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In developed economies, production requires not only such traditional factors as capital and labor but also skills, organizational structures and processes, culture, and other factors collectively referred to as "intangible assets." Detailed investigation of some of these types of assets has found that they are often large in magnitude and have important productivity benefits. For example, Dale Jorgenson and Barbara Fraumeni found that the stock of human capital in the U.S. economy dwarfs that of physical capital and has grown markedly over time.[1] Bronwyn Hall, Zvi Griliches, and Baruch Lev and Theodore Sougiannis found evidence that research and development (R&D) assets bring benefits in the form of positive marginal product and market valuation.[2] Timothy Bresnahan, Brynjolfsson, and Hitt have found that certain organizational practices, when combined with investments in information technology (IT), were associated with significant increases in productivity in the late 1980s and early 1990s.[3]

Investors also attempt to incorporate intangible assets into their valuation of firms, and this is one reason that the market value of a firm may differ markedly from the value of its tangible assets alone. In particular, stock market valuations of firms have increasingly diverged from their measured book value in the past decade or so.[4] Part of the explanation may be the growing use of IT and the associated investments in intangible

1. Jorgenson and Fraumeni (1995).
2. B. Hall (1993a); Griliches (1981); Lev and Sougiannis (1996).
3. Bresnahan, Brynjolfsson, and Hitt (1999, 2002).
4. Chan, Lakonishok, and Sougiannis (1999); R. Hall (2001b).

assets.[5] Whereas early applications of computers were primarily directed at factor substitution (particularly of low-skill clerical workers), modern uses of computers have both enabled and necessitated substantial organizational redesign and changes in the skill mix of employees.[6] Collectively, this research argues for a complementarity between computer investment and organizational investment, and specifically a relationship between use of IT and increased demand for skilled workers, greater decentralization of certain decision rights, and team-oriented production. Moreover, case studies and a growing body of statistical analyses suggest that these complementary investments are large.[7]

This paper analytically explores the hypothesis that new, intangible organizational assets complement IT capital just as new production processes and factory redesign complemented the adoption of electric motors over 100 years ago.[8] To realize the potential benefits of computerization, investments in additional "assets" such as new organizational processes and structures, worker knowledge, and redesigned monitoring, reporting, and incentive systems may be needed. We study how the financial markets can be used to help identify such assets.

In some cases the costs of implementing the new processes, training, and incentive systems may be many times greater than the costs of the computer technology itself. However, the managers who decide to incur these costs presumably expect the present value of the resulting benefits to be no less than these costs, even if they accrue over a period of years and are uncertain. In this sense managers' behavior reflects their belief that they are investing in an economic asset.

Assets that are intangible need not be invisible. On the contrary, the presence of intangible organizational assets can be observed in at least three ways. First, some of the specific changes that firms make may be directly observable. In particular, previous work has used survey methods to document a relationship between technology and some aspects of organizational change, such as new business processes, greater demand for

5. R. Hall (2000a); Brynjolfsson and Yang (1999).

6. On the impact of computers on organizational redesign see R. Hall (2000a), Brynjolfsson and Hitt (2000), Brynjolfsson, Renshaw, and Van Alstyne, (1997), Black and Lynch (2001, forthcoming); and Milgrom and Roberts (1990); on their impact on skill mix see Autor, Levy, and Murnane (2000) and Bresnahan, Brynjolfsson, and Hitt (1999, 2002).

7. See Brynjolfsson and Hitt (2000) for a review.

8. David (1990).

skills, and increased employee decisionmaking authority.[9] Firms sometimes try to highlight their investments in these areas, offering tours to customers, investors, and researchers who express an interest in them. A visit to the manufacturing operations of Dell Computer or of a steel minimill provides some insight into the effort these firms put into creating various kinds of organizational assets and the resulting productivity implications. Recently, researchers have begun more systematic efforts to help quantify the extent to which companies have adopted various organizational practices.[10]

Second, the effect of these changes on a firm's market valuation should be measurable. If these new practices really represent the types of organizational assets we described earlier, one would expect the accumulation of these assets to be reflected in firms' market value, as revealed by voluntary transactions among buyers and sellers of the firms' financial securities.

Third, these assets should provide real returns in the form of higher output. Thus a production function framework should reveal that firms that have put in place more of these intangibles saw greater output in subsequent years, after accounting for standard inputs (such as capital, labor, and materials).

Although we will examine all three of these indicators, our focus will be on the relationship between intangibles and the financial markets. Just as investors can visit various factories and buildings owned by a firm and attempt to judge their profit-making potential, they can also form their own judgments about the existence, relevance, and value of various intangible assets owned or controlled by the firm. One difference, however, is that firms do not report a value for many of the intangible assets on their balance sheets, forcing investors to rely on other sources of information to value these assets. As a result, investors and analysts appear to devote relatively more time and effort to assessing the value of companies with larger stocks of intangible assets.[11]

9. Bresnahan, Brynjolfsson, and Hitt (2000); R. Hall (2000a); Sauer and Yetton (1997).

10. See, for example, Osterman (1994), Huselid (1995), Ichniowski, Shaw, and Prennushi (1997), and Bresnahan, Brynjolfsson, and Hitt (2000). This is a welcome change. As Alfred Sloan (1964, p. 50) noted, "The principles of organization got more attention among us than they did then in universities. If what follows seems academic, I assure you that we did not think it so."

11. Barth, Elliott, and Finn (1997).

Although the data can be noisy, the valuations provided by the public capital markets do have some advantages for researchers in this area. Whereas the 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 companies' future revenues, provide an immediate indicator of whether these investments are expected to generate value for a firm's owners. In particular, the market value of a firm that has leveraged computer assets with organizational investments should be substantially greater than that of a similar firm that has not. 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.

An important characteristic of the organizational capital created by corporations is that its value may not be realized for years, if at all. Firms choose to invest in certain business models, organizational practices, and corporate culture. Later some of these investments turn out to be more productive and profitable than others. The financial markets recognize and reward those models that are well suited for the current technological and business environment. At that point, other firms may try to imitate the winners' best practices, but the complexity due to explicit and implicit complementarities among each collection of practices makes this difficult. Kmart may wish it could emulate Wal-Mart, and Compaq may try to learn from Dell, but their adjustment costs may prevent this from happening for years, even if they succeed in the end.

Thus it would be unwise to interpret high market values on an input such as IT as reflecting high adjustment costs for the successful investors. On the contrary, the market is mainly valuing the intangible assets correlated with IT; if anything, IT-intensive firms are likely to have *lower* adjustment costs than their rivals and hence higher levels of IT investment. At the same time, the higher investment costs of the rival firms is what prevents them from quickly dissipating the rents of the winners. When complex combinations of technology and organization are called for, the costs of imitation and investment are likely to be especially high. Furthermore, looking at the valuations of winning organizational strategies ex post can give a misleading impression of their returns. Many, perhaps most, efforts at organizational change fail, and projects involving extensive investments in IT often fall well short of expectations.[12] Ex ante, a rational manager must consider the substantial risk of failure before deciding whether a project is likely to deliver the required returns.

This has implications for how one should interpret the coefficients on asset variables in a market value equation. In the traditional interpretation,[13] when a high market value is found to be associated with IT, it reflects the adjustment costs of investing more in IT—the shadow value of installed IT capital. In our interpretation, however, relatively little of the market value is due to this effect. Most of the value springs from intangible assets, including factors such as business organization, that are disproportionately high in IT-intensive firms. At the end of our sample period, it was easy to see that Dell's business organization was a winning model; at the beginning of the period, as that organization was being created, its value was much less obvious.

This argument leads to five hypotheses, which are empirically testable:

—Each dollar of installed computer capital should be correlated with more than one dollar of market value, after controlling for other measured assets.

—Investments in computers should be correlated with increased investments in certain observable organizational practices.

—If these practices represent part of the productive assets of a firm, they should also be associated with increases in market value.

—If intangible assets are most common in firms that combine these specific organizational practices with investments in computer capital, those firms should have a higher market value than those that adopt these same practices in isolation.

—Any intangible assets correlated with computerization and these specific organizational practices should also result in higher measured output in future years, reflecting the returns to these intangible assets.

Using data on 1,216 large firms over eleven years (1987–97), we find evidence supporting all five hypotheses:

—Each dollar invested in computers is associated with an increase in firm market valuation of over $10 (depending on the assumptions of the estimation models), compared with an increase of just over $1 per dollar of investment in other tangible assets.

12. Kemerer and Sosa (1991) provide examples.
13. For example, Baily (1981).

—Firms that are intensive IT users are also more likely to adopt work practices that involve a specific cluster of organizational characteristics, including greater use of teams, broader distribution of certain decision rights, and increased worker training.

—This cluster of organizational characteristics increases a firm's market valuation beyond what can be accounted for by tangible assets.

—Firms that have adopted both these organizational characteristics and have a large computer capital stock have disproportionately higher market valuations.

—Firms with higher levels of computerization, especially when they also have higher levels of these organizational characteristics, have significantly higher output in subsequent years.

The primary alternative hypothesis for the high market-to-book ratio of many firms is some sort of investor mispricing, perhaps due to a market bubble, fads, or irrationality. Our argument is not that investors never make mistakes in pricing assets; undoubtedly this does happen. However, the five findings above are collectively difficult to explain as being due entirely to mispricing.

Furthermore, our examination of fixed-effect specifications and of specifications using differences over long periods suggests that our results are not driven by other types of unobserved firm heterogeneity or short-run correlated shocks between market value and computer investment. Similarly, the evidence suggests that they are not driven by a general complementarity between capital and skill: these results appear to be unique to IT capital and are not important for ordinary capital. Because our sample consists predominantly of large, established firms rather than new high-technology entrants, and because the time period of our data predates the large increase in the value of technology stocks in the late 1990s, our results are not driven by the possible presence of a bubble in high-technology stocks in the late 1990s. Moreover, our results are qualitatively similar for each individual year when estimated separately over our eleven-year sample period, which includes the peak and trough of a business cycle. This argues against the possibility that our results are simply driven by short-term stock market fluctuations. The results are consistent with earlier case-based research as well as with recent econometric work using production functions, which suggests 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.

Related Literature and Cases

We begin by summarizing some of the related literature, including some case examples that help provide some perspective and texture to the statistical results reported in that literature and later in this paper.

IT and Organization

This paper draws primarily on two strands of research and seeks to link them. Here we review some studies of the interaction of IT and firm organization; later, when we develop the model, we will draw on studies that use financial markets to provide insight into the size and nature of intangible assets.

For U.S. businesses the most important technological change in the last twenty years has been the increased power and ubiquity of computers and related technologies. The quality-adjusted price of logic and memory chips has declined by about an order of magnitude every five years, and that of many other components such as magnetic storage and data communications has declined at a comparable or faster rate; these trends show no signs of abating in the near future. Indeed, there is some evidence of an acceleration since 1995.

IT has effects on the organization that adopts it that are disproportionate to its share of the organization's costs. A firm's business processes, internal organization, and relationships with outside parties are significantly determined by the economics of information and communications.[14] For instance, lower-cost access to data and communications can exacerbate the information processing bottleneck at the tops of hierarchies and therefore increase the value of delegation and decentralized, nonmachine decisionmaking.[15] It can also have direct and indirect effects on the value of skilled labor, job design, and incentive systems. In particular, Bresnahan, Brynjolfsson, and Hitt analyze data on IT, organizational practices, and productivity from over 300 large firms and conclude that

14. See, for example, Milgrom and Roberts (1990) and Radner (1993).
15. Brynjolfsson and Mendelson (1993).

> IT use is also correlated with a pattern of work organization involving more decentralized decisionmaking and greater use of teams. Increases in firms' IT capital stock are associated with the greatest increases in output in firms that also have high levels of human capital or decentralized work organization, or both. However, firms that implement only one complement without the others are often less productive than firms which implement none at all.[16]

In other words, there is evidence of a complementarity between the use of IT and certain changes in work organization. Of course, the falling quality-adjusted price of IT raises the return to investments not only in IT but also in its complements. A significant literature, mostly outside of economics, has explored various aspects of the interaction between IT and organization, business processes, and even corporate culture.[17]

Although the organizational complements are valuable and, in some cases, even essential to the success of IT innovations, implementing organizational changes is costly and risky, yielding both successes and failures.[18] Both the case evidence and the econometric results suggest that the costs of these organizational complements to IT investments typically exceed the direct financial costs of the IT investments themselves.[19] Importantly, although many of these organizational practices may be readily visible to competitors and are copiously documented in articles by business school professors and consultants, they are notoriously difficult to imitate successfully.[20] This reflects complementarities and large effects of seemingly minor characteristics. Intel, for example, has adopted a "copy exactly" philosophy for any chip fabrication plant built after the first plant in each generation. Wholesale replication of even seemingly insignificant details has proved more reliable than trying to understand which characteristics really matter. Going from the plant level to the firm level only complicates the imitator's task.

The difficulty in implementing organizational complements can explain the apparent quasi-rents earned by firms that have been fortunate

16. Bresnahan, Brynjolfsson, and Hitt (2000, p. 184).

17. See, for example, Applegate, Cash, and Mills (1988), Barras (1990), Bresnahan and Greenstein (1997), Brynjolfsson and Hitt (1997), Brynjolfsson, Renshaw, and Van Alstyne (1997), Davenport and Short (1990), David (1990), Ito (1996), Malone and Rockart (1991), Milgrom and Roberts (1990), Autor, Levy, and Murnane (2000), Orlikowksi (1992), Scott Morton (1991), and Woerner (2001). Brynjolfsson and Hitt (2000) provide a review of the literature.

18. See, for example, Kemerer and Sosa (1991).

19. Ito (1996); Bresnahan and Greenstein (1997); Bresnahan (1999).

20. Brynjolfsson, Renshaw, and Van Alstyne (1997).

or skillful enough to have them in place. In some cases these quasi-rents, when measured in a production function framework, may show up as higher coefficients on other inputs to production. For instance, Brynjolfsson and Hitt and Frank Lichtenberg,[21] among others, find that heavy use of IT is correlated with significantly higher levels and growth rates of measured productivity. These rents may arise because nonadopters have not tried, or have tried and failed, to implement complementary workplace or product innovations. Brynjolfsson and Hitt interpret their productivity results as pointing to the existence of large but unmeasured inputs to production that are correlated with measured IT. A related literature finds that certain work practices and human resource policies are correlated with higher levels of productivity and thus constitute another type of typically unmeasured "input" to production.[22]

Because effective work organization can be costly to develop and implement but yields a stream of cash flows over time, it is natural to think of it as a kind of asset. This asset has variously been called "organizational capital," "e-capital," and "structural capital," depending on the context.[23]

Case Studies

Although statistical data are very useful for hypothesis testing, our own understanding of the role of organizational capital has been shaped in an important way through visits and interviews with managers who have implemented information systems projects and by teaching case studies on such implementation.[24] Some common themes in these cases are the following:

—Computers and software are just the tip of a much larger iceberg of implementation costs. Successful projects require enormous management attention, worker training, and changes in seemingly unrelated areas of the business and perhaps the entire industry. Successful chief information officers are now expected to combine knowledge of technology with an understanding of the firm's business opportunities and challenges.

21. Brynjolfsson and Hitt (1995, 2001); Lichtenberg (1995).
22. See, for example, Ichniowski, Shaw, and Prennushi (1997).
23. Brynjolfsson and Yang (1999); R. Hall (2000a); Lev (2001).
24. Many of these examples, as well as some of the broader econometric studies, are described in more detail in Brynjolfsson and Hitt (2000).

—Many of the practices that matter most are also to be found at the level of the business culture and work content of individual workers, not just in sweeping visions on the part of the chief executive officer or the chief information officer. As a result, organizational capital is quasi-fixed in the short run.

—Information technology initiatives are difficult and often fail. By the same token, one of the reasons they can provide competitive advantage and quasi-rents is that they are not trivial for other firms to duplicate.

Wal-Mart, with a recent market capitalization of $273 billion and net tangible assets of $25.5 billion, is an example.[25] Wal-Mart has spent over $4 billion on its "retail link" supply chain system, and it has been called "by far the commercial world's most influential purchaser and implementer of software and systems."[26] A recent McKinsey Global Institute report singles out Wal-Mart for playing a disproportionate role in the productivity revival in the 1990s:

> Productivity growth accelerated after 1995 because Wal-Mart's success forced competitors to improve their operations. . . . By the mid-1990s, [Wal-Mart's] productivity advantage widened to 48%. Competitors reacted by adopting many of Wal-Mart's innovations, including . . . economies of scale in warehouse logistics and purchasing, electronic data interchange and wireless bar code scanning."[27]

A key point in that report is that "[IT] was often a necessary but not sufficient enabler of productivity gains. Business process changes were also necessary. . . ."[28] Or, as Robert Solow puts it, "The technology that went into what Wal-Mart did was not brand new and not especially at the technology frontiers, but when it was combined with the firm's managerial and organizational innovations, the impact was huge." Solow concludes, "we don't look enough at organizational innovation."[29]

Other highly visible, computer-enabled business changes happen on factory floors and in back offices. For instance, Dell combined new materials management software with a set of redesigned workflows to roughly halve the floor space required in its main server assembly plant, while

25. Figures are as reported by Yahoo! Finance on March 29, 2002.

26. M. Schrage, "Wal-Mart Trumps Moore's Law" *Technology Review*, March **00**, 2002, p. 21.

27. McKinsey Global Institute (2001, p. 2).

28. McKinsey Global Institute (2001, p. 4).

29. M. Schrage, "Wal-Mart Trumps Moore's Law" *Technology Review*, March **00**, 2002, p. 21.

increasing overall throughput and reducing work-in-process inventories. Had Dell instead built a second factory on the site, the additional real estate and capacity would have been duly recorded on its balance sheet. In contrast, the processes that doubled the effective size of its existing facility went unrecorded.

Similarly, a Johnson & Johnson factory producing adhesive bandages dramatically increased the variety of products it could manufacture and reduced costs after combining new, computer-based flexible machinery with nearly a dozen carefully defined work practices and principles, including changes in the allocation of certain decision rights, incentive systems, and job responsibilities.[30] The right combination of work practices was discovered only after a lengthy and costly period of experimentation and false starts. When a system found to be highly effective was ultimately implemented, management ordered the factory windows painted black to prevent competitors from quickly learning the details of its implementation.

Other firms are more eager to disseminate their discoveries about organizational complements to IT. For instance, Cisco Systems has identified a set of practices and attitudes that the company associates with increased productivity from the use of the Internet; it calls these practices and attitudes its "Internet Culture." The firm has established a culture that produces the results it is looking for, and it invests heavily in maintaining that culture. Cisco not only has a "Director of Internet Culture" but also issues plastic cards, which employees are asked to carry with them, that summarize the eleven key components of that culture.[31] Furthermore, as a leading provider of some of the basic hardware of the Internet, Cisco encourages other firms to understand and adopt these practices, which they believe make investments in Internet technologies more productive.

Accounting for Intangible Assets

In each of these cases, the basic technology was available to all interested parties. However, the truly valuable assets were the complementary business processes, work practices, and even culture, all of which were harder to identify and implement. In effect, these constituted an organiza-

30. Bryjolfsson, Renshaw, and Van Alstyne (1997).
31. Woerner (2001).

tional asset with real value, although one not reflected on the firm's balance sheet.

Even many of the direct project costs of an IT project may elude documentation on a firm's balance sheet. For example, less than 20 percent of the typical $20 million installation cost of a SAP R/3 system (a widely used large-scale package designed to integrate different organizational processes) is for hardware and software, which is capitalized; by far the greater part of the investment is for hiring consultants to help develop requirements; evaluate, select, and customize the software; redesign organizational processes; and train the staff in the use of the new system.[32]

According to the American Institute of Certified Public Accountants, although the costs of software purchase and development should be capitalized if they exceed some threshold,[33] most of these other project costs must be expensed.[34] As firms devote more resources to various IT projects, this accounting policy drives a wedge between the market value of a firm's assets and their value on its balance sheet.[35] As noted by Lev and Paul Zarowin:

> restructuring costs, such as for employee training, production reengineering or organizational redesign, are immediately expensed, while the benefits of restructuring in the form of lower production costs and improved customer service, are recognized in later periods. Consequently, during restructuring, the financial statements reflect the cost of restructuring but not its benefits, and are therefore largely disconnected from market values which reflect the expected benefits along with the costs.[36]

The accounting policy of excluding many such intangible assets from a firm's balance sheet should not be taken as an implication that they have

32. Gormley and others (1998).

33. AICPA Statement of Position 98-1. This does not apply for "small" software purchases or development projects. Firms have some discretion as to the exact threshold: at FleetBoston Financial, for example, software development projects smaller than $500,000 are normally entirely expensed, according to Cherie Arruda, technology controller at FleetBoston (personal communication with the authors, March 22, 2002).

34. Specifically, "Examples of the kind of work that must be expensed include:? Alternatives development and evaluation, development of requirements, training, data conversion, evaluation of technology, and choosing one of the alternatives being proposed" (Colenso, 2000).

35. Before 1998, firms expensed even more of their internal software development costs (Ernst & Young, 1998). The exception is firms that produced software for sale, which began more aggressive capitalization in 1985 as a result of FASB Statement 86.

36. Lev and Zarowin (1999, p. 20).

no economic value, or even that their economic value is unknown and unknowable. On the contrary, it partly reflects the different goals of accountants and economists. No single number is a correct reflection of the value of an asset in all states of the world. A creditor, when evaluating a piece of collateral, might care most about that asset's value in those states of the world where the debtor is unable or unwilling to make interest payments. In those circumstances collateral may need to be seized and sold for salvage value, and then the value of many intangible assets, such as organizational capital, is likely to be very low or zero. Accountants, to the extent they are responsible for providing useful information to creditors and potential creditors, might reasonably adopt a conservative valuation for many assets, particular those that have little or no salvage value in "bad" states of the world. Furthermore, a financial accountant needs to provide, for outside parties, reliable numbers that are not easily subject to "earnings management" or other types of gaming by management, since the interests of management and creditors or potential creditors are not always aligned. According to the Financial Accounting Standards Board, more conservative rules for recognizing assets are called for when valuations are uncertain.[37]

Equity investors care less than other creditors about the value of assets in "bad" states of the world, and more about the expected cash flows those assets can generate across all states of the world. This is one reason that, when assets have different values in different states of the world, there may be a large, and perfectly sensible, gap between balance sheet assets and the market value of a firm. To the extent that an economist is interested in the expected value of a firm's assets, their market value as judged by interested investors may provide a more accurate guide than the balance sheet. In this paper we attempt to make use of these judgments.

Econometric Model and Data

Here we sketch the derivation of our stock market valuation model and describe the data used in the analysis.

37. FASB Concept No. 6, 1985, paragraph 175.

Derivation of Model for Stock Market Valuations

Our model draws on standard finance theory and assumes that managers are rational in their investment decisions and that investors are rational when they make their judgments about the valuation of corporate securities. Of course, this does not mean that their decisions will always be correct ex post; uncertainty and imperfect information make that unlikely. In addition, bubbles and other anomalies in the valuation of financial assets can make the interpretation of the econometric results more difficult. We attempt to address these possibilities in a variety of ways.

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 it owns.[38] Others have taken variations of this framework adapted for empirical use and applied them to the valuation of firms' R&D,[39] and the relationship between firm diversification and firm value, using firm-level data.[40]

Other authors have proposed using Tobin's *q* to capture intangible organizational assets empirically; this approach has been significantly advanced recently by Robert Hall. Discussing his quantity revelation theorem, Hall states that "the value of corporate securities, interpreted as a measure of the quantity of capital, behaves reasonably," and that the firm's intangible assets include "technology, organization, business practices, and other produced elements of the successful modern corporation."[41] Elsewhere Hall discusses the analogy between a flow of investment in reorganization and a flow of investment in physical capital.[42] Whereas he uses the label "e-capital" to describe all intangible assets revealed by the gap between the financial markets' value of firms and the value of their replacement assets in the 1990s, this paper seeks to identify more explicitly the role of computer capital and particular organizational practices.[43] Thus our paper is most closely related to that of Brynjolfsson

38. See, for example, Tobin (1969), Hayashi (1982), Naik (1994), Yang (1994), Bond and Cummins (2000), and R. Hall (2000a, 2001a, 2001b).

39. Griliches (1981); Griliches and Cockburn (1988); B. Hall (1993a, 1993b, 2000).

40. Montgomery and Wernerfelt (1988).

41. R. Hall (2001a).

42. R. Hall (2000a).

43. Interestingly, in related work using similar data on computers and organizational investments but a different framework, Bresnahan, Brynjolfsson, and Hitt (1999, 2002)

and Yang,[44] 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 cash flows $\pi(t)$ according to a discount function $u(t)$. The accumulation of capital investment, less depreciation (δ), produces a vector of the capital stock (**K**, which includes different components of capital K_j, $j = 1 \ldots J$, where the js are computer capital, other physical capital, and so forth). The capital stock, along with the variable inputs, is used to produce output through a production function (F). This yields the following program:

Maximize with respect to **I** and N

$$V(0) = \int_0^\infty \pi(t)u(t)dt, \tag{1}$$

where

$$\pi(t) = F(\mathbf{K}), N, t) - N - \mathbf{I}, \tag{2}$$

and the following holds:

$$\frac{dK_j}{dt} = I_j - \sum_{j=1}^{j} \delta_j K_j, \text{ for all } j = 1, \ldots, J. \tag{3}$$

Under the assumptions that $F(\mathbf{K}, N)$ is a homogeneous function of degree 1 over **K**, N, and **I** (constant returns to scale) and is twice differentiable, one can solve for the market value of the firm that results from this optimization problem. If all assets can be documented and no adjustment costs are incurred in making them fully productive, buying a firm is equivalent to buying a collection of separate assets.[45] Thus the market value of a firm is simply equal to the current stock of its capital assets:

$$V = \sum_{j=1}^{j} K_j. \tag{4}$$

also find empirical support for the second main claim of R. Hall (2000a) regarding the organizational drivers of the increased demand for college-educated workers.

44. Brynjolfsson and Yang (1999).

45. Baily (1981).

Econometric Issues

The formulation in equation 4 suggests a basic estimating equation that relates the market value of firm i to the assets that the firm possesses, allowing for repeated observations over time t:

$$(5) \qquad V_{it} = \alpha_i + \sum_{j=1}^{j} \nu_j K_{j,it} + \varepsilon_{it}^{V}.$$

If the vector of assets **K** for each firm contains all relevant capital assets and there are no other forms of specification or measurement error or adjustment costs, we would expect that $\alpha = 0$ and $\nu_j = 1$ for all j. However, $\boldsymbol{\nu}$ may deviate from 1 if adjustment costs are significant or if there are omitted variables that are correlated with the quantity of observed capital assets.

In the presence of adjustment costs, the shadow value of installed capital can exceed its acquisition costs. Capital that is installed may be more valuable than capital that is not yet installed. For example, if there are two types of capital, computers (K_c) and other physical capital (K_p), then (ν_c – 1) would represent the difference in val ue between computer capital that is fully integrated into the firm and otherwise identical computers that are available on the open market, and (ν_p – 1) would be the corresponding value for other types of capital.[46] As shown by F. Hayashi,[47] $\boldsymbol{\nu}'\mathbf{K}$ can be made observable when there are constant returns to scale, because marginal and average q will be equal. In essence, the value of the firm will simply be a function of the capital price vector ($\boldsymbol{\nu}$) and the capital quantity matrix (**K**) of each of the types of capital it owns.

Similarly, the observed market value of each capital asset may also deviate from 1 when there are other capital assets that are not measured, such as omitted intangible assets, or shocks to market value that are correlated with the levels of observed capital assets. For instance, these intangible assets might include organizational capital that is complementary to certain observed capital assets or persistent, firm-specific components of value (such as management quality) that are correlated with capital quantity. Market value shocks include persistent errors in stock market valuation that are simultaneously correlated with capital assets (for example, the stock market over- or undervaluing high-technology

46. See, for example, Abel (1990).
47. Hayashi (1982).

firms), or short-run events such as an increase in a firm's market size or opportunities that raises stock market value and induces capital investment. These specification errors can be represented as a systematic omitted component of market valuation (M_{it}) in the theoretical market value relationship:

(6) $$V_{it} = \alpha_i + \sum_{j=1}^{j} (1 + \nu_j^*) K_{j,it} + M_{it} + \varepsilon_{it}^V .$$

From standard omitted-variables arguments,[48] the presence of M_{it} in the market valuation equation will alter the estimates of the value of capital assets ($\boldsymbol{\nu}^*$, a vector) in a systematic way depending on the correlation of the observed capital assets (**K**, a matrix with rows representing different assets for each firm and columns representing different firm-year observations) with the omitted component of market value (**M**, a column vector with elements M_{it}). Specifically, in the absence of adjustment costs,

(7) $$\boldsymbol{\nu}^* = (\mathbf{K}'\mathbf{K})^{-1}\mathbf{K}'\mathbf{M}.$$

This implies that $\boldsymbol{\nu}^*$ is simply the vector of coefficients that would arise in a regression of the capital assets on the omitted market valuation component (**M**):

(8) $$M_{it} = \beta + \sum_{j=1}^{j} \nu_j K_{j,it} + \varepsilon_{it}^M .$$

Thus, in the absence of adjustment costs, a high value for a particular capital asset in the market value equation implies a correlation between that asset and **M**, for instance, a large stock of (valuable) intangible assets or investor errors in valuation that is correlated with the quantity of observed assets.

As noted by Stephen Bond and Jason Cummins,[49] distinguishing the exact nature of this relationship is more difficult. If we interpret **M** as arising from the omission of intangible assets such as organizational capital from the equation, we can write $M_{it} = Q_{it} K_{o,it}$, where Q_{it} is the market-determined shadow price of organizational capital and $K_{o,it}$ the quantity of organizational capital. In general, it is difficult without making further assumptions to distinguish the price and the quantity of organizational

48. Greene (1993, p. 246).
49. Bond and Cummins (2000).

capital individually,[50] but for purposes of identifying the value of organizational complements to computers we need only determine the value of M_{it}. However, if there is a bubble in the valuation of corporate securities (an "error" in the markets' perception of Q_{it}), this can alter estimates of M_{it}.

Instrumental variables techniques will be of little help insofar as they do not distinguish between true organizational complements and errors in valuation. Removing the influence of factors that are both unobserved and correlated with productivity would remove the very variables we seek to measure: intangible assets. If such a technique were successful, the coefficients on the observed capital assets would be driven close to their theoretical value of 1, but no light would be shed on the magnitude of the intangibles.

However, if data are available that allow one to measure some of the components of M_{it}, it may be possible to partially distinguish the relative contribution of market valuation errors and the relative contribution of the intangible assets that comprise M_{it}. We may also be able to reduce the impact of identifiable sources of correlated shocks by means of other econometric adjustments such as control variables for time periods or industries.

Our analysis focuses on obtaining data and measuring the contribution of various aspects of organizational capital (K_o) that, from our earlier discussion, represent potential components of **M** either alone or in combination with computer assets (K_C). We assume that the level of K_o is difficult to change (that is, quasi-fixed) in the short run and thus can be viewed as exogenous with respect to both computer asset levels and market valuations.[51]

There are several ways in which K_o can influence market valuation. First, it can have a direct correlation with market value while being orthogonal to all other assets. Directly incorporating measures of K_o in the regression will then improve the efficiency of the estimation while having no impact on the other coefficients.

Second, K_o can influence market value through its correlation with other assets. In general, the degree of bias in the estimated components of v depends on the correlations among all capital assets. However, if K_o is

50. See R. Hall (2001b) for one approach.
51. See the related discussion in Bresnahan, Brynjolfsson, and Hitt (2002).

positively correlated with K_C but orthogonal to the other capital components (including any components of **M** other than K_o), from equation 7 this will reduce the coefficient on K_C when direct measures of organizational capital are present in the regression.[52] The reduction is proportional to the correlation between K_C and K_o.

Finally, K_o may influence market valuation disproportionately when K_C is also large, if there are additional, unobserved intangible assets that are correlated with the simultaneous presence of both K_C and K_o. Under standard *q* theory, the coefficient on an asset can be interpreted as a function of the adjustment cost of increased investment in that asset. Thus the presence of arbitrage opportunities normally requires that the market value correlated with an asset be the same regardless of what other assets are also present. However, this need not be the case if the value of otherwise unobserved intangible assets varies systematically with the relationship among observed assets, yielding an additional correlation with market value above their simultaneous direct correlation. That is, there may be a distinct intangible asset that is correlated with the combination of K_C and K_o (but not necessarily with these inputs separately). In particular, the simultaneous presence of high values for both K_C and K_o may signal that a firm has successfully adopted a certain work system. If that work system is both valuable and costly to implement, even for firms that have already adopted K_C or K_o alone, firms with the combination of both inputs should be expected to have disproportionately higher market values. This interpretation is consistent with the findings of the literature on IT impacts.[53] Unlike the previous two relationships, which can be captured simply by introducing K_o into the regression in levels, this relationship will be revealed by the interaction $K_C \times K_o$.

All these relationships can be captured by including both K_o and $K_C \times K_o$ in the regression. In addition, we can also test the uniqueness of this organizational relationship to computers by estimating the correlations between the other components of K and K_o as well as their interactions in the market value equation.

The estimation of the contribution of intangible assets relies on minimizing other omitted variables that are correlated with asset levels. To the

52. To apply equation 7, replace **K** and **M** with their values conditional on K_O.
53. See, for example, Bresnahan, Brynjolfsson, and Hitt (2000) and Brynjolfsson and Hitt (2001).

extent that many of these types of variables are common across the entire economy (for example, changes in the price of new capital investment, or the rate of overall economic growth) or unique to particular industries (such as the introduction of a new production technology throughout an industry), they can be accounted for by controls for year and industry.

If instead the omitted variables are time-invariant factors that are specific to individual firms, they can be removed by estimating difference equations that remove the contribution of firm-specific effects. Moreover, differences measured over long intervals (long differences) may be robust to a variety of other short-run shocks to the extent that asset levels and market value have sufficient time within the difference interval to return to equilibrium levels following a shock. However, these types of techniques also remove at least some of the true organizational capital that we are looking for, to the extent that organizational practices differ across firms and are relatively slow changing.

Finally, some omitted variables, such as R&D investment or advertising, could be indicators of other assets. To the extent this is a problem, these variables can be directly incorporated into the estimating equation as additional covariates.

For purposes of estimation we divide assets into three categories: computers, other permanent physical assets (property, plant, and equipment, or PP&E), and other balance sheet assets (receivables, inventories, goodwill, and other assets). We deduct current cash balances both from market value and from other assets. We also include control variables: the ratio of R&D capital to sales, the ratio of advertising expense to sales, dummy variables to account for missing observations on R&D or advertising expenditure, industry dummies (usually at the two-digit Standard Industrial Classification, or SIC, level), and year dummies.[54]

54. Advertising and R&D are other types of nonstandard “assets” that have been considered in prior work. Because no capitalized value is reported for them, we simply include them as ratios in the reported regression. This can be thought of as treating current spending on these assets as a noisy indicator of their capital stock values (B. Hall, 1993a, 1993b; see also Brynjolfsson and Yang, 1999, for a more detailed analysis of these assets in this context). Because R&D is only available for about half the sample, and advertising for only about a third, we set the values of these variables to zero when they are missing and include a dummy variable to capture the mean contribution of these variables when the data are not available.

Data Sources and Construction

The data set used for this analysis is a panel of computer capital and stock market valuation data for approximately 1,216 firms over the 1987–97 period, matched to a cross-sectional survey of organizational practices conducted in 1995 and 1996. A brief description of each data source follows; the appendix provides additional detail.

COMPUTER TECHNOLOGY. The measures of computer use were derived from the Computer Intelligence Infocorp (CII) installation database, which details IT spending by site for Fortune 1000 companies. Data from approximately 25,000 sites were aggregated to form the measures for the 1,000 companies that represent the total population in any given year. This database is compiled from telephone surveys that gather detailed information about 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 for each year from 1987 to 1997 was used for the computer measures.[55] From these 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 communications 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.[56]

ORGANIZATIONAL PRACTICES. The organizational practices data in this analysis come from a series of surveys of large firms. These surveys adapted questions from previous surveys on human resource practices and workplace transformation.[57] The questions address the allocation of vari-

55. There was a change in the valuation methodology in the CII database in 1994. Thereafter the market value of central processors was no longer calculated at the equipment level. However, CII did continue to obtain the market value information going forward, and thus comparable measures could be constructed by multiplying the aggregate number of units (personal computers, mainframes, workstations, and so on) by the average value for the category. Year-by-year regressions do not suggest the presence of any structural change in the data.

56. 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.

57. Huselid (1995); Ichniowski, Shaw, and Prennushi (1997); Osterman (1994).

ous types of decisionmaking authority, the use of self-managing teams, the breadth of job responsibilities, and other miscellaneous characteristics of the workplace (further detail appears in the results section). Organizational data were collected at the end of 1995 and early 1996, covering most of the Fortune 1000. This yielded a cross section of 416 firms, with a survey response rate of 49.7 percent. We detected no significant pattern of response bias when the sample was compared with the population of firms in the Fortune 1000. Of the 416 firms that responded to the survey in some way, we have complete IT, organizational, and financial data for a total of 272.

MARKET VALUATION AND OTHER DATA. 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), PP&E, other assets, R&D expense, and advertising expense. For the productivity analysis we also compute constant-dollar value added, labor input, and the capital stock. We removed from the sample those firms for which the data were inconsistent from year to year, firms that principally produced computers or software, and firms in the communications sector (SIC 4813). The last two groups of firms were removed because the nature of computers and telecommunications equipment as both a production input and output makes these firms very different from the rest of the economy.[58]

The full data set comprises 7,564 observations over eleven years for market value and computer capital stock, with each of 1,216 firms represented by at least one observation. After matching these data to the organizational practices surveys, we had complete organizational and market value data for a subsample of 272 firms, for a total of 2,097 observations.

Results

We performed regression and correlation analyses to test our five hypotheses. First, we explored the basic relationship between IT and

58. For most of the economy, computers are a complement to other production assets. However, in the computer and software industries, computers are the principal production asset. Moreover, because these firms often use the technology assets they produce, they may face very different effective prices for these assets. Communications industries were excluded because of the difficulty in separating out corporate computer use from telephone switchgear, which is largely computer based.

stock market value for our full sample of firms. We then used correlation analyses to examine the relationship between computer capital and the adoption of specific organizational practices, and we constructed a single variable, *ORG*, to capture a portion of the relevant variation in organization across firms. It is this variable that will represent our (noisy) measure of organizational capital. Third, we investigated the effect of *ORG* on firm market value. Fourth, we studied how the combination of *ORG* and computers affects market value. Finally, we examined how these variables affect output in a production function framework. We also performed a number of checks on the robustness of our analysis and considered alternative hypotheses.

Computers and Market Value

BASIC FINDINGS. We begin by replicating earlier work by Brynjolfsson and Yang with our slightly larger data set.[59] Table 1 reports results of regression analyses examining the relationship between computers and market value. This equation relates market value to the three types of assets identified above: computers, PP&E, and other assets (principally, accounts receivable, inventories, and liquid assets other than cash).[60] Because we are pooling multiple firms in multiple years, we include dummy variables for each year and two-digit SIC industry. With the exception of our regressions using least absolute deviation (LAD) techniques, we use Huber-White robust standard errors or random-effects models to account for multiple observations of the same firm over time.[61] We also include measures of firms' R&D-sales and advertising-sales ratios. The ordinary least squares OLS regression reported in table 1 finds that each dollar of installed PP&E is valued at about $1.47, somewhat larger than the theoretical value of $1 that would be expected if there were no adjustment costs or correlated intangible assets. The market value of

59. Brynjolfsson and Yang (1999).

60. An alternative specification would include the book value of some of these other assets in the computation of market value and remove them from the list of independent variables. Leaving them in the regression allows us to test, rather than assume, that their market valuation is equal to their book value.

61. The LAD regressions, being nonlinear regression procedures, do not have analogous panel data corrections. Therefore the standard errors for analyses using these procedures may be understated by as much as a factor of 3.3 (the square root of the number of time-series observations), although in practice the error is well below this bound.

Table 1. Regressions of Market Value on Asset Quantities, 1987–97[a]

	Estimation method	
Independent variable	*OLS*	*LAD*
Computer assets	11.947	11.882
	(4.025)	(0.361)
PP&E	1.474	1.181
	(0.088)	(0.004)
Other assetsb	1.064	1.039
	(0.012)	(0.001)
R^2	0.950	n.a.

Source: Authors' regressions. See appendix for description of data sources.

a. The dependent variable is firms' market value. The sample contains 7,564 observations from 1,216 firms. All regressions control for year, the ratio of R&D to sales, the ratio of advertising expenditure to sales, and SIC industry; OLS regressions include two-digit controls, while LAD regressions include 1½-digit controls. Standard errors are reported in parentheses; for the OLS regression they are Huber-White robust standard errors.

b. Includes accounts receivable, inventories, and noncash liquid assets.

each dollar of other assets is close to $1; apparently these assets are less subject to adjustment costs or omitted components of market value.

Strikingly, however, each dollar of computer capital is associated with about $12 of market value. This apparent excess valuation of computers suggests the presence of substantial intangible assets, adjustment costs, or other omitted components of market value correlated with computer assets. In these and all subsequent regressions, time and industry controls are jointly significant (results not shown). We are thus able to remove some of the temporal shocks and other omitted components of market value unique to time period and industry. Although we do not have capital stock values for R&D or for advertising, we do have the investment flows for some of the firms in our sample, and we include their input shares as controls; these are also significant in most specifications (not shown).

Table 1 also reports estimates of the same equation using an LAD regression technique, which minimizes the sum of absolute values of the residuals rather than the sum of the squared residuals as in an OLS regression. This technique not only minimizes the influence of outliers but also reduces the impact of heterogeneity in firm size in our sample. This approach produces a similar estimate for the coefficient on computer capital (now 11.9), which is still far greater than the theoretical baseline of $1. The coefficient on PP&E falls slightly (to 1.18), whereas the coefficient on other assets is essentially the same.

LONG-DIFFERENCE SPECIFICATIONS. Our earlier discussion suggests that certain types of organizational practices are likely to have a significant influence on the value of computer assets. One way to account for these practices without measuring them directly is by estimating a difference specification that eliminates the contribution of any time-invariant, firm-specific component of market value. To the extent that organizational assets can be viewed as quasi-fixed, at least over moderately long periods, this suggests that we may be able to examine the amount of computer value potentially attributable to these types of factors. Table 2 reports estimates of our basic specification (including year and industry dummy variables) in differences ranging from those at one year to those at ten years.

Although any of these differences would presumably remove all time-invariant, firm-specific characteristics, these alternative specifications may yield different results for at least two reasons. First, longer differences are much less subject to bias from measurement error in the independent variables.[62] Thus, if measurement error were the only concern, we would expect the longest differences to produce estimates closest to the "true" coefficient values. Second, longer differences allow for more time for market values or asset quantities affected by short-run shocks to return to equilibrium values. Thus, varying difference lengths may enable comparisons of short-run and long-run relationships.[63]

The first several columns of table 2 suggest that, in equations using short (one- and two-year) differences, changes in computer asset levels appear to have no significant correlation with changes in market value, whereas in equations with longer differences the relationship is substantial. The coefficients rise from essentially zero for one-year differences to around 10 for five-year differences, and stabilize beyond that. The point estimate for the longest difference possible in the sample (ten years) is considerably higher, but because of the small sample size it is very imprecisely estimated and not statistically different from the other long-difference coefficients.

These results have several interpretations. First, they suggest that there may be considerable measurement error in the estimates of computer assets, biasing downward the short-difference more than the long-difference coefficients. This explanation also implies that the "true" estimate of the computer coefficient is more closely approximated by the

62. Griliches and Hausman (1986).

63. See, for example, Bartelsman, Caballero, and Lyons (1994) or Brynjolfsson and Hitt (2001) for further discussion.

Table 2. Long-Difference OLS Regressions of Market Value on Asset Quantities, 1987–97[a]

	Number of years differenced									
Independent variable	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Computer assets	–0.020)	–1.053)	3.276	8.396	10.435	9.525	10.986	11.006	11.452	18.211
	(1.214)	(1.748)	(2.687)	(3.895)	(4.279)	(4.504)	(5.443)	(6.185)	(8.586)	(16.331)
PP&E	1.101	1.305	1.413	1.547	01.709	1.895	01.971	02.043	02.026	2.072
	(0.111)	(0.120)	(0.139)	(0.159)	(0.181)	(0.212)	(0.240)	(0.274)	(0.275)	(0.287)
Other assets	1.096	1.104	1.101	1.095	1.096	1.103	1.114	1.124	1.140	1.156
	(0.016)	(0.012)	(0.012)	(0.011)	(0.011)	(0.012)	(0.013)	(0.016)	(0.018)	(0.020)
Summary statistic										
No. of observations	6,218	5,186	4,325	3,645	3,015	2,417	1,857	1,325	847	413
R^2	0.789	0.829	0.861	0.898	0.921	0.928	0.922	0.910	0.906	0.907

Source: Authors' regressions. See appendix for description of data sources.

a. The dependent variable is firms' market value. All regressions include controls for year and two-digit SIC industry. Huber-White robust standard errors are reported in parentheses.

longer-difference estimates, which are all considerably above 1. Second, the results may suggest that it may take a moderate period of adjustment for computer assets to become valuable; this would be consistent with the nature of the complementary organizational changes discussed earlier. These results also provide some evidence against many types of correlated shocks, such as a new invention that immediately raises market value and requires additional investment in computer equipment for new production facilities. Presumably these types of shocks would act on a much shorter time scale, such as one year. These regressions also eliminate the bias due to omitted variables that are time invariant. However, these results do rule out the possibility that the computer estimates are affected by gradual adjustment over long time periods to firm-specific shocks.

YEAR-BY-YEAR ANALYSIS. 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, some years will have disproportionately high values while others will be close to their equilibrium value. Table 3 presents regressions for each of the eleven individual years in our sample. Although there is some year-to-year variation in the computer asset coefficients, there is no particular time trend, and none of the estimates are statistically different from the estimate based on the pooled data of approximately 12. Although this does not rule out the possibility of considerable changes outside the 1987–97 time period or our sample of firms, it does show that, for our sample, computer asset values consistently show coefficient values of 9 or greater.[64]

Basic Findings Regarding the Role of Organizational Structure

Here we report correlations found between computer asset values and various measures of internal organization.[65] All correlations are Spearman rank-order correlations between various measures of computers and the organizational variables, controlling for firm size (employment), produc-

64. Nothing in the theory requires the installed price of computer capital to be invariant as technology evolves and investor expectations change, any more than the value of an oil company's proven reserves need be invariant.

65. These results build on earlier work reported in Brynjolfsson and Hitt (1997) and Bresnahan, Brynjolfsson, and Hitt (2002).

Table 3. Year-by-Year OLS Regressions of Market Value on Asset Quantities, 1987–97[a]

Independent variable	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*
Computer assets	19.156	14.329	10.696	9.175	11.989	12.718	16.264	21.798	9.450	18.809	30.038
	(5.936)	(4.585)	(5.064)	(8.001)	(10.218)	(9.556)	(6.744)	(7.154)	(3.804)	(6.692)	(13.612)
PP&E	1.018	1.109	1.283	1.286	1.389	1.449	1.547	1.457	1.581	1.667	1.822
	(0.063)	(0.057)	(0.068)	(0.079)	(0.080)	(0.091)	(0.095)	(0.093)	(0.123)	(0.155)	(0.207)
Other assets	0.979	0.979	1.008	0.979	1.020	1.040	1.027	1.012	1.066	1.081	1.114
	(0.008)	(0.009)	(0.018)	(0.016)	(0.026)	(0.021)	(0.016)	(0.014)	(0.014)	(0.011)	(0.012)
Summary statistic											
No. of observations	651	646	641	641	666	676	702	706	747	742	746
R^2	0.974	0.981	0.964	0.961	0.928	0.952	0.973	0.974	0.956	0.949	0.942

Source: Authors' regressions. See appendix for description of data sources.

a. The dependent variable is firms' market value. All regressions include controls for the ratio of R&D to sales, the ratio of advertising spending to sales, and two-digit SIC industry. Huber-White robust standard errors are reported in parentheses.

tion worker occupation, and industry.[66] We used three different measures of a firm's IT: the total value of the IT installed base , total central processing power (in millions of instructions per second),[67] and the total number of personal computers. We used multiple measures because they capture slightly different aspects of computerization (for example, central processing power measures centralized computing assets, whereas the number of personal computers measures decentralized computing assets).

Table 4 presents correlations between each of these different measures of IT and four dimensions of organizational design: structural decentralization, individual decentralization, team incentives; and skill acquisition. Previous theoretical and empirical work has linked these types of practices to IT investment.[68] Consistent with our argument that IT and organizational practices 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. These are only broad averages and do not apply to all firms in all circumstances: many successful IT users do not implement all or even any of these practices. In particular, computers have helped centralize a large subset of decisions involving aggregate data analysis (analyzing bar code data, for example), even as they have facilitated the decentralization of many decisions that require on-the-spot information, human relations, exception processing, and nonroutine inference.

In addition to being correlated with IT, these practices are all correlated with each other. Following Brynjolfsson and Hitt,[69] 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

66. Results are similar when probit or ordered probit regression techniques are used. We report Spearman rank-order correlations because they are easier to interpret given the nonmetric nature of most of our work system variables. Included in the regressions are separate controls for mining and construction, high-technology manufacturing (instruments, transportation, electronics, computers), process manufacturing (paper, chemicals, petroleum), other nondurable manufacturing, other durable manufacturing, transport, utilities, trade, finance, and services.

67. Not including the processing power of personal computers.

68. See Brynjolfsson and Hitt (1997), Bresnahan, Brynjolfsson, and Hitt (2002), and Bresnahan (1997). A survey of related work appears in Brynjolfsson and Hitt (2000).

69. Brynjolfsson and Hitt (1997).

Table 4. Correlations between Organizational Structure and Alternative IT Measures[a]

	Measure of IT investment		
Measure of organizational structure	*Installed IT base*	*Total central processing power*	*Number of personal computers*
Structural decentralization[b]			
Degree of team self-management	0.17***	0.22***	0.20***
Employee involvement groups	0.07	0.08	0.08
Diversity of job responsibilities	0.07	0.12**	0.10*
Individual decentralization[b]			
Who determines pace of work	0.04	0.06	0.02
Who determines method of work	0.16***	0.20***	0.15***
Degree of individual control	0.11*	0.15**	0.15**
Team incentives[c]			
Degree of team building	0.15***	0.19***	0.18***
Workers promoted for teamwork	0.02	0.10*	0.00
Skill acquisition			
Percent of workers that receive off-the-job training	0.14**	0.15***	0.14**
Degree of screening prospective hires for educationd	0.16***	0.18***	0.21***
ORG composite variable	0.24***	0.30***	0.25***

Source: Authors' calculations. See appendix for description of data sources.

a. Table reports Spearman partial rank-order correlations, controlling for firm size, worker occupation, and 1½-digit SIC industry. Sample size varies from 300 to 372, depending on data availability. * indicates significance at the 10 percent level, ** at the 5 percent level, and *** at the 1 percent level.

b. Scale of 1 to 5, where 5 represents greatest decentralization (most extensive use of self-managing teams or employee involvement groups, greatest diversity of job responsibilities, greatest worker control of pace and method of work, or greatest degree of individual control).

c. Scale of 1 to 5, where 5 represents greatest use of team incentives (projects requiring team efforts, or promotion of workers for teamwork).

d. Scale of 1 to 5, where 5 indicates most extensive use of screening.

capture an organization's overall tendency to use this collection of work practices in a single construct, which we could then use for further analysis. A principal components analysis (reported in table 5) showed that all components of this variable have high loadings on a single factor (which explains approximately 35 percent of the variance of these measures), and a scree plot (not shown) suggests that this is the only nonnoise factor. We interpret *ORG* as potentially capturing some aspects of the relevant organizational capital, K_O, as described above. We have no expectation that our simple measures will capture more than a small portion of such capi-

Table 5. Unrotated Principal Components Used to Construct the ORG Variable[a]

Work practices	*Loading on first principal component*	*Loading on second principal component*
Degree of team self-management	0.751	0.006
Employee involvement groups	0.707	0.176
Who determines pace of work	0.528	–0.628
Who determines method of work	0.572	–0.456
Degree of team building	0.747	0.250
Workers promoted for teamwork	0.401	0.367
Percent of workers that receive off-the-job training	0.425	0.408
Degree of screening prospective hires for education	0.466	–0.095
Memorandum: percent of variance explained	34.8	12.6

Source: Authors' calculations. See appendix for description of data sources.
a. See table 4 for definitions and scale measures.

tal, but rather see it as an early attempt to demonstrate the existence and economic relevance of work practices in this kind of framework.

The composite variable *ORG* is highly correlated with computerization, consistent with our earlier discussion. In what follows 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.

Our earlier arguments suggested that these types of organizational practices should be strongly related to computer assets, but they are presumably less related to traditional physical capital (PP&E) or other assets. One way to investigate this relationship is to examine a simple conditional correlation equation that relates the logarithm of asset quantity to the price of the asset (proxied by time dummy variables), firm size (proxied by the logarithm of employment), and *ORG*. We also include controls for two-digit SIC industry to control for sample heterogeneity.

Table 6 shows the results of this analysis for the three types of assets we consider. *ORG* is correlated with greater use of computer assets (first column): firms with a value for *ORG* 1 standard deviation above the mean have 18 percent more computer assets on average (this result is statistically significant at the 1 percent level). However, PP&E and other assets have no significant relationship with *ORG* (second and third columns). In addition to confirming our hypothesized relationship between computers

Table 6. OLS Regressions of Computer Assets on Organizational Assets, 1987–97[a]

	Dependent variable		
Independent variable	*Computer assets*	*PP&E*	*Othe*
	assets		
ORG	0.179***	0.033	0.009
	(0.055)	(0.050)	(0.048)
Employment	0.736***	0.801***	0.800***
	(0.102)	(0.091)	(0.084)
R^2	0.470	0.817	0.803

Source: Authors' regressions. See appendix for description of data sources.

a. All variables except *ORG* are expressed in natural logarithms. The sample contains 2,444 observations. All regressions include controls for year and two-digit SIC industry. Huber-White robust standard errors are reported in parentheses. *** indicates significance at the 1 percent level.

and *ORG*, this suggests that we can treat the other capital components as essentially orthogonal to *ORG*; thus any omitted-variables bias that is related to *ORG* is likely to affect the measured value of computer assets, but not that of the other assets. The correlation between IT and *ORG* implies that firms with high levels of *ORG* either receive greater benefits from investments in IT, or have lower costs of adoption, or both.

The Effect of Organizational Structure on Market Value

ORGANIZATION VARIABLE IN THE MARKET VALUE EQUATION. Here we extend our basic estimating equation to include *ORG* and its interaction with computer assets, using various regression techniques. Regression equation 7-1 in table 7 is the baseline OLS regression (comparable to the first column of table 1) for market value for the subsample of 272 firms for which we have data for the *ORG* variable. These results are similar to our earlier baseline results on the full sample. Next we introduce the *ORG* variable into the regression in several ways. Because the *ORG* variable is an index (with a mean of 0 and a variance of 1), it must be appropriately scaled to be comparable to the other inputs. As *ORG* is essentially a concept relating to the organization of labor (education levels, training costs, allocation of certain decision rights to employees), it is natural to scale *ORG* by employment in considering its direct contribution to market value. The results of including the scaled *ORG* term in the regression are shown in column 7-2. Note that the coefficient on computer assets drops from 14.5 to 11.5 (approximately 20 percent), suggesting that at least some of the high observed value of computers is a result of computers

Table 7. Regressions of Market Value on Organizational Assets and Related Interaction Terms, 1987–97[a]

	Estimation method						
	OLS			*Random effects*		*LAD*	*Fixed effects*
Independent variable	*7-1*	*7-2*	*7-3*	*7-4*	*7-5*	*7-6*	*7-7*
Computer assets	14.593	11.452	5.387	9.949	2.229	9.742	1.888
	(6.094)	(5.116)	(5.409)	(2.566)	(3.220)	(0.768)	(3.322)
PP&E	1.313	1.318	1.313	1.564	1.527	1.103	1.661
	(0.079)	(0.078)	(0.079)	(0.064)	(0.070)	(0.008)	(0.089)
Other assets	1.066	1.067	1.075	1.085	1.086	1.023	1.087
	(0.023)	(0.023)	(0.017)	(0.009)	(0.010)	(0.002)	(0.010)
ORG × employment		18.939	11.315		8.880	–0.934	5.262
		(8.431)	(7.661)		(8.451)	(0.945)	(12.085)
ORG × computer assets			13.089		13.352	4.264	12.596
			(6.443)		(3.654)	(0.894)	(3.745)
ORG × PP&E			0.016		0.060	0.026	0.163
			(0.059)		(0.065)	(0.007)	(0.095)
ORG × other assets			–0.029		0.026	–0.024	0.049
			(0.031)		(0.017)	(0.003)	(0.019)
R^2	0.928	0.928	0.929	n.a.	n.a.	n.a.	0.887

Source: Authors' regressions. See appendix for description of data sources.

a. The dependent variable is firms' market value. The sample contains 2,444 observations from 272 firms with reported organizational assets. All regressions include controls for year, the ratio of R&D to sales, the ratio of advertising spending to sales, and two-digit SIC industry. Standard errors are reported in parentheses; for OLS regressions they are Huber-White robust standard errors.

serving as a proxy for organizational assets, as would be expected from our earlier discussion on omitted variables.

Of course, the simple measures that constitute *ORG* represent only a small fraction of the putative organizational capital of a typical firm. Furthermore, there are undoubtedly circumstances in which these particular practices are not beneficial. Nonetheless, we do find some evidence that investors, on average, may be treating the organizational practices that we measure much like more tangible types of capital by recognizing their contribution to the market value of a firm. All else equal, firms that are endowed with workers with greater education and training, and that have developed systems that support more decentralization of certain decision rights, appear to be valued at a slight premium to their industry peers. This relationship accounts for at least a small part of the “excess” valuation of computers.

INTERACTION BETWEEN ORGANIZATION AND OTHER ASSETS. We next consider how *ORG* relates to the value of computer assets by including terms interacting *ORG* and each of the three capital components: computer assets, PP&E, and other assets. In computing these and other interactions that include terms already in the regression, we center both variables so that the existing linear terms in the regression have the same interpretation.[70] The results are shown using OLS regression (column 7-3) and alternative specifications (columns 7-5, 7-6, and 7-7).

First, we find that when the interaction term is included in the regression, the coefficient on IT drops substantially. In the OLS regression (column 7-3), the coefficient on IT drops by roughly 50 percent compared with the regression that includes only the scaled *ORG* term (column 7-2) and is only 40 percent of the original value in the baseline regression (column 7-1). A similar, perhaps slightly larger difference for the IT coefficient is found when we use a generalized least squares random effects model, which also yields slightly more precise estimates for the interaction terms.

70. If the variables are not centered, the interpretation of the direct coefficients is changed. Consider a hypothetical regression equation $V = \gamma_O O + \gamma_I I + \varepsilon$ (model A) compared with another equation representing the “true” model of the underlying relationship $V = \gamma'_O O + \gamma'_I I + \gamma'_{OI} (O \times I) + \varepsilon'$ (model B). When the interaction term is not centered, $\gamma_I = \gamma'_I + \bar{O}\gamma'_{OI}$, where $\bar{O}$ is the mean of O. Centering the interaction term removes the $\bar{O}\gamma'_{OI}$ term and thus preserves the interpretation of γ_I as the contribution of the linear term. However, in the centered regression it is possible that the linear term changes if the true underlying data relationship is not precisely the linear interaction model described by model B (for example, if there are additional unobserved assets).

This is notable because it suggests that much of the apparent excess value is located in firms that have *both* high levels of IT and of organizational assets. Note that, because we centered the interaction terms, this is not due to a simple correlation between IT and its interaction with *ORG*.

Second, the interaction of *ORG* with computer assets is significant in all specifications and is especially strong when we use a random-effects or a robust regression technique (LAD) to perform the estimates (equations 7-5 and 7-6).

Third, this relationship appears to be unique to computer assets. Although it appears that there is a small, positive interaction between *ORG* and PP&E, this relationship is relatively weak and statistically significant only in the LAD regression. The interaction between *ORG* and other assets is close to zero and inconsistent in sign.

As a final check on the results, we also perform a fixed-effects regression (column 7-7). Because *ORG* is time invariant, the interaction terms have to be interpreted as the relationship between changes in asset quantity (relative to the firm average) and changes in market value mediated by the level of *ORG*. Here we obtain similar coefficients on the interaction terms, suggesting that the intangible assets we are capturing through the interaction terms are not simply fixed firm effects but the result of factors that have varied, uniquely, at the firm level over time.

Taken together, these results suggest that firms that have high investments in computers have a disproportionately large amount of other intangible assets, and that these firms account for a substantial portion of the excess value of computers above and beyond the direct contributions of *ORG*. This finding is consistent with the case literature on the complementarities between IT and organizational structure. It is also consistent with the econometric finding of Bresnahan, Brynjolfsson and Hitt,[71] using similar data, that firms that combine IT and *ORG* are disproportionately more productive than firms with high levels of only one or the other. Our interpretation is that, in addition to their direct effects on productivity, IT and *ORG* may be parts of a broader system of technologies and practices that the financial markets value but that is costly to implement. Even if this system does not appear on firms' balance sheets, it can be at least partly identified by the *simultaneous* presence of high levels of two observable assets: IT and *ORG*.

71. Bresnahan, Brynjolfsson, and Hitt (2002).

On the other hand, it is difficult to reconcile this finding with the hypothesis that the results are a manifestation of a bubble or similar persistent mispricing by investors. That would require not only that a persistent mispricing be correlated with IT and with *ORG*, but also that such a persistent mispricing be disproportionately severe for those firms specifically with high values of both variables simultaneously.

NONPARAMETRIC ESTIMATION. The above results show that each dollar of computer capital is associated with more intangible assets in high-*ORG* firms than in firms that invest less in human capital and the other organizational characteristics we identify. If the stock market is valuing these firms properly, this suggests that the benefits of computerization are likely to go disproportionately to firms that have adopted the organizational practices we identify.

Figure 1 captures this idea by plotting results from nonparametric regressions. The figure is a level plot of fitted values from a regression of market value on both the computer capital and the *ORG* variables, after netting out the influence of other variables. It presents a clear picture of the interaction effect between computer assets and *ORG*. Firms that are abundant in both computers and *ORG* have much higher market values than firms that have one without the other. Moreover, market valuation is disproportionately high in the quadrant where both asset levels are simultaneously above the median (not shown).

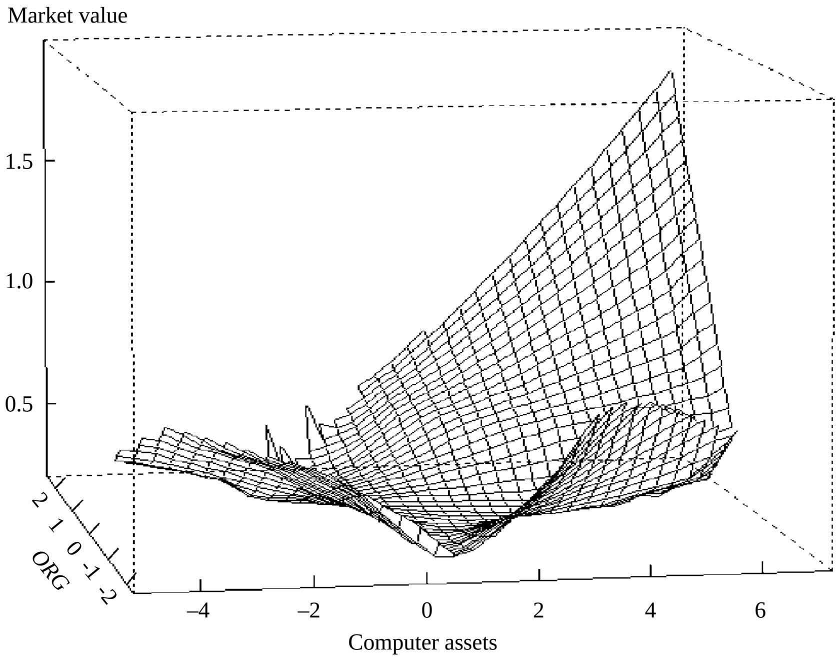
Intangible Assets and Productivity

One way to further distinguish the intangible asset hypothesis from alternatives such as investor mispricing is to look at production functions. If intangible assets really exist, they should be visible in the product markets as well as the financial markets. In particular, if indeed these assets are productive, firms possessing them should have higher future output. Previous work documented the importance of organizational assets in a production function framework and the existence of production complementarities between IT and organizational assets: firms with greater levels of *ORG* had both greater investments in IT and higher productivity of these investments.[72]

Using similar data on computers and output, but not considering the effects of organizational assets explicitly, Brynjolfsson and Hitt con-

72. Bresnahan, Brynjolfsson, and Hitt (2002).

Figure 1. Level Plot of Fitted Values from Nonparametric Regression of Market Value on Computer and Organizational Assets



Source: Authors' regressions. See appendix for description of data sources.

ducted a more detailed analysis of productivity growth and found that, as longer time periods were considered, the relationship between computer investment and productivity became stronger.[73] They found that the long-run productivity benefits are approximately five times the direct capital cost of computers, which would be consistent with a valuation of IT on the order of five times the valuation of ordinary capital. Both of these previous results support our assertion that the market value relationships we observe are consistent with the intangible assets hypothesis. However, neither of these studies considered the relationship among computer investment, organizational assets, and future output.

Table 8 reports production function estimates with IT and the interaction of IT with *ORG* lagged up to three periods. These regressions can

73. Brynjolfsson and Hitt (2001).

Table 8. OLS Regressions of Productivity on Computer and Organizational Assetsat Different Time Lags, 1987–97[a]

	No. leads of dependent variable			
Independent variables	*0*	*1*	*2*	*3*
Computer assets$_{t-1}$	0.045	0.047	0.043	0.045
	(0.020)	(0.025)	(0.029)	(0.036)
$ORG_{t-1} \times$ computer assets$_t$	0.024	0.020	0.030	0.058
	(0.014)	(0.014)	(0.015)	(0.019)
ORG_t	0.004	0.010	0.014	0.026
	(0.022)	(0.022)	(0.023)	(0.026)
Capital$_t$[b]	0.255	0.248	0.253	0.244
	(0.023)	(0.025)	(0.025)	(0.028)
Labor$_t$[c]	0.624	0.635	0.632	0.622
	(0.035)	(0.039)	(0.049)	(0.060)
Summary statistic				
No. of observations	2,091	1,605	1,182	791
R^2	0.835	0.836	0.849	0.839

Source: Authors' regressions. See appendix for description of data sources.

a. The dependent variable is value added in constant dollars. All variables except *ORG* are expressed in natural logaritms. The sample is restricted to 272 firms that have reported organizational assets. All regressions include controls for year and 1½-digit SIC industry. Huber-White robust standard errors are reported in parentheses.

b. Ordinary capital stock in constant dollars, computed by the method described in R. Hall (1990). See appendix for details.

c. Labor expense in constant dollars. See appendix for details.

be considered as identifying the relationship between current productivity and past investment in IT. Column 8-1 reports results from a regression that includes current-period IT, IT × *ORG*, and other production inputs (capital, labor) as well as time and industry controls (the latter at the 1½-digit SIC level).[74] We find that both IT and *ORG* and the IT × *ORG* interaction make positive contributions to multifactor productivity in a manner similar to results found by Bresnahan, Brynjolfsson, and Hitt.[75] Moreover, the relationship among IT, *ORG*, and IT × *ORG* grows stronger as we consider effects on output further in the future. Although some of this rise is due to the change in the sample, a comparison with a current-period regression (not shown) using the same sample shows that the coefficients are similar at one- and two-year leads and considerably larger at three-year leads.

74. Our 1½-digit controls divide the economy into ten sectors: high-technology manufacturing, process manufacturing, other nondurable manufacturing, other durable manufacturing, mining and construction, trade, transportation, utilities, finance, and other services. See appendix for details.

75. Bresnahan, Brynjolfsson, and Hitt (2002).

A natural interpretation of these results is that they reflect the net returns to a set of intangible assets, presumably some of the same intangible assets that investors are valuing. The fact that real output is higher for such firms suggests that the investors' beliefs have a reasonable economic basis.

Discussion and Conclusions

Our results suggest that the organizational complements to firms' installed computer capital are treated by investors as intangible assets. The financial markets treat the organizational assets associated with IT much like other assets that increase long-term output and profits. By covering several hundred firms over a period of eleven 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. If these assets are in fact becoming more important in modern economies, in part because of the information revolution engendered by computers and telecommunications, 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:

—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.

—Computer-intensive firms tend to have measurably different organizational characteristics, involving teams, more broadly defined jobs, and greater decentralization of certain types of decisionmaking.

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

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

—Firms with higher levels of IT, these organizational characteristics, or both have higher measured productivity in subsequent years.

Taken together, these results provide evidence that the combination of computers and organizational structures creates more value than the simple sum of their separate contributions. The evidence is consistent with the widespread perception among managers that IT is a catalyst for a broad set of organizational changes. It is also consistent with the econometric evidence that IT is more productive when combined with the specific cluster of organizational practices that we measure.

Our interpretation has focused on the assumption that the stock market is approximately correct in the way it values IT and other capital investments. Although econometrics alone cannot rule out all forms of potential omitted-variable bias, the evidence is not particularly consistent with alternative explanations such as a stock market bubble during the 1987–97 period. The fact that our results apply to a broad cross section of the economy over the ups and downs of a full business cycle suggests that fads, industry idiosyncrasies, and investor errors are not solely driving the results. Moreover, year-by-year estimation showed a consistently high valuation of computer capital throughout the 1987–97 period, although there is some evidence that valuations increased at the very end of the sample. Our analysis also predates the large increase in the market value of technology stocks in the late 1990s, and our sample is primarily composed of large, established firms (from the Fortune 1000) rather than new high-technology entrants. Indeed, we explicitly excluded information technology-producing firms because the role of computers in software or computer services firms is clearly different from the role they play in the computer-using sectors. For this reason also, our results are less likely to be sensitive to a high-technology stock bubble.

The fact that these intangible assets that are correlated with computers also appear to affect real production supports the hypothesis that the intangible assets are important. We find that our organizational assets variable is also correlated with increased subsequent output. These results appear to vindicate investors' beliefs that these assets are valuable. Nonetheless, it is also possible that some degree of mispricing has crept into the estimates. Furthermore, our results do not necessarily apply to other time periods or other types of firms or assets.

A particularly interesting finding is the significance of the interaction terms in our market value regressions. This result is difficult to explain in the traditional framework where the market values associated with assets simply reflect their shadow costs. Instead, it seems likely that we have identified a cluster of firms that, through skill, foresight, or luck, are endowed with a valuable form of business organization. Since the premium they command does not seem to have been quickly dissipated by competition, it must be difficult to imitate the specific technologies and practices they have implemented. Simply buying a lot of computers and implementing a stock set of practices such as we identify in our *ORG* variable is presumably not enough. Although both these types of assets are correlated with success as a business organization, much of the iceberg remains unidentified, and much that managers do not yet fully understand or, at least, cannot easily implement.

Our results give some support to one view of the productivity slowdown after 1973 and its revival in the 1990s. As several other researchers have argued,[76] the productivity slowdown may be explained by the changes in the value of assets and reorganization accompanying the transformation from a capital-intensive industrial economy to a computer-intensive, information-based economy. This view is reinforced by Robert Hall's interpretation of investment in reorganization.[77] In particular, the evidence is consistent with the view that certain work practices are complementary investments to computers, and the overall economic impact of these practices is being recognized by both managers and investors.

APPENDIX

Data Sources and Description

THE VARIABLES USED for this analysis were constructed as follows.

Computer Assets

Direct measurements of the current market value of computer equipment by firm are from Computer Intelligence Corp., Computer Intelligence

76. Yorukoglu (1998); Greenwood (1997); Greenwood and Jovanovic (1999); Hobijn and Jovanovic (2001).

77. R. Hall (2000b).

constructs a table of market values for each model of computer and uses this to calculate the current market value (replacement cost) of all computers owned by each firm.

PP&E

We considered two options to construct the physical capital variable, using data from Standard & Poor's Compustat Annual Dataset. The first, following the method in B. Hall (1990), takes the gross book value of physical capital stock (Compustat item 7: total gross PP&E) and deflates it 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: total net PP&E) to current depreciation (Compustat item 14: depreciation and amortization).

The other, simpler method uses the net physical stock depreciation (calculated from Compustat item 8). 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 assets variable was constructed as total assets (Compustat annual data item 6) minus physical capital, as constructed above. This item includes receivables, inventories, cash, and other accounting assets such as goodwill reported by companies.

Market Value

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

R&D to Asset Ratio

The R&D–asset ratio was 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 as in B. Hall (1993a, 1993b). She applied a 15 percent depreciation rate, and 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 the firms in our sample reported R&D expenses. The missing values were filled in using the averages for the same SIC four-digit industry.

Advertising to Asset Ratio

We constructed the advertising-asset ratio from advertising expenses (Compustat annual item 45). Fewer than 20 percent of our sample of firms reported the item. We applied the same rule as for the R&D–asset ratio.

Organization Variable

We constructed the *ORG* 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 to which firms have adopted new organizational practices as identified by Osterman (1994), MacDuffie (1995), and Huselid (1995).

Value Added

This variable was calculated as constant-dollar sales less constant-dollar materials. Sales (Compustat annual item 12) were deflated by price indexes for two-digit industry (from Gross Output and Related Series published by the Bureau of Economic Analysis). When an industry deflator was not available, we used the sector-level producer price index for intermediate materials, supplies, and components (from the 1996 *Economic Report of the President*). The value of materials was calculated by subtracting undeflated labor expenses (calculated above) from total expense and then deflating by the industry-level output deflator. Total expense was computed as the difference between operating income before depreciation (Compustat annual item 13) and net sales (Compustat annual item 12).

Ordinary Capital

This variable was computed from the total book value of capital (equipment, structures, and all other capital) following the method in B. Hall (1990). The gross book value of the capital stock (Compustat annual item 7) was deflated by the GDP implicit price deflator for fixed investment. The deflator was 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 annual item 8) to current depreciation (Compustat annual item 14). This calculation of average age differs slightly from the method in B. Hall (1990), who made a further adjustment for current depreciation. The constant-dollar value of IT capital (as calculated above) was subtracted from this result. Thus the sum of ordinary capital and IT capital equals the total capital stock.

Labor Expense

Labor expense was either taken directly from Compustat (annual item 42) or, when this was not available, calculated as a sector-average labor cost per employee multiplied by total employees (Compustat annual item 29). The average labor expense per employee was taken from BLS data on the hourly cost (including benefits) of workers for ten sectors of the economy. For firms whose labor expense as directly reported by Compustat did not include benefits, we adjusted the labor figure by multiplying the reported labor expense by the ratio of total compensation to wages for its sector as reported by the BLS.

1½-Digit Industry Controls

The industry controls used in some of our analyses correspond to an intermediate level between one- and two-digit Standard Industrial Classification (SIC) codes. Based on the firm's reported primary SIC code on Compustat, we constructed the following control variables: mining and construction, SIC 11 to 20; process manufacturing, SIC 26, 28, and 29; other nondurable manufacturing, SIC 20 to 23 and 27; high-technology manufacturing, SIC 36 to 38 and 3571 (computers); other durable manufacturing, SIC 24 to 25, 30 to 35 (except 3571), and 39; transportation, SIC 40 to 47; utilities, SIC 48 to 49; trade, SIC 50 to 59; finance, SIC 60 to 69; other services, and SIC 70 to 79.

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