517	149304	77459	947.93	348.33
38	Measuring instruments; photographic, medical, watches, & clocks	972	91373	27506	34218	538.96	521.58
39	Miscellaneous manufacturing	507	30973	12246	9367	218.79	89.07

Table 2C - Industry Summary Statistics (1992)

3. Results

3.1 Manufacturing Results

Table 3 shows the results of completing an OLS regression of equation (5) against the data by year with fixed effects for industry at the four digit SIC code level. The joint hypothesis test of the industry dummy variables shows that they are significant for all three years ($p<0.0001$). White's test for hetroskedasticity could not reject the null hypothesis of homoskedasticity of the error terms.

Year	Materials (β_1)	Capital (β_2)	Labor (β_3)	New Computer (β_4)	R^2	Number of Industries
1982	0.6162	0.0966	0.2824	0.0035^{**}	0.97	444
1987	0.6033	0.1168	0.2659	0.0081	0.96	458
1992	0.5788	0.1218	0.2789	0.0078	0.96	456

($p<0.0001$ unless otherwise indicated)

** $p<0.001$

Table 3 - OLS Estimates with Industry Fixed Effects

As expected, the regression reveals a small but positive elasticity associated with spending on new computer equipment. A one-tailed F-test reveals that the coefficient on computer spending for 1982 is less than both the 1987 and 1992 values ($p<0.0001$). No significant difference is found for the estimates for 1987 and 1992. Given that as a percentage of total durable equipment purchases, computer equipment spending was rising during that time, the benefit found from computer spending in 1982 is likely to reflect the benefit associated with earlier (and lower) computer spending. The data analyzed here roughly matches the pattern in spending identified elsewhere (Brynjolfsson, 1993). As a percentage of total capital for a given year, spending on new computers is approximately 0.42% in

1982 and ranges from 0.55% to 0.50% in 1987 and 1992 respectively. However, although the lower elasticity in 1982 suggests support for the argument of lagged benefits in computer spending, the stability of the estimated elasticities for 1987 and 1992, supports the argument that lagged effects shouldn't have much of an impact after computer spending stabilizes, which it did around 1983. Therefore, hypothesis 2, finding a positive result using data from the mid 1980's on will not require allowance for lagged impacts from computer spending, is supported by the data. Further, the findings provide a limited amount of support for the argument that lagged effects may play a role before the benefits associated with spending on computers are realized.

The first hypothesis, analysis of a large enough sample will show a positive output elasticity and positive average product for spending on computers, is also supported by these findings. Table 4 shows the yearly average products, calculated using equation (3), associated with each year's output levels, spending on new computer equipment, and estimated output elasticity for new computer equipment.

Year	**Estimated Average Product**
1982	210%
1987	332%
1992	362%

Table 4 - Estimated Average Products for New Computer Spending

These estimates are significantly larger than those found by Brynjolfsson and Hitt (1996) whose estimated marginal product by year ranged from approximately 35% to 150% during the 1987 to 1991 time period. However, the average products shown above are based solely on purchases of new computer equipment while Brynjolfsson and Hitt had a measure of total computer stock. Further, their data supported the estimation of a separate elasticity for “IS labor” which is not supported by the data available for the current analysis. Since new computer spending is the only cost captured here while the productivity benefits are fully reflected, the estimated average products are likely to be overstated. To develop more realistic estimated average products for each year, assumptions about total computer stock and support costs need to be made. Figure 5 shows the resulting average products by year under a variety of assumptions. First, based on a three year depreciation schedule, an estimate of computer stock is created by adding 1/3 (year t-2) and 2/3 (year t-1) of the spending on new computer equipment in year t to the spending in year t. Then, IS labor and support costs added to the already increased computer stock estimate by 2-5 times current year expenditures. This is based on estimates for support costs which range from around twice (Brynjolfsson and Hitt, 1996) to three to four times (Landauer, 1996). As the figure shows, once an allowance has been made to estimate the actual yearly costs for a plant’s computer systems, the average products are similar to the marginal products found by Byrnjolfsson and Hitt.

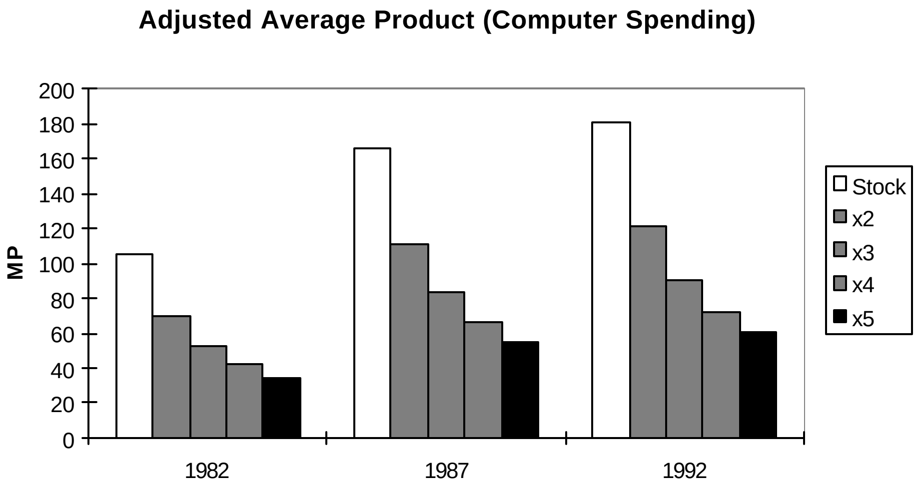

Figure 5 - Adjusted Average Products

The data support the first hypothesis. By analyzing a larger sample of data, the relatively smaller elasticity associated with spending on new computer equipment can be identified. Even with a small effect, the Cobb-Douglas assumptions and low percentage of spending on new computers relative to total output result in significant average products associated with spending on computers. Even under the most expensive assumptions for total computer spending (3 year depreciation schedule with support costs at five times the current year's expenditures), the average product for computer spending outperformed the average product associated with other capital stock, which ranged from 26% to 30% during the three years analyzed.

We next look at the relationship between spending on new computer equipment and output by year at the two digit SIC code industry level in an attempt to develop greater understanding of the potential for confounding results created by the sample mix in previous studies.

3.2 Industry Specific Results

As has already been shown, the relationship between spending on new computer equipment and plant output varies across industry when controlled for at the four digit SIC code industry level. We next turn our attention to individual analysis by industry (at the two digit SIC code level) by year. Table 6 presents the results of the OLS estimated output elasticities for new computer equipment, β_4 from equation (5), for each of the three years available. (Those plants from industry 21, tobacco products, have been excluded from this analysis due to Census Bureau disclosure requirements. However, they are included in the aggregate analysis presented in §3.1.)

SIC	Descripton	1982		1987		1992	
20	Food	0.0025		0.0064	*	0.0238	****
22	Textiles	0.0154	***	0.0152	****	0.0198	****
23	Apparel	0.1963		0.0210	***	0.0056	
24	Lumber and wood	0.0070		0.0116	*	0.0084	
25	Furniture	0.0177	***	0.0153	***	0.0191	****
26	Paper	-0.0002		0.0055		0.0008	
27	Printing and publishing	0.0128	***	0.0220	****	0.0234	****
28	Chemicals	0.0147	***	0.0203	****	0.0160	****
29	Petroleum refining	-0.0006		0.0115		0.0075	
30	Rubber and plastics	0.0033		0.0071		0.0148	****
31	Leather	-0.0051		0.0350	****	0.0057	
32	Stone, clay, glass and concrete	0.0089		-0.0003		0.0040	
33	Primary metals	0.0077	*	0.0064		0.0028	
34	Fabricated metals	0.0012		0.0067	**	0.0059	*
35	Industrial and commercial machinery (including computers)	0.0107	****	0.0098	****	0.0194	****
36	Electronics (excluding computers)	0.0108	***	0.0166	****	0.0207	****
37	Transportation equipment	0.0062		0.0115	****	0.0092	*
38	Measuring instruments; photographic, medical, watches, & clocks	0.0131	****	0.0184	***	0.0077	
39	Miscellaneous manufacturing	0.0070		0.0172	**	0.0096	

*	$p < .05$
**	$p < .01$
***	$p < .005$
****	$p < .001$

Table 6 - Estimated New Computer Equipment Output Elasticities by Industry by Year

As can be seen from the table, a significant ($p<.05$) relationship was found in 32 of the 57 possible instances analyzed. This indicates that taken as a whole the findings are well above what would be expected by chance alone. The impact of new computer spending on output ranged from nothing (for the 25 nonsignificant estimates) to 0.0350 for the leather goods industry (31) in 1987. Six industries (22, 25, 27, 28, 35, and 36) had a significant, positive output elasticity for new computer spending in all three years analyzed. Four industries (20, 34, 37, and 38) had a significant, positive output elasticity for two of the three years. Of those, all but one (38) showed significance in the last two years (1987 and 1992) but not the first (1982). Six industries (23, 24, 30, 31, 33, and 39) showed a significant positive relationship in only one of the three years. Four of those six industries had a positive relationship in 1987 when the average spending on new computer equipment was the highest in the sample at 0.55% of capital stock. The remaining three industries (26, 29, and 32) did not show a significant output elasticity for new computer spending in any of the three years analyzed.

Although only a cursory investigation has been completed at this time, it appears as if positive results are associated with manufacturing industries more associated with consumer goods or finished products (furniture, publishing, industrial and commercial machinery (including computers) and electronics) while the probability of no positive relationship is greater for those manufacturing industries associated with raw materials (lumber, paper, petroleum, rubber and plastics, stone/clay/glass/concrete, leather, and primary metals). However, the textile and chemical industries show a benefit from new computer spending while apparel does not. Obviously, more work into understanding the determinants for an industry of finding a benefit from spending on new computer equipment needs to be completed. Further, division by industry at only the two digit SIC code level is still rather broad. The data would support completing a similar analysis down to the four digit SIC code level, pending Census Bureau disclosure requirements.

The primary goal of this analysis was to provide support for the third hypothesis, the output elasticity for spending on computers will differ between industries when measured at the 2 digit SIC code level, beyond the general support provided by the joint hypothesis test of the 4 digit SIC dummy variables completed in §3.1. Table 6 provides the needed justification to support this hypothesis. As the intent of this analysis to develop an understanding of why the IS productivity paradox is supported by some prior research and not supported by others, showing that the estimated impact of computer spending on output does vary by industry is sufficient.

The next section discusses some of the limitations inherent in the data analyzed and the results achieved. The final sections then discuss the implications of these results.

3.3 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. 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 recent positive results of Brynjolfsson and Hitt (1993, 1996a, 1996b) and their results where obtained for analyzing only manufacturing data from a different source, this does not present a severe limitation on the results. The results of Loveman, Strassmann, and Barua, et al. 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 elasticity of new computer equipment with regard to plant output. A more vigorous approach would be to calculate plant productivity and analyze the relationship over time between spending on computers and productivity. The typical approach would be to calculate total factor productivity (TFP) as was done by Baily et al. (1992). Other definitions of productivity are possible and available from the data source analyzed. A possible area of future research would be to analyze the impact on the results when different measures for productivity are used. As only manufacturing locations are represented in the data, the traditional measure of productivity, output per unit of input, could be useful. 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 only reflects 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. As shown in §3.1, even with allowance for significant increases to allow for total computer stock value and support costs, the average product for computers for this sample is still larger than the average product associated with other capital.

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.

4. Discussion

4.1 Managerial Implications

Additional support for the finding that, at the margin, spending on new computer equipment is correlated with higher returns than other types of capital spending should be tempered with the same caveat as when Brynjolfsson and Hitt found a positive result in 1996. "The firms with high returns and high levels of computer investment may differ systematically from the low performers in ways that cannot be rectified simply by increasing spending." (Byrnjolfsson and Hitt, 1996, p. 556) The findings of this study strengthen that argument. By showing differing inter-industry impacts, it is clear that the impact of information technology on productivity is different for plants across the manufacturing sector. Simply increasing spending on computers is unlikely to lead to improved performance on its own.

By showing that finding a positive, significant output elasticity for computer spending across a wide-range of firms and industries requires a fairly large sample, this study helps to validate the approach taken by Weill (1992) who utilized a small sample but found significant results by focusing on a specific industry, value manufacturing. The implication for managers is that care should be taken when attempting to compare the IT spending and performance of one's own firm against a representative group. Although not readily available, the best comparison group should be as tightly focused as possible. Attempting comparisons to wide-ranging composites is likely to be meaningless at best. The finding of variation across industries adds further support to this argument.

This unit of analysis for this study was plants and not entire firms. This strengthens the arguments put forward by Barua et al (1995) who were able to identify a positive finding by matching the spending as closely as possible (for the data available) to where benefits would be expected. The implication is that justification of spending on computer technology is best done by focusing on where benefits are expected to accrue and not trying to look for justification across an entire firm.

4.2 Future Research

Given the finding of differing effects of computer spending on plant output, the obvious next step is to attempt and identify the determinants that influence the differences. Although industries have only been separated roughly at the two digit SIC code level, the data will support a much finer grain of analysis. Additionally, the data can be aggregated to the firm level either within an industry or across industries for all of the largest firms in the U.S. which would support an analysis of determinants both by firm and industry.

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 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, it is likely that the impact of lagged effects will also be moderated by industry or firm characteristics.

A substantial number of the plants in the sample did not report any spending on new computer equipment in a given year while still providing at least one of the other detailed capital spending figures. An analysis into the likelihood of a plant to report spending on new computer equipment can be completed in an attempt to develop an understanding of the determinants of the decision by a firm to invest in additional computers. Strassmann has suggested that there may be a bimodal distribution in the relationship between spending on information technology and the results achieved in that some firms can spend a lot and do well while others can spend the same amount and do poorly. In looking at the dispersion of productivity across several industries Baily, et al (1992) found that highly productive plants tended to continue to outpace their peers while those with lower productivity were more likely to exit the industry. Taken together, 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.

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. This will allow for a detailed analysis in the parts of the “service sector” of the economy and comparison with the results found for manufacturing.

5. Conclusion

The significance of this paper is that provides an explanation for *why* the IS productivity paradox was apparently found and then resolved. By developing an understanding of the process and assumptions that have been used in previous work, it is shown that only a relatively small effect needs to be identified for there to be a significant relationship between spending on information technology, firm output, and the average product associated with the computer investment. With only a relatively small effect to be found, a large sample size is needed. Most prior work in this area has used significantly smaller sample sizes making it possible for the anticipated effect to get lost in the noise.

Further sample difficulties are introduced when the sample contains observations from a variety of industries. The differences in effects among industries result in generating unnecessary noise that further clouds the analysis process. The results obtained provide an explanation for Weill's positive finding at a time when others were not finding a positive relationship between firm productivity and spending on computers. By focusing on a single industry (as he hypothesized it would) allowed any effect to be better isolated from the accompanying noise.

The results also show that a positive effect can be found without relying on either recency effects or lags. Although limited support is provided by these results that indicate the search for lagged effects may be useful, it was not necessary to postulate lagged effects leading to a recency requirement to be able to find a significant positive result. Finding a significant positive relationship between plant productivity and spending on computers requires either a large enough sample if overall effects are to be found or a focus on a specific industry. The three instances of positive results in this area relied on one of these two situations. Weill maintained a targeted industry focus. Byrnjolfsson and Hitt were able to obtain a much larger data set than had been used previous. Barua, et al, who found a positive result in a data set where none had been found previously, essentially found a way to increase the focus and number of observations in the sample. Negative results in this area have relied on small and or poorly focused samples.

This paper also replicates the results found by Brynjolfsson and Hitt, it adds support to their argument that the “productivity paradox” was an artifact of the data used in previous analyses. The results show not that the “IT productivity paradox” has “disappeared" but that it "never was."

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