INTANGIBLE ASSETS: HOW THE INTERACTION OF COMPUTERS AND ORGANIZATIONAL STRUCTURE AFFECTS STOCK MARKET VALUATIONS

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Abstract

An important theme in information systems research is that organizational factors are critical to the success of computer investments. This paper provides broad statistical evidence for this proposition. For our analysis, we have compiled a unique data set of over 1,000 firms which includes the total stock market value of firms, their installed base of computer capital, detailed measures of the organizational structures, and a battery of other factors.

Using a theoretically-grounded model, we find that a one dollar increase in a firm's installed computer capital is associated with an increase in the firm's stock market valuation of over five dollars, while controlling for all other tangible assets. For this to be equilibrium, the financial markets must believe that each dollar of computer capital is accompanied by an average of over four dollars of intangible assets. We then identify a candidate for these intangible assets: certain organizational characteristics, involving the structure of decision-making and the nature of job design, are highly correlated with computer investments. While these organizational characteristics do not appear on a firm's balance sheet, we find that they lead to higher stock market valuations.

Strikingly, firms that combine higher computer investments with these organizational characteristics have *disproportionate* increases in their market valuations. Our findings are quite robust to a variety of alternative models and the results are generally strengthened when we control for potential reverse causality. We conclude that the contribution of computers to a firm's market value is increased when they are combined with certain intangible assets, specifically including the cluster of organizational changes that we have identified.

1. INTRODUCTION

A major theme of recent work on information systems research is that investment in computers and other types of information technology (IT) needs to be coupled with boundary-spanning organizational changes in order to be effective. Similarly, scholars of organizational studies predict that new technologies "will require the development of new organizational forms and systems, such as teams and new incentive systems, which decentralize decision making…and harness the knowledge and intelligence of all members of the organization" (Florida and Kenney 1993). While the traditional, functional division of labor that dominated the industrial economy was efficient in economizing on information processing and communication costs, it can be dysfunctional in an age of cheap information ushered in by computers. In particular, when the costs of information processing and communications change radically, the optimal allocation of decision rights, human capital and incentive systems are likely to change as well (Anand and Mendelson 1997; Wyner and Malone 1997).

Numerous case examples highlight the importance of coupling computer investments with complementary changes in organization. Studies of the implementation of Lotus Notes (Orlikowski 1992) have shown that without organizational structures and incentives to promote information sharing, group collaboration and knowledge sharing features of groupware applications may go largely unused. Similar challenges have been documented in manufacturing environments where new information systems increased the need for cognitive skills in the work force (Zuboff and Bronsema 1984). However, the organizations that are effectively able to make concurrent computer investments and organizational "investments" often reap substantial benefits, although reports of high failure rates of business process redesign projects attest to the difficulty of this change (Sauer and Yetton 1997).

These cases suggest the both the high value and high costs of these types of additional investments. While these costs of organizational change create a barrier to the successful use of computers, the other side of the coin is that once firms have incurred such costs, they have something—a new business process, a new organizational form, a new set of supplier relations—that other firms cannot duplicate easily. In economic terms, they have created new assets.

But is all this painful restructuring worth it? Are their any measurable economic benefits associated with these new "intangible assets"?

We formally test the hypothesis that these intangible assets complement information technology capital just as aluminum wings complement jet engines. Complementary assets are more valuable when used together than when used separately. To realize the potential benefits of computerization, additional "assets," like worker knowledge, new organizational structures, or redesigned incentive systems, may be needed.

If these intangible assets really exist, they should be detectable in at least two ways. First, resulting effect on the firm's market valuation should be measurable, even when the underlying assets cannot be seen or touched. The financial markets, which seek to assess the discounted value of future revenues, provide a valuable telltale for whether these investments are generating value for the owners of the firm. In particular, the market value of a firm which has leveraged computer assets with organizational investments should be *greater* than that of a similar firm which has not incurred these investments. A computer that is combined with complementary intangible assets should be significantly more valuable to a business than a computer in a box on the loading dock.

Second, some of the specific changes that firms make may be directly observable. In particular, numerous authors have suggested that IT is likely to be associated with organizational changes such as greater demand for worker skills and increased levels of employee discretion and decision-making authority (Applegate, Cash and Mills 1988; George and King 1991; Sauer and Yetton 1997). If these practices represent the types of organizational assets we described earlier, then we would expect that the value of IT would be greater in organizations that also adopt these work practices.

Therefore, we can assert the following hypotheses:

> **Hypothesis 1:** *If computer capital is complementary with unmeasured, intangible assets, then firms with higher levels of computerization should have higher stock market valuations, even after controlling for all measured assets on their balance sheets.*
>
> **Hypothesis 2:** *If computer capital is complementary with certain organizational characteristics (e.g., broader job responsibilities for line workers, more use of self-managing teams), then firms with higher levels of computerization should have higher levels of these variables, even after controlling for other characteristics such as industry, year, size, and other assets.*
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> **Hypothesis 3:** *If these organizational characteristics create value, as other assets do, then firms with higher levels of these characteristics should have higher stock market valuations, even after controlling for all measured assets on their balance sheets.*
>
> **Hypothesis 4:** *If computer capital is complementary with certain organizational characteristics, then firms with* both *higher levels of computerization and higher levels of these characteristics should have* disproportionately *higher stock market valuations, even after controlling for other relevant variables.*

Using data on 1,031 large firms over eight years (1987-1994), we find strong evidence in support of all four hypotheses.

1. Each dollar invested in computers increases firm market valuation of from $5 to $20 (depending on the assumptions of the estimation models), compared with an increase of about $1 per dollar of investment in other assets.

2. Firms that are high IT users are also more likely to adopt work practices that involve a cluster of organizational characteristics, including greater use of teams and broader decision authority.

3. This cluster of organizational characteristics increases a firm's market valuation, and furthermore, these organizational characteristics explain some, but not all, of the unusually large valuation of computers.

4. Firms that use these organizational characteristics have a disproportionately higher market valuation of their computers assets.

Our results are robust to a variety of alternative estimating techniques. Most importantly, they cannot be explained by "reverse causality" running from higher stock market values to greater IT investments. They are consistent with earlier case-based research as well as recent econometric work using production functions. Taken together, these results lend strong quantitative support to the idea that IT is most valuable when coupled with complementary changes in organizational design.

In section 2, we present a sketch of the theoretical model and the data, in section 3 we present our statistical results, and we conclude with a summary and discussion in section 4.

2. ECONOMETRIC MODEL AND DATA

2.1 Derivation of Model for Stock Market Valuations

In this subsection, we sketch the derivation of the stock market valuation model. Additional detail is provided in Appendix A. The basic structure of the model follows the literature on the valuation of capital goods that relates the market value of a firm to the capital goods a firm owns (Brynjolfsson and Yang 1997; Hayashi 1982; Hayashi and Inoue 1991; Wildasin 1984). This literature is often referred to as the "Tobin's q" literature after the pioneering work by James Tobin (1969) in understanding the

relationship between firm value and capital investment.[1] This framework has been empirically adapted and applied to the valuation of R&D by Griliches (1981) and by Hall (1993a, 1993b) and the stock market impact of diversification (Montgomery and Wernerfelt 1988).

We assume that firms face the following dynamic optimization problem in which managers make capital investments (I) in several different asset types and expenditures in variable costs (N) with the goal of maximizing the market value of the firm V. In turn, V is equal to the present value of all future profits. The accumulation of capital investment, less depreciation (δ) produces a vector of capital stock (K, which includes different components of capital K_j). We use the subscript *j* as an index for each of the different capital goods. The capital stock along with variable inputs is used to produce output (F). Unlike traditional production function analyses, we assume that there is some additional cost of making a capital investment which represents an "organizational adjustment cost" ($\Gamma(I,K,t)$). These organizational costs represent the amount of output lost while integrating additional capital into the firm. This yields the following program:

$$(1)\quad \underset{I,N}{Maximize}\ V(0) = \int_0^{\infty} \pi(t)u(t)dt$$

$$(2)\quad \text{where}\ \ \pi(t) = F(K,N,t) - \Gamma(I,K,t)) - N - 1$$

$$(3)\quad \text{given,}\ \frac{dK_j}{dt} = I - \sum_{j=1}^{J} \delta_j K_j,\ \text{for all}\ j = 1,\ldots,J.$$

One can solve for the market value of the firm that results from this optimization problem (see Appendix A). If there are no organizational adjustment costs needed to make capital assets fully productive [Γ(I,K,t)=0], then buying a firm is no different from buying a collection of separate assets. Thus, the market value of a firm is simply equal to the current stock of capital assets:

$$(4)\quad V = \sum_{j=1}^{J} K_j$$

However, if there are organizational adjustment costs required to make full use of capital, then the value of an ongoing firm may exceed the value of its separate capital assets. The higher value represents the additional "intangible assets" created when each of the capital assets is integrated into the firm. In this case, the value of the firm is the sum of capital assets, but weighted by the size of the organizational adjustment costs, λ:

$$(5)\quad V = \sum_{j=1}^{J} \lambda_j K_j.$$

For example, if there are two types of capital, computers (c) and other capital (k), then $(\lambda_c - 1)$ would represent the difference in value between computer capital which is fully integrated into the firm vs. computers which are available on the open market, and $(\lambda_k - 1)$ would be the corresponding value for other types of capital. We can then calculate the size of the complementary organizational investments by comparing how much the market values a capital asset that is part of a running firm as compared to the same asset sold separately.

[1]Tobin's q is a ratio of the market value of a firm (including debt and equity) to the book value of its assets.

2.2 Econometric Issues of Market Valuation

To translate the result of our dynamic optimization model into a specification suitable for empirical testing, we need to specify the different types of capital that we will consider and a set of additional control variables (X) that are likely to influence this relationship. We also sometimes include a firm effect term, α, to capture residual firm differences that are not explained by other control variables. Including an error term, ϵ, we have our estimation equation:

$$(6) \quad V_{it} = \alpha_1 + \sum_{j=1}^{J} \lambda_j K_{j,it} + X_{it}\gamma + \epsilon_{it}$$

Here, i, t, and j are indices of firms, time, and different capital goods, respectively. The coefficients to be estimated are (vectors) α, λ, and γ.

Extending the prior literature on estimates of Tobin's q, we divide assets into three categories: computers, physical assets (property, plant, and equipment), and other balance sheet assets (receivables, inventories, goodwill, cash, and other assets). For the other control variables (X) we will use return on assets, the ratio of R&D capital to assets, and the ratio of advertising expense to assets.[2] This yields our base estimating equation, which we will extend to include organizational investments:

$$(7) \quad V_{it} = \alpha_i + \lambda_c K_{c,it} + \lambda_p K_{p,it} + \lambda_o K_{o,it} + controls + \epsilon_{it}$$

Here K_c, K_p, and K_o represent computer capital, physical capital, and other balance sheet assets, respectively.[3]

There are two issues about this specification that warrant concern. The first problem is that larger firms are likely to have larger residuals that may unduly influence the regression estimates. This can be addressed by using a generalized (or weighted) least squares technique (GLS) to dampen the influence of large residuals. Alternatively, we can use robust regression techniques (least absolute deviation—LAD), which is less sensitive to outliers of all sorts.

A second concern is the potential for reverse causality. While our model seeks to measure whether changes in the value of a firm's capital assets affect its stock market value, it may also be the case that unexpected increases in stock market valuations lead firms to make increased investment in capital assets. To reduce this problem, we apply the standard technique of instrumental variables regression (two stage least squares or 2SLS).[4]

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[2]Return on assets captures short run profit effects that may influence stock market valuation. Advertising and R&D capture other types of nonstandard assets that have been considered in prior work. Finally, we add additional control variables for industry to reduce sample heterogeneity and time to control for general economic trends in stock market valuation. Control variables include return on assets, R&D ratio, advertisement ratio, industry dummies (usally SIC 2-digits), and year dummies.

[3]Our methodology is an example of hedonic regression, which estimates the market's valuation using cross-sectional and time series variations in the market value and the computer capital of the firm. An interesting alternative for measuring the impact of IT on the market value might be an event study methodology. For example Dos Santos, Peffers, and Mauer (1993) and Im, Dow, and Grover (1998) found an interesting positive relationship between IT investment announcements and market value of the firm.

[4]In addition, to control for heterogeneity among firms and to gauge the robustness of our results, we will also perform the estimates using fixed effects and "between" regression, which enables us to separate out effects due to variation over time for the same firm and effects due to variation across firms. These techniques will be discussed further in the results section.

2.3 Data Sources and Construction

The data set used for this analysis is a panel of computer capital and stock market valuation data for 1,000 firms over the 1987 to 1994 time period, matched to a cross sectional survey of organizational practices conducted in 1995 and 1996. A brief description of each data source follows with additional detail in Appendix B.

Computer Technology: The measures of computer use were derived from the Computer Intelligence Infocorp (CII) installation database that details IT spending by site for companies in the Fortune 1000 (approximately 25,000 sites were aggregated to form the measures for the 1,000 companies that represent the total population in any given year). This database is compiled from telephone surveys that detail the ownership of computer equipment and related products. Most sites are updated at least annually with more frequent sampling for larger sites. The year-end state of the database from 1987 to 1994 was used for the computer measures. From this data, we obtain the total capital stock of computers (central processors, personal computers, and peripherals). The IT data do not include all types of information processing or communication equipment and are likely to miss that portion of computer equipment that is purchased by individuals or departments without the knowledge of information systems personnel.[5]

Organizational Practices: The organizational practices data in this analysis uses a series of surveys of large firms. These surveys adapted questions from prior surveys on human resource practices and workplace transformation (Huselid 1995; Ichniowski, Shaw and Prunnushi 1997; Osterman 1994). The questions address the allocation of various types of decision-making authority, the use of self-managing teams, the breadth of job responsibilities, and other miscellaneous characteristics of the workplace (further detail appears in the results section). Organizational data were collected in three waves, covering most of the Fortune 1000. A total of 416 firms provided at least some data for the study. Because some firms on the organizational practices survey do not have complete matching data from CII and Compustat or have missing data on key questions on the survey, most analyses are conducted using a sample size of approximately 380 firms.

Compustat: Compustat data was used to construct stock market valuation metrics and provide additional firm information not covered by other sources. Measures were created for total market value (market value of equity plus debt), property, plant and equipment (PP&E), other assets, R&D assets, and advertising expense.

Overall, the full dataset includes 4,578 observations over eight years for market value and computer capital stock. When we match these data to the organizational practices surveys, we have complete organizational and market value data for 250 firms for a total of 1,705 observations.

3. RESULTS

In this section, we perform regression and correlation analyses to test the four basic hypotheses outlined in the introduction. First, we explore the basic relationship between IT and stock market value for our full sample of firms. We examine the relationship between computer capital and the adoption of specific organizational practices using correlation analyses and construct a single variable, ORG, which captures most of the relevant variation in organization across firms. Third, we investigate the effect of ORG on firm market value. Finally, we study how the combination of ORG and computers affect market value. We also perform a number of robustness checks of our analysis in each section.

[5]Another potential source of error in this regard is the outsourcing of computer facilities. Fortunately, to the extent that the computers reside on the client site, they will still be properly counted by CII's census.

3.1 Basic Findings for Computers and Market Value

The basic regression analyses (estimates of equation 7) for calculating the effect of computers on market value is shown in Table 1. In the first column, we present basic ordinary least squares results and find that each dollar of property, plant and equipment (PP&E) is valued at about a dollar, and a dollar of other assets is valued at about $0.70. Strikingly, each dollar of computer capital is associated with over $15 of market value. This implies that the stock market imputes an average of $14 of "intangible assets" to a firm for every $1 of computer capital. All capital stock variables are significantly different from zero, and the high R^2 (~85%) suggests that we can explain much of the variation in market value across firms with our model.[6]

To probe this result further, we investigate how much the correlation between market value and computer investment is driven by variation across firms, e.g., GM vs. Ford (a "between" regression), and variation for the same firm over time, e.g., GM in 1988 vs. GM in 1989 (a "within" or "firm effects" regression). We find that both sources of variation are important but that the effect due to variation between firms is larger. The "between" regression implies a market value of computer capital of nearly $20. For the within regression, this value is $5 (but still strongly significant). The within regression can be interpreted as removing all the effects that are unique to a particular firm but constant over time (equivalent to including every possible cross-sectional control variable) so this suggests that factors unique to specific firms are important in determining the market value of computers.[7] Figure 1 and Figure 2 present the relative size of computer coefficients and those of other assets.

Table 1. Effects of Various Assets on Firms' Market Valuation: Baseline Regressions of Different Models

Market Value	Pooled	Fixed Effect Within		Between
	OLS	w/Year	wo/Year	OLS
Computer Capital	15.192*** 1.158	5.076*** 0.891	6.419*** 0.839	19.218*** 2.859
Physical Capital	0.967*** 0.020	1.147*** 0.053	1.251*** 0.053	0.960*** 0.037
Other Assets	0.691*** 0.008	0.830*** 0.012	0.829*** 0.012	0.664*** 0.018
Controls	ROA*** R&D Adv Year*** Industry***	ROA*** R&D Adv Year*** Firm***	ROA*** R&D Adv Firm***	ROA*** R&D Adv Industry***
R Square Observations	0.8758 4578	0.729 4578	0.721 4578	0.887 4578

Key: * - p < .1; ** - p < .05; *** - p < .01

[6]Among control variables, return on assets (ROA) is always significant and large. R&D to asset ratios and advertisement to asset ratios are not always significant. Firm effects, industry effects, and year effects as separate groups are always strongly significant.

[7]In other words, the difference in intangible assets between highly computerized firms and less computerized firms is greater, on average, than the difference within any single firm over time.

Table 2. Effects of Various Assets on Firms' Market Valuation: Balanced Panel Only, Between and Wihtin Regression

	Between Regression			Fixed Effect Within Regression		
	OLS	GLS	LAD	GLS	LAD	2SLS
Computer Capital	22.285*** 4.193	18.540*** 1.454	14.824*** 3.545	5.584*** 0.921	4.308*** 1.154	9.945*** 2.239
Physical Capital	0.968*** 0.049	1.014*** 0.016	0.984*** 0.019	1.244*** 0.055	1.169*** 0.113	1.069*** 0.057
Other Assets	0.654*** 0.024	0.656*** 0.010	0.652*** 0.088	0.811*** 0.015	0.814*** 0.086	0.820*** 0.015
Controls	ROA*** R&D Adv* Industry***	ROA*** R&D*** Adv*** Industry***	ROA*** R&D*** Adv*** Industry***	ROA*** R&D Adv Year*** Firm***	ROA*** R&D Adv*** Year*** Firm***	ROA*** R&D Adv Year*** Firm***
R square Observations	0.892 3312	0.069 3312	0.674 3312	0.681 3312	0.836 3312	0.670 3212

Key: * - p < .1; ** - p < .05; *** - p < .01

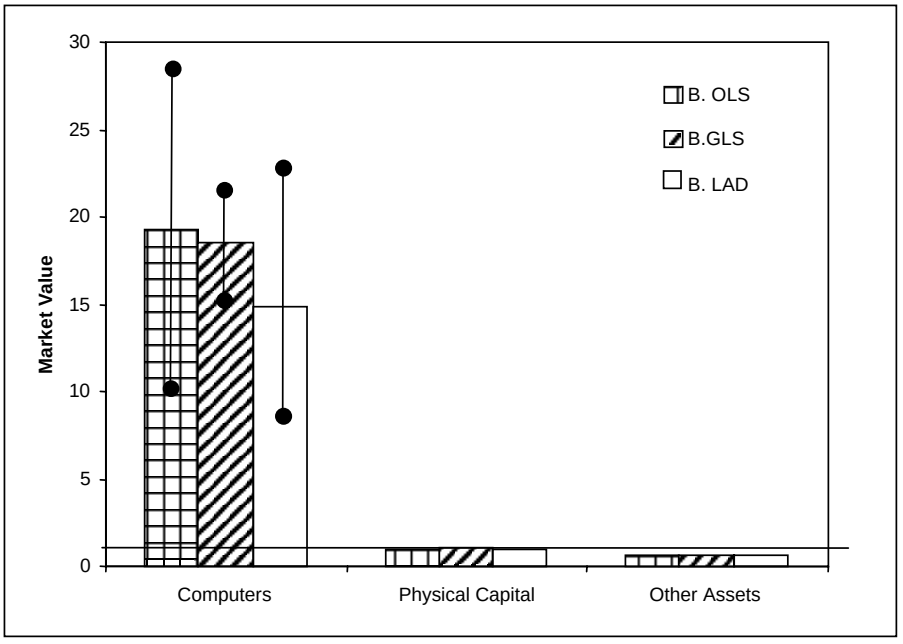
In Table 2, we examine how robust this result is to variations in econometric methods. For this analysis, we restrict the sample to a balanced panel[8] to get maximum data consistency and apply different regression techniques: generalized least squares (GLS) and least absolute deviation (LAD) regression[9] to control for heteroskedasticity, and two stage least squares (2SLS) to control for reverse causality. Overall, the basic results are consistent whether we use balanced or unbalanced panels and whether we correct for heteroskedasticity using GLS or LAD in both between and within regressions.[10]

The last column of Table 2 addresses the possible bias due to reverse causality. If investments in computer capital are very responsive to changes in market valuation, then the coefficient estimate of computer capital may be biased upward. The standard method of eliminating bias due to reverse causality is to identify variables that predict IT investment for fundamental, long-term reasons but are not affected by short term market fluctuations. Normally this is very difficult, but in this context we have access to computer prices, which are strong drivers of IT investment, but largely determined by fundamental technological progress in the semiconductor industry and not transitory stock market fluctuations.

[8]In other words, we exclude all firms which are missing any data in any year.

[9]LAD regression minimizes the absolute value of the deviation of the actual and fitted values, as opposed to the square of the difference as is done for OLS. Standard errors for the LAD estimates are done using bootstrapping techniques with 100 repetitions to obtain the empirical distribution of the coefficient estimates.

[10]While a plot of regression residuals (not shown) suggests strong size-based heteroskedasticity, the results are changed very little with alternative estimation methods.



- 95% confidence interval is drawn for computer coefficients.
- Other coefficients' two standard errors range from 0.02 to 0.16, too small.

Figure 1. Relative Size of Market Valuation: Between Estimates

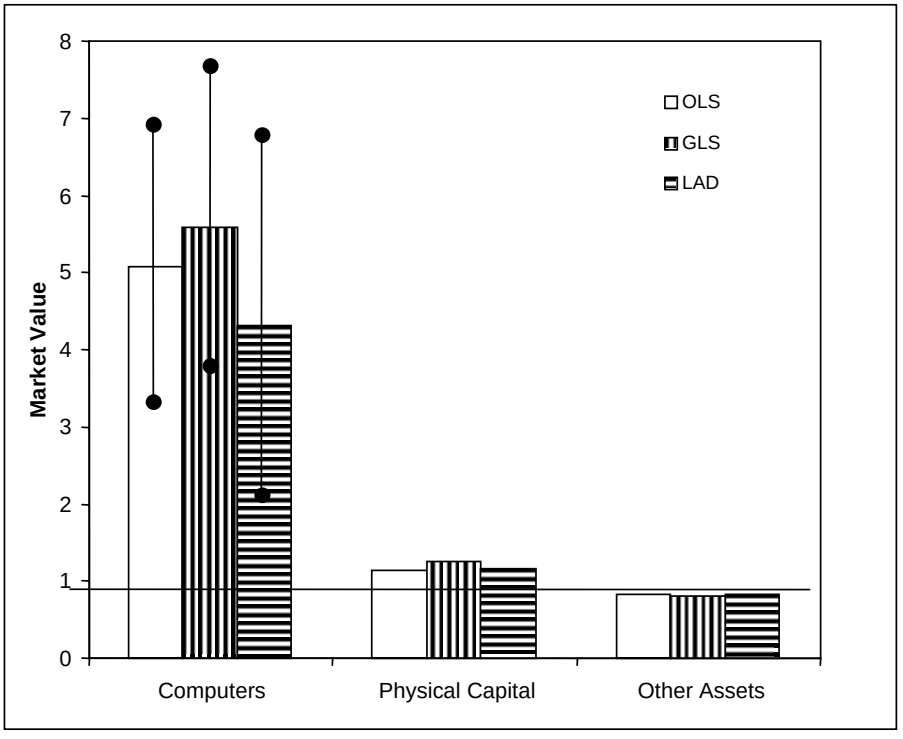


Figure 2. Relative Size of Market Valuation:
Firm Effect Within Estimates

We first model the investment in computers as a function of price and other exogenous variables in our model to obtain a predicted value of IT free from any reverse effects due to market.[11] We then use this measure of computer capital.

In this regression, the coefficient on computers is nearly doubled to $10. Thus, we find no evidence that the computer coefficient is biased upward by endogeneity. Although most of the other coefficients are similar, a Hausman test rejects the ordinary least squares (OLS) specification in favor of 2SLS. Therefore, if anything, the estimates in Table 1 and the rest of Table 2 appear to be conservative.

These regressions provide strong support for hypothesis H1—computers are associated with a substantial amount of intangible assets. Our estimates imply that these intangible assets dwarf the directly measured value of computer hardware that shows up on the balance sheet. In addition, the results on control variables and other factors give us confidence that our regression model is consistent with prior expectations: most other assets are worth approximately a dollar. In addition, the results corroborate an earlier exploratory analyses found by Yang (1994) using a different, smaller set of IT data from International Data Group. Furthermore, the basic results do not appear to be upward biased by reverse causality. Finally, the large difference between the "*between*" and "*within*" regressions suggests substantial effects of firm-specific characteristics on the value of computer capital. We will explore direct measures of one component of these organizational characteristics in the next section.

3.2 Basic Findings Regarding Role of Organizational Structure

In this section, we examine the correlation between computers and internal organization. All correlations use Spearman rank order correlations[12] between various measures of computers and the organizational variables, controlling for firm size (employment), production worker occupation, and industry.[13] Three different measures of IT are used, including the total value of IT installed base (ITCAP), total central processing power[14] in millions of instructions per second (MIPS), and number of personal computers (TOTPC). Multiple measures are employed because they capture slightly different aspects of computerization (for example, MIPS measures centralized computing, while TOTPC measures decentralized computing).

In Table 3, we present correlations between multiple measures of IT and four dimensions of organizational design: use of teams and related incentives, individual decision authority, investments in skills and education, and team-based incentives. Consistent with Hypothesis 2, we find that across multiple measures of IT and multiple measures of organization, firms that utilize more IT tend to use more teams, have broader job responsibilities, and allocate greater authority to their workers, even after controlling for firm size and industry.

In addition to being correlated with IT, these practices are all correlated with each other. Following Hitt and Brynjolfsson (1997) we construct a composite variable (ORG) as the standardized (mean 0, variance 1) sum of the individual work practice variables. This allows us to capture an organization's overall tendency to use this collection of work practices in a single construct which can be used for further analysis. A principal components analysis, Table 4, shows that all components of this variable load highly on a single factor (which explains approximately 35% of the variance of these measures), and a scree plot (not shown) suggests

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[11]Our assumption that computer prices are driven by supply shifts and not demand is born out by a negative correlation between computer price and quantity sold. To capture the possibility that the responsiveness of computer investment to price (price elasticity) varies across industry, we allow the price term to vary by industry (at the 2-digit SIC level).

[12]Results are similar when probit or ordered probit regression is used. We report Spearman rank order correlations because they are easier to interpret given the non-metric nature of most of our work system variables.

[13]Included are separate controls for mining/construction, high technology manufacturing (instruments, transportation, electronics, computers), process manufacturing (paper, chemicals, petroleum), other non-durable manufacturing, other durable manufacturing, transport, utilities, trade, finance, and services.

[14]Total central processing power does not include the processing power of personal computers.

that this is the only non-noise factor. The composite variable, ORG, is highly correlated with computerization. Thus, we have additional strong support for our second hypothesis. In the remaining section of the results, we will explore the influence that this cluster of practices has on the market value of the firm as well as the market value of computer capital.

Table 3. Correlations Between IT Measures and Organizational Structure

Measure (scale in parenthesis)	IT Capital	MIPS	TOTPC
Structural Decentralization			
Self-Managing Teams (1-5)	.17***	.22***	.20***
Employee Inv. Grps (1-5)	.07	.08	.08
Broad Jobs (1-5)	.07	.12*	.10*
Individual Decentralization			
Pace of Work (1-3)	.04	.06	.02
Method of Work (1-3)	.16***	.20***	.15***
Composite: 7 Measures^	.12*	.14**	.16***
Individual Control^	.11*	.15**	.15**
Team Incentives			
Team Building	.15***	.19***	.18***
Promote for Teamwork	.02	.10*	.88
Skill Acquisition			
Training (% staff)	.14**	.15***	.14**
Screen for Education (1-5)	.16***	.18***	.21***
ORG Composite	**.24*** **	**.30*** **	**.25*** **

Spearman partial rank order correlations controlling for industry, employment, and production worker occupation. N = 300-372, depending on data availability.

Key: * - p < .1; ** - p < .05; *** - p < .01
^ - Limited to second and third waves of survey (N = 276)

Table 4. Unrotated Principal Components for ORG Variable Construction

Work Practices	Loading First Principal Component	Loading Second Principal Component
Self Managing Teams	0.751	0.008
Employee Involvement Groups	0.707	0.176
Decentralized Pace Decision	0.528	-0.628
Decentralized Method Decision	0.572	-0.456
Team Building	0.747	0.250
Promote for Teamwork	0.401	0.367
Screen for Education	0.466	-0.095
Training (% Staff Involved)	0.425	0.408
Percent of Variance Explained	24.8%	12.6%

3.3 Findings Regarding Effect of Organizational Structure on Market Value

3.3.1 Organization Variable in Market Value Equation

To this base equation, we also consider the effects of adding terms representing organizational characteristics such as human capital and decentralized work systems. We then investigate the direct relationship of these measures on market value as well as their effect on the market value of computers through interaction terms. This yields the following estimating equation:

$$(8)\quad V_{it} = \alpha_i + \lambda_c K_{c,it} + \lambda_p K_{p,it} + \lambda_o K_{o,it} + \omega_1 ORG_i + \omega_2 ORG \cdot K_{c,it} + controls + \epsilon_{it}$$

A test of our third hypothesis (i.e., that organizational investments can be treated as intangible assets) is whether the ORG has a positive contribution to market value. Furthermore, if the estimated market value of IT drops when we include ORG in the equation, it suggests that part of the high market valuation of IT in the previous regressions that were based on equation 7 was due to a correlation with a previously unidentified and unmeasured organizational assets.

A test of our fourth hypothesis (i.e., a positive synergy between IT and organizational investments) is to examine whether IT is more valuable in high ORG firms; that is, testing the null hypothesis, $\omega_2 = 0$ against $\omega_2 \neq 0$.

We examine several market value equations that also include the ORG variable as a measure of organizational capital in Tables 5, 6, and 7. The first three columns in Table 5 report the same analysis of market valuation of computers with matched sub-sample. The coefficients broadly coincide with the results from the larger sample shown in Tables 1 and 2.

Table 5. Effect of IT and ORG on Market Value

	Matched Sample Baseline Estimates			**Adding ORG Variable Alone**	
	Pooled	Within	Between	Between	Pooled
Computer	10.901*** 1.578	7.946*** 1.297	13.845*** 4.213	8.487* 4.484	6.708*** 1.588
ORG				506.0* 271.2	529.5*** 122.1
Physical Capital	0.921*** 0.034	1.540*** 0.084	0.878*** 0.078	0.749*** 0.093	0.83138*** 0.0385
Other Assets	0.867*** 0.027	0.770*** 0.045	0.864*** 0.064	0.902*** 0.065	0.88359*** 0.02631
Controls	ROA*** R&D*** Adv Year*** Industry***	ROA*** R&D Adv Yar*** Firm***	ROA*** R&D** Adv NA Industry***	ROA*** R&D** Adv NA Industry***	ROA*** R&D*** Adv Year*** Industry***
R Square Observations	0.805 1705	0.741 1705	0.802 1705	0.805 1705	0.827 1705

When we simply add the ORG variable to the baseline market value equation, we find that it has a large and statistically significant contribution as shown in Table 5 columns 4 and 5. Firms that are one standard deviation above the mean in ORG, have a market value that is about $500 million higher, *ceteris paribus*. Evaluated at the mean, one standard deviation of ORG variable corresponds to the 8% increase in market value. The point estimate of computer capital coefficient drops about 40%. This suggests that ORG is a substantial component of the previously unidentified "firm effect" that influences the value of IT. The contribution of most of the other types of capital assets drops slightly, but not significantly.[15]

3.3.2 Interaction Between Organization and Computers

Table 6 presents the results when both ORG and its interaction with computer capital are included in the regression. The magnitude of the interaction term between IT and ORG is about 7 in pooled estimation. This strongly supports hypothesis 4. In fact, it suggests that each dollar of computer capital is associated with an increase in market value of an *additional* seven dollars in firms that are one standard deviation above average in ORG.[16]

[15]Results from between regression and pooled regression are essentially similar (within is omitted since it is not meaningful to estimate the coefficient of a time-invariant variable).

[16]In between regression, the coefficient of interaction term increases to ten, but the differences are not statistically significant. Pooled regression and between regression yield similar results for other coefficients.

Table 6. Effect of Interaction on Market Value

Market Value	Pooled	Pooled w/other Interactions	Between	Between w/other Interactions
Computer	3.112 2.082	3.077 2.181	7.151 4.652	6.747 4.777
ORG	251.** 123.9	230.2* 134.6	104.0 267.4	155.0 286.3
ORG x Computer	6.909*** 1.275	6.982*** 1.465	9.433*** 3.136	10.375*** 3.771
ORG x Physical Capital		0.019 0.032		-0.030 0.076
ORG x Other Assets		-0.010 0.021		-0.005 0.050
Physical Capital	0.928*** 0.034	0.913*** 0.042	0.880*** 0.078	0.902*** 0.096
Other Assets	0.815*** 0.028	0.823*** 0.036	0.775*** 0.069	0.784*** 0.086
Controls	ROA*** R&D*** Adv Year*** Industry***	ROA*** R&D*** Adv Year*** Industry***	ROA*** R&D*** Adv NA Industry***	ROA*** R&D*** Adv NA Industry***
R Square Observations	0.810 1705	0.810 1705	0.862 1705	0.862 1705

One possible explanation of these results is that ORG makes all types of capital more valuable and since capital investments tend to be correlated with each other, we are erroneously attributing this all to computers. When we include additional interaction terms between ORG and Other Capital (columns 2 and 4 of Table 6), we find that this relationship is *unique* to computers: the coefficients on the added interaction terms are not significant and there is little change in other coefficients. This indicates that ORG is an intangible asset that is particularly strongly associated with IT.

As the organization variable, ORG, is measured once per firm, we cannot apply fixed-effect model to estimate its coefficient. However, since computers do vary over time, their interaction with ORG is time varying as well, which enables firm effects estimation. The results (shown in Table 7) suggest that evidence of an interaction between ORG and IT is evident even in the firm effects analysis. The coefficient is reduced although still borderline significant ($p < .07$), but when the direct computer effect is also removed (which is highly collinear with the interaction term in this model), the coefficient rises to 4.4 and is strongly significant and the R^2 is little changed. Thus, we can conclude that the market value of computerizing is substantially higher in high ORG firms.

Table 7. Effect of Interaction: Firm Effect and Instrumental Variable Estimation

Market Value	Firm Effects	Firm Effects w/o Computer Direct	Pooled 2SLS
Computer	4.425*** 1.967		7.221 7.382
ORG			-135.3 168.2
ORG x Computer	2.202* 1.240	4.233*** 0.851	17.897*** 4.611
Physical Capital	1.467*** 0.088	1.476*** 0.088	0.991*** 0.066
Other Assets	0.718*** 0.047	0.722*** 0.047	0.598*** 0.047
Controls	ROA*** R&D Adv*** Year*** Firm	ROA*** R&D Adv*** Year*** Firm	ROA*** R&D Adv*** Year*** Firm
R Square Observations	0.743 1705	0.743 1705	0.790 1705

The final column of Table 7c shows the instrumental variable estimate.[17] In this regression, the interaction becomes stronger in magnitude and significance level suggesting that reverse causality is not leading to overestimates of the effect of computers or their interaction with ORG.

3.3.4 Non-parametric Estimation

The above results suggest that in high ORG firms each dollar of computer capital is associated with more intangible assets than it is in centralized, low-skill firms. If the stock market is valuing these firms properly, then this suggests that the benefits of computerization are likely to disproportionately go to firms that are highly decentralized.

Figures 3 and 4 graphically capture this idea by plotting results from non-parametric regressions. Figure 3 is a level plot of fitted values of market value regression on both computer capital and ORG variables, after netting out effects of other variables. Figure 4 is a contour plot from the same regression. We can see a clear picture of the interaction effect between computers and the ORG variable, which captures most of decentralized work practices. Firms that are high in IT and also high in ORG have much higher market values than firms that have one without the other.

[17]Treating ORG as exogenous, but including additional computer price x ORG instruments.

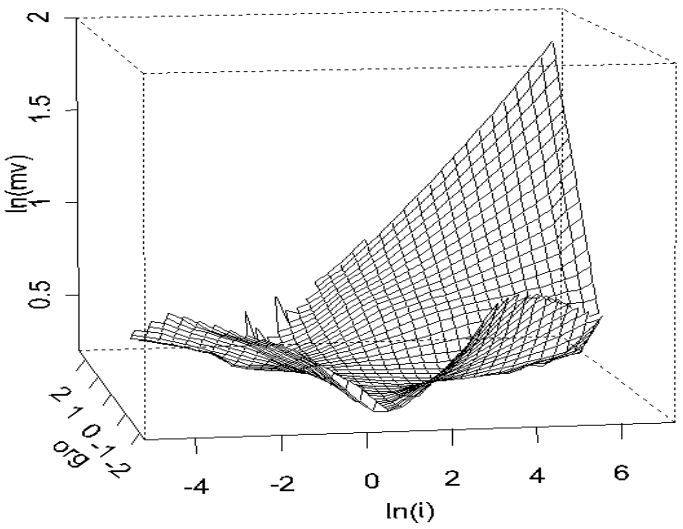


Figure 4. Market Value 3-D Plot by Organization and IT
Non-parametrically Estimated Values via a
Local Regression Model

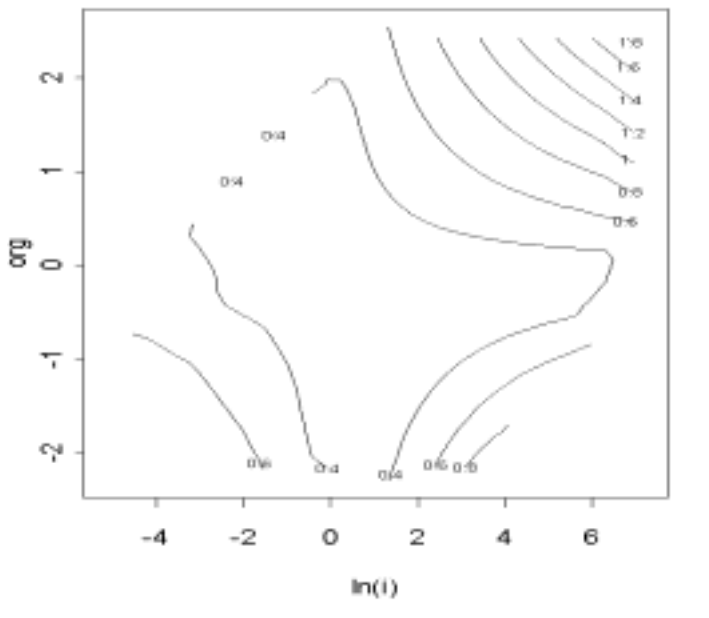


Figure 4. Market Value Contour Plot by Organization and IT
Estimated Fitted Values via a Local Regression Model

4. DISCUSSION AND CONCLUSIONS

The organizational adjustment costs that firms lament when installing computer capital, including costly investments in training, wrenching organizational change, and conscientious relationship-building are not simply wasted. Instead, on average, they create intangible assets that increase revenues but are difficult for competitors to duplicate. Therefore, our results demonstrate that the costs of creating intangible assets should not necessarily be viewed as expenses to be written-off, but rather can be viewed as investments that create an ongoing revenue stream.

Our main results are consistent with each of the four hypotheses described in the introduction:

- The financial markets put a very high value on installed computer capital, substantially exceeding the valuation placed on other types of capital.

- Computer-intensive firms have distinctly different organizational characteristics, involving teams, broader jobs, and greater decentralization of decision-making.

- Firms with these organizational characteristics have higher market valuations than their competitors, even when all their other measures assets are the same.

- Firms with *both* higher levels of computer investment and these organizational characteristics have a *disproportionately* higher market valuations than firms that are high on only one or the other dimension.

These striking findings are quite robust to different data sources, numerous different estimating equations, and corrections for reverse causality. Taken together, these results provide strong evidence that the combination of computers and organizational structures creates more value than the simple sum of these contributions separately.

Our interpretation has focused on the assumption that the stock market is approximately correct in the way it values information technology and other capital investments. The fact that our results apply to a broad segment of the economy over nearly a full business cycle suggesting that fads, industry idiosyncrasies, and investor errors are not driving the results. In

fact, year-by-by estimation shown in Table 8 indicates a consistently high valuation of computer capital throughout our period.[18] Interestingly, productivity analysis by Brynjolfsson and Hitt (1997) shows that the long run productivity benefits are approximately five times their capital cost, consistent with a valuation of IT five times higher than the valuation of ordinary capital.

By analyzing several hundred firms over a period of eight years, our research helps to document, analyze, and explain the extent to which computerization is associated with both direct and indirect measures of intangible assets. Furthermore, our methodology enables use to understand the pattern of interactions among IT, organizational practices and market valuations, and thereby detect complementarities. If these assets are in fact becoming more important in modern economies, in part because of the information revolution engendered by computers and communications, then it is incumbent upon us to understand not only particular cases, but also any broader relationships and patterns that exist in the data.

In summary, our model and evidence support the hypothesis that installing computers is typically associated with the creation of valuable, if previously unmeasured, organizational assets. These organizational assets are evident both directly, in the different work systems use by high IT firms, and indirectly, in the way that the financial market values computer-intensive firms proportionally higher. The performance regressions suggest that the reason that IT is associated with these organizational assets is *not* simply coincidence, but rather that they create more value when used together than when used separately.

Table 8. Year-by-Year Fluctuation of Market Valuation

Years	1987-88	1989-90	1991-92	1993-94
Computer Capital	28.435*** 3.962	15.966*** 3.483	21.082*** 3.647	11.965*** 1.665
Physical Capital	0.821*** 0.027	0.994*** 0.034	1.024*** 0.048	0.989*** 0.042
Other Assets	0.655*** 0.015	0.672*** 0.015	0.661*** 0.022	0.719*** 0.015
Contro.s	ROA*** R&D*** Adv Year Industry***	ROA*** R&D** Adv** Year Industry***	ROA*** R&D Adv Year Industry***	ROA*** R&D Adv Year** Industry***
R Square Observations	0.907 1090	0.909 1089	0.840 1182	0.887 1217

References

Anand, K., and Mendelson, H. "Information and Organization for Horizontal Multimarket Coordination," Mimeograph, Stanford University, 1997.

Appelgate, L.; Cash, J.; and Mills, Q. "Information Technology and Tomorrow's Manager," *Harvard Business Review* (November-December 1988.

[18]We can reject the null hypothesis that the market valuation of computers is less than eight in any one period. We can also strongly reject the hypothesis that computer capital's coefficient is equal to those of other types of capital.

Brynjolfsson, E., and Hitt, L. M. "Computers and Productivity Growth: Firm-level Evidence," Working Paper, Sloan School of Management, Massachusetts Institute of Technology, 1997.

Brynjolfsson, E. and Yang, S. "Intangible Benefits and Costs of Computer Investments: Evidence from the Financial Market," in K. Kumar and J. I. DeGross (eds.), *The Proceedings of the Eighteenth International Conference on Information Systems*, Atlanta, Georgia, 1997.

Dos Santos, B. L.; Peffers, K. G.; and Mauer, D. C. "The Impact of Information Technology Investment Announcements on the Market Value of the Firm," *Information Systems Research* (4:1), 1993, pp. 1-23.

Florida, R., and Kenney, M. "The New Age of Capitalism: Innovation-mediated Production," *Futures*, July/August, 1993.

George, J. F., and King, J. L. "Examining the Computing and Centralization Debate," *Communications of the ACM* (34:7), 1991, pp. 63-72.

Gordon, R. J. *The Measurement of Durable Goods Prices*, University of Chicago Press, Chicago, 1990.

Griliches, Z. "Market Value, R&D, and Patents," *Economic Letters* (7), 1981, pp. 183-187.

Hall, B. H. "The Manufacturing Sector Master File: 1959-1987," Working Paper 3366, National Bureau of Economic Research, 1990.

Hall, B. H. "The Stock Market's Valuation of R&D Investment During the 1980s," *The American Economic Review* (84:1), 1993a, pp. 1-12.

Hall, B. H. "Industrial Research During the 1980s: Did the Rate of Return Fall?" *Brookings Papers on Economic Activity: Microeconomics* (2), 1993b, pp. 289-343.

Hayashi, F. "Tobin's Marginal q and Average q: Neoclassical Interpretation," *Econometrica* (50:1), 1982, pp. 213-224.

Hayashi, F., and Inoue, T. "The Relation between Firm Growth and Q with Multiple Capital Goods: Theory and Evidence from Panel Data on Japanese Firms," *Econometrica* (59:3), 1991, pp. 731-753.

Hitt, L., and Brynjolfsson, E. "Information Technology and Internal Firm Organization: An Exploratory Analysis," *Journal of Management Information Systems*, Fall 1997.

Huselid, M. A. "The Impact of Human Resource Management Practices on Turnover, Productivity, and Corporate Financial Performance," *Academy of Management Review* (38:3), 1995, pp. 635-672.

Ichniowski, C. K.; Shaw, K.; and Prunnushi, G. "The Effects of Human Resource Management Practices on Productivity," *The American Economic Review*, June 1997.

Im, K. S.; Dow, K. E.; and Grover, V. "A Reexamination of IT Investment and the Market Value of the Firm: An Event Study Methodology," Mimeograph, University of South Carolina, Columbia, 1998.

MacDuffie, J. P. "Human Resource Bundles and Manufacturing Performance: Organizational Login and Flexible Production Systems in the World Auto Industry," *Industrial and Labor Relations Review*, January 1995.

Montgomery, C. A., and Wernerfelt, B. "Diversification, Ricardian Rents, and Tobin's q," *Rand Journal of Economics* (19:4), 1988, pp. 623-632.

Orlikowski, W. J. "Learning from Notes: Organizational Issues in Groupware Implementation," *Proceedings of the Conference on Computer Supported Cooperative Work*, Toronto, Canada, 1992.

Osterman, P. "How Common is Workplace Transformation and Who Adopts It?" *Industrial and Labor Relations Review* (47:2), 1994, pp. 173-188.

Sauer, C., and Yetton, P. W. "Steps to the Future: Fresh Thinking on the Management of IT-based Organizational Transformation," San Francisco, 1997.

Tobin, J. "A General Equilibrium Approach to Monetary Theory," *Journal of Money, Credit and Banking* (1:1), February 1969, pp. 15-29.

Triplett, J. E. "Price and Technological Change in a Capital Good: A Survey of Research on Computers," in D. W. Jooargenson and R. Landau (eds.), *Technology and Capital Formation*, MIT Press, Cambridge, MA, 1989.

Wildasin, D. E. "The q Theory of Investment with Many Capital Goods," *The American Economic Review* (74:1), 1984, pp. 203-210.

Wyner, G., and Malone, T. "Online Bureaucracy or Electronic Market: Does Information Technology Lead to Decentralization?" in K. Kumar and J. I. DeGross (eds.), *Proceedings of the Eighteenth International Conference on Information Systems*, Atlanta, Georgia, 1997.

Yang, S. *The Relationship between IT Investment and Market Value of Firms*, unpublished Master's thesis, Sloan School of Management, Massachustts Institute of Technology, 1994.

Zuboff, S., and Bronsema, G. "The Expense Tracking System at Tiger Creek," HBS Case 9-485-057, Harvard Business School, Boston, 1984.

Appendix A
Mathematical Notes

Derivation of the Estimating Equations

This mathematical note is a simpler variation of the appendix in Brynjolfsson and Yang (1997), which is in turn based on Wildasin (1984). It extends the earlier work by providing some auxiliary derivations needed for the discussion of this paper.

We may assume that firms face the following dynamic optimization problem.

(1) $\underset{I}{Maximize}\ V(0) = \int_0^\infty \pi(t)u(t)dt$

(2) where $\pi(t) = (F(K,N,t) - \Gamma(I,K,t)) - N - I$

(3) given $\frac{dK}{dt} = I - \sum_{j=1}^{J} \delta_j K_j$

Here a firm maximizes its objective function, market value *V(0)* at time t = 0, which is equal to the discounted profit stream $\pi(t)$ by the discount factor *u(t)*. The decision variable is the investment vector I, and the constraint is the depreciation rule given in the equation (3). *F(K,N,t))* is the amount of output the firm can produce using capital input vector equal to *K* and variable input vector equal to *N*. In addition, we posit that there is some adjustment costs taking the form of lost output $\Gamma(I,K,t)$. δ_j is the depreciation rate of the capital good K_j. All the variables except for time *t* and depreciation rate δ are in dollar value.

Then the hamiltonian of the optimization problem can be given:

(4) $H(I,K,Nt) = ((F(K,N,t) - \Gamma(I,K,t)) - N - I)u(t) + \lambda(I - \sum_{j=1}^{J} \delta_j K_j)$

Here the Lagrangian multiplier vector λ represents the shadow value vector of one unit of each capital good; i.e., λ_j is the shadow value of capital good K_j. If the valuation of financial markets is correct, λ_j is the value of one additional unit of capital good K_j.

We assume the following to make the analysis simple.

(A1) *F(K,N)* and $\Gamma(I,K)$ are linear homogenous functions over (*K*,*N*) and (*I*, *K*) respectively. This assumption is equivalent to constant to return to scale.

(A2) $\Gamma(I,K)$ are twice continuously differentiable in I and K. $\Gamma(0,K) = 0$, and $\Gamma(I,K) \geq 0$; $\Gamma_I > 0$, and $\partial^2\Gamma/\partial I\partial I'$ are positive definite.

A1 is nothing but the constant return to scale assumption and A2 captures the shape of adjustment cost function. It is increasing in investment and convex in investment.

The first order conditions of the hamiltonian under these assumptions can be given:

(F1) $F_N - l = 0$, where F_N is the partial derivative of F with respect to the vector N, and l is the vector of ones.

(F2) $\lambda_j - (\Gamma_j + 1)u = 0$ for all j and t.

(F3) $\dot{\lambda} = -(F_{k_j} - \Gamma_{k_j})u + \lambda_j \delta_i$ for all j and t

And the transversality condition is:

(F4) $$\lim_{t \to \infty} \lambda(t)K(t) = \lambda(\infty)K(\infty) = 0$$

Let us consider economic interpretations of these conditions. F1 is the familiar marginal productivity condition: the dollar values of marginal product of inputs equal to its dollar value of the input. F2, $(l + \Gamma_I)u = \lambda$, means that total cost of unit of investment is the shadow value of that capital. Now from the transversality condition, we can write

Now from the transversality condition, we can write

(5) $$\lambda_j(0)K_j(0) = \lambda_j(0)K_j(0) - \lambda_j(\infty)J_j(\infty) = -\int_0^\infty (\lambda_j K_j + \lambda_j \dot{K}_j)dt$$

Using the three first order conditions of the maximization problem, observe the following:

(6) $$\begin{aligned} &-(\dot{\lambda}_j K_j + \lambda_j \dot{K}_j) \\ &= [(F_{K_j} K_j - \Gamma_{K_j} K_j - \Gamma_{I_j} I_j) + \sum_k (F_{N_k} N_k - N_k)]u \end{aligned}$$

By the Euler's theorem for the first degree homogeneous funcion G in vector X.

$$\nabla G(X)^T X = \sum G_{X_i} X_i = G(X).$$

Applying this theorem, since π is homogenous of degree one in in K, I, and N, we can obtain:

(7) $$\sum_{j=1}^{J} \lambda_j(0)K_j(0) = \int_0^\infty ((F - \Gamma) - N - I)u(t)dt = \int_0^\infty \pi(t)u(t)dt = V(0)$$

High Market Value of IT Due to High Adjustment Costs

It is very easy to see if installment is costly, the installed capital worth more. Let us see this more formally.

By the homogeneity of degree one of the functions of $\Gamma(.)$, we can define:

$$\gamma(I/K) \equiv \Gamma(I,K)/K = \Gamma(I/K,1);$$

Then $\Gamma_I(I,K) = \partial\Gamma/\partial I = K\ \partial[\Gamma(K,I)/K]/\partial I = K\ \partial\gamma(I/K)/\partial I = K\ \gamma'(I/K)\ 1/K = \gamma'(I/K)$. By the assumptions of the adjustment functions we know or can easily derive the following:

(8) $\gamma'(I/K) > 0 \; < \gamma'(I/K)$

Now from one of the first order conditions, F2, we know the market value of one unit of capital goods is:

(9) $\gamma = (\Gamma_I + 1) = (\gamma + 1)$

Let u = I/K, then

(10) $\partial\lambda/\partial u = \gamma'' > 0$, by equation (8).

We just proved that the market value of one unit of capital good is higher when the investment rate is higher, *ceteris paribus*.

There may be another source of higher adjustment costs of IT investment. As IT is a new technology still being developed rapidly, IT investments may accompany considerable changes in the structure and behavior of organizations. In our model, this idea can be captured as $\gamma_c > \gamma_o$, computer capital's adjustment cost function is monotonically larger than those of other types of capital. If that is the case, by monotonic convexity of γ, respectively; $\gamma'_c > \gamma'_o$. According to equation (9), we can immediately see $\lambda_c > \lambda_o$.

Excess Marginal Product of IT Capital

The excess marginal product of computer capital also can be explained in the same framework. The output function can be restated as follows when adjustment costs take the form of foregone output. Let us assume that the adjustment cost function is $G(I,K,t) = \Sigma_j I^j(I_j, K_j, t)$, additively separable. Then the production function can be restated:

(11) $Y(K,L,I,t) = (F(K,L,t) - \Sigma_j I^j(I_j, K_j, t))$

Now we assume $\partial F/\partial K_j = \partial F/\partial K_j$ for all i and j. This assumption is for convenience only. In a no adjustment cost economy, there should be no excess returns on any specific capital. Otherwise, firms would invest more on that capital to exploit away the excess returns. We also assume $I^j = I^i$ for all i and j. The second assumption is temporary and harmless, and will consider the relaxation of this assumption. Then we can say that the first derivatives of all I^js with respect to K_j equal to γ as in the above subsection. Under this formulation, the marginal product of each capital good is:

(12) $Y_{Ki} = (F_{Ki} - \Gamma^i_{Ki} = (F_{Ki} + \gamma'(I_i/K_i)/K_i^2)$

The installed capital goods in the adjustment cost economy contribute to output in two ways: first, directly increasing output, $\partial F/\partial K$; and secondly reducing adjustment costs of new investments, $\gamma'(I/K)/K^2$. The computer capital's excess return can be viewed this way.

If one capital good's investment rate I/K is higher than that of others, then the marginal product of that capital should be higher as is monotonously increasing, *ceteris paribus*. Also if the level of one capital good is smaller than that of other's, the marginal product is also higher. These two conditions are exactly the case of computer capital. Thus the second term of the above equation is unambiguously larger for computer capital than for non-IT capital. The model suggests that even when computer capital is nothing special except for the rapid price decline, we should observe excess returns. If computer capital's adjustment cost function is also monotonously larger than that of other capital's as discussed in the above subsection, the excess returns should go up more. If it is costly to install computer capital, the installed capital should earn more.

This way of looking at the problem is so obvious that it is quite surprising hardly any researcher has yet formalized this idea. There is another interesting merit of the above formulation. Given the computer capital's excess returns identified by some researchers, we can actually estimate the adjustment cost parameters from equation (12).

Appendix B
Data Description

The variables used for this analysis were constructed as follow:

IT Capital. We take total purchase value of computer equipment as reported by Computer Intelligence Corp. and deflate it using an extrapolation of Gordon's (1990) deflator for computers (price change -19.3% per year).

Physical Capital. The source of this variable is Standard &Poor's Compustat Annual Dataset. We consider two options to construct the variable. The first is to construct the variable from gross book value of physical capital stock, following the method in Hall (1990). Gross book value of capital stock [Compustat Item #7 - Property, Plant and Equipment (Total - Gross)] is deflated by the GDP implicit price deflator for fixed investment. The deflator can be applied at the calculated average age of the capital stock, based on the three year average of the ratio of total accumulated depreciation [calculated from Compustat item #8 - Property, Plant & Equipment (Total - Net)] to current depreciation [Compustat item #14 - Depreciation and Amortization]. Another method is just to use the net physical stock depreciation [calculated from Compustat item #8 - Property, Plant & Equipment (Total - Net)]. In productivity literature the first method should be used, but in market value estimation we adopt the second approach for the consistency with market value and other assets, which is measured in current dollars. The dollar value of IT capital (as calculated above) was subtracted from this result.

Other Assets. The other assets variable is constructed by the total asset [Compustat Annual Data item #6] minus physical capital constructed above. This item includes receivables, inventories, cash, and other accounting assets such as goodwill reported by companies.

Return on Assets (ROA). Compustat PC plus mnemonic code ROAA, which is a two year moving average of return on assets.

R&D Asset Ratio. Constructed from R&D expenses [Compustat annual item #46]. Interestingly, this item includes software expenses and armortization of software investment. R&D stock is constructed using the same rule in Hall (1993a, 1993b). She applied a 15% depreciation rate, so we did. The final ratio is just the quotient of the constructed R&D stock and total assets. Less than half of the firms in our sample report R&D expenses. The missing values are filled in using the average of the same industry (SIC 4-digits).

Advertising Asset Ratio. Constructed from advertising expenses [Compustat annual item #45]. Less than 20% of our sample of firms report the item. The same rule with R&D assets ratio is applied.

Market Value. Fiscal year end s common stock value plus preferred stock value plus total debt. In Compustat mnemonic code, it is MKVALF + PSTK+DT, which represents total worth of a firm assessed by financial market.

Organization Variable (ORG). The variable is constructed from survey items conducted by us in 1995 and 1996. The construction procedure using principal component analysis is described in the text. This variable captures the degree of new organizational practices identified by Osterman (1994), MacDuffie (1995), and Huselid (1995).

Computer Price. The source of the price of computers is the National Income Product Account (NIPA) by National U.S. Bureau of Economic Analysis (BEA). This is quality adjusted price index described in Triplett (1989).