

Intangible Assets:
**How the Interaction of Computers and Organizational
Structure Affects Stock Market Valuations**

Erik Brynjolfsson

MIT Sloan School of Management
50 Memorial Drive, Suit E53-313
Cambridge, MA 02142-1347 USA
erikb@mit.edu

Lorin M. Hitt

University of Pennsylvania, Wharton School
1318 Steinberg Hall-Dietrich Hall, 3620 Locust Walk
Philadelphia, PA 19104-6366 USA
lhitt@wharton.upenn.edu

Shinkyu Yang

New York University, Stern School
44 West 4th St., Suite KMEC 9-76
New York, NY 10012-1106 USA
skyang@stern.nyu.edu

Acknowledgements: We thank Robert Gordon, Zvi Griliches, Bronwyn Hall, Robert Hall, Boyan Jovanovich, Jacques Mairesse, Paul Romer, Eli Snir and the participants at the Workshop on Information Systems and Economics, the MIT Center for Coordination Science, National Bureau of Economics Research, the Wharton School, and the AEA annual meetings for valuable comments on earlier versions of this paper. The National Science Foundation (IIS-9733877), the Organization for Economic Cooperation and Development, the Stanford Computer Industry Project, and IBM Research provided generous funding.

**Intangible Assets:
How the Interaction of Computers and Organizational Structure
Affects Stock Market Valuations**

This paper investigates the proposition that the widespread use of information technology has increased investment in intangible organizational assets. Using firm-level data, we find that each dollar of installed computer capital in a firm is associated with at least five dollars of market value, after controlling for other assets. We interpret this value as revealing the existence of a large stock of intangible assets that are complementary with computer investment. Using data on organizational practices at each firm, we identify a specific cluster of practices that appear to represent at least some portion of these intangible assets. Not only are these practices correlated with computer investments, but firms that combine higher computer investments with these organizational characteristics have *disproportionate* increases in their market valuations. We conclude that investors believe that the contribution of computers is increased when they are combined with certain intangible assets, specifically including the cluster of organizational changes that we have identified.

1. Introduction

In developed economies, production not only requires the traditional factors such as capital and labor, but skills, organizational structures, know-how, information, and other factors that are collectively referred to as “intangible assets.” Detailed investigation of these types of assets has found that they are often large and have substantial productivity benefits. For example, Jorgenson and Fraumeni (1995) found that the stock of “human capital” in the U.S. economy dwarfs the stock of physical capital and has grown substantially over time; B. Hall (1993a), Griliches (1981), and Lev and Sougiannis (1996) have found that the R&D assets bring benefits in the form of positive marginal product and market valuation. Results from analyses of “Tobin’s q” have shown that the stock market valuation of firms has increasingly diverged from their measured book value (Chan, Lakonishok and Sougiannis, 1999; R. Hall, 1999).

One possible explanation for the recent increase in Tobin’s q increasing importance of intangible capital is the growing use of information technology and the associated investments in intangible assets (R. Hall, 1999; Brynjolfsson and Yang, 1999). While early applications of computers were primarily directed at factor substitution (particularly of low-skill clerical workers), modern uses of computers and flexible manufacturing technologies have both enabled and necessitated substantial organizational redesign (Berman, Bound and Griliches, 1994; Brynjolfsson and Hitt, 1998; Brynjolfsson, Renshaw and van Alstyne, 1997; Hammer, 1990; Black & Lynch, 1999; Orlikowski, 1992) and changes in the skill mix of employees (Autor, Katz and Krueger, 1998; Bresnahan, Brynjolfsson and Hitt, 1999). Collectively, these papers argue for a

complementarity between computer investment and organizational investment, and specifically a relationship between information technology use and increased demand for skilled workers, greater decentralization of decision rights, and team-oriented production. Moreover, case studies suggest that these complementary investments are large. For example, less than 20% of the typical \$20 million installation cost of the SAP R/3 system (a common large-scale package designed to integrate different organizational processes) is for hardware and software; the vast majority of the investment is for consultants to customize the software, to redesign organizational processes, and to train the staff in the use of the new system (Gormely, et. al., 1999).

In this paper, we analytically explore the hypothesis that new intangible organizational assets complement information technology capital just as factory redesign complemented the adoption of electric motors (David, 1990) and memos and filing systems complemented the printing press. To realize the potential benefits of computerization, investments in additional "assets" like new organizational processes and structures, worker knowledge and redesigned monitoring, reporting and incentive systems may be needed.

The presence of intangible assets can be observed in two ways. First, the resulting effect on the firm's market valuation should be measurable. While effects on productivity or other measures of economic output may be spread over many years, the financial markets, which seek to assess the discounted value of future revenues, provide an immediate indicator of whether these investments generate value for the firm's owners.

In particular, the market value of a firm which has leveraged computer assets with organizational investments should be greater than that of a similar firm which has not incurred these investments. A computer that is integrated with complementary organizational assets should be significantly more valuable to a business than a computer in a box on the loading dock.

Second, some of the specific changes that firms make may be directly observable. In particular, numerous authors have suggested that information technology (IT) is likely to be associated with organizational changes such as greater demand for worker skills and increased levels of employee decision-making authority (Applegate, Cash and Mills, 1988; Bresnahan, Brynjolfsson and Hitt, 1999; George and King, 1991; Mendelson and Pillai, 1999; Sauer and Yetton, 1997). If these practices represent the types of organizational assets we described earlier, then we would expect that the value of IT would be greater in organizations that also adopt these work practices.

This complementarities argument leads to four implications which are testable in empirical data. First, each dollar of installed computer capital should be correlated with more than one dollar of market value, after controlling for other measured assets. Second, investments in computers should be correlated with increased investments in certain organizational practices. Third, if these practices represent part of the productive assets of a firm, they should also be associated with increases in market value. Finally, firms that combine these specific organizational practices with investments in computer

capital should have a higher market value than those that adopt these same practices in isolation.

Using data on 1031 large firms over 8 years (1987-1994), we find evidence in support of all four implications of our argument:

1. Each dollar invested in computers is associated with an increase in firm market valuation of \$5 to \$20 (depending on the assumptions of the estimation models), compared with an increase of about \$1 per dollar of investment in other assets.
2. Firms that are high IT users are also more likely to adopt work practices that involve a cluster of organizational characteristics, including greater use of teams, broader decision-making authority, and increased worker training.
3. This cluster of organizational characteristics increases a firm's market valuation beyond what can be accounted for by tangible assets.
4. In firms that use these organizational characteristics, the computer assets have a disproportionately higher market valuation.

Our results are robust to a variety of alternative estimating techniques. The results are not consistent with the alternative hypothesis that differences in the speed of adjustment to unexpected shocks biases the results. Similarly, they are not driven entirely by a general capital-skill complementarity; these results appear to be unique to IT capital and do not

appear for ordinary capital. Because our sample is predominantly large, established firms rather than new high technology entrants, and the time period of our data predates the large increase in the value of technology stocks in the 1990s, our results are not likely to be affected by the possible existence of a “high-tech stock bubble”. However, they are consistent with earlier case-based research as well as recent econometric work using production functions which suggest an important role for IT-enabled organizational changes in increasing productivity and the value of firms. Taken together, these results lend quantitative support to the idea that IT is most valuable when coupled with complementary changes in organizational design.

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

2. Econometric Model and Data

2.1 Derivation of Model for Stock Market Valuations

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

(1969) in describing the relationship between firm value and capital investment. This framework has been empirically adapted and applied to the valuation of R&D by Griliches (1981), Griliches and Cockburn (1988), and B. Hall (1993a,b; 1999) and the stock market impact of diversification (Montgomery and Wernerfelt, 1988) using firm-level data.

The empirical use of Tobin's q to capture intangible organizational assets has been proposed by other authors. R. Hall (1999a) states in his discussion of his quantity revelation theorem, "the value of corporate securities, interpreted as a measure of the quantity of capital, behaves reasonably" and the firm's intangible assets are "technology, organization, business practices, and other produced elements of the successful modern corporation." R. Hall (1999b) also discusses the analogy between a flow of investment in reorganization and a flow of investment in physical capital. Our paper is closely related to Brynjolfsson and Yang (1999) who found evidence of high q values for IT, but did not explicitly link them to organizational investments.

We assume that firms face a dynamic optimization problem in which managers make capital investments (I) in several different asset types and expenditures in variable costs (N) with the goal of maximizing the market value of the firm V . In turn, V is equal to the present value of all future profits with a discount function $u(t)$. The accumulation of capital investment, less depreciation (d), produces a vector of capital stock (K , which includes different components of capital $K_j, j=1 \dots J$ where the j 's are physical capital, computers, etc.). The capital stock along with variable inputs is used to produce output

via a production function (F). We depart from most of the traditional literature¹ by assuming that there is some additional cost of making a capital investment which represents an "organizational adjustment cost," ($G(I,K,t)$). These organizational costs represent the amount of output lost while integrating additional capital into the firm. This yields the following program:

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

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

$$(3) \quad \text{and the following holds: } \frac{dK_j}{dt} = I - \sum_{j=1}^J d_j K_j, \text{ for all } j=1, \dots, J.$$

One can solve for the market value of the firm that results from this optimization problem with additional assumptions on the structure of $F(\cdot)$ and $G(\cdot)$.² If there are no organizational adjustment costs are needed to make capital assets fully productive ($G(I,K,t) = 0$), then buying a firm is no different from buying a collection of separate assets. Thus, the market value of a firm is simply equal to the current stock of capital assets:

¹ See Yoshikawa (1980) and Wildasin (1984) for models where Tobin's q is affected by adjustment costs.

² We assume that $F(K,N)$ and $\Gamma(I,K)$ are homogeneous functions of degree 1 over K,N , and I (constant returns to scale) and are twice differentiable. We further assume that $\Gamma(I,K)$ is increasing and convex in investment, with no fixed costs ($\Gamma(0,K)=0$), and is non-negative everywhere. A detailed derivation of this estimating equation appears in Brynjolfsson and Yang (1999).

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

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

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

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

In addition to the capitalized adjustment costs, there may also be various intangible assets correlated with each of the K_j . When $(\bullet_j - 1)K_j$ is the other intangible assets correlated with K_j , then the market value equation (5) becomes:

$$(6) \quad V = \sum_{j=1}^J \mathbf{n}_j \mathbf{l}_j K_j .$$

2.2 Econometric Issues of Market Valuation

To empirically estimate the relationship in equation (6) it is necessary to specify the different types of capital assets that we will consider as well as a set of additional control variables (X) to account for sample heterogeneity. In addition, we will sometimes include a fixed effect, α , to capture differences across firms that are constant over time, thereby further controlling for firm heterogeneity. Including an error term, ϵ , we have our general estimation equation:

$$(7) \quad V_{it} = \mathbf{a}_i + \sum_{j=1}^J \mathbf{l}_j K_{j,it} + X_{it} \mathbf{g} + \mathbf{e}_{it}$$

Here, i , t , and j are indices of firms, time, and different capital goods, respectively. The coefficients to be estimated are (vectors) \mathbf{a} , \mathbf{l} , and \mathbf{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 the ratio of R&D capital to assets, and the ratio of advertising expense to assets industry dummies (usually at the SIC 2-digit level), and year dummies.³ This yields our base estimating equation which we will later extend to explicitly include certain organizational investments:

$$(8) \quad V_{it} = \mathbf{a}_i + \mathbf{I}_c K_{c,it} + \mathbf{I}_p K_{p,it} + \mathbf{I}_o K_{o,it} + \mathbf{controls} + \mathbf{e}_{it}$$

Here K_c , K_p , and K_o represent computer capital, physical capital, and other balance sheet assets, respectively. This methodology can be considered an example of hedonic regression, which estimates the market shadow "price" for various assets using cross-sectional and time series variations in their quantities and in the market value of the firm (B. Hall, 1999).

Because firm sizes vary substantially in our sample and our model is implemented in levels rather than logarithms, we anticipate significant size-related heteroskedasticity.

We address this problem by using generalized (weighted) least squares (GLS) as well as

³ Advertising and R&D are other types of nonstandard assets that have been considered in prior work. Because no capitalized value of these "assets" is reported, we simply include them as ratios in the reported regression. This can be thought of treating current spending on these assets as a noisy indicator of their capital stock values (B. Hall, 1993a,b; see also Brynjolfsson and Yang, 1999 for a more detailed analysis of these assets in this context). Finally, we add additional control variables for industry to reduce sample heterogeneity, and time to control for general economic trends in stock market valuation.

robust regression techniques (least absolute deviation - LAD) which are less sensitive to outliers of all sorts. We also address explicitly several sources of potential specification error in our analysis. One concern is that computers may be disproportionately correlated with other unobserved, but valuable, firm characteristics. Therefore, the measured marginal value of computers (essentially a hedonic price) will include not only the physical computers, but also the intangible assets that were excluded from the equation but are correlated with computers. This is not problematic in a larger sense, as it is perfectly consistent with the central story of this paper. However, we can separate out these effects in two ways. First, we can perform a fixed-effects ("within") regression that removes all time-invariant firm characteristics, and thus facilitates one estimate of the value of complementary organizational assets. Alternatively, we can explicitly include some measurable components of organization in the equation as an additional variable and measure its direct value and its interaction effect with computers.

Another potential difficulty is the endogeneity of computer investment. 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 greater investments in capital assets. For example, an unexpected shock to demand may increase investors' long-run expectations of profitability (increasing market value) and encourage the firm to expand production capacity. This is essentially the behavioral model that underlies the q-theory of investment (Tobin, 1969). If both the real investment and the financial markets adjust instantaneously to such shocks, then the coefficient values we observe can be interpreted as the correct "prices"

for each asset. Even short adjustment lags are not necessarily a problem. Over time, efficient markets will cause these types of shocks to average out; thus they may not be substantial as long as the adjustment period is relatively short (R. Hall, 1999). However, endogeneity could be problematic if the lags are fairly long relative to the estimation period. One approach to this problem is to lag the capital stock variables by one period. Few managers can forecast the unexpected components of stock returns better than the market and keep those forecasts a secret. Therefore, previous period investment can be considered predetermined relative to future market value shocks.

An additional difficulty arises if capital stocks do not adjust instantaneously. For example, suppose a demand shock arrives that requires increased use of IT and increases market value, but only some of the IT can be installed in time. This will tend to understate the current capital requirements and could lead to an overestimation of the market value of capital. However, the market value estimates that results from such shocks simply represent the capitalized value of future investments made possible by the firm's current investment position. In essence, they are the quasi-rents of having an installed base of computers, capital, and intangible assets. Under this interpretation, the per-unit value of IT may be larger than its long-run value, but still accurately reflects its current value. Future investments will in IT will not increase the market value incrementally, but will be essential to maintain the market value level already achieved.

A variant of this issue arises when the firm must adjust to more than one type of capital, and these adjustments occur at different speeds. For example, IT may adjust very

quickly to unanticipated shocks, while ordinary capital might require several years to adjust. In this case, especially for analyses conducted on first differences, more of the variation in market value will be explained by the newly-acquired computers since the IT appears to have a larger change than capital. Fortunately, this bias problem is reduced when the analysis is conducted over longer time horizons. In a one-year difference, small differences in adjustment rate will lead to large differences in capital stocks, but over 3 to 5 years all factors will be proportionally closer to their equilibrium value. We can therefore construct a test to determine whether varying adjustment rates lead to biases: conduct the analysis using different difference lengths. If computers are erroneously receiving credit for some of the benefits that should be attributed to slower-adjusting capital, the computer coefficient should fall as longer time periods are considered. Conversely, if the coefficients on computers rise as the time period considered lengthens (above and beyond any effects due to measurement error⁴), then this provides evidence that variation in adjustment rates is not biasing the results upward.

2.3 Data Sources and Construction

The data set used for this analysis is a panel of computer capital and stock market valuation data for approximately 1000 firms over the 1987-1994 time period, matched to a cross-sectional survey of organizational practices conducted in 1995 and 1996. A brief description of each data source follows, with additional detail in the Appendix.

⁴ Longer differences decrease bias when only a single variable is measured with error (or all the dependent variables are orthogonal). See Griliches and Hausman (1986).

Computer Technology: The measures of computer use were derived from the Computer Intelligence Infocorp installation database that details IT spending by site for Fortune 1000 companies. 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 of computer equipment and related products. Most sites are updated at least annually with more frequent sampling for larger sites. The year-end state of the database from 1987 to 1994 was used for the computer measures. From this data we obtained the total capital stock of computers (central processors, personal computers, and peripherals). The IT data do not include all types of information processing or communication equipment and are likely to miss some portion of computer equipment that is purchased by individuals or departments without the knowledge of information systems personnel.⁵

Organizational Practices: The organizational practices data in this analysis come from a series of surveys of large firms. These surveys adapted questions from prior surveys on human resource practices and workplace transformation (Huselid, 1995; Ichniowski, Shaw and Prunnushi, 1997; Osterman, 1994). The questions address the allocation of various types of decision-making authority, the

⁵ Another potential source of error in this regard is the outsourcing of computer facilities. Fortunately, to the extent that the computers reside on the client site, they will still be properly counted by CII's census. To the extent that these facilities are located at a third-party site, they will not be properly counted. However, despite all these potential limitations these data are broadly consistent with other survey work on a more limited sample from International Data

use of self-managing teams, the breadth of job responsibilities and other miscellaneous characteristics of the workplace (further detail appears in the results section). Organizational data were collected in three waves at the end of 1995 and early 1996, covering most of the Fortune 1000. This yielded a single cross section of 416 firms with a survey response rate of 49.7%. We detected no significant pattern of response bias when compared with the population of firms in the Fortune 1000.

Compustat. Compustat data were 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 book value of debt); property, plant and equipment (PP&E); other assets; R&D assets; and advertising expense.

Overall, the full data set includes 4592 observations over 8 years for market value and computer capital stock. By matching these data to the organizational practices surveys, we obtained complete organizational and market value data for 250 firms for a total of 1707 observations.

3. Results

In this section, we report on the regression and correlation analyses performed to test the four implications of our complementarities argument outlined in the introduction. First,

Group that measured the stock of IT capital at the firm-level as well as capital flow tables from

we explored the basic relationship between IT and stock market value for our full sample of firms. We then examined the relationship between computer capital and the adoption of specific organizational practices using correlation analyses, and constructed a single variable, ORG, which captured most of the relevant variation in organization across firms. Third, we investigated the effect of ORG on the firm market value. Finally, we studied how the combination of ORG and computers affects market value. We also performed a number of robustness checks of our analysis and considered alternative hypotheses, as we report in each section.

3.1 Computers and market value⁶

3.1.1. Basic Findings for Computers and Market Value

The regression analyses (Equation (8)) for estimating the effect of computers on market value are shown in Table 1a. As shown in the first column (ordinary least squares regression), we found that each dollar of installed property, plant and equipment (PP&E) is valued at about one dollar, which is what theory would predict if these assets are in equilibrium. A dollar of other assets, which includes accounts receivable, inventories and liquid assets, is valued at about \$0.7; apparently stockholders do not believe they will receive the full face value of these assets, on average. Strikingly, each dollar of computer capital is associated with nearly \$17 of market value. This implies that the stock market imputes an average of \$16 of intangible assets to a firm for every \$1 of

the U.S. Bureau of Economic Analysis (Brynjolfsson and Hitt, 2000).

⁶ This subsection parallels work discussed in Brynjolfsson and Yang (1999).

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 and time with our model.⁷

To probe this result further we investigated how much the correlation between market value and computer investment was driven by variation across firms (a "between" regression) and variation for the same firm over time (a "firm effects" regression). We found that both sources of variation were important but that the effect due to variation between firms was larger. The "between" regression implies a market value of computer capital of nearly \$20. For the firm effects regression, this value is \$5 (but still strongly significant). The firm effects regression can be interpreted as removing all the effects that are unique to a particular firm but constant over time. This suggests that firm-specific factors account for a substantial amount of the "excess market valuation" of computers.⁸ In Figure 1 and Figure 2, we present the relative size of computer coefficients and those of other assets.

In Table 1b, we examine the robustness of the base results to variations in econometric methods. For this analysis we restricted the sample to a balanced panel⁹ to get maximum data consistency and applied different regression techniques: generalized least squares

⁷ Among control variables, 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.

⁸ 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.

⁹ In other words, we excluded all firms which were missing any data in any year.

(GLS) and least absolute deviation (LAD) regression¹⁰ to control for heteroskedasticity and outliers. Overall, the basic results are consistent whether we use balanced or unbalanced panels and GLS or LAD in both the between and fixed effects regressions.¹¹

3.1.2 Leads and Lags of Computers and Market Value

The estimation of Equation (8) can be interpreted as a hedonic regression, where the value of a firm can be decomposed to the values of its component assets (Hall, 1993b; 1999). This interpretation is valid when shocks in stock market value do not affect the investment behavior of firms. However, according to the standard q theory of investment, if the desired level of capital is influenced by market value shocks, then the estimates of λ may be biased. In particular, when there exist non-zero time lags for adjustment and the lag differs for each type of capital, the biases are likely to be larger.

In Table 1c we explore this possibility empirically, adapting a framework based on the work of Granger (1969). For each regression shown in the table, we regressed the current period value of a measure (either IT or market value) on the lags of the other measure. As shown in the first and second columns of the table, the changes in current and lagged market values did not affect current computer investments. These columns represent regressions of lagged computers and market value on current computer quantity. In our

¹⁰ 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 calculated using bootstrapping techniques with 100 repetitions to obtain the empirical distribution of the coefficient estimates.

¹¹ While a plot of regression residuals (not shown) suggests strong size-based heteroskedasticity, the results changed very little with alternative estimation methods.

data, we did not observe that investments responded significantly to changes in market value. This result is consistent with studies that report that investment shows limited response to changes in q value (Abel and Blanchard, 1986; Jorgenson, 1986; Schaller, 1990).¹²

In the opposite direction, we found a substantial relationship between past computer investment and the current increase in market value. As shown in the second column of Table 1c, investments in computers Granger cause increases in market value in the “simple causation model” (Granger, 1969), and the coefficients of lagged computer investments are large. In the “instantaneous causality model”, where current computer quantity is included in addition to the first three lags (Column 3), current computer investments also lead to increases in the market value. Given that past investments in computers are associated with current increases in market value but not vice versa, it is harder to sustain an argument that the strong correlation between computers and market value can be attributed to reverse causation.¹³ A more plausible interpretation of these results is that firms continue to build follow-up intangible assets after they invest in computers, and moreover, that the follow-up investments are large. This explanation is consistent with a plethora of case evidence (See Brynjolfsson and Hitt, 2000 for a review).

¹² Able and Blanchard (1986) and Schaller (1990) discuss the issue in some detail and suggest alternative explanations.

¹³ If one wishes to maintain the hypothesis that future stock market increases “cause” past computer investments, one could tell a story in which managers have private foreknowledge of higher market value in the future and therefore invest in computers but do not take any actions (such as trading in their firms’ securities) which would reveal their private information. Econometrics alone cannot rule out such stories, though they may require increasingly implausible assumptions.

These results can also be reconciled with the empirical evidence on the q-theory of investment. If high q values mainly indicate the presence of intangible assets, rather than capital-using market opportunities, we would not necessarily expect a firm to accumulate additional tangible capital when its q value is high. This is consistent with the low observed correlation between q and capital investment. It is also consistent with the observation that economy-wide q values have increased in recent years concurrently with large investments in information technology.

3.1.3 Varying Difference Lengths

If the adjustment speed for investments in computers is higher than the adjustment speed for investments in other types of capital goods, the coefficient on computers may be biased upward when unexpected market value shocks occur.¹⁴

One way to address this problem is to perform the analysis varying the difference length. For example, if shocks are relatively infrequent and one type of capital adjusts within one year while another takes two years, then the variation in adjustment speeds may significantly influence the coefficient estimates for short differences, but become unimportant when time horizons over two years are considered. The between regressions represent the limit of this process, essentially corresponding to a difference with infinite length. If the computer coefficient falls relative to the capital coefficient over longer

¹⁴ This is especially true when the measures of capital stock variables are slow to detect changes. For example, in factors such as ordinary capital, the change in capital stock may be difficult to detect relative to the noise level, while large changes in the IT capital figures will substantially

difference periods, this suggests that some of the effects of capital on the market value have been erroneously attributed to IT in the short difference analyses. If the coefficient rises substantially, it suggests that any upward bias from relative adjustment speeds is not significant. The results of this analysis are shown in Table 1d.

We find that as we move from one-year differences to seven-year differences, the coefficient on IT generally rises from \$3 to about \$8, with a dip at fourth-year differences. The capital coefficient rises slightly from one-year differences to three-year differences and then stays level at approximately \$1.2. This substantial rise in the IT coefficient, over a factor of 2, suggests that differences in adjustment speed do not lead us to overestimate the contribution that computers make to market value in our basic specification.

Another way to examine the robustness of the results is to examine year-by-year cross sections of the results. If the results are biased upward by short run shocks then some years will have disproportionately high values while others will be close to their equilibrium value. In Table 1e we present regressions breaking our 8-year time period into four two-year intervals. Although there is substantial year to year variation in the coefficients, there is no particular time trend and in all four subsets the point estimate for the IT capital coefficient exceeds 11. This again suggests that while there is some time series variation, short run shocks do not appear to explain the high market valuation of IT capital.

exceed the noise level. Since bias due to errors in variables is proportional to the “signal-to-noise” ratio, this could lead to upward bias for IT.

Our results favor the argument that the high market valuation of computers reflects the presence of complementary intangible assets rather than alternative explanations such as stock price shocks, unobserved heterogeneity, and various forms of adjustment lags. These assets dwarf the size of actual computer investment and appear to be unique to computers – no similar effect is found for other types of capital. Moreover, the difference between the fixed-effects and between regressions suggests that much of these intangible assets are unique to particular firms. In the following section, we explicitly analyze one component of these intangible assets, and explore its effect on market value both directly and through complementarities with computers.

3.2 Basic findings regarding role of organizational structure¹⁵

In this section, we report on the correlations between computers and various measures of internal organization. All correlations use Spearman rank order correlations¹⁶ between various measures of computers and the organizational variables, controlling for firm size (employment), production worker occupation, and industry.¹⁷ We used three different measures of IT, including the total value of IT installed base (ITCAP), total central

¹⁵ These results build on earlier work reported in Hitt and Brynjolfsson (1997) and Bresnahan, Brynjolfsson and Hitt (1999).

¹⁶ Results are similar when probit or ordered probit regression is used. We report Spearman rank order correlations because they are easier to interpret given the non-metric nature of most of our work system variables.

¹⁷ Included are separate controls for mining/construction, high technology manufacturing (instruments, transportation, electronics, computers), process manufacturing (paper, chemicals, petroleum), other non-durable manufacturing, other durable manufacturing, transport, utilities, trade, finance, and services.

processing power¹⁸ in millions of instructions per second (MIPS), and number of personal computers (TOTPC). We used multiple measures because they capture slightly different aspects of computerization (for example, MIPS measures centralized computing, while TOTPC measures decentralized computing).

In Table 2a we present correlations between multiple measures of IT and four dimensions of organizational design: use of teams and related incentives, individual decision-making authority, investments in skills and education, and team-based incentives. These types of practices have been linked to IT investment in previous theoretical and empirical work (see Brynjolfsson and Hitt, 1997; Bresnahan, Brynjolfsson and Hitt, 1999 and Bresnahan, 1997 – a survey of related work appears in Brynjolfsson and Hitt, 2000). Consistent with our argument that IT and organization are complementary, we confirm that across multiple measures of IT and multiple measures of organization, firms that use more IT differ statistically from other firms: they tend to use more teams, have broader job responsibilities, and allocate greater authority to their workers, even after controlling for firm size and industry.

In addition to being correlated with IT, these practices are all correlated with each other. Following Hitt and Brynjolfsson (1997) we constructed a composite variable (ORG) as the standardized (mean 0, variance 1) sum of the standardized individual work practice variables. This allowed us to capture an organization's overall tendency to use this collection of work practices in a single construct, which we can then use for further analysis. A principal components analysis, Table 2b, showed that all components of this

¹⁸ Total central processing power does not include the processing power of personal computers.

variable load highly on a single factor (which explains approximately 35% of the variance of these measures), and a scree plot (not shown) suggests that this is the only non-noise factor. The composite variable, ORG, is highly correlated with computerization, consistent with our earlier arguments. In the remaining section of the results, we will explore the influence that this cluster of practices has on both the market value of the firm and the market value of computer capital.

3.3 The Effect of Organizational Structure on Market Value

3.3.1. Organization variable in the market value equation

In this section, we report how we modified our base estimating equation to include measures of organizational assets. We then investigated the direct relationship of these measures on market value as well as their effect on the market value of computers through interaction terms. This yielded the following estimating equation:

$$(8) \quad V_{it} = \mathbf{a}_i + \mathbf{I}_c K_{c,it} + \mathbf{I}_p K_{p,it} + \mathbf{I}_o K_{o,it} + \mathbf{w}_1 ORG_i + \mathbf{w}_2 ORG \cdot K_{c,it} + controls + \mathbf{e}_{it}$$

A test of our argument that organizational investments can be treated as intangible assets is whether the ORG has a positive contribution to market value.

To test our argument that there are positive synergies between IT and organizational investments we examined whether IT is more valuable in high ORG firms; that is, we tested the null hypothesis, $w_2 = 0$ against $w_2 \neq 0$.

We examined several market value equations that also include the ORG variable as a measure of organizational capital. The first three columns of Table 3a report the same analysis of market valuation of computers for the subsample matching panel data on IT and other factors and with a cross section of organizational data at the end of the sample period. The coefficients are qualitatively consistent with the results from the larger sample shown in Tables 1a and 1b.

When we simply added the ORG variable to the baseline market value equation, we found that it had a large and statistically significant contribution, as shown in Table 3a, columns 4 and 5. Firms that are one standard deviation above the mean in ORG have a market value that is about \$500 million higher than the mean, *ceteris paribus*. Evaluated at the mean, one standard deviation of the ORG variable corresponds to an 8% increase in market value.¹⁹ Thus, investors appear to treat organizational capital much like more tangible types of capital by recognizing its contribution to the market value of a firm.

3.3.2. Interaction between organization and computers

¹⁹ Results from between regression and pooled regression are essentially similar. The fixed effect specification is omitted since it is not meaningful to estimate the coefficient of a time-invariant variable.

In Table 3b, we present the results when we included both ORG and its interaction with computer capital in the regression. The magnitude of the interaction term between IT and ORG is about 6 in the pooled estimation, suggesting large complementarities between computers and organizational structure. In fact, it suggests that each dollar of computer capital is associated with an increase in market value of an *additional* six dollars in firms that are one standard deviation above the average in ORG.

One possible explanation of these results is that ORG makes all types of capital more valuable and since capital investments tend to be correlated with each other, we are erroneously attributing this all to computers. When we included additional interaction terms between ORG and other types of capital (columns 2 and 4 of Table 3b), we found that this relationship is *unique* to computers: the coefficients on the added interaction terms were not significant and the other coefficients changed very little. This indicates that ORG is an intangible asset that has a particularly strongly effect on the market value of IT.

Since ORG is measured once per firm at the end of the sample period, we could not apply a fixed-effect model to estimate its coefficient. However, since computers do vary over time, so does their interaction with ORG. This enables us to estimate firm effects. The results (shown in last two columns of Table 3b) provide evidence of an interaction between ORG and IT even in the firm-effects analysis. The coefficient was reduced although still significant. When we also removed the direct computer effect (which is highly collinear with the interaction term in this model), the coefficient on the interaction

term was 5.2 and was strongly significant while the R^2 changed very little. Thus, we can conclude that the market value of investing in computers is substantially higher in high ORG firms. Investors believe that certain organizational practices make it more valuable, and vice-versa.

3.3.3. *Non-parametric Estimation*

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

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

4. Discussion and Conclusions

Our results suggest that the organizational adjustment costs that firms incur when installing computer capital, including investments in training, organizational change, and relationship-building, appear to create substantial amounts of intangible assets. The financial markets treat the organizational assets associated with IT much like other assets that increase long-term profits but are difficult for competitors to duplicate. By analyzing several hundred firms over a period of 8 years, the analysis helps to document and explain the extent to which computerization is associated with both direct and indirect measures of intangible assets. Furthermore, this approach helps reveal the pattern of interactions among IT, organizational practices, and market valuations, and thereby detect complementarities. If these assets are in fact becoming more important in modern economies, in part because of the information revolution engendered by computers and communications, then it is incumbent upon us to understand not only particular cases, but also any broader relationships and patterns that exist in the data.

Our main results are consistent with each of the testable implications about complementarities between computers and organizational design described in the introduction:

- 1) The financial markets put a higher value on firms with more installed computer capital. The increase in market value associated with each dollar of IT substantially exceeds the valuation placed on other types of capital.

- 2) Computer-intensive firms have distinctly different organizational characteristics, involving teams, broader jobs, and greater decentralization of decision-making.
- 3) Firms with these organizational characteristics have higher market valuations than their competitors, even when all their other measured assets are the same.
- 4) Firms with higher levels of *both* computer investment and these organizational characteristics have *disproportionately* higher market valuations than firms invest heavily on only one or the other dimension.

Taken together, these results provide evidence that the combination of computers and organizational structures creates more value than the simple sum of these contributions separately. The evidence is not consistent with alternative explanations such as econometric biases created by endogeneity or differences in adjustment speeds of capital assets. The evidence is consistent, however, with the widespread perception among managers that information technology is a catalyst for a broad set of organizational changes (see e.g., Brynjolfsson and Hitt, 2000).

Our interpretation has focused on the assumption that the stock market is approximately correct in the way it values information technology and other capital investments. The fact that our results apply to a broad cross-section of the economy over nearly a full business cycle suggests that fads, industry idiosyncrasies, and investor errors are not driving the results. Moreover, year-by-year estimation showed a consistently high

valuation of computer capital throughout the 1988-94 period. Our analysis also predates the large increase in the market value of technology stocks in the late 1990s, and our sample is disproportionately weighted toward large, established firms rather than new high-technology entrants; thus, our results are not likely to be sensitive to a “high tech stock bubble.” Interestingly, productivity analysis by Brynjolfsson and Hitt (1997) found that the long-run productivity benefits are approximately five times the direct capital cost of computers, consistent with a valuation of IT on the order of five times higher than the valuation of ordinary capital.

Finally, what are the implications of our results given the emerging view on the productivity slowdown after 1973? As Yorukoglu (1996), Greenwood (1997), Greenwood and Jovanovic (1999), and Bart and Jovanovic (1999) point out, the productivity slowdown may be explained by the adjustment process accompanying the transformation from a capital-intensive industrial economy to a computer-intensive information-based economy. This view is reinforced by R. Hall’s (1999b) interpretation of investment in reorganization. In his model, when productivity slows down, economic actors invest more in reorganization, because the search for new production approaches provides higher marginal benefits than does expanding current production. Our results broadly support these observations, and further suggest that firms are investing heavily in reorganization. In particular, decentralized and/or team-based new work practices are complementary investments to computers, and the overall economic impact of these complementarities is substantial.

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

Market Value	Pooled	Fixed Effect Within		Between
	OLS	w/Year	wo/ Year	OLS
Computer Capital	16.951 ^{***} 1.180	6.436 ^{***} 0.897	7.684 ^{***} 0.837	21.21 ^{***} 3.32
Physical Capital	0.975 ^{***} 0.020	1.149 ^{***} 0.054	1.240 ^{***} 0.053	0.978 ^{***} 0.046
Other Assets	0.684 ^{***} 0.009	0.829 ^{***} 0.012	0.828 ^{***} 0.012	0.658 ^{***} 0.021
Controls	R&D Adv Year ^{***} Industry ^{***}	R&D Adv Year ^{***} Firm ^{***}	R&D Adv Firm ^{***}	R&D Adv Industry ^{***}
R-square	0.8698	0.7244	0.7178	0.8875
Observations	4592	4592	4592	4592

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

Table1b: 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
Computer Capital	22.285*** 4.193	18.540*** 1.464	14.824*** 3.545	5.584*** 0.921	4.308*** 1.154
Physical Capital	0.968*** 0.049	1.014*** 0.016	0.984*** 0.019	1.244*** 0.055	1.169*** 0.113
Other Assets	0.654*** 0.024	0.656*** 0.010	0.652*** 0.088	0.811*** 0.015	0.814*** 0.086
Controls	R&D Adv Industry***	R&D*** Adv*** Industry***	R&D*** Adv*** Industry***	R&D Adv Year*** Firm***	R&D Adv*** Year*** Firm***
R-square	0.892	0.869	0.675	0.681	0.836
Observations	3312	3312	3312	3312	3312

Table 1c: Leads and Lags between Changes in Market Value and Computer Investments

Computers (0)	Simple Causal Model	Instantaneous Causal Model	Market Value (0)	Simple Causal Model	Instantaneous Causal Model
Computers (-1)	-0.103 0.128	-0.104 0.127	Market Value (-1)	-0.108 0.197	0.009 0.128
Computers (-2)	-0.019 0.172	-0.037 0.170	Market Value (-2)	0.144 0.151	0.004 0.050
Computers (-3)	1.120*** 0.231	1.123*** 0.228	Market Value (-3)	0.045 0.065	0.054 0.070
Market Value (0)		0.0010 0.0006	Computers (0)		5.960*** 2.137
Market Value (-1)	0.0014 0.0010	0.0014 0.0010	Computers (-1)	14.665*** 4.722	0.597 4.526
Market Value (-2)	0.0006 0.0018	0.0006 0.0018	Computers (-2)	16.546*** 5.864	16.565 14.700
Market Value (-3)	0.0001 0.0006	0.0001 0.0006	Computers (-3)	-3.578 16.759	-10.701 16.209
Controls	year*** Industry***	year*** Industry***	Controls	Year*** Industry***	year*** Industry***

* All variables except controls are in yearly changes

Table 1d: Long Difference Estimation

Market Value	Differences						
	1 year	2 years	3 years	4 years	5 years	6 years	7 years
Computers	2.949*** 1.031	4.644*** 1.332	5.523*** 1.611	6.539*** 1.655	4.041*** 1.710	4.746*** 1.757	7.806*** 2.370
PP&E	0.368*** 0.074	0.695*** 0.079	0.973*** 0.083	1.244*** 0.089	1.226*** 0.093	1.240*** 0.099	1.206*** 0.133
Other Assets	0.863*** 0.013	0.852*** 0.017	0.828*** 0.019	0.837*** 0.021	0.853*** 0.020	0.848*** 0.020	0.728*** 0.029
Controls	year*** industry***	year*** industry***	year*** industry***	year*** industry***	year*** industry***	Year*** industry***	industry***
Observations	2898	2484	2070	1656	1242	828	414
R-square	0.66	0.62	0.66	0.71	0.77	0.84	0.86

**Table 1e: 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	R&D ^{***} Adv Year Industry ^{***}	R&D ^{**} Adv ^{**} Year Industry ^{***}	R&D Adv Year Industry ^{***}	R&D Adv Year ^{**} Industry ^{***}
R ² Observations	0.907 1090	0.909 1089	0.840 1182	0.887 1259

Table 2a: Correlations between IT measures and organizational structure

Measure (scale in parenthesis)	IT Capital	MIPS	TOTPC
<u>Structural Decentralization</u>			
Self-Managing Teams (1-5)	.17***	.22***	.20***
Employee Inv. Grps. (1-5)	.07	.08	.08
Broad Jobs (1-5)	.07	.12**	.10*
<u>Individual Decentralization</u>			
Pace of Work (1-3)	.04	.06	.02
Method of Work (1-3)	.16***	.20***	.15***
Composite: 7 Measures [^]	.12*	.14**	.16***
Individual Control [^]	.11*	.15**	.15**
<u>Team Incentives</u>			
Team Building	.15***	.19***	.18***
Promote for Teamwork	.02	.10*	.00
<u>Skill Acquisition</u>			
Training (% staff)	.14**	.15***	.14**
Screen for Education (1-5)	.16***	.18***	.21***
ORG Composite	.24***	.30***	.25***

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

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

Table 2b: Unrotated Principal Components for ORG Variable Construction

	Loading 1 st Principal Component	Loading 2nd Principal Component
Work Practices		
Self Managing Teams	0.751	0.006
Employee Involvement Groups	0.707	0.176
Decentralized Pace Decision	0.528	-0.628
Decentralized Method Decision	0.572	-0.456
Team Building	0.747	0.250
Promote for Teamwork	0.401	0.367
Screen for Education	0.466	-0.095
Training (% Staff Involved)	0.425	0.408
Percent of Variance Explained	34.8%	12.6%

Table 3a: Effect of IT and ORG on market value

	Matched Sample Baseline Estimates			Adding ORG variable alone	
	Pooled	Within	Between	Pooled	Between
Computer	8.866 ^{***} 1.670	8.684 ^{***} 1.393	9.776 ^{**} 5.073	8.399 ^{***} 1.697	9.292 [*] 5.061
ORG				490.7 ^{***} 130.5	496.0 ^a 306.7
Physical Capital	0.895 ^{***} 0.040	1.438 ^{***} 0.088	0.834 ^{***} 0.103	0.863 ^{***} 0.041	0.799 ^{***} 0.104
Other Assets	0.859 ^{***} 0.028	0.728 ^{***} 0.046	0.876 ^{***} 0.074	0.859 ^{***} 0.028	0.876 ^{***} 0.074
Controls	R&D ^{***} Adv Year ^{***} Industry ^{***}	R&D ^{**} Adv Year ^{***} Firm ^{***}	R&D ^{**} Adv NA Industry ^{***}	R&D ^{***} Adv Year ^{***} Industry ^{***}	R&D ^{**} Adv NA Industry ^{***}
R square	0.8005	0.7197	0.7987	0.8022	0.8460
Observations	1707	1707	1707	1707	1707

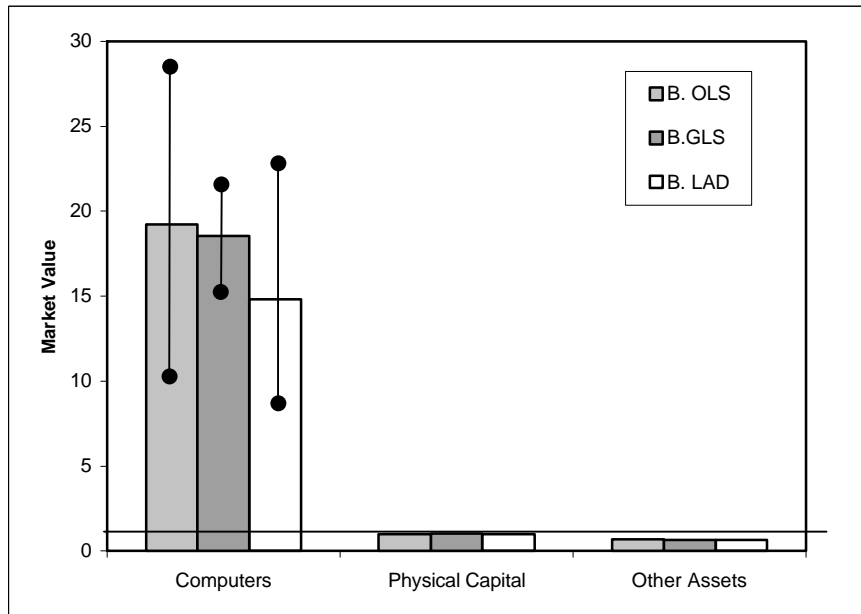
a: p-value = .107

Table 3b: Effect of interaction on market value

Market Value	Pooled	Pooled w/other interactions	Between	Between w/other interactions	Within Firm Effect	Within Interaction Only
Computer	2.231 2.195	2.760 2.282	4.947 5.47	4.988 5.588	5.818 ^{***} 2.001	
ORG	314.3 ^{**} 135.8	246.5 [*] 146.5	261.3 326.1	266.1 346.1		
ORG x Computer	5.907 ^{***} 1.344	5.401 ^{***} 1.552	7.493 ^{**} 3.735	7.394 ^a 4.594	2.506 ^{**} 1.267	5.152 ^{***} 0.880
ORG x Physical Capital		0.041 0.035		-0.007 0.092		
ORG x Other Assets		-0.035 0.022		0.005 0.059		
Physical Capital	0.896 ^{***} 0.042	0.859 ^{***} 0.051	0.830 ^{***} 0.105	0.835 ^{***} 0.132	1.471 ^{***} 0.090	1.471 ^{***} 0.090
Other Assets	0.813 ^{***} 0.030	0.809 ^{***} 0.038	0.801 ^{***} 0.082	0.796 ^{***} 0.101	0.699 ^{***} 0.048	0.705 ^{***} 0.048
Controls	R&D ^{***} Adv Year ^{***} Industry ^{**} *	R&D ^{***} Adv Year ^{***} Industry ^{***}	R&D ^{**} Adv Industry ^{***}	R&D Adv Industry ^{***}	R&D Adv ^{**} Year ^{***}	R&D Adv ^{**} Year ^{***}
R square Observations	0.8045 1707	0.8047 1707	0.8491 1707	0.8491 1707	0.7196 1707	0.7101 1707

a: p-value = .109

Figure 1. Relative size of market valuation: Between estimates



- 95% confidence interval is drawn for computer coefficients.
- Confidence intervals for other assets are too small to be shown on this scale.

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

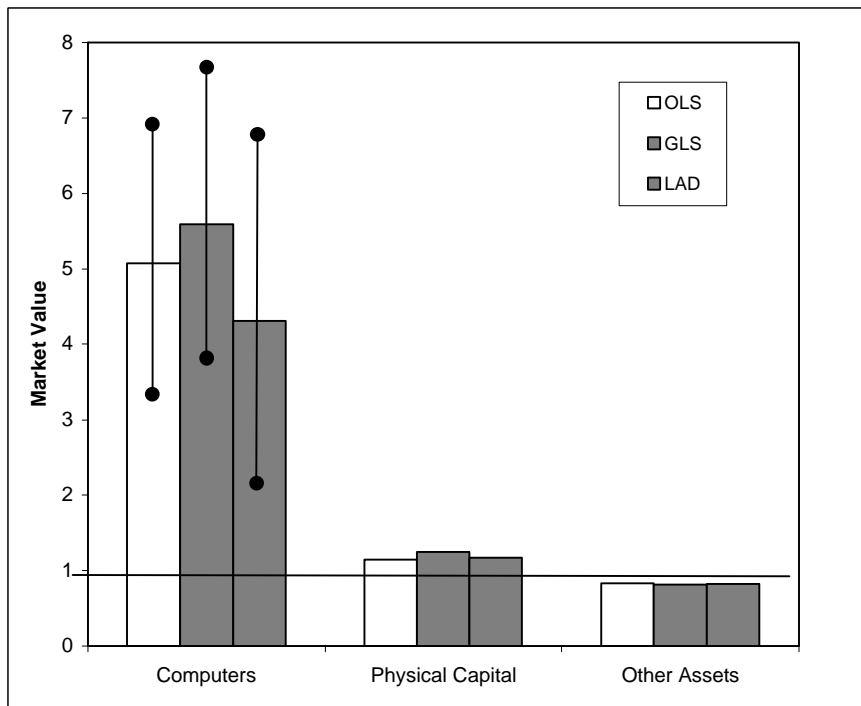


Figure 3: Market value 3-D plot by organization and IT
Non-Parametrically Estimated Fitted Values via a Local Regression Model

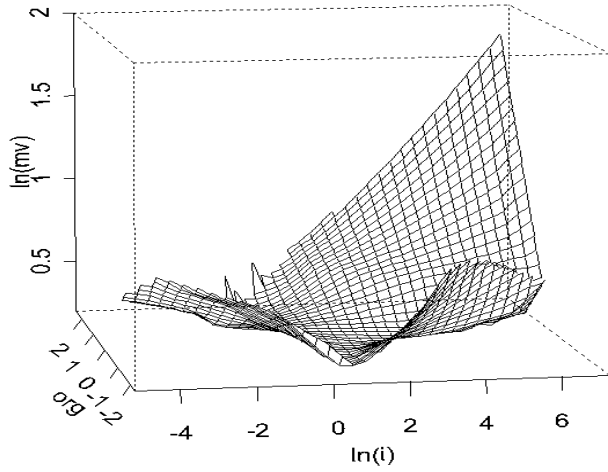
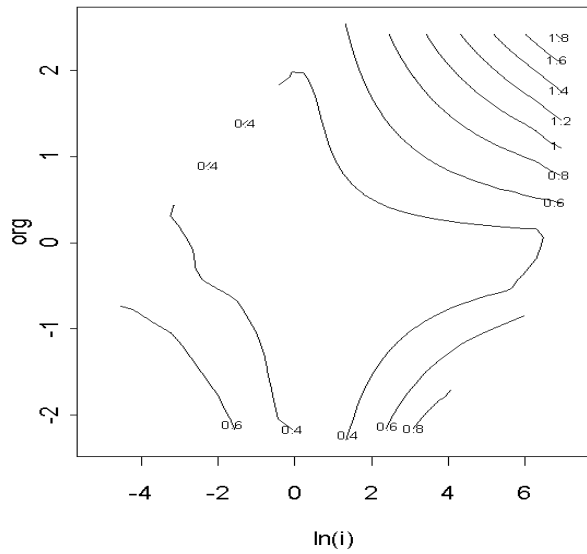


Figure 4: Market value contour plot by organization and IT
Estimated Fitted Values via a Local Regression Model



Appendix: Data Description

The variables used for this analysis were constructed as follows:

IT Capital. We have a direct measure of the current market value of each firm's computer equipment as reported by Computer Intelligence Corp. The market value was constructed for each model of computer. Computer Intelligence calculates the current market value, the replacement cost, of computers, using their current market value table of computer equipment.

Physical Capital. The source of this variable is Standard and Poor's Compustat Annual Dataset. We considered two options to construct the variable. The first was 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]. The other simpler method is to use the net physical stock depreciation [calculated from Compustat item #8 - Property, Plant & Equipment (Total - Net)]. According to the productivity literature the first method should be used, but to conduct the market value estimation we adopted the second approach to ensure consistency with market value and other assets, which are measured in current dollars. The dollar value of IT capital (as calculated above) was subtracted from this result.

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

R&D Asset Ratio. Constructed from R&D expenses [Compustat annual item #46]. Interestingly, this item includes software expenses and amortization of software investment. R&D stock was constructed using the same rule in Hall (1993a, b). She applied a 15% depreciation rate, so we followed her lead. The final ratio is simply the quotient of the constructed R&D stock and total assets. Fewer than half of firms in our sample reported R&D expenses. The missing values were filled in using the averages of the same industry (SIC 4-digits).

Advertising Asset Ratio. We constructed this from advertising expenses [Compustat annual item #45]. Fewer than 20% of our sample of firms reported the item. We applied the same rule with R&D assets ratio.

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

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

Bibliography

- Abel, A. B and O. J. Blanchard (1986). "The Present Value of Profits and Cyclical Movements in Investment." Econometrica, 54(2), pp. 249-274.
- Anand, K and H. Mendelson (1995). "Information and Organization for Horizontal Multimarket Coordination." Stanford University Mimeo.
- Appelgate, L, J. I. Cash, and D. Q. Mills (1988). "Information Technology and Tomorrow's Manager." Harvard Business Review (November-December).
- Autor, D. L, F. Katz and A. B. Krueger (1998). "Computing Inequality: Have Computers Changed the Labor Market?" Quarterly Journal of Economics, v113 n4, November 1998, pp. 1169-1213.
- Bart, H and B. Jovanovic (1999). "The Information Technology Revolution and the Stock Market: Preliminary Evidence." Working Paper, Department of Economics, New York University.
- Berman, E, J. Bound and Z. Griliches (1994). "Changes in the Demand for Skilled Labor within U. S. Manufacturing Industries." Quarterly Journal of Economics, v109 n2, May 1994, pp. 367-397.
- Bresnahan, T.F. (1997), "Computerization and Wage Dispersion: An Analytic Reinterpretation," Mimeo, Stanford Department of Economics.
- Bresnahan, T. F, Brynjolfsson, E. and L. M. Hitt (1999). "Information Technology, Workplace Organization, and the Demand for Skilled Labor: Firm-Level Evidence." National Bureau of Economic Research (NBER) Working Paper 7136. Cambridge, MA: NBER.
- Brynjolfsson, E and L. M. Hitt (1997). "Computers and Productivity Growth: Firm-level Evidence." MIT Sloan School Working Paper.
- Brynjolfsson, E and L. M. Hitt (2000). "Beyond Computation: Information Technology, Organizational Transformation and Business Performance," *forthcoming* Journal of Economic Perspectives, November.
- Brynjolfsson, E and A. Renshaw, and M. Van Alstyne (1997). "The Matrix of Change: A Tool for Business Process Reengineering." Sloan Management Review, Winter.
- Brynjolfsson, E and S. Yang (1999). "Intangible Benefits and Costs of Computer Investments : Evidence from the Financial Market." Proceedings of the International Conference on Information Systems, Atlanta, Georgia, December, 1997. Revised May, 1999.

Chan, L. K. C., J. Lakonishok and T. Sougiannis (1999). Stock Market Valuation of the Research and Development Expenditures, National Bureau of Economic Research (NBER) Working Paper 7223. Cambridge, MA: NBER.

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

Drucker, P. F. (1988). "The Coming of the New Organization." Harvard Business Review (January-February): 45-53.

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

Gormley, J., W. Bluestein, J. Gatoff and H. Chun (1998), "The Runaway Costs of Packaged Applications," The Forrester Report, Vol. 3, No. 5, Cambridge, MA.

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

Griliches, Z. and Cockburn, I (1988). "Industry Effects and the Appropriability Measures in the Stock Market's Valuation of R&D and Patents," American Economic Review (Papers and Proceedings), 78(May): 419-23.

Griliches, Z. and Hausman, J. (1986). "Errors in Variable in Panel Data." Journal of Econometrics 31(1) February 1986, pp. 93-118.

Greenwood, J. (1997). The Third Industrial Revolution: Technology, Productivity, and Income Inequality. Washington, D.C., The AEI Press.

Greenwood, J. and B. Jovanovic (1999). "The Information Technology Revolution and the Stock Market." American Economic Review Papers and Proceedings, 89(2): 116-122.

Jorgenson, D. W. and B. M. Fraumeni (1995). "The Accumulation of Human and Nonhuman Capital, 1948-1984." in Jorgenson, Dale W. (ed.), Productivity. Volume 1. Postwar U.S. economic growth. Cambridge and London: MIT Press, 1995, pp. 273-331.

Hall, B. H. (1990). The Manufacturing Sector Master File: 1959-1987. National Bureau of Economic Research Working Paper 3366. Cambridge, MA: NBER.

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

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

Hall, B. H. (1999). "Innovation and Market Value." University of California Berkeley Mimeo.

Hall, R. E. (1999a). The Stock Market and Capital Accumulation, NBER Working Paper 7180.

Hall, R. E. (1999b). Reorganization, NBER Working Paper No. 7181.

Hammer, M. (1990). "Reengineering Work: Don't Automate, Obliterate." Harvard Business Review(July-August): 104-112.

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

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

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

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

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

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

Jorgenson D. W. and B. M. Fraumeni (1995). "Investment in Education and U.S. Economic Growth," in D. W. Jorgenson (eds.) Productivity. Volume 1. Postwar U.S. Economic Growth. Cambridge and London: MIT Press. p 273-331.

Lev, B. and T. Sougiannis (1996), "The Capitalization, Amortization, and Value-Relevance of R&D." Journal of Accounting and Economics 21.

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

Malone, T. W. (1996). Is Empowerment Just a Fad? Sloan Management Review 38(2).

Mendelson, H. and R. Pillai. (1999) Survival of the Smartest. Working Draft.

Montgomery, C. A. and B. Wernerfelt (1988). "Diversification, Ricardian Rents, and Tobin's q ." Rand Journal of Economics 19(4): 623-32.

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

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

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

Schaller, H. (1990). "A Re-Examination of the Q Theory of Investment Using U.S. Firm Data." Journal of Applied Econometrics, 5(4). October-December, pp. 309-325.

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

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

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

Wyner, G. and T. Malone, W. (1997). "Online Bureaucracy or Electronic Market: Does Information Technology Lead to Decentralization?" Proceedings of the International Conference on Information Systems, Atlanta, Georgia.

Yang, S. (1994). The Relationship between IT Investment and Market Value of Firms. Master's Thesis. MIT Sloan School of Management.

Yorokoglu, M. (1996). "The Information Technology Productivity Paradox." Unpublished Mimeo, Department of Economics, University of Chicago.

Yoshikawa, H. (1980). "On the ' q ' Theory of Investment." American Economic Review 70(4): 739-743.