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Overall, increased use of IT is found to be associated with substantial decreases in vertical integration and weak increases in diversification. In addition, firms that are less vertically integrated and more diversified have a higher demand for IT capital. While we cannot rule out all alternative explanations for these results, they are consistent with previous theoretical arguments that both internal and external coordination costs are reduced by IT.

Keywords

Firm Boundaries, Transaction Costs, Markets, Hierarchies, Information Technology, Computers, Diversification, Vertical Integration

Disciplines

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1. Introduction

Emerging technologies can often have a substantial impact on the design of organizations. Milgrom and Roberts (1992) argue that the shift from small-scale handicraft production methods to the mass-production oriented, international industrial enterprise was largely driven by the appearance of three key coordination technologies: the steamship, the railroad, and the telegraph. These technologies eliminated the time and cost barriers of coordinating activity over long distances, enabling large economies of scale to be realized. Chandler (1977) argues that these technology-driven changes were even more far reaching, leading to a redefinition of the role of firm owners and the rise of professional management.

Some authors have argued that because information technology reduces the cost of coordination within and between firms, the rapid price and quality improvement of IT may enable a shift in the structure of organizations analogous to the Industrial Revolution (Drucker, 1988; Malone and Rockart, 1991).   An important manifestation of this restructuring is the change in firm boundaries (Malone, Yates and Benjamin, 1987; Gurbaxani and Whang, 1991; Clemons and Reddi, 1993). Firms may expand or contract in size while performing the same activities or may shift the types of production activities performed. For example, if IT makes it easier for firms to access the market for needed materials, then firms may decrease vertical integration.   Similarly, if IT makes it possible to coordinate diverse production activities inside the firm, companies may further diversify into new product markets or increase vertical integration.

Previous work has provided some evidence that IT is associated with a change in firm boundaries. Case studies have linked coordination benefits arisng from IT use to decreased vertical integration (Malone, Yates and Benjamin, 1987; Clemons, Reddi and Row, 1993) and provided some evidence that the level of diversification has changed (Gurbaxani and Whang, 1991). A statistical study has also linked IT to decreased firm size, consistent with coordination cost arguments, using data for six sectors of the economy (Brynjolfsson, Malone, Gurbaxani and Kambil, 1989; 1994). No previous study, however, has combined statistical analysis with micro-level data to obtain the generalizability of industry-level studies with the precision of case studies. Furthermore, previous statistical work could not

distinguish the effects of IT on internal and external coordination.

The goal of this paper is to examine empirically the connection between information technology and coordination-related changes in organizational form.   The analysis will be focused on two related questions:

1) What are the empirical relationships between IT capital use and two measures of firm structure: vertical integration and diversification?

2) Are the observed relationships between IT capital and firm structure consistent with arguments about the effects of IT on coordination costs?

The first question will be addressed by constructing models for measuring the interrelationships between IT and firm structure. Ideally, to address the second question we would like to perform correlations between IT capital and measures of coordination costs. Because coordination costs can include a wide range of activities, are likely to be highly setting specific, and are not captured in any known data source, we instead use evidence on the relationship between computer capital and firm structure to *infer* a relationship between IT and coordination costs.

More specifically, previous literature has suggested that IT leads to a reduction in both internal and external coordination costs. Some authors have also extended this argument to suggest that the effect of IT on external coordination cost is greater than the effect of IT on internal coordination cost.   For our empirical investigation, we relate these arguments to the following testable hypotheses which we then explore using our data: a) IT capital use should be negatively related to vertical integration, and b) IT capital use should be positively related to diversification.

In this paper, we first argue how the correlation between firm structure and IT capital can be used to test the relationship between IT and coordination costs. We then develop estimating equations to evaluate these effects, rule out some alternative causes and distinguish two causal directions, the effects of IT on firm structure and the effects of firm structure on the demand for IT. These equations are then estimated using a large, detailed panel data set for 549 firms over 8 years (1987-1994).

Overall, we find evidence that suggests IT causes a decrease in vertical integration, and weaker evidence that IT causes an increase in diversification. Both firm-level IT capital and industry-level IT capital influence firm structure in the same way when considered separately, although the actual level of IT in the firm is a better predictor of firm structure than the overall intensity of IT in the industries in which a firm participates. That is, the choices on IT use by individual firms appears to outweigh the general tendency of firms in IT-intensive industries to have less vertical integration and more diversification. In addition, firms that are less vertically integrated and more diversified have a higher demand for IT after controlling for other determinants of IT demand. Finally, similar results are found when the analysis is performed using changes in IT capital and changes in firm structure.

These results provide support for our hypotheses and the predictions of earlier theory papers. Malone, Yates and Benjamin (1987) argued that IT leads to an overall decline in coordination costs. Clemons and Row (1993) suggested that the effect of IT on external coordination costs (which combines both coordination and transactions costs) is likely to dominate the effects of IT on internal coordination costs. This is the first analysis that could distinguish these two arguments empirically and both are supported.

2. Previous Research

In this section, we briefly review the previous theoretical and empirical work that is relevant to the modeling and empirical analysis in this paper.   More comprehensive discussions of the literature on IT and vertical integration appear in Clemons and Reddi (1992) and Brynjolfsson, Malone, Gurbaxani and Kambil (1989, 1994). A general overview on IT and firm structure, which is used extensively in the discussion below, appears in Gurbaxani and Whang (1991).

2.1 Prior Theoretical Work

Most analyses of IT and firm structure adopt a transactions cost perspective. Some papers from the IT community focus on the frictional costs of transacting such search and communications costs (Malone, Yates and Benjamin, 1987), while others emphasize

issues of incentives and opportunism (Gurbaxani and Whang, 1991; Clemons, Reddi and Row, 1993; Bakos and Brynjolfsson, 1993).

To evaluate these previous arguments, suppose all costs of operations can be divided into three categories: internal coordination costs, external coordination costs and production costs.   Internal coordination costs represent expenses incurred for communications, data transfer, and other actual expenditures on managing dependencies between activities (Malone and Crowston, 1994). In addition, internal coordination costs also include losses from incentive misalignment such as *agency costs* (Jensen and Meckling, 1974). External coordination costs represent the actual costs of writing contracts, locating suppliers and other costs of using market procurement, as well as the *transaction costs* that arise because of possible opportunistic behavior by suppliers (Coase, 1937; Williamson, 1975). Production costs are all expenses other than internal and external coordination, and are generally believed to be lower for outside procurement because of economies of scale or specialization.

The impact of IT on vertical integration is determined by the degree to which IT changes the cost of internal coordination, external coordination, and production. Malone, Yates and Benjamin (1987) argue that, because market procurement is more coordination intensive than producing intermediate products in-house, a reduction in both types of coordination costs, relative to production costs, will generally favor external procurement over vertical integration. Clemons and Row (1993) argue that IT has a disproportionate effect on the transactions cost component of external coordination, also favoring external procurement. Specifically, IT reduces transaction risks such as "shirking" and "opportunistic renegotiation" through improved monitoring and a reduction of sunk investments in coordination. In general, a more vertically integrated firm can be viewed as having "accepted" greater production costs and internal coordination costs in return for lower external coordination costs. Similarly, less vertically integrated firms economize on production and internal coordination costs, but incur increased external coordination costs (Gurbaxani and Whang, 1991).

A similar framework can be employed to evaluate the impact of IT on diversification.

Diversification entails increased internal coordination costs because firms have to manage more complex and diverse activities. However, there should be little effect of external coordination costs on diversification because, unlike the vertical integration decision, if a firm chooses not to produce an unrelated product in-house, there is no need to obtain the same product in the marketplace. Under some circumstances diversification may have productivity advantages to offset the increased internal coordination cost. Montgomery (1994) argues that diversification can be valuable if it allows a firm to have market power from size or multi-market contact with competitors or allows a firm to leverage underutilized resources which cannot be sold in a competitive market (e.g., knowledge, firm-specific human capital or a specialized organizational structure).

2.2 Prior Empirical Work

Several studies have examined these relationships using statistical approaches. Brynjolfsson, Malone, Gurbaxani and Kambil (1989, 1994) examined the time series relationship between average firm size and IT investment in six broad sectors of the U.S. economy. Overall, they found evidence that increased IT investment was associated with decreasing firm size. They argue that this is due to decreased vertical integration, consistent with coordination cost arguments.   There have also been at least two papers on the relationship between IT and firm structure at the firm level. Brynjolfsson, Hitt and Viswanathan (1995) found that IT intensity of the firm or of the economy as a whole increased as firms focused on a narrow range of industries. Dewan, Min and Michael (1996) report that IT demand is higher for firms with more related diversification, but found little impact of vertical integration or unrelated diversification in a cross-sectional analysis.

2.3 Integration of Previous Theory

To summarize, previous authors have suggested that reductions in internal coordination costs will allow firms to become larger, increasing vertical integration and diversification. Reductions in external coordination cost will favor decreased vertical integration, but should have no effect on diversification. Therefore, by observing the effect of IT on vertical integration and diversification, we can evaluate whether or not

this is consistent with IT having an effect on coordination cost. More specifically, if we observe that increased use of IT is associated with decreases in vertical integration and increases in diversification, then this is consistent with our original hypothesis stated in the introduction: a) IT lowers both types of coordination cost, and b) the effect of IT on external coordination cost is greater than the effect of IT on internal coordination cost.

3. Analytical Model and Empirical Implementation

3.1 Theoretical Concerns

Based on previous work, three alternative hypotheses can also be distinguished. First, if IT has no influence on internal coordination cost, but decreases external coordination cost, there will be a negative relationship between IT and vertical integration and no effect on diversification. This is consistent with previous work that had not considered the role of coordination in affecting diversification (see e.g. Malone et. al., 1987, or Clemons and Row, 1993). Similarly, if IT has no influence on external coordination, but decreases internal coordination cost, or if the internal coordination cost effects are greater than the external coordination cost effects, both vertical integration and diversification should increase with IT use. This is the prediction that would be reached if IT had a minimal effect on inter-firm communication. Finally, if there are no effects of IT on coordination, then we should see no relationship between IT and either vertical integration or diversification.

There are several important characteristics of this analytical setting that are important for empirical implementation. First, there is the potential for multiple causal directions in the relationship between IT and firm structure. Both firm structure and technology use are choice variables, whose costs and benefits are affected by exogenous factors such as technology prices and the value of vertical integration and diversification (apart from coordination concerns). If the price of IT drops, leading firms to obtain more IT, then this will lower marginal coordination costs and enable firms to decrease vertical integration and increase diversification.[1] Similarly, if market forces dictate that a firm

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[1] This relies on the fact that IT is a general purpose technology which can easily be adapted to multiple uses. For example, vast improvements were made in the availability of management information as a by-

needs to become less vertically integrated, then the firm will adopt more IT to support external coordination. This is in essence an argument that IT and firm structure are complementary (in the sense used by Holmstrom and Milgrom, 1994); that is, an increase in one dimension (e.g., IT capital use) will be associated with changes in other complements (e.g., decreased vertical integration) and vice-versa in response to exogenous drivers (e.g., IT price declines). Because the different causal directions may be of interest, we will attempt to separate them using empirical techniques.

Second, there may be other factors that might simultaneously lead a firm to change IT and firm structure aside from coordination cost reasons. Firms with skilled workers may have an increased value of IT, and may also be more diversified to exploit their general knowledge or human capital resources in multiple industries. Alternatively, managers of firms with highly skilled, well-paid workers may be less risk averse, leading a firm to have less need to smooth cash flow through diversification. Taken together, these examples would lead to a correlation between IT and structure in an indeterminate direction that could potentially offset any coordination effects. To rule out these types of factors, we also analyze the relationship between changes in structure and IT for the same firm over time (a first difference specification). This removes the effect of any factor that could confound the results that is unique to a particular firm but constant over time.

3.2 Empirical Implementation

The simplest empirical test of our hypotheses is to calculate rank order correlations between three observable variables: IT capital (C), vertical integration (V), diversification (D). However, this approach has a limited ability to rule out other causes of the results and cannot distinguish the two causal directions.[2] An alternative is to specify equations that relate the variables of interest in each causal direction and then use instrumental variables estimation techniques to separate out the different causal effects. A

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product of automation of financial and sales operations. In more modern times, networked PCs on workers' desktops, acquired for various purposes, now make it possible to communicate extensively within and between firms through electronic mail or access to the World-Wide Web.

[2] The fact that IT, diversification, or vertical integration can be caused by other factors is not important for this analysis unless these factors change IT and firm structure at the same time. Otherwise, they just introduce random variation in the regressions, increasing standard errors but leaving coefficients estimates

general structure for these estimating equations is:

1a: $V = \mu_0^v + \mu_c^v C +$ other determinants of V $+ \varepsilon_v$

1b: $D = \mu_0^d + \mu_c^d C +$ other determinants of D $+ \varepsilon_d$

1c: $C = \mu_0^c + \mu_v^c V + \mu_d^c D +$ other determinants of C $+ \varepsilon_c$

where: $\varepsilon_c, \varepsilon_d, \varepsilon_v$ are i.i.d. error terms (which could be correlated)

The parameters μ_c^d and μ_v^d are proportional to effect of computer investment on reductions in internal coordination costs and should be positive. The parameters μ_c^v and μ_v^c are proportional to the how much more computers reduce external coordination costs than internal coordination cost and should be negative. Technically, the exact test of the hypothesis stated in the introduction can be described as the joint test $\mu_c^d > 0, \mu_d^c > 0, \mu_v^c < 0, \mu_c^v < 0$ against the null hypothesis that all coefficients are zero. However, since we always reject the null hypothesis in our analysis for this joint test, we emphasize analysis of individual coefficients. This allows inference about relative effects and causal direction.

To define "other determinants" in equations (1a-1c), we adapt empirical specifications that have been used previously where available. While previous research has identified some variables that may influence firm structure (see footnote 12), there is no common theoretical model that has been employed to predict vertical integration or diversification. Thus, little additional structure is placed on the vertical integration and diversification equations from previous work. However, for the IT equation (1c) we can use the theory on estimating demand for factors of production.   In the factor demand framework (see Berndt, 1992, Chapter 9), IT is a function of relative factor prices and output. To incorporate firm structure, we assume that firm structure choices affect the overall level of IT, but do not change the responsiveness of demand to price. We start with the assumption of a transcendental logarithmic cost function, which is commonly applied in empirical production research (Berndt, 1992). Let ordinary capital be designated by K (with price p_k), ordinary labor designated by L (with price p_l), and firm output by O. In

unbiased.

our case the cost function is (not yet incorporating firm structure):

$$2: \quad \log Cost = \sum_{i=K,L,C} \alpha_i \log p_i + \sum_{i=K,L,C} \sum_{j=K,L,C} \alpha_{ji} \log p_i \log p_j + \alpha_o \log O + \sum_{i=K,L,C} \alpha_{io} \log p_i \log O$$

We then apply Shepard's Lemma ($C = \dfrac{\partial Cost}{\partial p_c}$, see Varian, 1992, p. 210) and incorporate the

vertical integration and diversification terms to obtain the demand equation to be estimated:

$$3: \quad IT\, Cost\, Share = \frac{p_c C}{p_{it} C + p_k K + p_l L} = \alpha_c + \mu_v^c V + \mu_d^c D + \alpha_{cc} \log p_c + \alpha_{cl} \log p_l + \alpha_{ck} \log p_k + \alpha_{co} \log O$$

While the equation is not linear in the IT capital term (C), it is linear in the ratio of computer capital input to total costs, which include (current dollar) direct costs for labor and capital costs for computers and ordinary capital to account for their durable nature. This equation does not place any restrictions on which factors are substitutes or complements. In addition, it also requires no assumptions about economies of scale; for example, it does not matter whether or not larger firms require less input factors (in total or individually) per unit of output than smaller firms.

Measuring computers as a cost share also has another advantage for our purposes: it provides a normalization for size that is motivated by economic theory. Larger firms are likely to use more IT and be larger in terms of the vertical integration and diversification measures irrespective of any other relationship. We therefore use IT cost share as the measure of IT capital in pooled analyses to prevent the results from being obscured by normal variations in IT use and firm structure due to variation in firm size.

4. Data and Variable Construction

There are three types of data that are used for this analysis: information technology hardware spending provided by Computer Intelligence InfoCorp (CI), firm specific financial information from Compustat, and measures of firm structure constructed from

Computer Intelligence data. In addition, as a validity check, we compare the CI data with data from Trinet Corporation and Compustat (see Appendix B).   Each of these sources is summarized below.

4.1 Information Technology and Financial Variables

CI Information Technology Measure. Computer Intelligence InfoCorp conducts a series of surveys that track specific pieces of computer equipment in use at approximately 25,000 sites; these sites represent different locations of firms in the Fortune 1000. CI conducts telephone surveys of information systems managers (site sampling frequency ranges from monthly to annually, depending on size) to obtain detailed information on each site's information technology hardware. Each piece of hardware is then market-valued and aggregated to form an estimate of the value of hardware in use at the firm. We have data for the Fortune 1000 annually for the period 1987 to 1994 although we restrict the sample to firms which have 6 out of 8 years present to limit changes in the sample over time, reducing the number of firms to 549.[3]

To gauge the quality of these data we checked it against similar data from Computerworld (described in Brynjolfsson and Hitt, 1996) which include 1500 overlapping data points (1988-1993) with the CI dataset.   The computer capital figures show high correlations (>75%) between the two sources, which provides some indication of accuracy, particularly given different collection methodologies between the sources. In addition, the computer capital data from CI shows a high correlation (75-80%) with broader measures of IT such as IS labor expense and a composite measure ("IT stock"), that includes both capital and labor (Brynjolfsson and Hitt, 1996). Thus, we can use the

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[3] The firms that are included in the analysis are somewhat larger on average than the potential population of all firms that appeared on the CI database over 8 years, although much of this difference is probably a result of small firms dropping out of the relevant population over time. However, there are no differences on measured IT cost share between the firms in and out of the sample in 1994, and no economically significant differences between the firm structure measures for the restricted sample we use and the full sample of firms with complete data. Furthermore, the correlation structure between firm structure measures and IT is similar whether or not we restrict the sample. Altogether, this suggests that there does not appear to be any sample selection bias as a result of using a near-balanced panel or from deviations from the population (Fortune 1000 firms).

CI computer capital stock measure as a good indicator of overall firm IT.[4] While we cannot rule out the existence of measurement error, we have some comfort that these data are consistent with other sources.

Compustat Financial Information.   The firms on the CI dataset were matched to Standard & Poor's Compustat II database to obtain information on labor expenses, capital stock, and employment.[5] These data were supplemented with price deflators from a variety of sources to construct measures of the sample firms' inputs and output using standard procedures (Hall, 1990; Brynjolfsson and Hitt, 1996). See Appendix B for variable construction, including detail on the calculation of input quantities and rental prices needed for the IT cost share measure.

4.2 Firm Structure Measures

The unique data for this analysis come from several databases that track firms' participation in different industries. As part of its surveying process, CI also collects data on the primary industry for every site that they survey for IT data. The core of the data is developed from Dun and Bradstreet's database of firm locations and is updated during CI's interview process.   For each site, CI collects or verifies a 4-digit SIC[6] code, number of employees and approximate sales, although for the early years (1987-1988) only size buckets (e.g. 1-5, 5-20…) rather than actual numbers are reported.

The advantage of these data is that they have a nearly complete panel over the 8 years, although there is likely to be some error in the data due to variation in site sampling and random respondent error. To be satisfied with the validity of these data, we compare summary statistics and firm structure measures between CI and other data sources with comparable measures and find high levels of correlation (see Appendix B), with

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[4] Correlational results between IT and firm structure are similar when Computerworld IT data are used.

[5] Standard & Poor's Compustat data have been widely used to estimate firm-level production functions for capital, labor, and other inputs. For instance, the underlying data for "The Manufacturing Sector Master File: 1959-1987" maintained at the National Bureau of Economic Research by Hall (1990) are drawn from Compustat.

[6] The Standard Industrial Classification (SIC) coding system is a way of assigning firms to industries. Four digit codes represent detailed industry classifications (e.g. meat packing), while 2-digit codes represent broader industries (e.g. food manufacturing).

correlation coefficients on the order of 0.6 to 0.8 across measures and data sources. We also corroborate our results using different data sources and find that the correlation between IT and firm structure is broadly similar (results not shown). Again, this suggests that errors in data are not corrupting the results.

Using the CI data, we are able to construct three measures of diversification that have been used in prior research to capture different aspects of diversification: the Concentric index which measures "relatedness" of industries (Montgomery and Wernerfelt, 1988; Wernerfelt and Montgomery, 1988), a Herfindahl index of industry shares which measures industry dispersion, and counts of SIC codes (Lichtenberg, 1990) which measures general industry participation.

One shortcoming common to all of these diversification measures is that they confound vertical integration and diversification. For example, a firm may have 20% of its employees in a steel mill and 80% in an automobile manufacturing plant. Even though this is indicative of vertical integration since steel is a major input factor in the production of automobiles, the firm would be measured as diversified by two of the three measures (SIC count=2, Herfindahl = .16, concentric =0). To control for this effect, we remove the variance in the diversification measure shared by vertical integration, leaving a residual that captures diversification uniquely.[7]

For vertical integration, we employ the vertical industry connection index (VIC) developed by Maddigan (1981). This measure represents the strength of input-output dependencies between the industries in which a firm participates, using the aggregate input-output (IO) tables for the U.S. economy (Lawson and Teske, 1994). A firm that participates in industries that have strong make-buy relationships according to commodity flows in the IO table (e.g., automobile manufacturing and steel) will have a high value of this index. Alternatively, a firm that participates in industries that little or no make-buy relationships (e.g. automobile manufacturing and insurance) will have lower values of this index. While this measure does not incorporate industry shares, it

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[7]We first run a regression of the diversification measure on vertical integration and use the residuals as a measure of "true" diversification.

has the advantages that it is motivated by economic theory instead of being ad hoc, it requires no subjective judgment, and it captures vertical integration uniquely.

 4.3 Control Variables

In addition to the base variables described previously, several control variables are included in the regressions to correct for possible data error and provide additional insight into the relationships of interest. First, because CI is a site level census for each firm and the number of sites sampled varies over time, it is possible that error is induced in the IT measures as a result of variation in the CI sampling. To eliminate the variation in measured IT that is solely due to variation in site sampling, we add a variable (SITES) which counts the number of sites the firm reports on CI for that year.[8] Unfortunately, because some variation in SITES is driven by true changes in firm structure, controlling for SITES also removes some of the true variance of the other measures. Because this potentially leads to underestimates of the impact of IT on structure (and vice-versa), we perform some analyses without this control.

Second, while we are primarily interested in the firm-level effects of IT on structure, it may also be useful to consider the effect of industry IT on firm structure since this ties to previous empirical work. In addition, some of the firm-level variation in IT is due to choices of industry participation. Because some industries are more IT intensive than others, these industry affects may obscure the variation in chosen IT investment with variation due to the pattern of industry participation. To reduce this problem, a variable is included that measures the IT a firm would have if it were at the industry average for each 2-digit SIC industry in which the firm participates. This is calculated by multiplying the share of the firm in each industry in which it participates by the average IT/Output ratio for that industry as reported by the Bureau of Economic Analysis and summing over all industries for that firm. Thus, by including this variable we can isolate the effects of industry IT and IT investment unique to each firm.

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[8] This variable removes the variance in measured IT and firm structure due to variation in site sampling preventing a spurious correlation between IT (increasing as more sites are sampled) and the number of industries the in which a firm participates (also increasing with the number of sites sampled).

5. Results

In this section we perform statistical analysis of our basic testable hypothesis that IT should be negatively related to vertical integration and positively related to diversification. We begin by reporting data characteristics. We then formulate estimation equations based on the structure shown in equations 1a-1c and perform instrumental variables estimation (specifically, two-stage least squares) to yield parameter estimates for each causal direction between IT and firm structure. Finally, we estimate a first difference model that relates changes in IT to changes in firm boundaries to rule out potential confounding effects.

5.1 Sample Characteristics

The average firm in the sample is very large, with value added of about $1 billion and employment of approximately 16,000 in 1990.   Not surprisingly, these firms are both highly diversified and vertically integrated. The average firm participated in 15 4-digit SIC industries and 8 2-digit SIC industries, although the level of industry participation is much larger for manufacturing firms (an average of 18 4-digit SIC industries) than for service firms (averaging 9 4-digit SICs).   There is also a substantial difference in the vertical industry connection index between manufacturing and services (0.25 vs. 0.07), although the magnitude does not have an easy interpretation.[9] All measures have high variance, suggesting substantial variation across firms (see Table 1).

Interestingly, over the sample period, there has been little change in average diversification, vertical integration or firm size (as measured by employment) for the sample of firms, although the average may mask substantial differences among firms. IT cost share is relatively stable over time since it represents the proportion of IT in total cost in current dollar terms. This would imply increases of 20-30% per year in constant dollar IT stock which is consistent with press reports of dramatically increasing IT investment.

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[9] The VIC is bounded below by zero (single industry or no vertical linkages) and above by one, although the upper bound would not be attainable in our sample given the structure of the I-O matrix. See Maddigan (1981) for more discussion of the properties of this index.

5.2 Estimating Equations

We estimate equations using the structure for the model described earlier and the two additional variables (Industry IT, Sites) described in the data section. This yields our final estimating equations:

4a: $V = \mu_0^v + \mu_c^v Cshare + \lambda_{sites}^v Sites + \lambda_{I-IT}^v Industry\ IT + \varepsilon_v$

4b: $D = \mu_0^d + \mu_c^d Cshare + \lambda_{sites}^d Sites + \lambda_{IIT}^d IndustryIT + \varepsilon_d$

4c: $Cshare = \mu_0^c + \mu_v^c V + \mu_d^c D + \lambda_{sites}^c Sites + \lambda_{IIT}^c IndustryIT +$

$\qquad + \ \alpha_{cc} \log p_c + \alpha_{cl} \log p_l + \alpha_{ck} \log p_k + \alpha_{co} \log O + \varepsilon_c$

To isolate each causal direction as well as control for some types of confounding effects we employ two-stage least squares (2SLS) for each equation. For instruments for IT we use factor prices for computers, capital and labor. We also employ an additional instrument set that applies to general production factor inputs proposed by Bartelsman, Caballero and Lyons (1994): the level of defense expenditures, the BAA bond yield, the ratio of the price of oil to the price of durable goods, and ratio of the price of oil to the price of non-durable goods. The instruments are all prices or other factors that are determined outside the firm and thus can be considered exogenous. For firm structure, we use an instrument set suggested by Wernerfelt and Montgomery (1988) for their analysis of the productivity impact of diversification. The instruments are a set of dummy variables for each 2-digit SIC industry that take the value 1 if the firm participates in that 2-digit industry at all, and zero otherwise.

5.3 Results

Tables 2a-2c contain 2SLS estimates[10] of all three equations using one of our three measures of diversification (SIC count, Herfindahl, concentric). To show the relative magnitude of the various effects, standardized coefficients are reported. Estimates of the first equation (identical for all diversification measures) suggest that increased firm-level IT and increased industry level IT cause a decline in vertical integration. A one standard

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[10] Across all equations and measures, a Hausman specification test rejects the ordinary least squares formulation of the model in favor of two-stage least squares. Three stage least squares estimates could not

deviation increase in firm-level IT is associated with a 0.74 standard deviation decline in vertical integration. The industry-IT coefficient is positive when included with firm-level IT, but changes to -0.14 when firm-level IT is omitted, suggesting that the majority of the effect is at the firm level.

The estimates of the diversification equation are more equivocal (Table 2b). The 4-digit SIC and concentric measures of diversification are both positive and significant, while the Herfindahl is only positive. The effect of industry IT is small, and only barely significant in the concentric equation. As before, the industry IT coefficients rise and are all positive when firm-IT is not included. However, while this collection of results is consistent with the prediction that IT should have a positive influence on diversification, the small explained variance in these regressions suggests caution in interpretation.

 The final equation (Table 2c) measures the effect of firm structure on the demand for IT. Firms that are less vertically integrated and more diversified use more IT. The price terms suggest that, at the sample mean, computers and capital are price complements, while computers and labor are price substitutes. In other words, as the price of computers declines relative to the prices of capital and labor, firms (on average) will use more ordinary capital and less labor. The coefficient on output suggests there are weakly increasing returns to scale in IT. As a firm grows in output, holding industry participation constant, it requires slightly less IT per unit of total cost. The effect of vertical integration is somewhat smaller than found in the earlier regression (standardized coefficient 0.22-0.24), while the effect of diversification is in the 0.05 to 0.10 range.[11]

Interestingly, there do not appear to be clear economic differences in the relationship of IT to the various conceptions of diversification. Both the most general measure of diversification (4-digit SICs) as well as the measure that most directly captures firm "focus" (Concentric) appear to have approximately the same effect, while a measure

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be performed because the available instruments are not believed to be exogenous for all equations.

[11] Because the vertical integration and most of the diversification scales are indices rather than simple counts of an observable characteristic, it is difficult to interpret the magnitude of the effects beyond standardized coefficients. However, the interpretation is clear for the count of 4-digit SIC codes. A firm with double the mean IT spending would participate in approximately 5 more 4-digit SICs diversification "demand" equation. The effect of diversification on IT demand is somewhat smaller -- for the firm to

which is in between these two shows the weakest effect. As such, it is difficult to make a statement stronger than a general concept of diversification and IT are positively related. Our analysis has little to say about whether firms are diversifying in particular ways (e.g., related versus unrelated), given the pattern of these results.

Overall, this provides substantial support for previous arguments. There is a strong and consistent relationship between IT and reduced vertical integration and a weaker but still substantial relationship between IT and diversification, at least in the causal direction between firm structure and IT demand. Joint tests that all effects are simultaneously zero are strongly rejected (p<.001) irrespective of which diversification measure is used in the analysis.

5.3 Controlling for differences among firms

All of the results thus far have not distinguished between effects that occur across firms and those that occur as the same firm adopts more (or less) IT over time. There are several reasons why it may be advantageous to focus on time-series variation for a given firm. First, previous theoretical arguments may be closer to predicting a time-series effect than a cross-sectional effect. The original argument in Malone, Yates and Benjamin (1987) was not about cross sectional variation, but changes in the cost of IT over time enabling a shift toward more coordination intensive structures. Second, while the instrumental variables estimates reduce the possibility of spurious correlation, this method relies on untestable assumptions about the instrumental variables. An alternative assumption is that most of these external confounding factors are unique to individual firms, such as staff quality, management risk seeking tendency or specialized knowledge. To remove these effects, we estimate the relationship between year to year changes in the variables for a given firm.

The IT cost share term already accounts for changes over time due to price changes in IT. As such, it removes most of the time-series variation in this measure. Since IT cost share was used primarily to control for firm size and heterogeneity in input composition, a suitable alternative for this analysis is to use the change in the logarithm of IT capital

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increase IT spending by 10%, the organization would have to be in 10 additional SIC codes.

(which is effectively the percent change in the level of IT capital). We use this measure and the previous instrument set with all instruments in first differences except for the dummy variable instruments for firm structure.

Two-stage least squares estimates of the equations in first differences are shown in Tables 3a and 3b. The results suggest a strong negative relationship between IT and firm structure in both causal directions.   IT appears to have a positive effect on diversification, although the results are mixed in the demand equations. However, the industry-level IT measure has a positive relationship to IT demand, which is consistent with our arguments. In particular, if industry IT is measured with less error than firm-level IT (which is likely due to aggregation), then it may show a stronger effect in first difference regressions, since differencing increases the impact of random measurement error. Nonetheless, we can reject the hypotheses that there are no effects between IT and firm structure at (p<.001), and can also reject the joint hypothesis that IT has no effect on diversification at p<.10 or better in all regressions. The fact that these hypothesis tests are still consistent with other results even in first differences with instrumental variables is striking since this formulation places the strongest demands on the data.[12]

5.4 Empirical Analysis Summary

Altogether, the results show a consistent negative relationship between vertical integration and IT that is approximately the same magnitude in both causal directions. Firms that are more vertically integrated have less IT and are in industries where the IT intensity is lower. The firm-level effect is somewhere between two and four times as

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[12] We also performed the analysis including additional control variables in the equations that have been used in prior research on firm structure. For vertical integration, we included capital intensity, debt-equity ratio and industry growth. In the diversification equation, we included firm average market share, industry growth and debt-equity ratio. All of these variables were also included in the IT demand equation. Growth is likely to be a determinant of firm structure, since firms may use diversification to improve growth rates. Debt-equity ratio may influence structure since firms with high debt may diversify to smooth cash flow. Market share is a measure of market power; firms may seek to diversifiy when they can exploit market power in their respective product markets. Finally, capital intensity may influence vertical integration since high sunk capital investments may encourage opportunism; thus, firms with capital intensive production processes will tend to control more of the production process in their value chain. The basic conclusions are the same when these control variables are included, and the controls generally have the predicted sign suggesting further robustness of our results.

strong as the industry effect.[13] Similarly, IT appears to support diversification: firms that are more diversified tend to use more IT. However, we find only marginal support for the idea that increased IT leads to greater diversification. These results are similar in pooled cross section and time series analysis, and appear to be consistent across diversification measures.

Our results are consistent with prior coordination cost arguments: IT is associated with both a decline in vertical integration and a (possibly weak) increase in diversification. We are also able to rule out many of the alternative hypotheses about the relationship between IT and coordination.   First, we convincingly reject the null hypothesis that IT on coordination has no effect in all specifications. We can also rule out the alternative hypothesis that IT has no effect on external coordination. In most specifications, we also have some evidence that allows us to reject the alternative that IT has no effect on internal coordination.

Unfortunately, we cannot eliminate the possibility that some unmeasured external factor other than coordination effects is driving these results. However, by performing the analysis in differences as well as levels, using instrumental variables, and applying models motivated by previous work as closely as possible, we substantially reduce the possibility of spurious correlation.

6. Discussion

6.1 Contribution

Previous work has suggested that the effect of IT on coordination should lead to a change in firm boundaries. We use these arguments to motivate a test of the relationship between IT and firm boundaries and use the results of this test to make inferences about the effect of IT on coordination costs. Our results suggest a strong negative relationship between IT and vertical integration and a weaker positive relationship between IT and diversification.   This supports the hypothesis that IT is associated with decreases in

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[13] The lower bound assumes that all the common variance these measures share with vertical integration is due to industry effects, while the upper bound holds if all the common effect is attributed to the firm-level.

internal and external coordination costs, and that the effect of IT on external coordination costs is stronger and more consistent. This also provides evidence supporting previous theoretical analyses linking IT to changes in firm boundaries, and indicates the utility of the coordination cost approach for evaluating the effect of IT on large-scale organizational structure.

The results are also consistent with the previous work by Brynjolfsson et. al. (1989, 1994) who found that IT and firm size are negatively related at the industry level. Our analyses also show a strong negative effect between industry IT and vertical integration, consistent with their arguments, although the firm-level effect is much stronger. In addition, we link IT specifically to vertical integration which could only be inferred in their analysis by changes in firm size, examine two causal directions for the relationship, extend the analysis to include diversification, and examine much more detailed data which improves the precision of the estimates, and eliminate some problems of using industry data that could affect the results, such as changes in industry composition over time or differences among firms.

These results imply that the economy is beginning the transition from an era of the large, vertically integrated enterprise, to organizational forms that draw on the resources of small, independent, specialist suppliers, as has been suggested by previous authors. In many high technology (and high IT) industries this trend is already apparent; in Boston (MA), Rochester (NY), and Silicon Valley, there are extensive networks of small suppliers that have been created by departing employees or spun-off from large, dominant technology firms. Similar structures have been described in the automotive and apparel industries (Peters, 1992). However, these results suggest that the transition is more broad-based, occurring at high-IT firms irrespective of their industries. This change also has implications for firm performance; as supplier networks become more developed, large integrated firms will be at an increasing cost disadvantage, which should lead to an increased rate of restructuring or an extended period of poor performance. This is consistent with recent announcements that General Motors is spinning off AC Delco (its parts subsidiary); as stated by one industry analyst "what was once the greatest source of strength at General Motors – its strategy of making parts in house – has become

its greatest weakness" (Schnapp, 1998). Announcements by Ford of the operating results of their internal parts supplier might suggest a similar move in the near future.

While it is not clear that technology adoption has caused firms to diversify more broadly, firms that utilize coordination intensive structures tend to use substantially more IT. This would suggest that IT use is not simply driven by firm size, which would be true if scale were a major determinant of adoption cost, but by the demand for coordination activity.

These results leave two important questions unanswered. First, we have not addressed the question of whether "alternative" organizational structures lead to higher firm performance. Correlational results suggest that firms are attempting to match IT investment to organizational structure, although this may be due to institutional (such as mimicry) as well as economic factors. While industry anecdotes suggest performance is a major factor in recent restructurings, large sample performance comparisons may help distinguish economic optimization from other motivations held by managers who are restructuring their firms. Second, while we observe that large firms are becoming less vertically integrated, we do not know what types of arrangements are appearing to provide the services previously performed in-house. These services could be performed by arms-length supply contracts, partnerships or even "virtual corporations"; each has different implications for the way in which inter-firm relationships need to be managed and supported through technology.

 6.2 Limitations and Qualifications

These types of large sample results should always be interpreted carefully. While we attempted to control for external factors that could lead to spurious correlation by including control variables for potential data problems and employing differencing or instrumental variables estimates, there is always the possibility for unmodeled data error or external factors that could bias the results. Since we cross-checked the analysis using multiple data sources and different estimating equations, the likelihood of these problems has been reduced. The robustness of the vertical integration results across analyses gives us fairly strong confidence in these results, although the diversification results are potentially more suspect. It may be that the effect of IT on internal coordination is

weaker, that measurement error is influencing the results, or that the coordination cost framework needs to be extended to consider other factors.

6.3 Long Term Implications

Overall, the analysis suggests that as computing becomes more prevalent in organizations, firms are increasingly adopting coordination intensive structures. The key technological factor that is driving this trend, the decline in computing costs, is likely to continue at least for the next ten years, and may even accelerate as internet and intranet technology enables greater level of inter- and intra-organizational coordination. While this should continue to lead to further levels of outsourcing and potentially the rise of a large number of specialist suppliers or even network corporations, the part of this transition related to coordination may have limits. As coordination becomes essentially "free", it will become a less important factor in determining firm boundaries (assuming that there are decreasing returns to increasing investment in coordination). Other aspects of computer enabled transformation of organizations, such as the rise of knowledge as a key corporate asset and the demands of organizing and providing incentives to knowledge workers, will become increasingly important determinants of firm boundaries.

Table 1: Sample Characteristics

Measure	Mean	Standard Deviation	Median	Minimum	Maximum
Diversification: 4-Digit SICs	14.6	11.0	11	3	100
Diversification: Herfindahl	0.608	0.239	0.333	0.0327	1.00
Diversification: Concentric	0.978	0.477	1.03	0.000330	1.85
Vertical Industry Connection	0.180	0.234	0.0657	0	0.973
IT Cost Share	0.717%	0.795%	0.447%	0.0068%	9.29%

All measures computed from CI data (N=4155).

Table 2a. Relationship between vertical integration and IT cost share (2SLS Estimates)

	Vertical Integration	Vertical Integration
IT Cost Share	-0.742***	
	(0.0569)	
Industry IT	0.101***	-.143**
	(0.0249)	(0.0142)
Sites	.387***	.381***
	(0.0166)	(0.0142)
R^{2*}	20.9%	16.3%

* - R^2 expressed in terms of original variables (not after first stage projection) to be comparable across columns
N=4155; (Key: *** - p<.001, ** - p<.01, * - p<.05); Standard errors in parenthesis

Table 2b. Relationship between diversification and IT cost share (2SLS Estimates)

	Diversification as 4-digit SIC Count	Diversification as Herfindahl	Diversification as Concentric
IT Cost Share	0.448***	0.0941	0.235***
	(0.0484)	(0.0533)	(.0548)
Industry IT	-0.0382	0.0412	-0.0529*
	(0.0202)	(0.234)	(0.0241)
Sites	0.546***	0.125***	0.0843***
	(0.0141)	(0.0156)	(0.0160)
R^2	28.9%	2.1%	1.2%

N=4155; (Key: *** - p<.001, ** - p<.01, * - p<.05); Standard errors in parenthesis

Table 2c. IT demand equation (2SLS Estimates)

	IT Cost Share	IT Cost Share	IT Cost Share
Diversification as 4-digit SIC Count	0.0872*** (0.0242)		
Diversification as Herfindahl		0.0359 (0.0296)	
Diversification as Concentric			0.0904*** (0.0266)
Vertical Integration	-0.218*** (0.0191)	-0.231*** (0.0192)	-0.242*** (0.0195)
Industry IT	0.281*** (0.0151)	0.287*** (0.0152)	0.284*** (0.0151)
Sites	0.0979*** (0.0222)	0.0139*** (0.0186)	0.141*** (0.0184)
log(IT Price)	-0.0173 (0.0213)	-0.0119 (0.0214)	-0.00887 (0.0215)
log(Labor Price)	0.0292 (0.0150)	0.0325* (0.0152)	0.0398*** (0.0154)
log(Capital Price)	-0.0784*** (0.0213)	-0.0752*** (0.0214)	-0.0734*** (0.0214)
log(Value-Added)	-0.0761*** (0.0173)	-0.0609*** (0.0171)	-0.0627***
R^2	14.5%	14.2%	14.3%

N=4155; (Key: *** - p<.001, ** - p<.01, * - p<.05); Standard errors in parenthesis

Table 3a: First Difference Analysis: IT effects on firm structure (2SLS Estimates)

	ΔVertical Integration	ΔDivers. as 4-digit SIC Count	ΔDivers. as Herfindahl	ΔDivers. as 4-Concentric
ΔIT Capital	-0.148*** (0.0274)	0.0163 (0.0260)	0.0934*** (0.0285)	0.0469*** (0.0287)
ΔIndustry IT	-0.0794*** (0.0159)	0.0975*** (0.0151)	0.0235*** (0.0166)	-0.0421* (0.0167)
ΔSites	0.314*** (0.0171)	0.412*** (0.0151)	0.0967*** (0.0178)	0.0626*** (0.0179)
R^2	9.4%	18.2%	1.7%	0.8%

N=3564; (Key: *** - p<.001, ** - p<.01, * - p<.05); Standard errors in parenthesis

Table 3b: First Difference Analysis: IT Demand (2SLS Estimates)

	Change in IT	Change in IT	Change in IT
Diversification as 4-digit SIC Count	-0.0441 (0.0750)		
Diversification as Herfindahl		-0.0434 (0.0770)	
Diversification as Concentric			0.0917 (0.0814)
Vertical Integration	-0.276*** (0.0659)	-0.246*** (0.0513)	-0.264*** (0.0527)
Industry IT	0.0674*** (0.0134)	0.0667*** (0.0131)	0.0659*** (0.0128)
Sites	0.128*** (0.0430)	0.108*** (0.0198)	0.0106*** (0.0197)
Other Variables	K, L, IT Price Change, Change in Output	K, L, IT Price Change, Change in Output	K, L, IT Price Change, Change in Output
R^2	14.5%	55.3%	55.1%

N=3564; (Key: *** - p<.001, ** - p<.01, * - p<.05); Standard errors in parenthesis

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Appendix B: Variable Construction (not otherwise described in the text)

Ordinary Capital. This figure was computed from total book value of capital (equipment, structures and all other capital) following the method in Hall (1990). Gross book value of capital stock [Compustat Item #7 - Property, Plant and Equipment (Total - Gross)] 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 item #8 - Property, Plant & Equipment (Total - Net)] to current depreciation [Compustat item #14 - Depreciation and Amortization]. The calculation of average age differs slightly from the method in Hall (1990), who made a further adjustment for current depreciation. The constant dollar value of computer capital was subtracted from this result. Thus, the sum of ordinary capital and computer capital equals total capital stock.

Computer Capital (CI). Total market value of all equipment tracked by CI for the firm at all sites. Market valuation is performed by a proprietary algorithm developed by CI that takes into account current true rental prices and machine configurations in determining an estimate.

This total is deflated by the deflator for computer systems of -19.4% per year developed by Robert Gordon (1990). The time trend Gordon found in prices through 1984 is assumed to continue through 1994.

Labor Expense. Labor expense was either taken directly from Compustat (Item #42 - Labor and related expenses) or calculated as a sector average labor cost per employee multiplied by total employees (Compustat Item #29 - Employees), and deflated by the price index for Total Compensation (Council of Economic Advisors, 1992).

The average sector labor cost is computed using annual sector-level wage data (salary plus benefits) from the BLS from 1987 to 1994. We assume a 2040-hour work year to arrive at an annual salary. For comparability, if the labor figure on Compustat is reported as being without benefits (Labor expense footnote), we multiply actual labor costs by the ratio of total compensation to salary.

Rental Prices. Rental prices for ordinary capital inputs were computed using the Jorgensonian cost of capital formula, assuming an annual real rate of return of 9%, 4% expected inflation, and depreciation rates provided by the BLS for 2-digit industries over time. For computers, we use the same required rate of return but assume a 10% depreciation rate and a -20% capital gains term, reflecting the regularity in price declines of computers (Moore's law).   After accounting for taxes, this results in a constant annual rental price of 42% for computers and an average rental price of 13.5% for ordinary capital. See Christensen and Jorgensen (1969) for the general theory of rental prices, and Jorgenson and Stiroh (1995) for typical estimates of the parameters not described above. The price for current capital is the economy-level deflator for fixed investment.

Labor Price. The price of labor is defined as total labor expense divided by total

employment adjusted by the price index for Total Compensation by the BLS. This variable varies by firm.

Computer Price. The aggregate computer deflator provided by the BEA is used for the computer price.

Diversification Measures.

Definitions. The SIC count measure is simply the count of different 4-digit SIC codes that the firm participates in. The Concentric Index is defined as follows:

$$Concentric = \sum_{i=1}^{N} \sum_{j=1}^{N} \alpha_i \alpha_j W_{ij}$$

where: $i,j = 1... N$ where N is the number of 4-digit industries a firm participates in
          α_i is the share of industry i in the firms' total employment
          W_{ij} is a weighting function:
                     0 if the industries share the same 3-digit SICs
                     1 if the industries have different 3-digit SICs but the same 2-digit SIC
                     2 if the industries have different 2-digit SICs

Using the same notation the Herfindahl index is defined as follows.

$$Herfindahl = 1 - \sum_{i=1}^{N} \alpha_i^2$$

Validation. To examine the properties of these indices, we calculate the correlation between data sources for these measures. For 1987 we have a dataset from Trinet Corporation that tabulates percentage of the firm in each industry (an earlier year of these data were used by Wernerfelt and Montgomery, 1988). The second source is Compustat which has two measures. The first are segments data, which includes information (SIC code, and sometimes sales and assets) on up to 10 business segments of a firm. In table C1 we report correlations between diversification measures computed from each source.
Table C1: Correlations between CI measures and other sources

Comparison	Concentric	Herfindahl	# 4-digit SICs
Trinet vs. CI (1987)	.61	.59	.85
Segments vs. CI (1988-94)	.47	.51	.53
Compustat - CI (1994)	x	x	.71

Altogether, this suggests that the SIC count measures are fairly consistent across data sets, except for segments which are limited to 10 different SICs. The Concentric and Herfindahl are also directionally consistent although this calculation suggests that the employment share data have some substantial component of random error. However, it should be noted that Trinet excludes most locations that are outside of SIC 20 to SIC 50, so it can only be an incomplete characterization of firms. This may account for some of the variance. Similarly, the employment share data for Compustat Segments data are highly incomplete, also potentially contributing to a reduced correlation.