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Abstract

A model is presented of how the financial market valuation of firms can be used to estimate the intangible costs and benefits of computer capital and several new empirical results based on this model are presented. Using eight years of data for over 1,000 firms in the United States, the study finds 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.

The model suggests that intangible assets can provide an 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.

"matter itself is only a deposit, a stratum, which yields only to the most meticulous examination what constitutes the real treasure hidden within"
—Walter Benjamin, *A Berlin Chronicle* (1970)

"When I was a kid in the bank, the key economic indicator we looked at was freight-car loadings. Who the hell cares about them now? What we need is a way to measure the knowledge we bring to the work we do."
—retired Citicorp chairman Walter Wriston

1. INTRODUCTION

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 twentieth 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.

A 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 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 10 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 199; Hitt and Brynjolfsson 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 without cost. In other words, they have created a new asset.

This paper argues that the intellectual, cultural, organizational ,and interorganizational 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 here all will simply be included under the rubric of “intangible assets.”

For the purposes of this study, there is no need to assume that IT “causes” the creation of intangible assets or vice-versa. Instead, the hypothesis that intangible assets complement information technology capital just as software complements computer hardware is tested. 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 interorganizational relationships. Hence, a dynamic optimization model is developed 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 the 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 1,00 firms over a period of eight years, the study 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 are here called 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.

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 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 Black and Lynch (1996), Brynjolfsson and Hitt (1995, 1996), Dewan and Min 1997), Greenan anMairesse (1996), and Lichtenberg (1995).

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 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 that 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 that are associated with the 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.

[1]See, for example, Strassmann (1990).

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

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, the following hypotheses can be asserted:

> **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.

The analysis of data from over 1,000 firms over eight years finds evidence that the financial markets do in fact value each dollar of computer capital at up to 10 times the valuation placed on a dollar of conventional capital.

The remainder of the paper is organized as follows. In section 2, some of the relevant research is summarized. In section 3, the estimation equations are derived from a dynamic optimization model in which both computers and market valuation are endogenous. In the fourth section, several empirical results are presented 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 (Barua et al. 1991 Loveman 1994), 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 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 research and development (R&D), estimating the stock market valuation of R&D capital is a common strategy. Griliches (1981) was one of the pioneers using this measure of R&D performance and more recently Hall (1993) documented declining R&D market value in the 1980's. 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 computer capital is added as an explanatory regressor.

[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).

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 Hayashi (1982), Lucas (1967), Tobin (1969), and especially, Wildasin (1984).

3. ECONOMETRIC MODEL AND DATA

3.1 Derivation of Econometric Model

If one assumes that firms seek to maximize profits, not just for the current year but for future years, and if market value reflects these profits, then one can derive the following equations. A firm maximizes its market value V(0) at time t = 0, which is equal to the discounted profit stream $\pi(t)$ by the discount factor u(t):

$$(1)\quad V(0) = \int_0^\infty \pi(t)u(t)dt$$

In turn, the profits at time t can be written as a function of the price of the firm's output (p), the amount of output it can produce using capital inputs equal to K and labor inputs equal to L (F(K,L,t)), wages of labor (w), the quantity of labor (L),[4] the price of capital goods (z) and investments in capital (I). In addition, it is posited that there will be some adjustment costs taking the form of lost output $\Gamma(I,K,t)$. This yields the following profit[5] equation:

$$(2)\quad \pi(t) = p(F(K,L,t) - \Gamma(I,K,t)) - wL - zI$$

In other words, the profit at time t is equal to the price of output times the quantity of output that can be produced less adjustment costs, minus labor costs, minus capital investment costs.

If there were no adjustment costs, and inputs can be freely purchased on the open market, then the market value of the firm, V, would simply be equal to the sum of the value of all its existing capital assets.[6] If there are J different types of capital assets, this yields:

$$(3)\quad V = \sum_{j=1}^{J} K_j$$

However, if there are adjustment costs required in order to make a unit of capital effective, then the value of the firm will be *greater* than the sum of the values of the separate capital assets. The difference between the value for the firm and the value of the separate assets reflects the adjustment costs that would be required to extract value from the separate assets, or equivalently, the investments that the firm has made in intangible assets.

[4]For simplicity and without loss of generality, L is used to represent not only labor, but also all other variable costs, i.e., flow inputs. Similarly, K represents all stock inputs

[5]In accounting terms, this is the expression for cash flow, not profit. However, the paper follows the convention in the literature on Tobin's q (e.g., Wildasin 1984) and use the term "profit" which reflects the long-run equilibrium of cash flow and profit streams.

[6]The formal derivation of the following equations in this section is provided in the appendix.

Specifically, the following result can be derived, which equates the value of the firm to the shadow value of the capital assets *after* they are in place:

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

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 versus 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.

The strategy is to directly estimate the λ's using the variance across firms and over time in the panel data. Because the relationship between market value and capital assets may vary depending on the industry in which the firm operates, the year of the observation, or other factors, a vector of control variables, X, needs to be included in the estimation equation. Finally, a constant term, α_i, and an error term, ϵ_i, are included to derive the estimating equation:

$$(5)\quad V_{it} = \alpha_{it} + \sum_j \beta_j K_{itj} + X_{it}\gamma + \varepsilon_{it}$$

Here, i, t, j are indices of firms, time, and different capital goods, respectively.

Alternatively, a formulation with log transformation of output and all capital variables is also possible. [7]

$$(6)\quad \ln(V_{it}) = \alpha_{it} + \sum_j \beta_j \ln(K_{itj}) + X_{it}\gamma + \varepsilon_{it}$$

Depending on the assumptions about the the nature of the constant and the error term, different estimating techniques will be appropriate. If it is assumed that the constant term does not vary across firms or years ($\alpha_{it} = \alpha$) and the error terms are identically and independently distributed, then the equation can be estimated by ordinary least squares (OLS) on the pooled data. Alternatively, α_i may be a firm-specific constant term, which calls for firm-effects estimation techniques. α_i, the firm-effect, may be treated as random, in which case random-effects estimation is performed. Furthermore, when non-spherical error terms are present, generalized least squares (GLS) should be more efficient than OLS. Finally, to better understand the robustness of the results, maximum likelihood estimation can also be performed and the time dummies can be included.

In keeping with the existing literature on estimates of Tobin's q, the other control variables, X, return on assets, return on investments, R&D expenditure, advertising expenditure, industry dummies, and in some cases output will be included..

3.2 Data Sources and Construction

Two different data panels were constructed.

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[7]In equation (5), the estimated market value of K_j is $\partial V/\partial K_j = \alpha_j$, while in the equation (6) it is $\alpha_j V/K_j$.

IDG panel: The computer stock data for the first panel was provided by International Data Group (IDG). A detailed description of the this data set can be found in Brynjolfsson and Hitt (1993) and Lichtenberg (1995). This panel combined three different sources: IDG computer capital, Stern Stewart Performance 1000 dataset's market value and other capital,[8] and Hall's (1993) construction of R&D stock. The latter two data sources were in turn constructed from Standard & Poor's Compustat. This panel includes 380 different firms over five years from 1988 to 1992. Because observations for some firms are not available for some years, this panel has approximately 1,000 observations.

CI panel: The second panel is constructed based on a completely separate and independent database provided by the Computer Intelligence (CI) Corporation. A more detailed description of data items in the CI panel can be found in Brynjolfsson and Hitt (1997).[9] Other data items are extracted directly from Compustat. This panel spans 1,031 firms in eight years from 1987 to 1994 for a total of over 5,000 observations.

Most of the results are based on the CI panel because it is more comprehensive. Both of these panels are subject to measurement error, which may reduce the precision of the estimates in this paper. The large size of the sample mitigates the problem to some extent. Furthermore, because two data panels were constructed from several independent sources, systematic biases across variables should be reduced. The findings are remarkably similar regardless of which data set is used for the estimation, which bolsters our confidence in the overall results.

4. RESULTS

4.1 Basic Findings with Industry and Firm Effects Models

The main results obtained from the CI panel are presented in Table 1(a and b), traditional pooled estimation, and Table 2 (a and b), panel estimation with firm effects.

Tables 1a and 1b show the results of traditional pooled regressions with year and dummy variables for each of 82 different industries (industry effects model). In Table 2b, the same regressions are presented for a completely balanced panel of firms.[10] Non-computer capital is subdivided further into physical capital, such as property, plant, and equipment, and other assets, such as goodwill, inventories, and account receivables. According to the point estimates, the financial market puts value of about $15 on each dollar of installed computer capital. This is consistent with the hypothesis that computers are associated with the creation of substantial intangible assets. The market valuation for other physical capital is about one dollar per dollar of book value, but it is only about 70 cents on the dollar for other assets. These coefficients and those of other variables are close to those predicted by the theory.[11]

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[8]Stern Stewart Management Services (1994). The market value is the sum of the equity value plus the adjusted debt value using term structure and risk. In other words, this is the financial market's valuation of a firm's total assets.

[9]CI constructs a yearly database that details information technology spending for Fortune 1000 firms. Their estimates of the total value of the computer stock are used, including the central processors, personal computers, and peripherals.

[10]The results are essentially the same as those of Table 1a, which suggests that firms with missing data are not significantly different from firms for which complete data are available. The reported t-values are based on Newey-West robust standard errors, which take into account very general non-spherical error structure, including heteroscedasticity and serial correlation.

[11]Return on assets has strong effects on market value, while R&D intensity has some. The advertisement intensity has a big standard error, so the coefficient cannot be estimated precisely. Only half of firms report R&D, and less than a third report advertisement expenditure. R&D and advertisement of two-digit SIC industry were averaged out and the average for the firms who do not report was used. When the dummy variable approach for the non-respondents is used, the results are similar.

Table 1. Pooled Estimation

Table 1a. Pooled Estimation (Level Specification, Robust Standard Errors)

Market Value	Coefficient	t-value	Scale Control Coefficient	Scale Control t-value
Computer Capital	15.399	4.771	14.855	4.180
PP&E	0.975	15.582	0.887	9.801
Other Assets	0.689	16.065	0.660	8.582
ROA	112.905	3.428	111.167	3.398
R&D intensity	5284.771	1.679	4723.739	1.582
Advertisement intensity	-766.692	-0.306	-1049.507	-0.409
Sales			0.070	0.698
Industry (SIC 2 digit)		significant		significant
Year dummies		significant		significant
Number of obs	4578		4578	
R^2	0.876		0.876	

Table 1b. Pooled Estimation (Balanced Data Only, Robust Standard ERrors)

Market Value	Coefficient	t-value	Scale Control Coefficient	Scale Control t-value
Computer Capital	16.029	4.539	15.551	4.016
PP&E	0.972	14.955	0.893	9.449
Other Assets	0.686	16.080	0.661	8.640
ROA	138.618	2.407	137.143	2.390
R&D intensity	6929.788	1.540	6124.522	1.445
Advertisement intensity	-2203.558	0.664	-2404.565	-0.718
Sales			0.062	0.603
Industry (SIC 2 digit)		significant		significant
Year dummies		significant		significant
Number of obs	3481		3481	
R^2	0.8761		0.8764	

One concern with the pooled estimation may be that it does not control for unrelated firm differences in market value and computer use. It is possible certain types of firms have both high market value and high computer capital for some other reason. To take into account this potential firm heterogeneity, several firm effect models are estimated. These models are among the most stringent tests of computer capital's market value.[12] Tables 2a and 2b present the results of firm effect models. The coefficients are statistically different from those of the pooled models.[13] This

[12]The firm effect models essentially include a separate dummy variable for *each firm* to control heterogeneity among firms. However, this strategy sometimes may be an over-correction, since we may still be interested in how the financial market values different firms with different computer stock. Similarly, year dummies aim to control the year-by-year fluctuation, but the ye ar control effects are also a potential over-compensation.

[13]The null hypothesis of no difference can be rejected with a 1% confidence level. With Newey-West robust standard error, we can reject the null of same coefficients with 10% confidence level.

Table 2. Panel Estimation

Table 2a. Panel Estimation (Log Specification), CI Panel

	Fixed Effect — Within	**Random Effect GLS**	**Scale Control, Random E. GLS**
variables	**Coefficient** (t-value) Market Value	**Coefficient** (t-value) Market Value	**Coefficient** (t-value) Market Value
	0.067	0.063	0.062
Computer Capital	11.621	11.770	11.406
	8.270	7.790	7.690
	0.783	0.862	0.619
Non-Computer	59.118	89.903	45.427
Capital	0.700	0.770	0.560
ROA	0.012	0.015	0.014
	18.037	23.185	21.051
R&D	0.057	0.495	0.774
	0.156	1.662	2.638
Advertisement	-0.332	1.090	1.405
	-0.611	2.896	3.527
Sales			0.263
			16.414
Number of obs	4577	4577	4576
R^2 overall	0.7673	0.8695	
within	0.5593	0.5571	
between	0.7760	0.8872	

*GLS, generalized least squares.
*Including year and SIC 2 dummies.

implies that differences among firms are important, even within a two-digit industry; and the firm-effects models presented in Tables 2a and 2b are preferred, if we want to control the firm differences in market values and computer investments.

In Table 2a, the log specification of firm effect models is used to estimate the elasticities of computer capital to market value. Table 2b presents comparable results for the estimation of level specification. Interestingly, the implied mean market values of computer capital in both models are remarkably similar. In the log linear model, the estimates are fairly precise, ranging from 0.067 to 0.062, with t-statistics of about 8. The market valuation of a dollar of computer capital, that is the estimated q-value for computers, can be calculated by differentiating equation (6): $\partial V/\partial K_j = \alpha_j V/K_j$. Depending on different specifications, the estimated q-value for computer capital ranges from 7.7 to 8.2.

These estimates indicate that for every one dollar increase in computer capital that a firm has installed, the stock market value of the firm increases by about eight dollars, after controlling for changes in all other tangible assets and

Table 2. Panel Estimation (continued)

Table 2b. Panel Estimation (Level Specification), CI Panel

variables	Fixed Effect — Within **Coefficient** (t-value) Market Value	Random Effect GLS **Coefficient** (t-value) Market Value	Scale Control, Random E. GLS **Coefficient** (t-value) Market Value
Computer Capital	6.613	8.288	7.138
	7.929	10.173	8.772
PP&E	1.248	1.029	0.764
	23.805	31.320	17.295
Other Assets	0.830	0.790	0.749
	68.381	77.148	66.719
ROA	36.838	43.073	40.488
	5.789	6.903	6.564
R&D Intensity	8121.969	7342.307	6342.346
	1.508	2.008	1.730
Advertisement Intensity	-0575.726	-5358.548	-5022.170
	-2.683	-1.837	-1.728
Sales			0.196
			9.053
Number of obs	4578	4578	4578
R^2 overall	0.8519	0.87	0.8684
within	0.7218	0.7205	0.7329
between	0.8715	0.8887	0.8867

*SIC 2 digit is used as dummies.

possible heterogeneity across firms. This finding further supports the basic hypothesis that computer capital is associated with the creation of substantial intangible assets. The large adjustment costs that firms incur when installing computer capital, including custom software, training, restructuring, and development of new relationships with suppliers and customers, appear to create intangible assets with a clearly measurable economic value. The estimates imply that these intangible assets dwarf the directly measured value of computer hardware that shows up on the balance sheet.

Using these regressions, we can formally test how much more valuable a unit of installed computer capital is as compared to other types of capital. The null hypothesis that the installed computer capital is valued less than four times as much as other physical capital in the market can be rejected at the 5% confidence level.[14] For this to be an equilibrium relationship, the organizational adjustment costs associated with installing a dollar's worth of computer capital must be at least four times greater than the adjustment costs for ordinary physical capital. If this were not the case, then firms would be able to boost their market value simply by investing more heavily in computers.

[14]The test is based on the result of the first column in Table 2b, the most conservative estimates among the results. At the 1% level, we can reject that IT capital is valued less than three times as much as other physical capital.

4.2 Robustness

The robustness of the basic results to alternative data sources and specifications are now examined.

Table 3 presents the regression results obtained from the IDG panel. The coefficients and the implied market values are remarkably similar to those of Tables 1 and 2, although due to the smaller size of sample the standard errors of the estimates are about twice as high as the CI panel results. Once again, the implied market value of one unit of installed computer capital ranges from 5.7 to 7.8, which is about five to seven times higher than that of other capital.

4.3 Scale Effects

The strong association between computers and market value could be spurious if an increase in firm scale, as measured by sales, leads to both an increase in the market value and also an increase in computer capital stock. The last columns of Tables 1a, 1b, 2a, and 2b are not consistent with this alternative hypothesis. In these regressions, total sales is included as an explanatory variable, but the change of the computer capital coefficient is essentially nil.

4.4 Ratio Specifications

Table 4 presents two related regressions using ratios. In column one, both the dependent variable and computer capital are divided by total assets. Tobin's *q* (market value divided by total assets) is found to have a significant association with the computer intensity (computer capital divided by other physical capital). In the second column, the effect of computer intensity on current profitability, as measured by return on assets (current profits divided by total assets) is looked at directly. Interestingly, the paper finds that computer intensity is not correlated with current profitability.[15] Because the market value of the firm is supposed to equal the net present value of all future profits, this appears to conflict with the other results. However, if computer capital does in fact require additional organizational investments in the short run, but leads to higher profits in the long run (as a return on these investments), then we should expect the correlation with *current* profits (as traditionally measured) to be lower than the correlation with long run profits.[16]

4.5 Endogeneity and Reverse Causality

Another important concern is endogeneity. A same shock may affect both computer capital and market value, thereby leading to biased estimation of their true relationship. In addition, the causality may be reversed: perhaps firms with high stock market values decide to go on computer capital investment binges.

Table 5 shows two similar approaches to deal with these problems. The upper part of the table presents the result of two-stage least squares using computer prices in the U.S. economy, industry dummies, and their interaction as instrumental variables.[17] As seen in Table 5, the point estimates do not change much from Table 1a, although the standard errors increase a bit, as expected.

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[15]Hitt and Brynjolfsson (1996) also found no significant profit effect for intensity. Their intensity measure is IT capital per employee.

[16]However, the explanatory power of the profitability regressions, as measured by R^2, is fairly low so we are hesitant to attach too much significance to this finding.

[17]Using prices as instruments for an input is not always a good idea, since an increase in demand may boost a firm's market value, and also increase input demand, and thus increase input prices. However, in the case of computers, the changes in prices due to supply shifts, which are dictated by Moore's law, are an order of magnitude larger than any exogenous shifts in the demand curve. Brynjolfsson (1996) used this fact to estimate the demand function of computers.

Table 3. Robustness Check: IDG Panel

	Without R&D	With R&D
variables	Coefficient (t-value) Market Value	Coefficient (t-value) Market Value
Computer Capital	***0.0669***	***0.0919***
	6.69	4.595
	5.70	**7.80**
Other Capital	0.809	0.72
	40.45	24
	1.04	0.92
R&D Stock		0.068
		2.27
Number of obs	1064	546
R^2	0.85	0.82

* all coefficients are elasticities, the regressions are based on log-linear form

Table 4. Computer Intensity Versus Market Value and Profit, CI Panel

Dependent variable: MV/TA		Dependent variable: ROA		
	Fixed-effects		Sector Effects	Fixed-effects
variable	Coefficient t-value	item	Coefficient t-value	Coefficient t-value
C/PPE	0.015	C/PPE	0.392	-0.778
	2.753		1.11	-1.377
ROA	0.012	MV/TA	5.37	2.303
	20.252		42.12	16.754
RD/TA	0.021	CFL/OUTPUT	28.07	50.19
	1.505		36.41	42.21
AD/TA	0.009	RD/TA		5.575
	0.796			1.317
		AD/TA		23.109
				7.095
obs	4577	obs	4734	4569
R^2		R^2		
overall	0.2795	overall	0.6218	0.421
within	0.0855	within		0.572
between	0.388	between		0.382

Variable Legend

- MV: Market Value
- C: Computer Capital
- PPE: Property, Plant, and Equipment
- ROA: Return on Assets
- TA: Total Assets
- RD: Research and Development Expenditure
- AD: Advertisement Expenditure
- CFL: Free Cash Flow
- OUTPUT: Sales Volume

Table 5. Address Potential Endogeneity

Instrumental Variable Estimation (Level Specification, CI Panel)

Market Value	**Coefficient**	**t-value**
Computer Capital	15.365	3.549
PP&E	0.975	42.658
Other Assets	0.689	44.966
ROA	112.915	12.361
R&D Intensity	5293.923	1.943
Advertising Intensity	-766.572	-0.32
Number of obs	4578	
R^2	0.8756	
Adjusted	0.8738	

*Computer prices x SIC 2 digit dummies are used as instruments

System of Equations 1 (Level Specification: SUR Estimation)

LHA: Market Value			**LHS: Computer Capital**		
variable	Coefficient	t-value	variable	Coefficient	t-value
Computer Capital	29.902	26.415	Market Value	0.004895	26.871
PP&E	0.939	47.012	PP&E	-0.0025	-8.059
Other Capital	0.644	77.846	Other Assets	-0.00051	-3.075
ROA	106.329	11.636	ROA	-0.24381	-2.075
Advertising Intensity	-721.391	-0.307	Computer Price	-44.5294	-13.707
R&D Intensity	4794.853	1.973			
Number of obs	4577			4577	
R^2	0.8757			0.4993	

System of Equations 2 (2 Year Lags: SUR Estimation)

LHS Market Value			**LHS: Computer Capital**		
variable	Coefficient	t-value	variable	Coefficient	t-value
Com.Capital (-1)	19.596	5.729	Market Value (-1)	0.003014	6.948
Com Capital (-2)	11.548	2.540	Market Value (-2)	0.001826	4.012
PP&E	0.981	36.997	PP&E	-0.002503	-5.917
Other Capital	0.663	61.455	Other Assets	0.000086	0.426
ROA	117.034	9.674	ROA	0.039048	0.254
Advertosomg Intensity	-1159.501	-0.330	Computer Price	-43.5794	-12.77
R&D Intensity	7348.553	2.098			
Number of obs	3060			3060	
R^2	0.87			0.51	

*SIC 2 digit and year dummies are used.

The lower part of Table 5 is the result of a simultaneous equation regression model, which is a second way to correct for endogeneity. The first equation is the usual market valuation regression and the second equation is the regression for computer inputs. This is a direct test for reverse causality. R&D and advertisement variables in the first equation work as instruments for market value variable of the second equation. Conversely, the computer price variable is

Table 6. Divided Sample Estimation (Level Specification, Robust Standard Errors)

	manufacturing		**non-manufacturing**		**First Half**		**Second Half**	
Market Value	Coef.	t-value	Coef..	t-value	Coef.	t-value	Coef.	t-value
Computer Capital	**17.99796**	4.463	**20.7396**	3.24	**21.65528**	2.362	**13.829**	3.833
PP&E	0.914768	11.831	0.99428	14.806	0.925491	14.147	1.01398	10.42
Other Assets	0.72231	16.705	0.39914	7.093	0.662732	16.765	0.69791	11.323
ROA	112.4522	2.637	111.078	4.864	121.2981	5.156	108.121	2.428
R&D Intensity	7060.405	1.994	7000.93	1.192	6174.064	1.662	4594.15	0.958
Advertising intensity	-2614.02	-1.003	21139.2	2.097	-776.979	-0.298	-969.88	-0.227
Number of obs	2987		1591		2179		2399	
R^2	0.8941		0.8185		0.9066		0.8627	

*SIC 2 digit and year dummies are used.

an instrument for the computer capital of the first equation. In the simultaneous equation model, it is found, the computer coefficient and its t-value increased compared with Table 1a. Thus neither of the corrections for the endogeneity problem affected the significance of the basic results. Finally, the system was estimated with lagged variables and similar results were found. The sum of the coefficients of lagged variables is roughly equal to the coefficient of the current variables in the previous formulation. The results suggest that there is some causality in both directions, reflecting a mutual reinforcement of market value and computer capital stock.

4.6 Manufacturing Versus Services

The computer capital's market valuation may differ across industries. The left half of Table 6 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.

4.7 1980s Versus 1990s

The right half of Table 6 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 1990s, but the difference in computer capital coefficients across time is not statistically significant at the 5% level.[18]

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

[18]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.

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 the 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?

5.1 Computers Capital, Adjustment Costs, and Intangible Assets

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.[19] 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. The model presented here 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 usage 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 is done in the appendix. 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.

5.2 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 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.

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[19]Hammer and Champy (1993), the leading proponents of "reengineering," have estimated that up to 70% of all such efforts fail.

In summary, the model and evidence presented here 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 10 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.

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Appendix

Mathematical Notes: Derivation of the Estimating Equations

Much of this derivation is adopted from Hayashi (1982) and Wildasin (1984). We first consider the case in which there are no adjustment costs associated with new investments, so that the profit stream can be written:

A.1 $\pi(t) = p\, F(K,L,t) - w\, L - z\, I$

All the notations follow the main text. The stock input vector K and the investment vector I are connected by the following depreciation rule.

A.2 $\dot{K} = I - D \bullet K$, where $D = \begin{bmatrix} \delta_1 & 0 & . & 0 \\ 0 & \delta_1 & . & 0 \\ . & & . & . \\ 0 & 0 & . & \delta_1 \end{bmatrix}$

.

D is the depreciation matrix of which j[th] diagonal element represents the depreciation rate of the capital good K_j. Under the assumption that there are no adjustment costs, the firm's problem at time t = 0 is to maximize V(0) of equation A.1 subject to the constraint, equation A.2.

The adjustment costs can be thought of as destroying some of the output or as destroying a fraction of the invested good. In the literature, these two alternative forms of adjustment cost functions have been proposed. Let Γ(I,K,t) be the lost output when the firm with capital K, invests I at time t. In addition, as the capital is destroyed during installment, the above equation of motion (2) may be changed into the following:

A.3 $\dot{K}{-}j = \psi_j(I_j,K_j,t)\ \delta_j \bullet K_j$, for all j = 0, 1,...,J.

We will drop subscripts and write $\psi(I,K,t)$ as a vector-valued function satisfying the above equation (3), for the sake of simplicity. If adjustment costs exist, then the vector relationship $I \geq \psi(I,K)$ is satisfied for all values of I and K. For the sake of convenience, we also define $\phi(I,K,t) = (I - \psi(I,K,t))$, lost capital during installation.

We need the following assumptions to make the analysis more tractable.

(1) $\Gamma(I,K)$ and $\psi(I,K)$ are linearly homogenous functions over I and K; (2) $\Gamma(I,K)$ and $\psi(I,K)$ are twice continuously differentiable in I and K; (3) $\psi_j(0,Kj) = \Gamma(0,K) = 0$ for all j and $\psi(I,K) \geq 0 \leq \Gamma(I,K)$; (4) $\Gamma_I > 0 < \psi_I$, and $\partial^2\Gamma/\partial I\partial I'$, $\partial^2\iota/\partial I\partial I'$ are respectively positive and negative definite (convex and concave, respectively).

Now the profit function with adjustment costs can be written:

A.4 $\pi(t) = p(F(K,L,t) - \Gamma(K,I,t)) - wL - z(I + \varphi(I,K,t))$

The first term is the output, the second term is the costs of variable inputs, and the third is investment costs. The firm's decision rule is ready to set. The firm's objective function is given in equation (1) of the main text. The constraint is given in equation A.3; and the instantaneous profit at time is given in equation A.4.

Then the current value Hamiltonian of this maximization problem can be given:

$$H(I,K,L,t) = (p(F(K,L,t) - \Gamma(I,K,T)) - wL - zI) + \lambda(\psi(I,K,t) - D \bullet K)$$

where $\lambda = (\lambda_1, \lambda_2, \ldots, \lambda_J)^T$ is the shadow value of one unit of additional capital K, or equivalently, the value to the firm of having one additional unit of capital stock in place. Tobin's q is defined as the ratio of the stock market value of the firm to the book value of its capital assets. Thus, λ is equal to the marginal Tobin's q.

The first order conditions of this problem can be given:

A.5 $pF_L - w = 0$, where F_L is the partial derivative of F with respect to the vector L.

A.6 $-p\,\Gamma_I - z + \lambda\,\psi_I = 0$, where Γ_I and ψ_I are the first derivatives with respect to the vector I.

A.7 $\dot{\lambda}_j = (r + \delta_j - \Psi_{jK_j})\lambda_j\ p(F_k{-}j - \Gamma_K{-}j)$, for all j.

And the transversality condition:

A.8 $\lim_{t\to\infty} \lambda(t)K(t) = 0$

Let us consider economic interpretations of these conditions. Equation A.5 is the familiar marginal productivity condition: marginal product of the inputs equals the factor price of inputs equals. When we change the equation A.8 as follows, we have a nice interpretation.

A.9 $z + p\,\Gamma_I + (I - \iota_I)\,\lambda = \lambda$, where I is an identity matrix with the dimension J x J.

z is the price to pay to buy one unit of investment goods, $p\,\Gamma_I$ is the output loss due to adjustment costs, and $(I - \psi_I)\,\lambda$ is the shadow value of the lost capital due to adjustment costs. Taken as a total, the left hand side is the total cost of one unit of investment. The right hand side is the shadow value of one unit of investment. At the optimal choice of I, the costs and benefits of marginal investment are equal. Equation A.7 gives the current value of the discounted stream of the future benefits due to one unit of current additional investment.

Now from the transversality condition, we can write

A.10 $$\lambda_j(0)K_j()) = \lambda_j(0)K_j(0) - \lambda_j(\infty(= -\int_0^\infty (\dot{\lambda}_j K_j + \lambda_j \dot{K}_j)dt$$

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

A.11 $$\begin{aligned} &-(\dot{\lambda}_j K_j + \lambda_j \dot{K}_j) \\ &= p(F_{K_j}K_j - \Gamma_{K_j}K_j - \Gamma_{I_j}I_j) + (p\nabla_L F - w)L - z_j I_j - z_j(\varphi_{I_j}I_j + \varphi_{K_j}K_j) \end{aligned}$$

By the Euler's theorem for the first degree homogeneous function G in vector X, $\nabla G(X)^T X = \sum G_{x_i} X_i = G(X)$,

we can easily see, $\sum_{j=1}^{J} \lambda_j(0)K_j(0) = \int_0^\infty (p(F-\Gamma)-wL-z\varphi)u(t)dt = \int_0^\infty \pi(t)u(t)dt = V(0)$