DISAGGREGATING THE RETURN ON INVESTMENT TO IT CAPITAL

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Abstract

Several firm-level empirical studies have found positive and excess returns to investments in information technology (IT) capital. Using a production function framework that typically includes such inputs as IT capital, non-IT capital, and labor, these studies estimate the return on investment in IT. Taken together, this body of research provides evidence of a payoff to investments in IT contrary to the often-cited productivity paradox. However, while these studies have provided an empirical foundation supporting the assertion that IT spending at the firm level pays off, the distribution of returns across different forms of IT capital remains unclear.

This study represents one of the first attempts at disaggregating the heterogeneous IT capital category into its salient constituents and examining their respective contributions to the value of the firm. Specifically, we focus on three hardware categories: mainframe computers, minicomputers, and microcomputers. Rather than simply reflecting different technological characteristics, these categories of computers also reflect the different kinds of applications that typically run on these systems. Moreover, we explicitly take into account the degree to which a company's employees are networked since connectivity is likely to affect the payoff. We use new data on the capital stock of these categories of systems as well as the level of computer networking at the firm level for a nearly balanced panel of large firms spanning the eight-year period 1987-1994, representing more than 3600 observations.

We find strong evidence of positive returns to investments in mainframe computers and PCs, but mixed results in the case of minicomputers. The output elasticity of PC capital exceeds that of mainframes, and the degree to which a company's employees are networked positively impacts the overall efficiency of the production process. The results of this study are important for both research and practice. From a research perspective, the disaggregation of IT capital into constituent categories represents a logical next step in the small but growing literature that examines the returns to information systems spending. Our results, and in particular, the estimates of the output elasticities and marginal products, have significant implications for determining the optimal level of investment in different technologies.

Introduction:

The productivity paradox of information technology has attracted significant attention in the business and academic press. Recent research using economic theories of production (Brynjolfsson and Hitt 1996, 1997; Dewan and Min 1997) has succeeded in demonstrating the payoffs from IT investment to firm performance. The production function approach involves estimating a relationship between inputs – usually stocks or flows of capital and labor – to measures of firm output such as revenue and value added. Given the focus of these analyses on estimating the contribution of IT, these analyses naturally include both IT and non-IT capital as factors of production. All forms of IT are aggregated into a single variable, the stock of IT capital, usually defined as the market value of the hardware owned by a firm including mainframes, minicomputers, and microcomputers and related peripherals. While these results are of obvious importance in resolving the debate on the payoffs from IT and have broad implications for the importance of investing in IT, more research is necessary to derive specific implications to guide a firm's investments in IT.

Research Objectives:

There are many potential extensions to this literature. For example, it does not address the issue of the relative contributions of different forms of IT capital.[1] Given the mix of technology assets in any firm's technology portfolio, it is unknown whether the distribution of payoffs from each class of assets is roughly

[1] The working paper by Lehr and Lichtenberg (1997) does include disaggregated categories of IT, however, inferences regarding returns on investment are limited by the authors' use of quantities, and not values, for these categories.

similar or whether there is considerable heterogeneity in the payoffs. This is of considerable importance to companies that are continually faced with choices related to migrating existing systems to newer platforms. For example, as PCs proliferate, questions regarding the wisdom of a relentless increase in investments in PCs continue to be raised by senior managers. Our specific interest is to try and understand the relative contributions of different classes of technology to firm output.

This paper examines the relative contribution of different categories of information technology – mainframe systems, minicomputers, and desktop systems – to firm performance. More than simply reflecting a set of hardware platforms, a typical organization runs substantially different classes of applications on these systems. Accordingly, findings that support differential payoffs from each of these categories of systems would also have implications for the classes of applications that create value for companies.

Methodology:

Consistent with previous studies (Brynjolfsson and Hitt 1996; Dewan and Min 1997), we model the production process using a standard production function framework. The production process of the firms in our sample is denoted by a production function, f, that relates firm value-added, V, to labor, L, non-IT capital stock, K, and IT capital, C. We further model C as a function of three different classes of hardware, C_1, C_2 and C_3, each of which represents a different category of hardware. Dewan and Min (1997) have shown that the production process is consistent with Cobb-Douglas type production; therefore we model the production process using the Cobb-Douglas type production function.

The production process can be written as:

(1) $V = f(L,K,C(C1,C2,C3))$,

or when the production function is Cobb-Douglas,

(2) $V = AL^{\alpha}K^{\beta}C_1^{\gamma_1}\, C_2^{\gamma_2}\, C_3^{\gamma_3}$.

Taking logarithms on both sides yields:

(3) $\text{Log } V = \text{Log } A + \alpha \text{ Log } L + \beta \text{ Log } K + \gamma_1 \text{ Log } C_1 + \gamma_2 \text{ Log } C_2 + \gamma_3 \text{ Log } C_3$.

The coefficient of each of the terms in the above equation is the output elasticity of the corresponding input, and measures its relative contribution to output.

Data Sources and Variable Construction:

In previous studies that use the production function approach in which the output elasticity of "computers" is estimated, the source, definition and construction of the computer capital stock variable has varied. In studies that use the International Data Group (IDG) data set, the computation of IT stock begins with the market value of central processors (MVCP), where central processors are defined as mainframes, minicomputers, and supercomputers (Brynjolfsson and Hitt 1996). The data is collected via surveys and is self-reported, leaving it up to the responding IS manager to quantify the numbers and the market value of each category of computer. The computer capital stock has been computed alternatively as the sum of MVCP and the value of PCs (Brynjolfsson and Hitt 1996), or as the sum of MVCP, the value of PCs, and the capitalized value of IS staff (Brynjolfsson and Hitt 1995, Dewan and Min 1997).

The Computer Intelligence Technology Database, constructed by ZD Market Intelligence, is an alternative data source that has rarely been used by IS researchers (Brynjolfsson and Hitt 1997). In contrast to the IDG data set, the computer variable supplied by ZD represents the purchase value of all systems: computer hardware systems, peripherals, networking equipment, etc. IS managers supply quantities of the various technology categories; a complex, proprietary algorithm that matches a machine configuration to rental prices is employed to convert quantities to values. ZD provided us with data on 1,694 companies for the years 1987-1996. We are unable to use the data for 1995 and 1996 because they are not comparable to previous years. Our analysis utilizes an unbalanced panel averaging nearly 600 observations per year.

As the authors of previous studies readily admit, the data from both IDG and ZD are not without error (Brynjolfsson and Hitt 1996, Dewan and Min 1997). However, due to superior data collection methodology we believe the ZD data set represents the most accurate data currently available on the stock of computing capital in large U.S. firms.

The first technology stock variable is general-purpose computers, which corresponds to mainframes and includes such models as IBM 3000, 360, 370, 4000, and 9000; DEC VAX9000; and UNISYS 1100 and 2200. Roughly 12 types of mainframes are included in our data set. The second technology variable is minicomputers, which, over the 1987 to 1994 time period, includes both minis and small business systems incorporating such models as IBM System 36, System 38, AS/400; HP 3000; Data General AV; and DEC PDP. The third technology variable is the quantity of personal computers, which includes both desktop computers as well as portable computers. Finally, we utilize the number of network nodes normalized by the number of employees as a proxy for distributed computing.

We use the Compustat database for financial and managerial accounting data such as revenue, labor cost, and total capital stock. Variable construction and deflation methodology follow standard procedures and are omitted for brevity (Brynjolfsson and Hitt 1997; Dewan and Min 1997); details are available from the authors upon request. Summary statistics are presented in Table 1.

Table 1: Summary Statistics

	1987	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*
Value Added	2039.81	2031.59	2066.87	1938.93	1899.07	1770.66	1840.38	2025.49
IT Capital	14.13	19.44	21.69	25.27	36.42	34.25	53.98	81.84
Non-IT Capital	2695.71	2718.25	2695.67	2817.08	2945.31	2837.10	2968.51	3068.54
Labor Expense	1111.35	1121.05	1104.07	1135.44	1142.69	1124.12	1168.99	1189.80
Mainframes	11.0	11.0	10.4	9.0	8.1	8.2	7.4	6.9
Minicomputers	49	66	87	124	160	175	212	244
Microcomputers	1230	2083	2782	3401	3865	4487	5107	5924
N	593	607	611	602	586	593	577	559

All values in millions of 1990 dollars except hardware variables, which are quantities.

The companies in our sample are quite large. Average value added for the eight-year period ranges from $1.8B to almost $2.1B. The average stock of IT capital in these firms ranges from $14M in 1987 to around $81M in 1994, while the average stock of non-IT capital ranges from $2.7B to $3.1B. The average number of mainframes in a company has dropped from around 11 in 1987 to around 7 in 1994. The number of minicomputers has increased by a factor of 5, from 49 to 244 in the period. Similarly, the average number of microcomputers has increased by almost a factor of 5, from 1,230 to nearly 6,000. Recognizing further that the computing capacity within each category of machine has increased significantly during this period, it is clear that the stock of IT capital in a company is increasingly dominated by microcomputers and minicomputers.

Analysis:

First, as a baseline we estimate a regression equation using aggregate IT as the only IT input. Next, we estimate equation (3), which requires the market value of the stock of computers for each of the three categories of hardware. In order to compute these valuations, we use an estimation methodology previously utilized by Lehr and Lichtenberg (1997). The methodology is as follows. For each year, we estimate a linear model specified as

(4) $IT\_1990 = \rho + P_{MF}\,Mainframes + P_{MI}\,Minicomputers + P_{PC}\,PCs + P_{TERMS}\,Terminals,$

where IT_1990 is the market value of the IT stock of the company in 1990 dollars and the right hand side variables are the quantities of each class of machine held by a company in our sample. The results of the estimations provide us with estimates of the price of each category of computer for a given year. In all cases, the coefficients are significant at the 0.01 level. We then use these estimates to compute the market value of each category of computer in a company's inventory by multiplying quantity by the associated imputed price.

Regression results are summarized in Table 2. In all cases we use ordinary least squares to estimate a cross-sectional time series model with time dummies to account for time-dependent intercepts. In the base regression (I), we find that all regressors are significant at the 99% level, consistent with previous research finding positive returns to investment in IT capital. Disaggregating IT capital (II), we find that the output elasticities of mainframes and PCs are positive and significant at the 99% level, whereas that of minicomputers is not. The higher output elasticity of personal computers suggests that its growing share in IT capital stock relative to mainframes is a justifiable investment strategy for companies.

Table 2: OLS Regression Analysis

	I	*II*	*III*	*IV*
IT Capital	.0761* (.00563)		.0847* (.00864)	
Non-IT Capital	.2181* (.00481)	.2322* (.00490)	.2095* (.00697)	.2290* (.00724)
Labor	.6511* (.00784)	.6324* (.00886)	.6408* (.01242)	.6137* (.01454)
Mainframes		.0367* (.00746)		.0290* (.0107)
Minicomputers		.0054 (.00533)		.0213* (.00771)
Microcomputers		.0638* (.00709)		.0643* (.0117)
Distributed Computing			.1062* (.02190)	.0682* (.0234)
N	5365	4728	2699	2314
R^2	87.4%	88.1%	86.0%	86.9%

* p<.01; Year dummies included in all regressions.

We also introduce a dummy variable, Distributed Computing, (III and IV) to account for the degree to which a company is networked (defined as unity if a company is in the top quartile of companies in a given year ranked by the number of network nodes per employee, and zero otherwise). Interestingly, there is a significant difference in the overall production efficiency between the two groups of firms. Companies which have a higher proportion of their employees connected to networks perform better than those that are less connected. As a robustness check, we re-defined the dummy variable to be the top 10% and the top 50%; the results are consistent with our expectations. The magnitude of the impact grows as the threshold for inclusion is raised, and decreases as the threshold is decreased. Finally, computing gross marginal product as in Brynjolfsson and Hitt (1996) reveals higher payoffs in the distributed computing categories, with the value for minicomputers doubling that of mainframes and that of PCs more than tripling that of mainframes. Further research is necessary to develop more precise estimates of the payoffs.

In summary, our preliminary results show that the move to decentralized and distributed computing is paying off. Extensions to this research include more advanced econometric specifications, utilization of more recent data, and the inclusion of industry sector dummy variables.

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