The Intangible Benefits and Costs of Computer Investments: Evidence from the Financial Markets

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May 1, 1997; Revised May 31, 1998

ABSTRACT

We model how the financial market valuation of firms can be used to estimate the intangible costs and benefits of computer capital and we present several new empirical results based on this model. Using eight years of data for over 1000 firms in the United States, we find that an increase of one dollar in the quantity of computer capital installed by a firm is associated with an increase of up to ten dollars in the financial markets' valuation of the firm. Other forms of capital do not exhibit these high valuations.

Our model suggests that intangible assets can provide and explanation for the high market valuation found for computers in this study as well as the excess returns found for computer capital in other studies. Costly investments in software, training and organizational transformations that accompany computer investments can be regarded as creating intangible assets. These intangible assets do not appear on firms' conventional balance sheets but they can produce both higher market valuations and "excess" returns. The empirical evidence suggests that up to nine-tenths of the costs and benefits of computer capital are embodied in otherwise unobserved intangible assets.

A earlier version of this paper with was published in the *Proceedings of the International Conference on Information Systems*, Atlanta, GA, December, 1997. Significant changes have been made, including the new results using instrumental variable estimation and a comparison to R&D. We thank Lorin Hitt, Josh Angrist and two anonymous referees for valuable comments; the MIT Center for Coordination Science, the Stanford Computer Industry Project and NationsBanc Montgomery Securities for generous financial support and International Data Group and Computer Intelligence Corporation for providing valuable data.

1. Introduction

Business Environment and Computers

Many business leaders have come to the conclusion that the essential assets are no longer land or unskilled labor, as they were in centuries past, or factories and financial capital as they were for most of the 20th century. Instead, the most successful firms are often those that best leverage information and knowledge assets. WalMart came to surpass Sears in large part because of better use of information from the store level back to supply chain management. Federal Express customers tracked 800,000 packages in January, 1997 via the world wide web, and the company is aiming for 100% electronic transactions. "How many customer service reps would I have to add to process 800,000 tracks?" asked CEO Fred Smith in a recent article (Reuters, 1997).

Important as they are, knowledge and information assets are largely intangible and invisible. They do not show up on most firms' balance sheets. Instead, some of these assets are expensed as software and training and others are manifested in the shared learning, organizational design, and communications architecture that transmit information within and across functions. This evolving matrix of relationships and knowledge represent a hidden asset that can enable a firm to react faster and to innovate better than its rivals.

An major theme of recent research in the field of information systems has been that computers and other types of information technology (IT) enable new ways of organizing, at the level of the work group, the firm and even the whole industry (Malone, Yates et al. 1987). Furthermore, numerous case studies have documented that simply overlaying computer investments on old ways of doing business often leads to disappointing results. For instance, Orlikowski's study of "Alpha corporation" found that providing workers with access to Lotus notes did not automatically lead to increased sharing of information; new incentives systems, training, and patterns of interaction also needed to be developed (Orlikowski, 1992). It may be no coincidence that the past ten years, which have witnessed a significant acceleration in real computer investment, have also been accompanied by substantial restructuring of firms and even industries. Indeed, broad scale quantitative evidence of an association between IT investments and organizational change has recently emerged (Brynjolfsson and Hitt, 1997).

The additional costs required when firms make significant computer investments are sometimes called organizational "adjustment costs". While these costs 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 – new routines, a new organizational form, a new set of supplier relations – that other firms cannot duplicate costlessly. In other words, they have created a new asset.

In this paper, we argue that the intellectual, cultural, organizational and inter-organizational changes that are needed to make computers effective can be modeled as investments in capital assets. In various contexts, these assets have been termed human capital, social capital, organizational capital, and relationship capital, but we will simply include them all under the rubric of "intangible assets".

For our purposes, we do not need to assume that IT "causes" the creation of intangible assets or vice-versa. Instead, we test the hypothesis that intangible assets complement information technology capital just as software complements computer hardware. Complementary assets are more valuable when used together than when used separately. To realize the potential benefits of computerization, additional investments may be needed in "assets" like worker knowledge, new organizational structures or inter-organizational relationships. Hence we develop a dynamic optimization model in which both kinds of investments are jointly determined.

If the intangible assets really exist, the resulting effect on the firm's market valuation should be measurable, even when the underlying assets are not directly observable. The financial markets, which heed the discounted value of future revenues, provide a valuable telltale for whether CEO's decisions to make these investments are generating value for the owners of the firm.

In particular, if a firm needs to make investments in intangible assets in order to unlock the full value of computer capital, then the market value of a firm with substantial computer assets already in place should be greater than that of a similar firm which has not yet integrated computers into its organization. A computer that has been leveraged with complementary intangible assets should be significantly more valuable to a business than a computer in a box on the loading dock. As a result, the business value of a computer is *NOT* simply what it can fetch on an auction block, as some consultants have quipped.[1]

By analyzing 1000 firms over a period of 8 years, our research seeks to document, analyze and explain the extent to which computerization is associated with the creation of intangible assets and thus, market value. This broad sample empirical work serves to complement the rich case study work which has already shown that what we call intangible assets can be important complements to computer capital in particular situations. If these assets are in fact becoming more important in modern economies, paralleling 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.

Excess Return of Computer Capital and its Market Valuation

In addition, this approach has the potential to solve an open puzzle regarding the economic effects of information technology. The puzzle follows from the discovery that computer capital appears to be persistently associated with higher levels of output than other types of plant and equipment. As shown by Brynjolfsson and Hitt (1993), estimates of production functions on large samples of data consistently find that the gross marginal

1 See, for example, Strassmann (1990).

product – the increase in output associated with each dollar of input – is substantially higher for computer capital than for other types of capital. This finding was confirmed in a several subsequent studies, some using the same data and some using different data, including Brynjolfsson and Hitt (1995); Lichtenberg (1995); Dewan and Min (1997); Black and Lynch (1996); and Greenan and Mairesse (1996). A more detailed survey of the literature is in Brynjolfsson and Yang (1996).

If merely investing in IT did actually create more value than other investments, an inescapable question arises: why don't rational managers simply invest more in IT until these excess returns are all captured, driving down the marginal product of the computer capital? Or as Robert Gordon put it: "if IT has excess returns, what is the hidden force that prevents greater investments?"[2]

One explanation for this puzzle is that the high levels of output associated with computer investments reflect not only the contributions of computers, but also the contributions of costly, but unmeasured intangible assets that are often coincide with investments in computers. While these intangible assets are overlooked in standard production functions, they may be just as real as other assets in their ability to generate value. In other words, the output increases associated with computer capital are not necessarily “excess” returns, but rather reflect returns on a collection of partially unmeasured assets.

Because none of the previous studies explicitly included intangible assets in the production functions that they estimated (which is understandable, since by definition, these assets are unmeasured), value created by these assets would tend to show up in the coefficients of other variables, such as computer capital. As noted as early as in the first paper which found high returns to computer capital (Brynjolfsson and Hitt 1993), this suggests that computer capital can be thought of as a "marker" for a broader set of investments which include not only tangible computer hardware, but also software, organizational routines, relationships and human capital which are associated with the

[2] In the comments on Oliner and Sichel (1994).

measured computer investments. If intangible assets are an important contributor to firms' output and if they tend to be correlated with investments in computers, then this could explain the persistently high levels of output associated with computer capital in empirical research.

If this explanation is true, it has a clear, testable implication: firms with higher levels of intangible assets should be able to generate greater profits over time (as a return to their investments in intangible assets) and the financial markets should value these firms more highly, reflecting the present value of this stream of expected profits. Therefore, we can assert the following hypotheses:

Hypothesis: *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.*

Our analysis of data from over 1000 firms over 8 years finds evidence that the financial markets do in fact value each dollar of computer capital at up to ten times the valuation placed on a dollar of conventional capital.

The remainder of the paper is organized as follows. In section 2, we summarize some of the relevant research. In section 3, we derive the estimation equations from a dynamic optimization model in which both computers and market valuation are endogenous. In the fourth section, we present the several empirical results using various data sources and regression. Detailed discussion about the result and a fresh new look on the old productivity puzzles are presented in the conclusion.

2. Related Research

As noted above, there have been numerous studies that have examined the relationship between computers and productivity at the firm level. While the early work on small samples did not find a productivity impact (Loveman 1994; Barua, Kriebel & Mukhopadhyay 1991), the more recent work has consistently found a positive correlation between computers and productivity and between computers and output, as noted above.

In contrast to the growing number of studies focused on output measures, there is almost no research that investigates the relationship between IT and market value. Dos Santos and others showed that an announcement of innovative IT investments had positive effects on the stock market. However, since a non-innovative IT investment was associated with negative stock price movement, the overall effects of IT investment announcement resulted in zero effect among their sample of firms (Dos Santos et al. 1993). A more recent study did not find a statistically significant relationship between profitability and computer capital (Hitt and Brynjolfsson 1996). However, the authors stressed that the estimates of computer's effects on profitability had high standard errors, so the failure to identify a significant association might simply have been due to the relatively low power of their hypothesis tests.

In addition to the IT-oriented literature, the empirical part of this paper draws on another research tradition. Many researchers in economics and business have used stock market valuation as an alternative measure of business performance. Especially in the literature on the economics of R&D, estimating the stock market valuation of R&D capital is a common strategy. Griliches was one of the pioneers using this measure of R&D performance (Griliches 1981) and more recently Hall documented declining R&D market value in the 1980's (Hall 1993a, b). In the business literature as well, many researchers have used market value as a performance measure.[3] This paper's empirical estimation equations are very similar to those of Griliches or Hall, except of course, that we add computer capital as an explanatory regressor.

Finally, this paper provides a formal derivation of Griliches's and Hall's estimation equations. The theoretical base and derivation of equations of this paper rely heavily on papers by Tobin (1969), Lucas (1967), Hayashi (1982), Wildasin (1984), and Hayashi & Inoue (1991).

3. Econometric Model and Data

Derivation of the Estimating Equations

This subsection is a simpler variation of Wildasin [1984] and Hayashi & Inoue [1991]. We add some auxiliary derivations needed for the discussion of this paper.

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

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

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

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

Here a firm maximizes its objective function, market value *V(0)* at time t = 0, which is equal to the discounted profit stream *p(t)* by the discount factor *u(t)*.[4] 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 *G(I,K,t)*. d_j is the depreciation rate of the capital good K_j. All the variables except for time *t* and depreciation rate *d* are in dollar value.

Then the hamiltonian of the optimization problem can be given:

[3] For example, the "resource-based" theory of the firm is often empirically analyzed using market value or the closely related variables Tobin's q, i.e. the market value divided by book value (Montgomery 1995).

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

Here the Lagrangian multiplier vector *l* represents the shadow value vector of one unit of each capital good; i.e. l_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 *G(I,K)* are linear homogenous functions over (*K*,*N*) and (*I*, *K*) respectively. This assumption is equivalent to constant to return to scale.
(A2) *G(I,K)* are twice continuously differentiable in I and K. *G(0,K) = 0,* and *G(I,K)* ³ *0*; $G_I > 0$, and $¶^2G/¶I¶I$ ¢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) $l_j - (\Gamma_j + 1)u = 0$ for all j and t.

(F3) $\dot{l}_j = -(F_{K_j} - \Gamma_{K_j})u + \ l_j d_i$ for all j and t

And the transversality condition is:

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

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, $(l + G_I)u = l$, means that discounted total cost of unit of investment is the shadow value of that capital. Now from the transversality condition, we can write:

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

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

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

By the Euler's theorem for the first degree homogeneous funcion G in vector X, we have:

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

Applying this theorem since π is homogenous of degrere on in K, I and N, we obtain:

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

High Market Value of Computers due to High Adjustment Costs

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

By the homogeneity of degree one of the functions of *G(.)*, we can define:

$g(I/K)$ º $G(I,K)/K = G(I/K,1);$

Then $G_I(I,K) =$ ¶G/¶I = K ¶$[G(K,I)/K]$/¶I = K ¶ $g(I/K)$/¶I = $K\ g?(I/K)\ 1/K = g?(I/K)$. By the assumptions of the adjustment functions we know or can easily derive the following:

(8) $g?(I/K) > 0 < g??(I/K)$

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

(9) $l = u(G_I + l) = u(g? + l)$

Let $i = I/K$, then

(10) ¶ l/¶$i = u\ g??$ > 0 , by equation (8).

We just showed that the market value of one unit of capital good was higher when the investment rate was higher, ceteris paribus.

There may be another source of higher adjustment costs of computer 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 $\lambda_c > \lambda_o$. In our model, we can not distinguish the sources of high adjustment costs: higher investment rate or higher adjustment cost function parameters of computer investment.

Excess Marginal Product of Computer 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 be $G(I, K, t) = \Sigma_j G^j(I_j, K_j, t)$, additively separable. Then the output function can be restated:

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

Now we assume $\partial F/\partial K_j = \partial F/\partial K_j$ for all i and j. 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 $G^j = G^i$ 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 G^j's with respect to K_j equal to γ as in the above subsection. Under this formulation, the marginal product of each capital good is:

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

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 $\gamma(I/K)$ 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-computer 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 may estimate the adjustment cost parameters from the equation (12).

Econometric Issues of Market Valuation

The equation (7) of the above section represents our basic estimation equation, which equates the value of the firm to the shadow value of the capital assets *after* they are in place:

(7)' $$V = \sum_{j=1}^{J} l_j K_j$$

where λ_j is the shadow value of one unit of capital asset j . 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. Tobin's *q* is defined *dV/dK*, hence λ_i can be considered the Tobin's *q* value for a particular type of capital K_i .

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:

(13) $$V_{it} = a_i + \sum_{j=1}^{J} l_j K_{j,it} + X_{it}\, g + e_{it}$$

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

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.[5] This yields our base estimating equation which we will extend to include organizational investments:

(13)’ $$V_{it} = a_i + l_c K_{c,it} + l_p K_{p,it} + l_o K_{o,it} + controls + e_{it}$$

Here K_c, K_p, and K_o represents computer capital, physical capital, and other balance sheet assets, respectively.

There are two important 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 predicted problem of heterogeneity can be addressed by using a generalized (or weighted) least squares technique (GLS) to dampen the influence

[5] Return on assets captures short run profit effects that may influence stock market valuation. Advertising and R&D captures 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.

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 and/or endogeneity problem of market value and computer capital. 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).[6]

Data Sources and Construction

The data set used for this analysis is panel of computer capital and stock market valuation data for 1000 firms over the 1987-1994 time period. A brief description of each data source follows with additional detail in the data appendix.

Computer Capital: The measures of computer use were derived from the Computer Intelligence Infocorp 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 1000 companies that represent the total population in any given year). This database is compiled from telephone surveys that detail the ownership for 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 computer data do not include all types of information processing or communication equipment and are

[6] 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

likely to miss that portion of computer equipment that is purchased by individuals or departments without the knowledge of information systems personnel.[7]

Other Capital and Control Variables. 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.

Instrumental Variables. Three instrumental variables are used: computer price variable, a dummy variable indicating the existence of chief information officer (CIO), and the age of chief executive officer (CEO). Computer prices are based on National Income and Product Account (NIPA) by the U. S. Bureau of Economic Analysis (BEA). The data on the presence of CIO and the age of chief executive officer are gathered from Hoover's Handbook of American Companies (1996).

Overall, the full dataset includes 753 firms and 4578 observations over 8 years for market value and computer capital stock. When we match these data to the instrumental variables, we have data for 481 firms with the total of 3274 observations.

4. Results

Basic findings for market value of computers

The basic regression analyses (estimates of equation 8') for calculating the effect of computer on market value is shown in Table 1a. 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

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[7] Another potential source of error in this regard is the outsourcing of computer facilities. Fortunately, to the

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.[8]

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.[9] Figure 1 and figure 2 present the relative size of computer coefficients and those of other assets.

Balanced panel results from various specifications

In table 1b, we examine how robust this result is to variations in econometric methods. For this analysis we restrict the sample to a balanced panel[10] to get data consistency and apply different regression techniques: generalized least squares (GLS) and least absolute deviation (LAD) regression[11] to control for heteroskedasticity, and two stage least squares (2SLS) to control for reverse causality. Overall, the basic results consistent whether we

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extent that the computers reside on the client site, they will still be properly counted by CII's census.

[8] 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.

[9] 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.

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

[11] 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

use balanced or unbalanced panels and whether we correct for heteroskedasticity using GLS or LAD in both between and within regressions.[12]

The last column of table-1b 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. 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-1a and the rest of table-1b appear to be conservative. Other instrumental variable estimation results are discussed in the next subsection.

These regressions provide strong support our hypothesis -- 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 analysis 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

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bootstrapping techniques with 100 repetitions to obtain the empirical distribution of the coefficient estimates.

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

suggests substantial effects of firm-specific characteristics on the value of computer capital.

Instrumental Variable (IV) Estimation

Among our three instrumental variables, the computer price is time-varying-unit-invariant while the presence of CIO and the age of CEO at the end of the period (1994) is time-invariant-unit-varying. The first stage analysis is presented in table-3a. The first two columns present the results from log-log specification to get the elasticity coefficients, and the last two columns are the results from level specification.

The rapid price decline of computers leads to heavy computer investments during the last couple of decades. We should expect strong negative correlation between computer price and computer capital. During our sample period, the computer price drops by 70%.

As computer capital investments involve new skill development among workers and new organizational practices, one might think that younger generation of managers tend to exploit computer technology more enthusiastically. The rewards of learning knew knowledge should be higher for the younger, as their expected span to get benefits from the new knowledge is longer. In addition, the social environment for the younger to learn computer knowledge is more favorable. If this is the case, the age of managers may affect the computer investments. Conversely, a firm with heavy computer capital may tend to hire younger managers. In either case, the age of managers may have negative correlation with computer capital. In this sense the age of CEO can be an instrument of computer capital, since we cannot think of any reason why high market value firms hire younger managers.

Other variable considered is a dummy variable indicating the existence of position of chief information officer (CIO). For the last two decades, many firms created a new position to control corporate-wide computer related resources. Among our sample of firms, 34% of companies have chief information officer. It is likely for heavily computerized firms to hire a chief information officer. However, one might argue that a high market value firms may create CIO position as it is a fad during the last two decades. If this objection is right, then the CIO variable is not a very good instrument.

Results of the first stage analysis are given in table-2. The first two columns are in log specification and the last two are in level specification. In both specifications, the signs of coefficients are as expected and significant except for the CEO's age in level's specification. Controlling the industry effects with 2-digit SIC and 4-digit SIC does not make much difference.

The columns of table-3ba present results from two stage least squares from pooled estimation. All instruments are used after being multiplied by 2-digit SIC dummy variable. The first column is a non-IV estimate of the pooled model. The market valuation of computer capital estimated from sub-sample with instrumental variables is around 20, which is 33% larger than the estimate from the whole sample. The difference, however, is not statistically significant. The last three columns present results with various combinations of instrumental variables. The market valuation estimates range from 18 (with computer price instrument) to 27 (with CEO age instrument). When we include all three instruments in the pooled model as in the last column, the two stage least square procedure gives 20 for the computer coefficient.

In table-3b, we show results of IV estimation in the within and between models. As CEO age and CIO variable is time-invariant, we can use these variables only in the between model. Likewise, we can use computer price only in the fixed effect within model, as it is unit-invariant.

Sample Split: Manufacturing vs. Services

The computer capital's market valuation may differ across industries. The left half of table 5 shows the result of manufacturing versus non-manufacturing sample split exercise. There is no statistically significant difference in computer capital coefficients, which suggests that the adjustment costs are not significantly different across industries. This is consistent with the finding of Brynjolfsson and Hitt (1996) that the productivity effects of computerization do not differ statistically between manufacturing and non-manufacturing.

Sample Split: 1980s vs. 1990s

The right half of table 5 is the time dimension sample split. The first half comprises data from 1987 to 1990, and the second half from 1991 to 1994. There is some evidence that computer capital's valuation may have dropped during 1990's, but the difference in computer capital coefficients across time is not statistically significant at the 5% level.[13] Table 4 also presents the year-by-year estimation. The coefficients in all years are similar to those from between models.

Market Valuation of Computers and R&D Investment

As disscused in Section 2, this paper's market valuation equation is similar to Hall's (1993a, b) and Griliches's (1981). According to Hall (1993a), the market valuation of R&D capital has fallen during the 1980s. For the whole sample period from 1973 to 1991, her market value estimate of R&D capital is 0.48, which indicates sub-par valuation. During the seventies the market to book ratio of R&D capital is roughly-one-to one; but during the late eighties and early nineties the ratio drops to the range of 0.2 – 0.4.

Our matched sample of firms with computers and R&D investments comprises only 250 firms in manufacturing, which is one-tenth of the size of Hall's data and less than half of our full sample. The R&D capital is constructed by the same procedure with 15% depreciation rate described in Hall (1990), and used in Hall (1993a, b).

The first two columns of table 6a document the pooled estimation coefficients of various types of capital. The first column is the result from all manufacturing companies in our full sample. The second column documents the same regression results for those companies that reported R&D spending in Compustat. Again, computer's coefficients is around 18, and those of physical capital and other balance sheet assets are 0.9 and 0.7, respectively.

The last three columns of table 6a report the market valuation results including R&D capital. Here we combine both non-computer assets into one, because including too many variables causes the problem of multi-collinearity. With or without R&D, computer coefficient remains high, as shown in the center and last column of table 6a. Without computers, R&D capital's market valuation is 0.32, very similar to Hall's result. Including computers makes the R&D coefficient no longer significant.

Table 6b report similar regression results with a different specification. In fact, Griliches (1981) and Hall (1993a) used this log-ratio specification. The regression of table 6a is the replication of the Hall's including computers. As shown in the third column, the R&D's market valuation is 0.25, which is similar to Hall's result for the late eighties and early nineties although our sample size is just one-tenth of hers. The computer coefficient using this specification drops considerably to 2.3. In addition, adding R&D capital drops computer coefficient even further to 0.8.

The lower computer coefficient in this specification is not surprising. First, this specification relies on an approximation, $\log(1 + a) \sim a$., for small a. This approximation makes high intensity R&D firms or heavy users of computers more inaccurate. Griliches's

[13] However, we can reject the joint null hypothesis that all assets' coefficients are the same, which may, in part, reflect the consequences of the recession during the early 1990s.

or Hall's derivation of the specification is as follows. A firm's market value is the value of physical capital plus intangible assets:

$$V = K + b_1 C + b_2 R, \text{ with multiplicative error term.}$$

Here K is the physical capital, C is the computer capital and R is the R&D capital. Log transformation of the above equation gives:

$$\begin{aligned} logV &= log(K + b_1 C + b_2 R) + e \\ &= logK + log(1+ b_1 C/K + b_2 R/K) + e \\ &\sim logK + b_1 C/K + b_2 R/K + e \end{aligned}$$

Relaxing the restriction of coefficient one of physical capital and adding constant terms and control variables, we have the estimation equation:

$$logV \sim a + b_K logK + b_C C/K + b_R R/K + Controls + e$$

Observe the approximation: $log(1+ b_C C/K + b_R R/K) = b_C C/K + b_R R/K$.
If beta's or the ratios of C/K and R/K are high, then the approximation becomes increasingly difficult to justify. Our estimate of β_C was 20. For a mean firm, our estimate of β_1 C/K was nearly 40 %, which is well above the range of justifiable small value. Especially, this approximation becomes disproportionately worse for high intensity firms of R&D or computers; the coefficients are bound to be lowered by this stretching of x-axis without corresponding changes in the y-axis. In our sample some high computer intensity firms has the C/K ratio as high as 0.5. If we assume the true computer coefficient to be ten, for such firms the approximation, $log(1+ b_C C/K) \sim b_C C/K$, results in a very large error rate.[14]

[14] The reverse transformation of the approximation generates as an error of as much as 1,500 %. In fact, when we restrict the sample of firms to those with $C/K < 5\%$, (98.4% of the sample), the computer coefficient increases to 5.3, with a similar p-value. When we use 72.5% of the sample including firms with

Second reason, we believe this is also critical, is due to more mundane statistical properties of log transformation. The log transformation (logV) renders the variation of variables considerably smaller. On the contrary, dividing two variables (C/K or R/K) does not necessarily result in smaller variance. Contracting the variance of y-variable smaller without similar changes for the x-variable must lower the coefficient. These two reasons, we believe, account for most of drops in computer and R&D coefficients in the log-ratio specification. Nonetheless, the computer coefficient is still higher than those of other non-computer physical capital or R&D capital.

5. Discussion and Conclusions

The primary discovery of this paper is that the financial market puts a very high value on installed computer capital. Market valuations for each dollar of installed computer capital are at least four times greater than the market values for each dollar of conventional assets. This finding is robust to different data sources, numerous different estimating equations, and tests for endogeneity. Furthermore, the high financial market valuations for computer capital occur in both manufacturing and services industries and in both the 1980s and the 1990s.

This finding and our theoretical framework can shed light on two important questions in the IT research literature. First, do computers typically necessitate large hidden costs or do they create valuable intangible assets? Second, how can the "excess returns" found for IT in so many studies be reconciled with economic theory which predicts that all assets should earn a "normal" rate of return in equilibrium?

Computers Capital, Adjustment Costs and Intangible Assets

C/K <3%, the computer coefficient increases to 14; and when we use 60% of the sample with C/K < 2%, the coefficient increases to twenty, the same from the level specification.

Many researchers and practitioners have documented the difficulties of transforming organizations to exploit a new technology. As IT is a new technology still being developed rapidly, IT investments may accompany considerable changes in the structure and behavior of organizations. Not only are the costs of IT-enabled organizational change large, but there is a very real risk of failure.[15] Including these risks, the expected costs of embarking on a significant IT-based restructuring can be daunting.

A pessimist might bemoan these organizational costs, while an optimist is likely to celebrate the assets that are implicitly created in the process. Our model suggests that they are *both* right – confirming the maxim that "nothing good ever comes easy". Ironically, the very costs that firms incur when they undertake the organizational changes associated with computer using are the same factors that create barriers for competitors seeking to match the investment.

The formal relationship between hidden costs and intangible asset values can be shown mathematically, as we do in the section 3. However, the test of this hypothesis is that the stock market values a firm's installed computer capital much more highly than the equivalent amount of computer capital on the open market, before it has been integrated into any firm. For the high market valuation of installed computer capital to persist across eight years and across different sectors of the economy, it must reflect commensurately high costs of complementary assets. If not, firms would simply purchase more computer capital and arbitrage away any difference between the value of installed computer capital and computers on the open market.

Excess Marginal Product of Computer Capital

The excess marginal product of computer capital which has been reported in studies by Brynjolfsson and Hitt and others, can also be explained using the same framework. At

[15] Hammer and Champy, the leading proponents of "re-engineering" has himself estimated that up to 70% of all such efforts fail (Hammer and Champy, 1993).

equilibrium, after higher adjustment costs have already been incurred, the installed computer capital *must* contribute more to output than other types of capital, simply to compensate for the higher costs previously incurred as part of the investment. In other words, the existence of adjustment costs guarantees "excess" returns to already-installed capital.

Equivalently, the adjustment costs can be thought of as an investment in an invisible organizational asset. This asset tends to accompany its more visible partner, computer capital, bestowing higher returns wherever it is found. In equilibrium, the combined asset consisting of computer capital plus intangible assets may well earn normal returns, but if only the computer capital is actually measured, then computer capital appears to be earning excess returns.

In summary, our model and evidence support the hypothesis that installing computers not only requires adjustment costs, but also that it can create a valuable, if invisible, asset in the process. The managerial implication of the model and evidence is very clear. Be aware that IT implementation may cost up to ten times more than the installation of other physical assets. However, if computers are in place the financial market values their future contribution to the firms proportionally higher.

Recent stock market surge and increase in computer investments

During our sample period of 1987 – 1994, the mean of market value increased by 84% for our sample of firms in the balanced panel, from 5.0 billion to 9.2 billion. The computer capital increased by six-fold, from 16 million to 96 million. Using our estimates of computer capital's market valuation, we can ascribe the percentage of total increase of 4.2 billion to the increase of computer capital. Using our fixed-effect estimate of 5, 9.5 % of this market value increase can be viewed as computer's contribution to the increase of market value. By using between effect estimates of 20, 38% can be ascribed to the computer capital.

Using only stock value as the left-hand-side of variable makes the computer coefficient even higher. The fixed effect coefficient of computer capital is 10 and between effect coefficient is 30. Although this estimation is hard to justify theoretically, we can use these estimates in the calculation of contribution of computer capital. During the same period, the mean stock market value of our sample of firms increased by 77%, from 3.6 billion to 6.3 billion. Among this 2.7 billion increase, 29% can be attributed to the computer capital, when we use the fixed effect estimate. Astonishing 87% of the increase of stock market value may be attributed to the computer capital, when we use the between estimate.

Table 1a. Effects of various assets on firms' market valuation
Baseline Regressions of different models

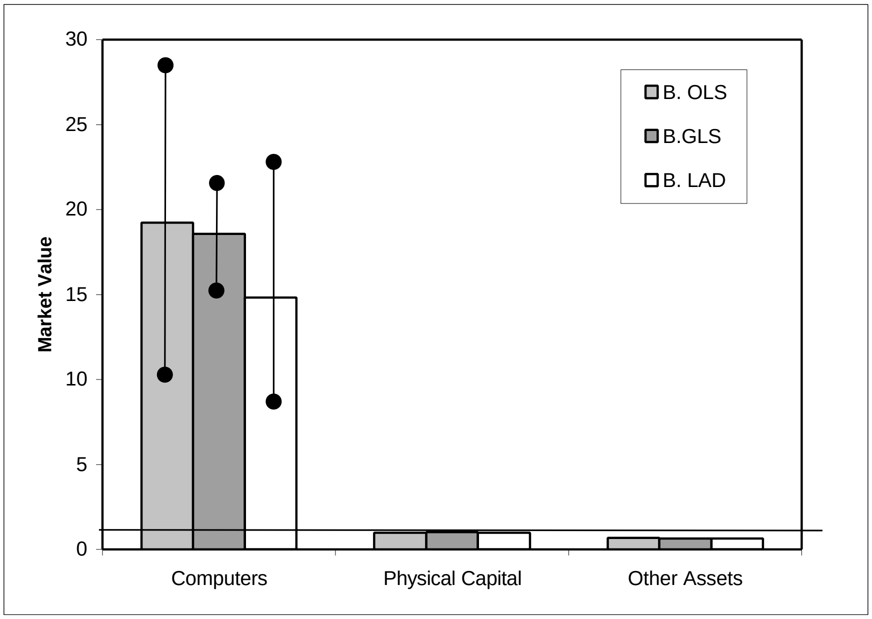
Market Value	Pooled OLS	Fixed Effect Within w/Year	Fixed Effect Within wo/ Year	Between OLS
Computer	15.192***	5.076***	6.419***	19.218***
Capital	1.158	0.891	0.839	2.859
Physical	0.967***	1.147***	1.251***	0.960***
Capital	0.020	0.053	0.053	0.037
Other	0.691***	0.830***	0.829***	0.664***
Assets	0.008	0.012	0.012	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	0.8758	0.729[a]	0.721	0.887
Observations	4578	4578	4578	4578

Key: * - p<.1, **- p<.05, *** - p<.01
a: in fixed models we report within variation R square

Table 1b: Effect of various assets on firms' market valuation
Balanced panel only, between and within regressions

	Between Regression			Fixed Effect Within Regression		
	OLS	GLS	LAD	GLS	LAD	2SLS
Computer	22.285***	18.540***	14.824***	5.584***	4.308***	9.945***
Capital	4.193	1.464	3.545	0.921	1.154	2.329
Physical	0.968***	1.014***	0.984***	1.244***	1.169***	1.069***
Capital	0.049	0.016	0.019	0.055	0.113	0.057
Other	0.654***	0.656***	0.652***	0.811***	0.814***	0.820***
Assets	0.024	0.010	0.088	0.015	0.086	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	0.892	0.869	0.675	0.681	0.836	0.670
Observations	3312	3312	3312	3312	3312	3312

Figure 1. Relative size of market valuation : Between estimates



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

Figure 2. Relative size of market valuation: Firm effect within estimates

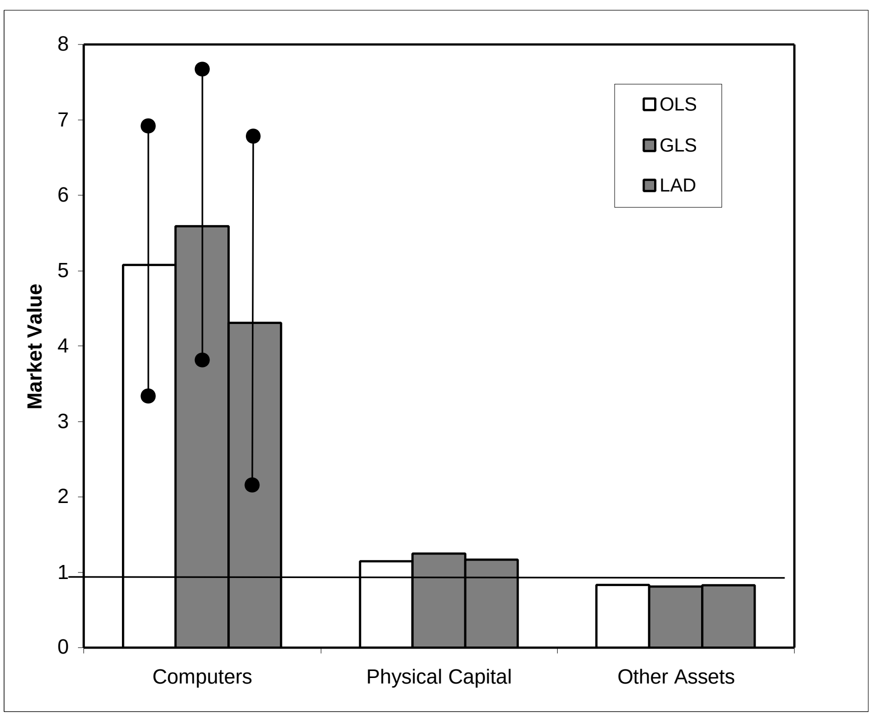


Table 2: First stage analysis of instrumental variable estimation (Pooled Estimation, Robust Standard Errors)

	Elasticity Specification		Level Specification	
	SIC 2-digit	SIC 4-digit	SIC 2-digit	SIC 4-digit
Computer Price	-0.994*** 0.038	-1.017*** 0.035	-76.98*** 5.120	-82.2*** 5.028
CIO presence	0.336*** 0.030	0.347*** 0.033	13.370*** 2.418	7.540** 2.711
CEO age	-0.014*** 0.002	-0.010*** 0.003	-0.093 0.120	0.051 0.163
Physical Capital	0.379*** 0.024	0.409*** 0.028	0.004*** 0.001	0.004*** 0.001
Other Assets	0.500*** 0.024	0.454*** 0.027	0.002*** 0.0002	0.002*** 0.0002
Controls	ROA SIC 2*** Year***	ROA SIC 4*** Year***	ROA** SIC 2*** Year***	ROA SIC 4*** Year***
R square	0.712	0.8023	0.4921	0.5888
Observations	3724	3724	3724	3724

**Table 3a: IV estimation, Pooled Regression
(Robust Standard Errors)**

	No IV	Comparing Various Instruments			All Three
Instruments		Price	CIO	CEO age	IV's
Computers	20.237*** 3.745	18.336*** 6.203	25.012*** 6.295	27.829*** 6.571	20.150*** 4.511
Physical Capital	0.988*** 0.069	0.990*** 0.067	0.981*** 0.072	0.977*** 0.068	0.988*** 0.069
Other Assets	0.673*** 0.042	0.679*** 0.050	0.657*** 0.040	0.648*** 0.045	0.673*** 0.043
Controls	ROA*** R&D** Adv. Year*** Industry***	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	0.8819 3274	0.8819 3274	0.8816 3274	0.8810 3274	0.8819 3274

Note: Instrumental variable is used after being multiplied by 2-digis SIC dummies.

**Table 3b: IV Estimation, Between and Fixed Effect Regression
(Robust Standard Errors)**

	Between Models		Within Models	
	No IV	IV (CIO&CEO)	No IV	IV (Computer Prices)
Computers	27.193*** 4.621	20.832*** 4.053	6.663*** 1.181	16.787*** 4.390
Physical Capital	0.985*** 0.059	1.040*** 0.046	1.119*** 0.063	1.042*** 0.210
Other Assets	0.636*** 0.026	0.631*** 0.030	0.827*** 0.014	0.792*** 0.061
Controls	ROA*** R&D Adv. NA Industry***	ROA*** R&D*** Adv.*** NA Industry***	ROA*** R&D Adv. Year*** Firm***	ROA*** R&D* Adv.* Year*** Firm***
R square Observations	0.9034 3274	0.8964 3274	0.7434 3274	0.7247 3274

Table 4: Year-by-Year Fluctuation of Market Valuation (robust standard errors)

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
Controls	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

Table 5: Split Sample (robust standard errors)

Market Value	Manu-facuring	Non-manu-facturing		First Half	Second Half
Computer Capital	17.689*** 4.075	20.740*** 6.401		21.655*** 9.168	13.829*** 3.608
Physical Capital	0.903*** 0.075	0.994*** 0.067		0.925*** 0.065	1.014*** 0.097
Other Assets	0.726*** 0.043	0.399*** 0.056		0.663*** 0.040	0.698*** 0.062
Controls	ROA*** R&D** Adv.** Industry*** Year***	ROA*** R&D Adv. Industry*** Year***		ROA*** R&D Adv. Industry*** Year***	ROA*** R&D Adv Industry*** Year***
R square Observations	0.894 2989	0.819 1591		0.907 2179	0.863 2399

Table 6a: Computers and R&D (Level Specification)

Market Value	All Manu-facturing	R&D Companies		R&D Companies			
					Computer	R&D	Both
Computer Capital	17.689*** 1.507	17.724*** 1.688		Computer Capital	21.349*** 1.597		20.908*** 1.646
				R&D Capital		0.317*** 0.076	0.084 0.076
Physical Capital	0.903*** 0.025	0.863*** 0.033		Physical + + Other Assets	0.835*** 0.008	0.860*** 0.011	0.827*** 0.010
Other Assets	0.726*** 0.010	0.736*** 0.011					
Controls	ROA*** R&D** Adv.** Industry*** Year***	ROA*** R&D** Adv.** Industry*** Year***		ROA*** Adv.** Industry*** Year***	ROA*** Adv.** Industry*** Year***	ROA*** Adv.** Industry*** Year***	ROA*** Adv.** Industry*** Year***
R square Observations	0.894 2989	0.912 1920		R-square Observations	0.917 1920	0.91 1920	0.917 1920

Table 6b: Computers and R&D (Log-Ratio Specification)

Log(Market Value)	All Manu-facturing	R&D Companies		
		Computer	R&D	Both
Log(Physical Capital)	0.910*** 0.008	0.909*** 0.009	0.904*** 0.009	0.908*** 0.009
Computer/Physical Capital	2.263*** 0.209	2.217*** 0.246		0.834*** 0.251
R&D/Physical Capital			0.250*** 0.019	0.218*** 0.021
Controls	ROA*** Adv.** Year*** Industry***	ROA*** Adv.** Year*** Industry***	ROA*** Adv.** Year*** Industry***	ROA*** Adv.** Year*** Industry***
R square Observations	0.844 2989	0.877 1920	0.882 1920	0.883 1920

Appendix: Data Description

The variables used for this analysis were constructed as follows:

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]. Other 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. Other asset variable is constructed 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, b). She applied 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 firms in our sample report R&D expenses. The missing values are filled in using 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.

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).

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