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Many changes in the organization of work in the United States since 1975 have been attributed to the increased capabilities and use of information technology (IT) in business. However, few studies have attempted to empirically examine these relationships. The primary goal of this paper is to assess the hypothesis that investments in information technology are at least partially responsible for one important organizational change, the shift of economic activity to smaller firms. We examine this hypothesis using industry-level data on IT capital and four measures of firm size, including employees and sales per firm. We find broad evidence that investment in IT is significantly associated with subsequent decreases in the average size of firms. We also find that these decreases in firm size are most pronounced two to three years after the IT investment is made.
(*Information Technology; Firm Size; Downsizing; Restructuring; Computers*)

1. Introduction

Industrialized economies have recently entered a period of substantial organizational change. This transition has been likened to a "second industrial divide" (Piore 1989) or the "coming of the new organization" (Drucker 1988) and has been widely discussed in both the business and academic literature (see (Malone and Rockart 1991, Huber 1990), and the studies reviewed therein). Among the postulated aspects of the transition are decreases in firm size, a shift to externally provided services, and a shift from mass production to more flexible arrangements. The growing attention to these organizational changes has coincided with a rapid drop in the price of computing power (Gordon 1987), significant increases in information technology (IT)[1] investment, and one infers, decreases in the costs of information processing in general.

Because both firms and markets have often been modeled as information processing entities (Arrow, 1973; Galbraith, 1977), one might reasonably suspect that some of the recent organizational changes are related to the massive deployment of IT. Indeed, the theoretical links between the two have often been made in the literature (see (Crowston and Malone 1988) for a review). Yet, empirical research on the relationship between IT and organizational structure has produced few if any reliable generalizations, in part because case studies have predominated. Indeed, when taken as a whole, the literature presents many contradictory results (Attewell and Rule 1984).

The principal aim of this paper is to empirically examine the relationship between IT and one important characteristic of economic organization: firm size. To address this question, we have obtained recently-published economy-wide data on investment in IT in the U.S., enabling the use of econometric techniques to more broadly study its impact. To our knowledge, this is the only public domain data on IT investments in the U.S. economy. It includes fairly accurate hedonic price deflators which take into account quality improvements of over 20% per year in computing power. In order to understand the changes more fully, we examined four

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[1] We will use the term "IT" as shorthand for the Bureau of Economic Analysis (BEA) category "Office, Computing and Accounting Machinery," which is comprised primarily of computers.

different measures of firm size: (1) the number of employees per establishment, (2) the number of employees per firm, (3) the sales per firm, and (4) the value-added per firm.

Our results show clearly that the deployment of IT is correlated with a decrease in the number of employees per establishment and per firm in all sectors that we analyzed, and is associated with a decrease in sales and value added per firm in the manufacturing sector (the only sector for which data on these measures are available). Taken as a whole, our results demonstrate empirically the inverse relationship between IT and firm size.

To the best of our knowledge, this is the first study to empirically confirm the existence and direction of the relationship between IT and firm size. We recognize that this is a provocative finding. We also note that given the state of theory and data in this arena, it is impossible to conduct direct tests of the causal links in this relationship. Our results therefore represent only an initial step in analyzing the potentially complex relationship between the use of IT and the attributes of firms. However, we believe that our results provide significant insight into the nature of the relationship between IT and firm size, and will be of value in resolving the uncertainty about IT's impacts on firm size. Moreover, since our approach relies exclusively on secondary data analysis, it is subject to replication and triangulation, (see Gurbaxani & Mendelson 1991). Accordingly, we hope that our results will stimulate further research to provide additional insights into the nature of this relationship.

The paper consists of six sections. Sections 2 and 3 provide background on the recent trends in IT investment and average firm size, and discuss the theoretical relationship between these two variables. In § 4, we explain the methodology and data used in this study. Section 5 presents the results of the regressions and explores some explanations for the results. We conclude with some interpretations of the results and suggestions for further research in § 6.

2. Background

In this section, we summarize existing evidence of two significant trends in the last 15 years: (1) The number of employees in the average business establishment has decreased substantially, and (2) the real stock of IT has grown enormously.

Firm Size: According to several sources, firm size, as measured by the number of employees, has declined.[2] Piore (1986) cites data from County Business Patterns (CBP) showing that the average establishment size has been decreasing since the 1970s, reversing an earlier trend towards ever-larger firms. The Bureau of Labor Statistics (BLS) reports that from 1980 to 1986, firms of under 100 employees created six million new jobs while firms of over 1000 employees experienced a net loss of 1.5 million jobs. The BLS data also showed that for intermediate size classes, employment shifts were inversely proportional to their size. This phenomenon is also being experienced by a number of other major industrial countries (Huppes 1987) with firm size growing until about 1970 and decreasing significantly since then.

Our examination of data from Compustat and CBP reveals that the number of employees per firm has indeed declined in the manufacturing sector, but there is no strong trend in the service sector (figure 1). We also find that although firms tend to be smaller in the service sector, employment has grown more rapidly in services than in manufacturing. In addition, we examined two other measures of firm size, sales per firm and value-added per firm, for manufacturing industries. We did not find any overall declines in these measures of firm size.

Information Technology: Data from the Bureau of Economic Analysis (BEA) confirm the self-evident increase in the ubiquity of IT. We find that investment in computers has increased steadily and dramatically since at least 1971. After taking into account the quality improvements reflected in the BEA price deflator (which allow each dollar to buy more IT), there has been over a tenfold increase in IT investments between 1971 and 1990. Each of the major business sectors shows the same accelerating trend toward increased use of IT (figure 2). Driving much of this investment are exponential declines in the price/performance of computers and re-

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[2] Other interpretations of the term "firm size"—for instance, in terms of sales, assets, or market capitalization—are less common in the empirical literature. As we show below, a decline in employees per firm does not necessarily imply a decline in these other characteristics.

Figure 1   Establishment Size by Sector
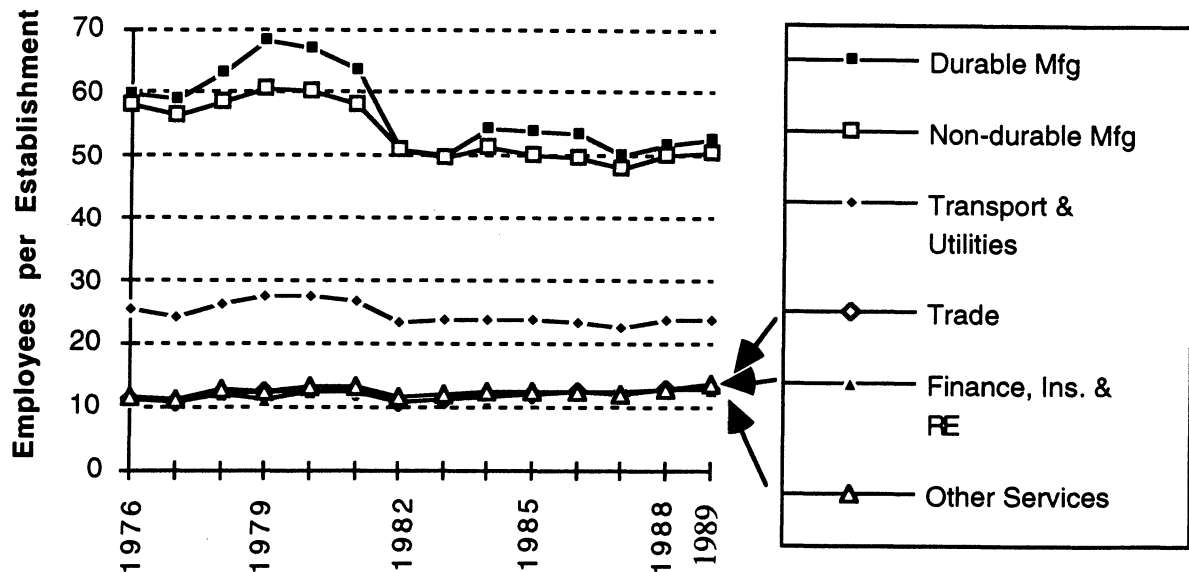
lated technology (Gurbaxani and Mendelson 1990). Furthermore, "Moore's Law," which posits a doubling of transistor density every 18 months is projected to hold into the next century (Grove 1990). Whatever effects of IT we detect today, these numbers are of sufficient magnitude to augur even greater effects in the near future.

3. The Relationship Between IT Investment and Firm Size

In order to understand the impact of IT investment on firm size, it is useful to understand the economic rationale underlying the determination of firm size. Friedman (1955, p. 233) notes that "the existing distribution [of

Figure 2   IT Spending by Sector
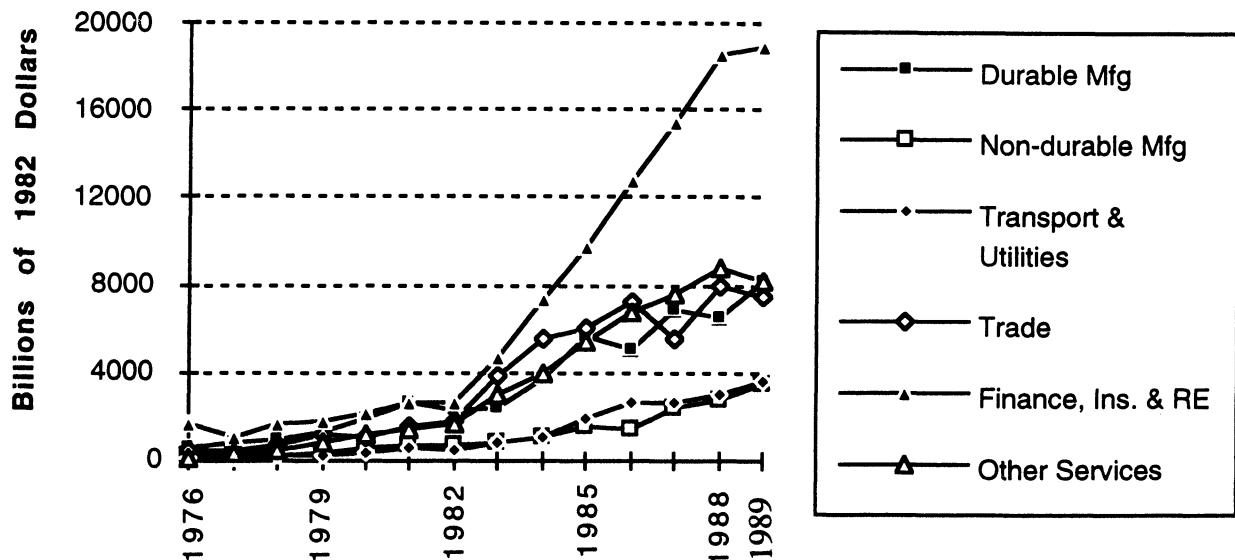
firm sizes] reflects both 'mistakes' and intended differences designed to take advantage of the particular specialized resources under the control of different firms." Accordingly, the size of two firms engaged in the same activity may be different, with both existing simultaneously. Ijiri and Simon (1977) provide more detailed models of the processes that give rise to a distribution of firms of different sizes in an industry. They note that the size distribution of firms in an industry is a result of the successes and failures of numerous individual firms over time. The success of each individual firm, in turn, is determined by a number of factors, including how well it adapts to changing conditions in the industry as a whole.

In this paper, we are especially concerned with how firms adapt to one particular kind of change: the availability of increasingly powerful and inexpensive IT. The overall effects of this technology clearly depend on how individual firms use it and how this usage affects their subsequent performance. If each firm's investment in IT leads to widely varying results, then there might be no overall patterns of change in the economy as a whole. On the other hand, if certain kinds of adaptation to IT are generally more successful than others, then we may be able to observe the resulting changes as overall trends in the economy. For instance, if the widespread use of IT increases the viability of smaller firms relative to larger ones, then this might be part of the reason for the decrease in average firm size that we noted above.

A central theoretical question, then, is why the increasing use of IT might change the relative viability of small and large firms. We summarize the arguments that have been proposed to answer this question in two basic categories: (a) *labor substitution*, and (b) *make versus buy*.

3.1 Labor Substitution

Perhaps the simplest explanation that has been proposed for why firm size might be related to IT is that firms can sometimes use IT to produce the same output with fewer people. By substituting automated processing for human labor, the argument goes, these firms can increase productivity and reduce costs. Somewhat surprisingly, however, previous studies have not provided broad support for the hypothesis that IT substituted for labor or even increased the productivity of labor, at least in the 1975–1985 time period. (Brynjolfsson 1993 provides a review of the literature. See also Roach 1987.)

Furthermore, in direct studies of the relationship between IT and employment, there is some evidence that IT may actually increase employment. For instance, Osterman (1986) found that IT investment resulted in a complementary increase in the number of clerks and managers employed after a lag of several years. Recently, Berndt and Morrison (1991), using essentially the same IT data set we are using, found that IT was on balance a *complement*, not a substitute for labor, especially white collar labor. Specifically, they conclude: ". . . rather than being aggregate labor-saving, increases in [IT] tend to be labor-using" (Berndt & Morrison 1991, p. 1).

While the previous work casts some doubt upon the *labor substitution* hypothesis as an explanation for decreasing firm size, our study will allow us to examine the hypothesis from another perspective. If labor substitution due to IT is the primary explanation for decreasing firm sizes, then we should expect to see a decrease in the number of employees per firm associated with IT use, but no decrease in the sales per firm. In fact, if this hypothesis is correct, we might even see an increase in the sales per firm associated with IT use.

3.2 Make Versus Buy

Another possible explanation for why IT might be related to firm size is that IT might affect the firms' "make" versus "buy" decisions for the components and services needed to make their primary products. For instance, when a firm like Ford needs tires for the cars it produces, it has two choices about how to obtain these tires: It can make them internally, or it can buy them from an outside tire supplier. Which of these choices is preferable in a given situation depends, in part, on their respective costs.

We can divide these costs into two categories—*production costs* and *coordination costs*. Production costs refer to the costs of the physical production process itself—tasks like molding and cutting the rubber for tires. Coordination costs, on the other hand, refer to the costs of managing the dependencies between production tasks. For example, coordination tasks include

making sure that the rights things and the right people are in the right places at the right times.

We can further divide coordination costs into two subcategories—*internal coordination costs* and *external coordination costs*. When Ford produces its own tires, for instance, the internal coordination costs include the costs of managers and others who decide when, where, and how to produce the tires. When Ford buys tires from an outside supplier, the external coordination costs include (a) the supplier's costs for marketing, sales, and billing and (b) Ford's costs for finding suppliers, negotiating contracts, and paying bills.

In both cases, coordination costs include information-intensive activities such as gathering information, communicating, and making decisions. Since IT is particularly useful in these kinds of information-intensive activities, several previous theories suggest how IT might affect firm size by reducing these coordination costs. As the following subsections describe, the theories make different predictions, depending on which kinds of costs are affected most (see Gurbaxani and Whang 1991 for a summary).

3.2.1 Reducing Internal Coordination Costs More Than External.

If IT reduces the costs of *internal coordination* more than external coordination, then we would expect firms to do more things internally. This means we would expect firms to grow in size. For example, if IT greatly reduced the costs for managers to monitor and control what their subordinates were doing throughout a large organization, then this might lead firms to do more things internally.

One kind of internal coordination cost simply involves moving information to the places where decisions are made and then informing others about the decisions. Another important kind of internal coordination cost arises because the interests of individual employees are often not the same as those of the firm as a whole. Research in agency theory has studied extensively how these conflicts of interest can be managed by approaches such as monitoring employees or providing them with performance-based pay (Jensen 1983). Since these approaches involve information-intensive activities, it seems plausible that IT might affect their costs (Brynjolfsson 1990). More generally, since many early applications of computers have focused on internal systems rather than interorganizational systems, we might expect that these systems would affect internal coordination costs more than external ones.

3.2.2 Reducing External Coordination Costs More Than Internal.

If IT reduces the costs of *external coordination* more than internal coordination, then we would expect to see firms buy more things externally. In this case, the average size of firms should decrease. For example, if it is easier and cheaper for a firm to find an external supplier for new parts than to make them internally, then the firm is more likely to buy the parts outside and less likely to need as much internal manufacturing capacity.

The factors that lead to high "transaction costs" for external coordination have been analyzed extensively by research in transaction cost theory (Williamson 1975, 1985). In general, the "opportunistic" behavior of firms negotiating contracts with each other often leads to costs (such as legal and accounting expenses) that would not be necessary if the same transactions were coordinated internally. For example, when a supplier invests in special machinery that is useful only for one customer, the supplier is vulnerable if that customer threatens to buy somewhere else. Similarly, when it is difficult for buyers to find out about alternative sources of supply, they are vulnerable to excessive charges from the supplier they customarily use.

While IT certainly cannot eliminate opportunistic human behavior, its functions (such as increasing the availability of information) can reduce the problems opportunism causes (Brynjolfsson, Malone, and Gurbaxani 1988; Malone, Yates and Benjamin 1987). More generally, by reducing the costs of many of the information searching and accounting activities that are needed for coordination with external suppliers, IT can make buying things externally more attractive to firms.

A related effect of IT is that it might reduce market coordination costs by changing the "specificity" of assets themselves. For instance, Grossman and Hart (1986) have emphasized that when assets are specific to one another, market coordination will be inefficient and this may lead to common ownership of large, related sets of assets. However, if IT facilitates techniques like flexible manufacturing, it may decrease the specificity of assets, and thus transform internal production to pro-

duction organized through smaller units coordinated by markets. Applying the Grossman-Hart paradigm, Brynjolfsson (1994) formally models how asset flexibility and the distribution of coordination knowledge can favor market coordination.

3.2.3 Reducing Coordination Costs More Than Production Costs.

The theories reviewed so far allow us to predict either kind of change: if internal coordination costs decrease most, firms should grow; if external coordination costs decrease most, firms should shrink.

Malone and colleagues argue that, in general, we should expect *both* kinds of coordination costs to decrease relative to production costs. They further argue that this would still favor buying rather than making (Malone 1987; Malone, Yates & Benjamin 1987). The basis of their argument is summarized in Table 1 below. First, as noted above, the costs of finding suppliers, negotiating contracts, and paying bills often make external coordination more expensive than coordinating the same activities internally would be (Williamson 1985). However, when external suppliers pool the demands of multiple customers, they can often realize economies of scale or other production cost advantages that internal production could not achieve. Thus, in general, buying rather than making leads to higher coordination costs but lower production costs.

Now, how will IT affect these costs? In the cases where IT can directly improve the production process (e.g., via computerized typesetting or factory robots), we should expect IT to reduce production costs. However, these effects will be very specific to particular production processes and, thus, to particular industries.

In almost all industries, however, IT should be able to reduce the costs of the information intensive activities involved in coordination. In general, if IT reduces both internal and external coordination costs more than it reduces production costs, then it will decrease the importance of the dimension on which buying has a disadvantage. Thus, it should increase the number of situations in which buying is more attractive than making.

If more *outsourcing* occurs because of this or any of the other effects described in this subsection, we should expect to see a decrease in the average number of employees per firm. Unlike the labor substitution hypothesis, however, the outsourcing hypothesis predicts that the activities required to produce a product will be divided among more separate firms. This means that, if the outsourcing hypothesis is correct, the average amount of "value added" and the average sales per firm should decrease.

There is some evidence suggesting that IT has led to a decline in firm size in certain industries. A detailed study of the metal-working industry found that vertical integrated firms were "decoupling" into smaller firms in 88 of 106 sectors between 1972 and 1982 and that this could be tied to increased use of IT (Carlsson 1988). In an article on how "value-adding partnerships" are supplanting vertically integrated companies, Johnston and Lawrence (1988) also cite examples in which this phenomenon is partly enabled by IT. However, to date there has been no economy-wide study to determine whether these changes are part of a broader trend.

3.3. Summary

The theoretical literature suggests that IT will reduce the costs of coordination both within firms and between firms. We cannot know, a priori, however, which effect predominates and whether a resulting shift is of an economically-significant magnitude. Furthermore, these theoretical arguments do not allow us to determine whether the decrease in average firm size noted above is related—either positively or negatively—to the increasing use of IT. Fortunately, the question of how IT affects firm size is subject to empirical investigation, and as noted above, the different theories make different predictions about what changes we should see. In the remainder of this paper, we use econometric techniques to analyze the relationship in the U.S. economy as a whole between IT investments and firm size. We also interpret these results in light of the theories just described.

Table 1 Relative Costs of "Buying" Components and Services Externally vs. "Making" Them Internally

Coordination Mechanism	Coordination Costs	Production Costs
Internal ("making")	Low	High
External ("buying")	High	Low

4. Data and Methodology

Our approach uses available U.S. data to directly examine the relationship between IT and average firm size. The data are divided into six sectors: durable goods manufacturing; non-durable goods manufacturing; transport and utilities; wholesale and retail trade; finance, insurance, and real estate; and services. These six sectors represent substantially all manufacturing and services industries in the U.S. A series of regressions were run on these data to identify the direction and magnitude of the relationship between IT and firm size, while controlling for total capital stock, foreign trade, industry, and capital costs. Several regression models were examined and data from alternative sources were also used to help validate the results.[3]

4.1. The Data

There are at least three basic ways to measure the size of firms: number of employees, total sales, and total value added.

Employees per firm: We measure the average number of employees both for all business "establishments" and for publicly-traded companies.[4] Data on the number of business establishments and number of employees are provided for each sector of the economy by County Business Patterns. Average establishment size is derived by dividing the latter by the former, generating the variable SIZE1. Consistent data on establishment size were available from 1976 to 1989, so we used those years as the primary period of our study. A second measure of firm size, SIZE2, is developed using COMPUSTAT,[5] which maintains data on every publicly-traded company, including number of employees and

the SIC code of its principal line of business. Using the SIC code, we grouped all the companies into the same sectors of the economy used above and added up the number of employees and number of firms in each sector.

Sales per firm and value added per firm: We also analyzed the impact of IT on two other measures of firm size: value of sales per establishment (SIZE3), and value added per establishment (SIZE4). These regressions serve as an additional robustness check on the employment-based measures of firm size. They also help provide insight into the mechanism by which IT affects firm size: if IT leads to a decrease in shipments and value-added per firm then substitution effects alone do not underlie the shift to smaller firms. The data required for these two series is available from the Census of Manufacturers and the Annual Survey of Manufacturers for the manufacturing sectors of the economy. Unfortunately, no comparable data is available for other sectors of the economy. The data were analyzed for the period 1976 to 1989 at the two digit SIC code level of aggregation. This distinguishes 20 different industries within the manufacturing sector.

IT Capital and Total Capital BEA Data was used to derive figures for IT investments, and total capital investments by industry for each year. The BEA data classifies all economic activity in the United States into 61 industries, while total annual investments are measured in 27 asset categories. We used category 14—"office, computing and accounting machinery" (OCAM) for our IT figures[6] and the sum of all other categories for our total capital figures. It should be noted that the OCAM data include capital equipment only, and do not include spending on software development, maintenance, or related services. Furthermore, some computing power is embedded in scientific instruments, robotic machinery, and even appliances. These "computers" are also excluded from our data. Instead, we focus on a some-

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[3] More details on data sources and construction are available in (Brynjolfsson, Malone, Gurbaxani & Kambil 1991). See also Berndt and Morrison (1991) for additional detail and interpretation. We thank John Musgrave for useful conversations on the data gathering methodology.

[4] Although often used synonymously, establishments are not, strictly speaking, equivalent to firms. Nonetheless, the vast majority of firms consist of a single establishment. A study by Carlsson (1988) found that the correlation between changes in the number of establishments and the number of firms in a sample of manufacturing industries was over 97%.

[5] While the Compustat sample is presumably biased towards large

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firms (small firms are not usually publicly traded), it still includes over 2000 firms for each year.

[6] We also tested a model which included the communications equipment category with substantially similar results. See (Brynjolfsson, Malone, Gurbaxani & Kambil 1991).

what narrower definition of information technology that stresses office and coordination uses.

Each asset category also has an associated quality-adjusted (hedonic) price deflator. Most deflators were based on Producer Price Indexes published by the Bureau of Labor Statistics. Those for computers were based on industry data as described in Cartwright (1986). By dividing each investment by its associated deflator, nominal investments were converted into constant-dollar or "real" investments.

Foreign Trade and Interest Rates A principal alternative explanation for the decline in firm size is that increased competition from foreign companies has forced American companies to "downsize" and become more efficient (Kanter 1989, Roach 1987a). To explore this hypothesis, and to help control for the impact of changes in foreign trade, we included it as an independent variable. Trade was defined as the sum of U.S. merchandise exports and imports for each year, as reported by the Department of Commerce. The data exclude military transactions and were converted from nominal dollars into constant dollars using the GNP deflator. Because high interest rates discourage business expansion and could also lead to a decline in firm size, the yearly rate of interest on AAA rated bonds was also included. This data was obtained from the Economic Report of the President (Bush 1991).

4.2. Methodology

The basic technique used for analyzing the data is a two stage least-squares regression estimate of the correlation between IT and various measures of firm size, while controlling for other explanatory variables. The data for all sectors over the time period were pooled and, as described below, corrections were made for potential heteroskedasticity, serial correlation, and simultaneity.

A distributed lag structure for the investments is appropriate because it enables us to assess the impact of several years of investment and to determine the time-path of the effects. We allow for general patterns of depreciation (or more accurately, effectiveness) by examining a polynomial distributed lag for IT investments. A second-order polynomial distributed lag structure allows us to include the current and four previous years

of IT investment data without introducing excessive collinearity or unduly reducing the degrees of freedom. A concave pattern (peaking in an arbitrary year), as well as other patterns such as the conventional straight-line or declining-balance depreciation, can be approximated by second order polynomials.

To control for effects specific to a particular sector that do not change over time, we included dummy variables for each of the industry sectors. The most natural interpretation of the interaction among the dependent and explanatory variables is in terms of percentage-effect, so in accordance with common practice, all the relevant variables were expressed in terms of the natural logarithm. Another feature of this specification is that it can be interpreted as a multiplicative structural model in which the parameters are exponents. The estimating equation we use is then derived by taking the natural logarithm of both sides.

By construction, only changes in firm size *within* a sector were examined by our models. However, part of the decline in average firm size was due to shifts *among* sectors. This effect was expressly excluded from our specification, because so many other factors may affect shifts among sectors, and because it does not appear to account for most of the decline in firm size.[7] Nonetheless, to the extent that the value chain for any one product involves production across several sectors, the outsourcing hypothesis discussed above would also be consistent with an intersectoral shift which is not captured in our specification.[8] Finally, as discussed above, four different dependent variables were fitted, to reduce the sensitivity of the results to particular data-gathering biases and to further explore the mechanism(s) by which IT affects firm size.

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[7] For instance, a recent study of Canadian data concluded that "the increasing importance of service sector employment played a role in the growth of small firm jobs, but was generally less important than shifts in the size distribution within the major industrial sectors" (Wannell 1990).

[8] Presumably, not all of the "new" firms created when a vertically integrated firm decouples will be classified in the same industry as their "parent." Consider for instance the outsourcing of design work from a manufacturer. However, the remaining manufacturing firm would be smaller than before, so the outsourcing would still be reflected in average firm size within the sector as well.

4.3. The Model

The model measures the relationship between levels of IT stock and the average size of firms for a given sector in a given year, while controlling for total capital, foreign trade, interest rates, and industry-specific effects.

The basic regression model is:

$$SIZE_t = \beta_0 + w_0 IT_t + w_1 IT_{t-1} + w_2 IT_{t-2} + w_3 IT_{t-3}$$
$$+ w_4 IT_{t-4} + v_0 TOT_t + v_1 TOT_{t-1} + v_2 TOT_{t-2}$$
$$+ v_3 TOT_{t-3} + v_4 TOT_{t-4} + \beta_3 TRADE_t$$
$$+ \beta_4 BOND_t + \Sigma\beta_{5i} INDUSTRY_{it} + \epsilon_t \quad \text{where}$$

$$(1)$$

$SIZE_t \equiv$ the natural log of firm size in year t,

$IT_t \equiv$ the natural log of the quality-adjusted IT investments in year t,

$TOT_t \equiv$ the natural log of the quality-adjusted non-IT capital investments in year t,

$TRADE_t \equiv$ the natural log of foreign trade in year t,

$BOND_t \equiv$ the interest rate on AAA corporate bonds,

$INDUSTRY_{it} \equiv$ a dummy for each of the six sectors (for SIZE1 or SIZE2), or 20 industries (for SIZE3 of SIZE4), and

$\epsilon_t \equiv$ an i.i.d error term with zero mean.

The weighting coefficients, w_i and v_i are constrained to satisfy:

$$w_i = c_0 + c_1 i + c_2 i^2, \quad \text{for} \quad i = 0 \cdots 4 \text{ and}$$

$$v_i = d_0 + d_1 i + d_2 i^2 \quad \text{for} \quad i = 0 \cdots 4.$$

This specification constrains the lag weights to follow a second degree polynomial for the first five lagged values. By substituting into the initial equation, a coefficient for each of the lagged values of IT can be computed and the resulting equation can then be directly estimated using ordinary least squares.[9] Predicted values of all the coefficients are given in § 4.5 below.

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[9] The substitution yields:

$$c_0 IT_t + (c_0 + c_1 + c_2)IT_{t-1} + (c_0 + 2c_1 + 4c_2)IT_{t-2}$$
$$+ (c_0 + 3c_1 + 9c_2)IT_{t-3} + (c_0 + 4c_1 + 16c_2)IT_{t-4}.$$

Combining terms, we have:

$$c_0(IT_t + IT_{t-1} + IT_{t-2} + IT_{t-3} + IT_{t-4}) + c_1(IT_{t-1} + 2IT_{t-2}$$
$$+ 3IT_{t-3} + 4IT_{t-4}) + c_2(IT_{t-1} + 4IT_{t-2} + 9IT_{t-3} + 16 IT_{t-4})$$

which can be directly estimated.

4.4. Data Pooling and Correction Procedures

To increase the efficiency of the estimation, the time series and cross-sectional observations were pooled. This provided an adequate sample size but introduced the potential problems of heteroskedasticity among sectors and serial correlation between successive years. Furthermore, pooling the data implicitly restricts the effect of IT and the other explanatory variables to be the same across sectors and across time. Moreover, if the true values differ across sectors or the relationship is nonlinear, the resulting estimates will be a weighted average, and should be interpreted in this light. For instance, a zero coefficient could be the result of positive effects in one sector being canceled by negative effects elsewhere, or a positive relationship over one range of values being canceled by a negative relationship for other values. Finally, the explanatory variables (IT and other capital) may be jointly determined with firm size, at least in the long run, and thus may be correlated with the error term leading to inconsistent estimates. Fortunately, we were able to correct for each these potential problems by modifying the specification of the model as outlined below.

Heteroskedasticity was a potential problem because the size of the six sectors varied significantly in the pooled data. Although the exact relative error variances cannot be determined, it is commonly assumed that they vary inversely with the size of the sector. Accordingly, the weighted least squares correction technique was applied: each observation on a sector was weighted by the size of the sector, as proxied by the share of gross domestic product (GDP) produced in that sector that year. We first computed the mean of the weighting series ($\overline{GDP}$) and then multiplied all the variables by the ratio of the weighting series to its mean ($GDP/\overline{GDP}$) yielding a specification that corrects for heteroskedasticity and provides efficient parameter estimates (Pindyck & Rubinfeld 1991). As might be expected in time series regressions, the initial regressions also revealed the potential presence of serial correlation, as manifested in generally low Durbin-Watson statistics. Accordingly, the Hildreth-Lu (1960) correction procedure was used in all regressions. The corrected regressions did not exhibit significant serial correlation.

As mentioned above, some of the independent vari-

ables (IT and other capital stock) could be correlated with the error term for a number of reasons. First, the optimal levels of the various factors of production: employment, IT capital, and other capital are each functions of the other two (at least in the long run) as well as other exogenous variables which are observable to managers, but not to us. Second, theory suggests that managers minimizing coordination costs will choose both the firm size and IT investment with regard to levels of the other. Either of these would result in simultaneity: a shock that affected firm size might also affect investment in the same year. Third, all of the variables are measured only with some error. Measurement errors for the independent variables may therefore be correlated with the error term from the regression. The appropriate correction for these possible biases is to use Instrument Variables (IV) estimation, instead of Ordinary Least Squares (Pindyck and Rubinfeld 1991).

To derive consistent parameter estimates, we ran the regressions in two stages, using lagged values of IT and TOT as well as the price index for IT investments as instruments to minimize the simultaneity problem. The first stage consisted of estimating a reduced form equation for IT_t, TOT_t and the other independent (and presumably exogenous) variables using ordinary least squares by regressing them on a constant, a polynomial distributed lag of IT_{t-1}, a polynomial distributed lag of TOT_{t-1}, $TRADE_t$, $BOND_t$, the industry dummies and polynomial distributed lag of $PRICE_t$ (a price index for computers, to over-identify the equation). By using these variables, all of which are presumed to be predetermined, the fitted values of IT and TOT will be asymptotically independent of the current error term, by construction. The second stage regression simply replaced the original variables in equation (1) with these fitted variables, yielding consistent estimators, at the expense of somewhat higher standard errors.

It should be noted that, although we modified the regression to correct for potential sources of bias and to improve efficiency, the interpretation of the sign and magnitude of the coefficients is the same as for ordinary least squares (Pindyck and Rubinfeld 1991).[10]

[10] In any event, the OLS coefficients were very similar. On the recommendation of a referee, we report the IV estimates because statistical

4.5. Possible Interpretations for the Signs of the Coefficients

As discussed in § 3, different previous theories lead to different predictions about the signs we should expect for the coefficients in the regression. If the primary effect of IT is to facilitate external coordination (or to facilitate both internal and external coordination proportionally), then we should expect to see negative coefficients for the regressions on all size variables. On the other hand, if IT facilitates internal coordination more than external coordination, we should expect to see positive coefficients on all size variables. Finally, if the labor substitution theory is correct, we should expect to see negative coefficients for SIZE1 and SIZE2, but SIZE3 and SIZE4 would not be significantly affected. Thus, while all four measures give indications of the significance of IT's impact of firm size, the latter two can provide some insight into the mechanisms of the effect.

The magnitude of these coefficients will tell us how much a percentage change in IT will affect firm size, all else being equal. The sum of the coefficients can be interpreted as the percentage change in firm size associated with a 1% change in IT capital. Because of lags due to learning and other adjustments to the technology, we expect the impact of the IT investments will be increasing for small lags and then returning close to zero in distant years, exhibiting a concave pattern. The rise results as the technology is more fully exploited and the fraction of purchased IT stock that is "effective" increases. As the IT capital begins to deteriorate, the coefficient would fall.

It is sometimes argued that the rapidly increasing globalization of the economy increases competitive pressures on American firms and forces them to "downsize" (Roach 1987). The underlying assumption is that previously they were inefficiently large or overstaffed. This effect would lead to a negative coefficient on TRADE, at least for SIZE1 and SIZE2. However, an opposite effect is at least equally plausible. Globalization

tests to choose between IV and OLS estimates do not always exhibit desirable statistical power properties and hence IV estimates, which are consistent, are preferred to possibly biased OLS estimates (Nakamura and Nakamura 1985).

leads to larger markets and provides an opportunity to further exploit scale economies (Caves and Bradburd 1988). This could lead to a larger average firm size, and a thus positive coefficient on TRADE.

The control variables have relatively straightforward interpretations. Growth in the output of the economy is indicative not only of cyclical business expansion, but also increased opportunity to exploit scale economies. This should lead to a positive coefficient on GNP. According to a transaction cost framework, industries which require large fixed capital investments will, ceteris paribus, have larger average firm size. The coefficient on TOT should thus be positive. The current costs of capital, as proxied by interest rates on AAA bonds, should be negatively correlated with growth of firms, leading to a negative coefficient on BOND. The sector dummy variables control for systematic variations in firm size between sectors. For instance, manufacturing firms are typically much larger firms than firms in the service sector, and this should be reflected here.

5. Results

The overall results indicate that IT is correlated with a decline in all measures of firm size and the TRADE is correlated with an increase in average firm size. We also found evidence that the impact of IT is not immediate but rather that it is strongest after about two years.

5.1. Results for SIZE1

We found that the current level of IT stock is strongly correlated with a decline in average establishment size, SIZE1. The coefficients indicate that each 1% increase in IT investment over five years is associated with a 0.13% decrease in the number of employees per establishment, after controlling for the other variables, and is significant at the 99.9% level (see table A). A distinct concave pattern of effects is evident in the individual years' investments in IT. Declines in establishment size are correlated with IT investments for all lags, but the strongest impact is for investments that have been lagged for one to two years, with coefficients of 0.032 and 0.031 respectively and *t*-statistics of 3.5 and 2.7. Interestingly, TRADE was strongly and unambiguously

correlated with an *increase* in average firm size, as measured by SIZE1. The coefficient was 0.32 and the *t*-statistic was 4.5.

The other variables are consistent with our predictions. Total capital stock and GNP are positively correlated with establishment size. The coefficient on BOND was negative, but it was not significantly different than zero. Dummy variables for each sector show that manufacturing establishments tend to be larger than service establishments. The unusually high R^2 is encouraging but somewhat misleading because it is largely due to the dummy variables which "explain" the large intersectoral variations in firm size.

The results of this regression suggest that increased levels of IT in a sector lead to a decrease in the average size of firms in that sector. The null hypothesis that IT does not affect firm size can be rejected at the 99.9% level of significance.[11] Furthermore, the magnitude of the impact of IT on establishment size is quite large. Because of the large increase in IT investment over the period, this effect could account for the 20% decline in establishment size between 1977 and 1985, reversing its previous upward trend. The alternative hypothesis that increased globalization leads to smaller firms is not supported. It is in fact contradicted by the data.

While the data from County Business Patterns is the most comprehensive available, we sought to confirm our findings by running the same regressions on several different datasets to help guard against the possibility that our findings were somehow an artifact of the County Business Patterns data. These results are presented in the next sections.

5.2. Results for SIZE2

This impact of IT was further examined by constructing a different measure of firm size (SIZE2) from data available through Compustat as described in § 2. In addition to providing a second, independent source for data on firm size, the Compustat data allow us to detect changes in the size of multi-establishment firms. For instance, it is possible that IT reduces the size of indi-

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[11] An *F*-test rejected the restriction that the coefficients on IT were equal to zero at the 99.9% level.

Table A

	Regression Tables			
Variable	SIZE1 (Employees per Establishment) Coefficient	SIZE2 (Employees per Firm) Coefficient	SIZE3 (Sales per Establishment) Coefficient	SIZE4 (Value Added per Establishment) Coefficient
Constant	−3.806***	−2.911**	−4.225***	−4.728***
IT Investment by year				
ITINV (0)	−0.02803	−0.1375*	−0.01185	−0.01611
ITINV(−1)	−0.03217***	−0.05542***	−0.04352***	−0.03780***
ITINV(−2)	−0.03144***	−0.00063	−0.05094***	−0.04125**
ITINV(−3)	−0.02583**	0.02687	−0.03409***	−0.02646**
ITINV(−4)	−0.01535	0.02708	0.0070	0.00657
SUM of IT Investment	−0.1328***	−0.1395***	−0.1334***	−0.1150***
Non-IT investment by year				
TTINV(0)	0.1522***	0.2194*	0.05650*	0.02419
TTINV(−1)	0.09994***	0.07407*	0.06273***	0.03339**
TTINV(−2)	0.05854***	−0.02057	0.06131***	0.03473*
TTINV(−3)	0.02809	−0.06446	0.05224***	0.02820*
TTINV(−4)	0.00857	−0.05760	0.03553	0.01380
SUM non-IT investment	0.3474***	0.1509	0.2683***	0.1343**
GPD	0.2418*	0.2749	0.1492***	0.009204
Bond Rate	−0.0002447	0.003698	−0.009570***	−0.01318***
Foreign Trade	0.3211***	0.2826**	0.5544***	0.6775***
Sector Dummies				
Durable Manufacturing	0.7530***	0.4523***		
Non-durable Manufacturing	0.7259***	0.3915***		
Transport & Utilities	0.1952***	0.8495		
Trade	−0.04841**	0.4001***		
Finance, Insurance & Real Estate	−0.07374***	−0.2277***		
R-Squared	0.9910	0.9608	0.9956	0.9874
Durbin-Watson	2.0360	1.868	1.464	1.342
F Statistic	655.6	145.0	2040	706.0
Number of Observations	84	84	280	280

Key: * = Significant at 90% level; ** = Significant at 95% level; *** = Significant at 99% level.

vidual establishments but allows firms to grow by adding more establishments.

The results using this new source for the dependent variable also show that increasing IT stock is associated with decreases in this measure of firm size (table A). Thus sum of the coefficients on IT was −0.14, almost

identical to that in the SIZE1 regressions, and it was significant at the 99% level of confidence. Furthermore, TRADE again had a positive coefficient, and it was significant at the 95% level. Two differences from the previous regression were that (1) the fit, while still of high quality, did not seem to be quite as good, as indicated

by the slightly lower F-statistic, R^2 and t-statistics and (2) the coefficients on the individual lags for IT investment did not follow the hypothesized concave pattern, although the once-lagged value was still the most significant.

The coefficients on the other variables are also qualitatively similar to those in the previous regressions with the notable exception that the trade sector tends to have larger firms, ceteris paribus, as measured by Compustat, presumably because chain stores involving multiple establishment are counted as only one firm.[12]

The combined evidence of the preceding analysis of CBP and Compustat data strongly suggest that increases in IT capital stock are associated with significant declines in the number of employees per firm. This result is consistent with both the hypothesis that IT leads to a reduction in the proportion of internal coordination as well as the hypothesis that IT substitutes for labor within firms, enabling firms to continue to provide roughly the same scope of activities, but with fewer employees.

5.3. Results for SIZE3 and SIZE4

We next examined the relationship between IT and two alternative measures of firm size: gross shipments per firm (SIZE3) and value-added per firm (SIZE4). As discussed in § 4, data for these variables were available at the two-digit SIC code level of aggregation for manufacturing.

The results for both these alternative measures provide strong additional evidence that IT has lead to a decline in the average size of firms (table A). They suggest that, *ceteris paribus*, doubling IT stock in an industry leads to a decrease in average sales per firm in the same industry of about 13% and a decrease of about 12% in average value added per firm over a period of five years. Both of these estimates are significantly different from zero at a 99.9% level of confidence and are quite con-

sistent with the estimates from the SIZE1 and SIZE2 regressions on different data. The distributed lag specification for both SIZE3 and SIZE4 show the expected concave shape, peaking after two years. The coefficients on the 1 to 3 year lags are all negative and significant at the 99% level.

Because these alternative measures of firm size are less likely to be significantly affected by substitution among factors of production, the combined evidence of these regressions with other studies of the effect of IT on labor intensity and productivity (Berndt and Morrison 1991, Osterman 1986), suggest that the decline in employees per firm was *not* caused solely by the substitution of capital for labor.

As discussed earlier, the observed reduction in all measures of the size of firms is consistent with the hypothesis that IT is facilitating the "decoupling" of existing vertically integrated firms and the supplanting of existing firms by value-adding networks of new, smaller firms.

5.4. Results on Subsamples of the Data

5.4.1. Different Time Periods. To assess whether the relationship between IT and firm size changed over time, we ran the model on subsamples disaggregated by year. There was sufficient data to examine the effect on each of the four measures of firm size in three overlapping samples corresponding respectively to the first 2/3 of the time period (i.e., 1976–1984), the second 2/3 (1981–1989), and a long difference of the first and last third of the period (excluding 1981–1984). The net relationship between IT and all four measures of (SIZE1, SIZE2, SIZE3, and SIZE4) was consistently negative in all three time periods. The effect was statistically significant at least the 99% level in 9 of the 12 cases examined. The sum of the coefficients on the IT investments ranged from 0.08 to 0.39. For all four measures of firm size, the effect was strongest in the latter 2/3 years as compared to the first 2/3 of the sample. In all twelve cases, IT had the statistically most significant impact after a lag of 1–2 years and a concave pattern was apparent in 6 of the 12 regressions. Interestingly, during both the 1976–80 and 1985–89 periods, value-added per establishment was *increasing* in the overall

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[12] A review of the residuals from both regressions revealed one possible outlier in the Transport and Utilities sector. Because this outlier could be due to an error in data coding, we re-ran the regression without this data point. The revised results do not significantly affect findings discussed in the text except to further strengthen the negative relationship between IT and firm size.

sample, yet it continued to be negatively related to IT, when other factors were controlled for.[13,14]

5.4.2. Manufacturing Versus Services. For the SIZE1 and SIZE2 regressions, we were also able to disaggregate the data into "manufacturing" and "services."[15] "Manufacturing" consisted of two of the six sectors (Durable and Non-durable goods manufacturing) grouped together. The other four sectors (Transport and utilities; Trade; Finance, insurance and real estate; and, other Services) comprised "services." Although the number of observations were limited for each subsample, we were able to identify some potential differences and to further assess the robustness of our overall results.

In manufacturing industries, IT investments were associated with declines in both SIZE1 and SIZE2 at the 99% level of significance when all five years of investment were considered (table B). For service industries, IT was correlated with declines in SIZE1 at the 99% level of significance and at the 95% level for SIZE2. Once again, IT investments were most strongly correlated with declines in firm size when they were lagged by either one or two years. International trade in both sectors was correlated with increases in both measures of firm size. This increase was statistically significant in all regressions except the manufacturing subsample for SIZE2. In our sample, there was only a small difference between manufacturing and services; the coefficients were slightly smaller in the service industry regressions for both measures of firm size, but a Chow test indicated that the difference was not statistically significant.

On balance, the results of this set of regressions and those on the different time periods suggest that the correlations between IT and declines in various measures of firm size are not unique to any one sector or any one time period. Although some differences were found, they were relatively small so we are hesitant to draw any inferences from them. Instead, we conclude only

[13] We thank a referee for pointing this out.

[14] The details of these 12 regressions were omitted to save space. However, they are available in a longer version of this paper, (Brynjolfsson, et al. 1991), along with several related regression results.

[15] Recall that the data needed for SIZE3 and SIZE4 was only available for manufacturing industries.

Table B

Variable	Dependent Variable is SIZE1		Dependent Variable is SIZE2	
	Manufacturing Sector Coefficient	Service Sector Coefficient	Manufacturing Sector Coefficient	Service Sector Coefficient
Constant	−0.4570	−3.949***	2.576*	−7.258**
SUM of IT Investment	−0.1713***	−0.09137***	−0.1476***	−0.1327**
SUM non-IT investment	−0.1489	0.1160	−0.1698	−0.3798**
GDP	0.08427	0.3930*	0.03315	1.230**
Bond Rate	0.007045	−0.001389	−0.000003392	0.003728
Foreign Trade	0.4897***	0.3543***	0.001297	0.4083**
R-Squared	0.9979	0.9864	0.9946	0.9674
Durbin-Watson	2.712	2.46	2.364	2.726
F Statistic	1138	328.4	438.6	133.6
Number of Observations	28	56	28	56

Key: * = Significant at 90% level; ** = Significant at 95% level; *** = Significant at 99% level.

that the relationship between IT and firm size appears to be fairly widespread in the economy.

6. Conclusion

6.1. Summary

There is substantial evidence of a relationship between increased levels of IT investment and smaller firm size. The overall relationship is robust to a variety of specifications and at least four measures of firm size. However, our findings should not be interpreted to apply to all industries and all time periods. Our data were limited, and the relatively undeveloped state of the economic theory of the firm and of its relationship to IT, in particular, made the use of detailed functional specifications unrealistic. Our purpose was primarily to develop generalizable models that could be applied broadly across the economy. As more detailed and industry-specific models are developed, and better data sets are created, it will be possible to make sharper predictions. Nevertheless, our findings are consistent with the hypothesis

that IT leads to a decline in the average size of firms, enabling us to empirically distinguish among some of the predictions of prior theoretical work.

The decline in firm size is greatest after a lag of one to two years following investments in IT, suggesting that the impacts of the new technology are not fully felt immediately. This finding may shed light on previous studies which found little or no impact of IT in the same year that the investments were made, and is consistent with earlier work on the effective time-path of capital depreciation (Pakes and Griliches 1984). The decline in two of our measures of firm size (SIZE1 and SIZE2) could be explained by the substitution of IT capital for labor, but the substitution hypothesis would not explain the decline in sales per firm (SIZE3) or value added per firm (SIZE4). In contrast, our findings on all four measures are fully consistent with a relative increase in the reliance on markets for coordination following IT investments. Such a shift is specifically predicted by Malone and Smith (1988) and Malone, Yates and Benjamin (1987).

It is worth noting that an important alternative explanation for the decline in firm size in this period, increased international competition, apparently does not explain the strong correlation we found with increased investments in IT. On the contrary, trade is strongly correlated with increases in firm size in virtually all of our regressions.

Although the null hypothesis that IT was not correlated with declines in firm size is strongly rejected by the data, other factors may also have played a role. Furthermore, we cannot rule out more complex relationships. For instance, if some third trend, like increased turbulence in the economy, is associated with both increased IT investment and with younger, smaller firms after a brief lag, it could produce the correlation we found in our regressions.

There is, however, strong reason to believe that most of the growth in IT investment has an exogenous technological basis. Increased investment in IT appears to be almost entirely explained by the rapid drop in its price (Gurbaxani and Mendelson 1990), and these price declines are directly attributable to improvements in the technology. Although causality can never be proven by statistical regression, the data do support the hypothesis that improvements in technology have enabled a shift toward smaller firms.

6.2. Managerial Implications

One implication of our findings is that the current downsizing of firms, the popularity of outsourcing, and the rise of value-adding partnerships is not simply a management fad, but rather may have a technological and theoretical basis. Companies evaluating success strategies in an environment of increasingly inexpensive information technology will benefit from considering alternative forms of organizing which depend more heavily on market coordination. For instance, the comment by the former chairman of GM that their historically high levels of vertical integration were no longer a competitive advantage, but had instead become a "semi-disadvantage" worth several hundred dollars per car is indicative of the way in which less integrated smaller firms have benefited (*Businessweek* 1987). Our findings also suggest that it may be no accident that IT is often the catalyst for "re-engineering" projects that result in greater outsourcing and leaner internal staffing.

6.3. Future Research

In this paper, we have focused on changes in firm size associated with IT investments within the same sector or industry. However, to the extent that IT also enables the externalization of services, it may be contributing to the shift in employment from the manufacturing sector to the service sector. Because the service sector generally has smaller firms, such a shift would tend to amplify the trend we identified in this study. An examination of this possibility would be a fruitful direction for future research.

Secondly, in interpreting our results we have largely followed the standard approach of presuming a dichotomy between markets and firms, and therefore clear firm boundaries (Williamson 1985). Perhaps some of the most interesting effects of IT will be the enabling of new organizational forms such as "networks" (Antonelli 1988, Piore 1989), "ad-hocracies" (Toffler 1982) or more complex forms. Future research should seek to identify and where possible quantify these new forms in order to establish whether, how, and why IT affects their implementation.

Thirdly, while the reduced form models analyzed in this paper are provocative, a better understanding of the theory of the firm and a more formal theory of the relationship between IT and firm structure are needed for more definitive hypothesis testing. The recent work in agency theory and the property rights approach to the theory of the firm are promising avenues to explore and should lend themselves to econometric analysis of specific functional forms (Brynjolfsson 1994).

Finally, this paper has examined the relationship between IT stock and one key indicator of the restructuring of the American economy, firm size. By examining more refined measures, it will be possible to evaluate stronger conclusions about the size and form of these changes. While IT constituted less than 10% of all capital stock in most of the period we examined, net investment in IT amounts to up to 30% of net increases in capital stock in 1990. This trend, combined with the relationship between IT and firm size identified above, portend a potentially more radical restructuring of the American economy in the next decade.[16]

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