Markets, Hierarchies and the Impact of Information Technology

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Abstract

The adoption of information technology (IT) significantly affects the costs of different modes of economic organization. As the stock of IT capital grows, therefore, one might expect shifts in the balance between two principal modes of organization: markets and hierarchies. However, despite numerous conceptual and case studies, relatively little empirical work has been done to date on the overall impact of IT on organization structure. In this paper, we discuss the theoretical impact of IT on markets and hierarchies and then perform a series of econometric tests of the hypothesis that IT will lead to a relative shift away from hierarchies towards market coordination.

In our analysis of panel data from the major industry groups in the United States between 1975 and 1985, we find clear empirical support for the above hypothesis: regressions on employment categories and firm size both indicate a significant reduction in the proportion of hierarchical coordination relative to market coordination correlated with IT investments. More detailed analysis of employment categories data reveals that increases in the stock of IT capital in an industry are correlated with decreases in the number of managers employed. This result is consistent with many previous predictions about IT reducing managerial levels. Unlike previous predictions, however, but consistent with our hypothesis, the number of salesworkers in the industry increases as much as the managers decrease. As a secondary finding of the paper, we are also able to identify and quantify a significant learning curve in the impact of IT which can lead to delays of up to five years before the effects are fully felt.

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I. Introduction

The impact of information technology on organizational structure has long been a central concern of the field of Information Systems. For instance, a number of theorists have argued that the radical reductions in the costs of information processing made possible by IT will result in commensurate changes in the types of organizations that govern economic activity. We are increasingly in a position to measure econometrically the validity of these theories. Although IT capital stock is still less than seven percent of total capital stock,[1] the organizational structures which are optimal today are likely to be somewhat different from the organizational structures which were optimal ten years ago. Furthermore, if the use of information technology continues to grow at anything near its past growth rate[2], any changes we detect in today's economy are likely to foreshadow even more dramatic changes in the next ten years.

In this paper, we build on earlier theoretical work by Malone and colleagues, (Malone, 1987; Malone, Yates and Benjamin, 1987; Malone & Smith, 1988) which explored the impact of cheaper information processing on two organizational structures: markets and hierarchies. We build on the connection of their work to the transaction cost theories of organizational structure developed by Williamson (1975, 1981, 1985) and find further theoretical support for the hypothesis that while both markets and hierarchies may be made more efficient by IT, we should expect a proportionately greater shift towards markets. The theory leads us to develop a series of testable hypotheses. In a series of regression models, we find substantial empirical support for the hypothesis that the growth in the use of IT in an industry is associated with increasing use of markets to coordinate economic activity in that industry.

To understand the impact of IT on markets and hierarchies, we must first understand the relative advantages of each mode of organization. This is discussed in Section II. In Section III, the impact of information technology is modeled as a means of lowering coordination costs with the result of reducing reliance on hierarchies. Broad trends in the economy which support this model are identified and referenced in Section IV. The statistical analysis is presented in Sections V and VI. Section V examines the impact of IT on employment categories and Section VI analyzes trends in firm size. In section VII, we present our concluding remarks. Several extensions to the models are examined in Appendix I.

II. Markets and Hierarchies: A Transaction Cost Approach

Markets and hierarchies can be viewed as two alternative governance structures for coordinating economic activity. In a market, agents interact through a decentralized price system to allocate resources and products. Hierarchies rely on a "visible hand" which explicitly directs the resources within the hierarchy's span of control. In the US economy, we see elements of both systems; indeed, every time a firm is faced with a make-or-buy decision, it must evaluate where to draw the line between its internal hierarchy and the market. For instance, if IBM decides to make their own disk drives for a new computer, they are using a hierachy to coordinate the production of the disk drives. If, on the other hand, they decide to purchase the disk drives on the open market, they are using market transactions to determine factors such as price, quality and delivery date.[3] Of course, other mechanisms for coordinating activities such as long-term contracts, franchising, value-adding partnerships, and emerging "ad-hocracies" also play a role, but they can often be thought of as having properties intermediate to markets and hierarchies.

Each mode of transacting has efficiency advantages relative to the other which makes it appropriate in certain circumstances. Among the most visible contributors to the "transaction cost" approach to analyzing these trade-offs are Williamson (1975,1981) and his students, who have built upon foundations laid by Coase (1937), Simon (1965) and Arrow (1974) among others. In a recent empirical study of the determinants of vertical integration, Caves and Bradburd (1988) found "considerable explanatory power to models which emphasize contractual and transaction cost factors."

Following Williamson, we will assume that an important criterion for organizing commercial transactions is cost economizing. As he put it, "essentially this takes two parts: economizing on production costs and economizing on transaction costs" (1981). Market transactions have a number of recognized *production cost* advantages relative to hierarchical transactions (Williamson, 1981). First, a firm may not by itself generate sufficient demand to exhaust all economies of scale in the production of a good. By combining its needs with other firms in a market, these economies can be more fully exploited. Second, by aggregating uncorrelated demands, the market can also realize risk pooling and load leveling benefits. Third, markets may enjoy economies of scope in supplying a set of related activities of which the firm's needs are only one. More generally, specialization, heterogeneous inputs, or other factors may lead to a distribution of production costs for a given good across firms. Absent transaction costs, a firm will then find it efficient to produce the good in-house, (as in a hierarchy) only if its own production costs happen to be the lowest of all potential producers of that good. In general, the production cost in the market will be less than or equal to the production costs of a hierarchy.

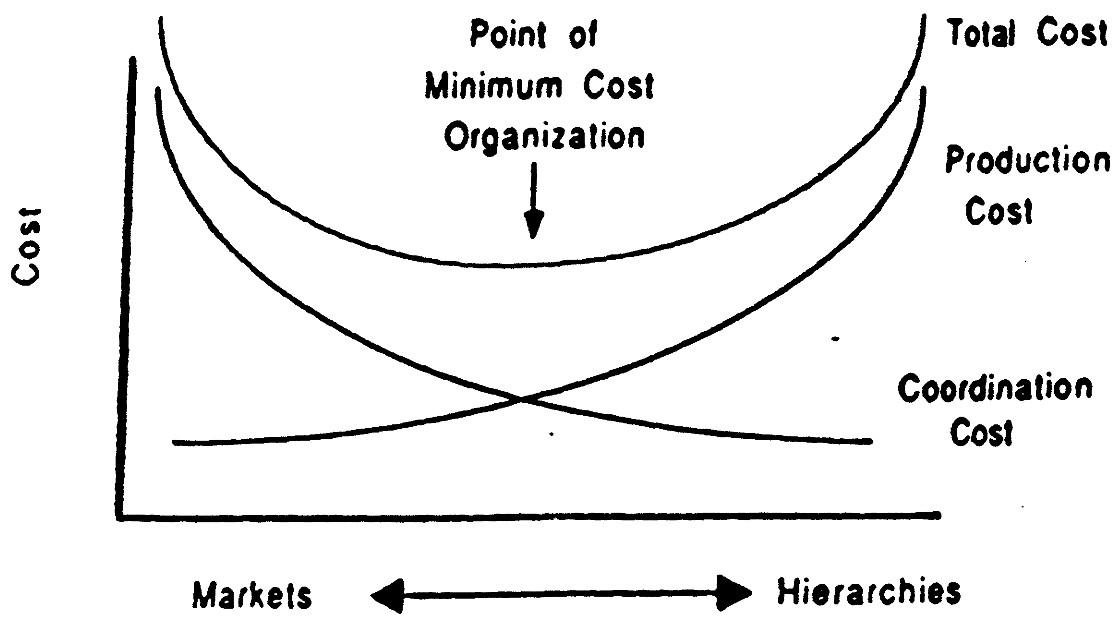
However, these potential production cost savings can be reaped only at the expense of additional coordination costs. Clearly, some search is required to locate a suitable supplier and then additional costs may be incurred in specifying a mutually agreeable contract covering all contingencies, monitoring compliance with the contract and enforcing its terms. In a formal model, Malone (1987) and Malone and Smith (1988) show that the additional contacts required by the market system lead to higher coordination costs than in hierarchies. This is true as long as each buyer contacts at least two potential suppliers in equilibrium and assumes that individual coordination and communication links in the market are comparable in cost to links within a hierarchy.

This result is strengthened when one considers that the transaction cost of individual links may in fact be significantly higher in markets than in hierarchies. Williamson builds a substantial case for large transaction costs in certain markets. He argues that bounded rationality, small numbers bargaining and opportunism, impacted information and atmosphere each contribute to make market contracting expensive.[4] These costs are particularly exacerbated in transactions which involve high asset specificity leading Williamson (1981) and Klein, Crawford and Alchian (1978) to single out this characteristic as being a key determinant of organizational structure. As Williamson put it "*the normal presumption that recurring transactions for technologically separable goods and services will be efficiently mediated by autonomous market contracting is progressively weakened as asset specificity increases*" (his italics).(Williamson, 1981)

A common criticism of Williamson is that while he demonstrates how transactions in markets might be very costly leading to "market failure", his analysis is weaker in showing why hierarchies should be any less costly. This shortcoming has been substantially alleviated by Grossman, Hart and Moore (Grossman and Hart, 1986; Hart and Moore, 1988). The essence of their analysis is to show that by covering only a few (or no) contingencies in an explicit contract and conferring all remaining or "residual rights" to one or the other parties, many of the costs of market transactions are avoided. They argue that the authority of these "residual rights" are what we call ownership and are typical of the authority of a hierarchy within a firm. Kreps (1984) makes an analogous, though less formal argument showing how a firm can use reputation and "corporate culture" to internalize transactions and overcome market failure.

In summary, markets can be expected to generally have higher coordination costs than hierarchies while the production costs of markets are typically lower than in hierarchies (figure 1). It follows from this that coordination costs are a proportionately larger share of total costs in markets than in hierarchies. This accords with models which describe hierarchies as a mechanism for economizing on information processing costs (Galbraith, 1977; Cyert and March, 1963; Williamson, 1981). A key determinant of the boundaries between firms and markets (and implicitly the size of firms) then is relative total costs of transacting internally versus through the market.

FIGURE 1

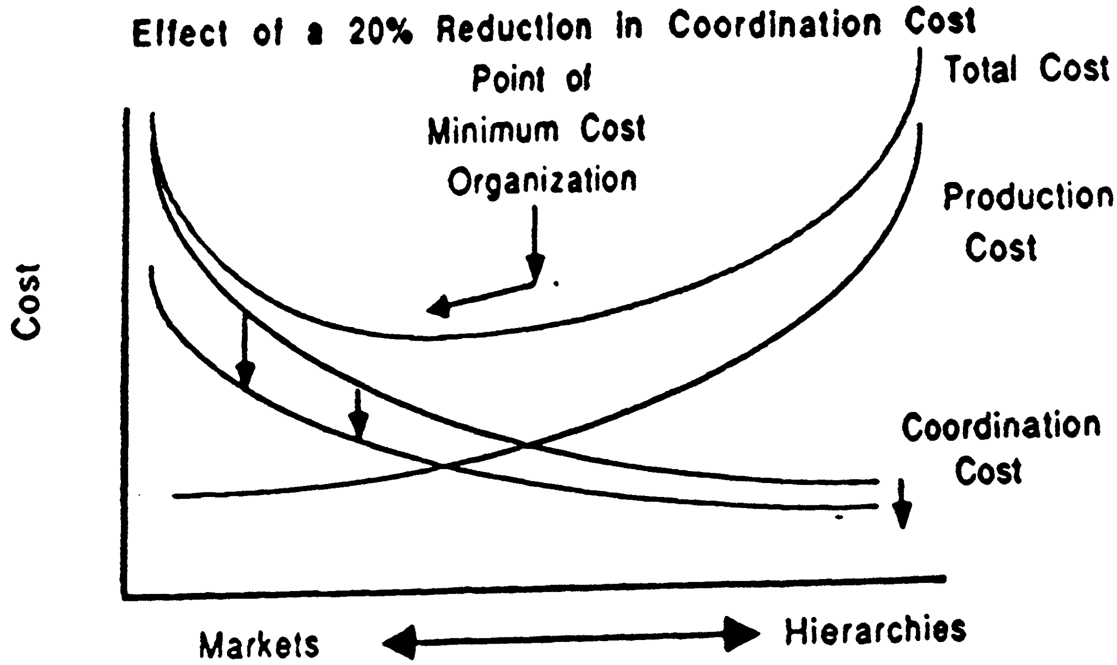


III. The Impact of Information Technology: Theory

What effect, if any, should information technology have on these structures?

Organizations do not typically invest in IT explicitly to move from hierarchical coordination to market coordination. More often, the organizational imperative is to reduce costs, improve quality or otherwise boost profitability.[5] The impact of IT on the relative desirability of markets and hierarchies should therefore be a function of how it affects their relative costs. Clearly, at a very general level, more and cheaper IT seems likely to decrease the costs of coordination, because the essence of coordination is communication and information processing. In particular, IT can be expected to reduce such costs as selecting suppliers, establishing contracts, billing customers, paying

FIGURE 2



creditors and tracking financial flows. This accords with the typical uses of IT such as telecommunications, computing, and transaction processing.

Because coordination is a greater share of costs in markets, Malone, Yates and Benjamin (1987) have argued that a reduction in coordination costs will favor markets over hierarchies to the extent that markets depend more on coordination.[6] Graphically, we can see that if coordination costs drop by the same percentage for both forms of organization, the minimum cost structure moves towards markets (figure 2).

Of course, if the cost reductions engendered by IT were sufficiently biased towards those types of coordination required predominantly within hierarchies, the opposite effect might be seen. Similarly, to the extent that IT lowers production costs more than coordination costs, the result might be a shift towards hierarchies. Consider that desktop publishing on personal computers has so lowered the costs of typesetting that currently such work is often done in-house. The costs savings from finding a cheap outside source no longer justify the search and transaction costs. In this case, the effect is no different from that of any other technology that lowers production costs. Malone and Smith (1988) speculate that the historical growth of hierarchies until the 1960s may in fact partly result from the greater strides in reducing production costs versus coordination costs during this period. In this paper, we focus on IT as a method of lowering *coordination* costs because this seems to be a more typical use of the technology, and because IT can be used to lower coordination costs in almost all industries, whereas its effects on production costs are very industry specific. It is interesting that this characteristic of IT as a *coordination technology* sets it apart from most earlier technologies which were used primarily for production.

Whether or not IT lowers the coordination costs of markets sufficiently to increase their use relative to hierarchies is, of course, precisely the sort of empirically testable hypothesis we analyze later in the paper.

However, there is strong suggestive evidence that many of the specific causes of market failure identified by Williamson can be mitigated by IT. Meanwhile the importance of residual rights may actually be reduced by IT and with them the benefits of hierarchies. Consider Williamson's framework of asset specificity, small numbers bargaining, bounded rationality, information impactedness and atmosphere, and the Grossman-Hart-Moore analysis of residual rights.

First, IT can be an important technology for reducing physical asset specificity. The essence of a computer, what Turing called the "universal machine", is its programmability. Malone, Benjamin and Yates (1987) pointed out that IT has enabled the shift towards more flexible manufacturing technologies, making it easier for buyers to switch to new suppliers without excessive set-up costs. Piore and Sabel (1984) have argued that this change in technology has been the key to enabling the transition from an economy based on mass production to one of "flexible specialization".

Second, electronic markets and advances in telecommunications technology are transforming local markets into national and even global markets by reducing the search and transaction costs caused by distance. This reduction in the importance of site specificity tends to amplify the reduction of asset specificity discussed above, resulting in less need for the protective device of vertical integration. Because firms are no longer as locked in by geography or idiosyncratic capital to local suppliers or buyers, IT weakens the likelihood of small numbers bargaining and its attendant opportunism.

Third, to the extent that IT acts as an "intelligence amplifier" to decision-makers, the bounds of rationality are pushed back – ever more complex or uncertain market situations can be analyzed without resorting to the simplifying device of hierarchies. For example, the burgeoning use of decision support systems such as spreadsheets and other modelling tools has enabled individuals to analyze more scenarios and account for a larger set of contingencies. This has increased the scope of contractible transactions, reducing the need for hierarchies. It seems likely that more sophisticated decision aids will further enhance this effect.

Of course, hierarchies may benefit from the increased processing power as well. A new, more complex class of projects or strategies might now be undertaken when IT is combined with the information-economizing properties of hierarchies. If the marginal benefit of additional complexity is increasing then this effect could even dominate the growth of market-mediated transactions.[7] Thus the ultimate effect may be somewhat ambiguous if we allow for projects of increasingly complex nature.

Fourth, to the extent that IT facilitates the free flow of information and reduces its cost, it leads to a concomitant reduction in information impactedness. This can take the form of having Dun and Bradstreet credit ratings available on-line, having access to nationwide pricing data, or simply having more inexpensive means of communicating directly with other firms, by telephone or electronic mail. More generally, IT can transform many intangible knowledge products into tangible goods, making them easier to buy and sell on the market. The most dramatic examples of this are expert systems software which can capture a portion of the knowledge of an expert, thereby simplifying its reproduction, distribution, pricing and sale through arm's length markets. Most software contains at least some embedded know-how which would otherwise be difficult to quantify, much less price for the market.

Fifth, in terms of atmosphere it is not clear that IT will have much of an effect either way on any perceived benefits of hierarchies over markets. When IT is used to monitor workers it may make hierarchies more "calculative", like markets. But IT can also be used to enrich or to eliminate some of the routine tasks that have been necessary to the running of large companies. Cases of both types of consequences of IT have been documented (Zuboff (1988)). To the extent that IT automates the mechanics of markets, as with NASDAQ or the emerging genre of "negotiation software", one can argue that it reduces the need for unpleasantness of explicit haggling between the human parties, thus making markets more attractive.

Finally, the Grossman-Hart-Moore argument for hierarchies to capture the benefits of "residual rights" may be reduced to the extent that IT enables better forecasting reducing the likelihood of unforeseen contingencies while at the same time facilitating the writing of more complete contracts ex ante through improved document storage and manipulation.

These arguments are summarized in table 1.

Table 1. Impact of IT on the Relative Efficiency of Markets and Hierarchies.

Source of Potential Market Failure	Impact of IT
Asset specificity	Facilitates Markets
Site Specificity	Facilitates Markets
Bounded Rationality	Uncertain
Information Impactedness	Facilitates Markets
Atmosphere	Uncertain
Difficult to Assign Residual Rights	Facilitates Markets

IV. The Impact of Information Technology: Empirical Measures

The impacts of IT would be hard to detect if its use did not change over time but IT use is unquestionably soaring. We found that IT capital stock as a share of overall capital equipment stock grew fivefold between 1970 and 1985 in the United States[8] (figure 3). The computing power available per dollar has also grown by 20% to 30% per year, driven by successive miniaturization of the components (Cohen (1987), Gurbaxani (1987), Mendelson (1989)). While computing advances have received the most prominent attention, other technologies for handling information, from facsimile machines, to photocopiers to telecommunications have also experienced dramatic growth.[9] The net result of all this should be a substantial reduction in the costs of handling the information needed for coordination.

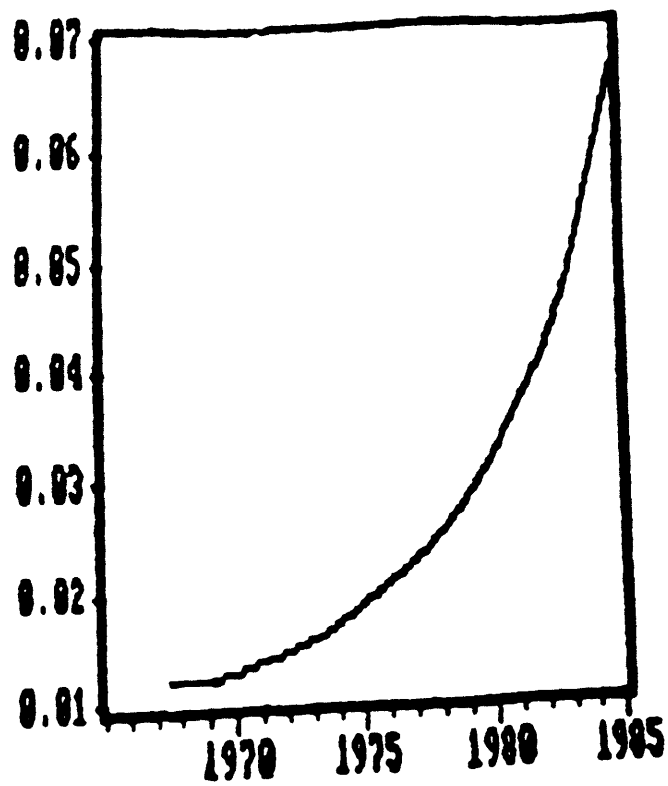


Figure 3. IT Capital Equipment Stock as a Share of Total Capital Equipment Stock in the United States, 1968- 1985.

Graph based on data from the Bureau of Economic analysis for investment in information technology equipment, investment in total equipment, and average useful life of each type of equipment.

Meanwhile, the proportion of the workforce engaged in information-handling and coordinating activities has also grown steadily. A widely quoted study shows the share of such workers increased to 50% of the workforce by the late 1970s (Porat (1977)). This employment trend should enhance the importance of any changes in IT.

Given these changes in IT and after adjusting for other factors, the argument presented above predicts an increase in the relative share of market based transactions. How can we detect such a shift?

Measures of Shift from Hierarchies to Markets

There are a number of ways of measuring the extent to which economic activity is organized via markets or through hierarchies. First, fairly detailed data exists on employment occupations by industry. Ceteris paribus, a shift from hierarchies to markets should be accompanied by a shift in employment from managers, who handle coordination in hierarchies, to salesworkers and purchasing agents, who handle coordination in markets, and also by increased use of temporary workers, consultants and contractors, whose employment is coordinated by markets. Second, we would expect average firm size to decrease as smaller firms supplant large, integrated firms. Third, direct measures of vertical integration, such as value added per dollar sales, should decrease as firms conduct more intermediate transactions through the market. Finally, more subtle changes like increased use of "intrapreneurs" within firms, faster product cycles, and generally more flexible links both within and between firms should be seen with the decline of hierarchical organization.

As the following subsections show, there is already suggestive evidence that our economy is undergoing all of these changes.

Decreasing Numbers of Managers

The thinning ranks of middle management has been widely discussed in the context of international competitiveness (especially vis-a-vis Japan), as a result of corporate takeovers and streamlining, (Drucker (1988)). Since Leavitt and Whisler's seminal article (1958), a number of papers have specifically related this phenomenon to the introduction of IT . A recent study found that firms had pared down middle management by one third, (Pilla et al. (1984)) while another study by found that a new IT system had eliminated the need for 1000 of the 2000 "controllers" at the regional level (Dawson and McLaughlin (1984)). However, more typical is not the elimination of jobs but changes in their content. Talbott et al. (1987), found that the most significant change in the distribution of managers' activities following the introduction of IT was a 30% drop in the amount of time spent "coordinating". Crowston, Malone and Lin (1987) found that computer conferencing led to a drop in the number of middle managers followed by an equivalent increase in the number of staff "specialists" at the same pay level.

Decreasing Firm Size

Piore (1986) noted that data from County Business Patterns showed that the average establishment size was increasing through the 1960s and then began decreasing in the 1970s. Birch (1979) found that in the period 1969 to 1976, establishments of under 20 employees created 66% of all new jobs and those with less than 100 employees created 88%.[10] Talk of the growth of big business notwithstanding, the trend to smaller firms continues in the 1980s, with firms of under 100 employees generating over six million new jobs in the period 1980 to 1986, while firms of over 1000 lost about 1.5 million jobs.[11] Nor is the trend unique to the United States. Data from the UK, the Netherlands and Germany all show the same dramatic reversal in the growth of average firm size (Huppes (1987).

Decreasing Vertical Integration

Direct measures of vertical integration, such as value-added per dollar sales, are harder to interpret because they are significantly affected by the changes in profitability associated with business cycles and tax code changes, and because forward and backward integration are treated asymmetrically. Tucker and Wilder (1977) found that vertical integration showed a slight reversal between 1953 and 1973, rising at first and then beginning to drop. Other analyses show integration increasing throughout the period. Johnston and Lawrence (1988), identify a trend toward numerous "value-added partnerships" of separate firms functioning in the role of large, vertically integrated companies and they argue that this shift is facilitated by low cost computing and communication.

More Market-like Activity Inside Firms

Finally, there is evidence that *within* firms, coordination is becoming less hierarchical and more market-like. Several studies have documented the increasing reliance on "intrapreneurialism" to break-down rigidities within firms and reap some of the benefits of a market. (Alsop (1988), Economist (1982), Businessweek (1983)).

Furthermore, the number of outside consultants and contractors used by firms increased by 45% between 1980 and 1986 (Wall Street Journal (1988)). Temporary employees were up 75% and part-time workers were up 20%, all evidence of a reduced reliance on long-term hierarchical employment relations. Bussey and Sease (1988) also identified a relationship between increased IT usage and more reliance on outside suppliers in an article on the quickening of product cycles.

VI. Regressions on Employment Categories

We have seen that there is both a theoretical basis and diverse supporting evidence for the hypothesis that the increased use of IT leads to a shift from hierarchical modes of coordination to market-based methods. In a complex economy, a broad causal relationship such as this cannot always be cleanly tested but we have been able to examine some empirical implications of the theory in a rigorous manner.

Of the four measures of the balance between markets and hierarchies discussed above, this paper specifically examines the relationships of the the first two, employment categories and firm size, to changes in IT capital. The third measure, vertical integration, requires a different data set and is being carried out in a separate study at MIT (Kambil, 1988).

The first implication that we considered is of a change in the labor force correlated with increased investments in IT. If the use of information technology causes or facilitates a move from hierarchies to markets, then, ceteris paribus, we would expect to see *a positive relationship between IT stock and the relative proportion of market-oriented coordinators such as salesworkers, as opposed to hierarchical coordinators such as managers*. In an earlier study using detailed occupational data from the census bureau, Jonscher (1987) found some evidence that the proportions of various "coordination" occupations was changing in favor of more use of markets and he suggested that this change was related to the growth of IT. Unfortunately, the census data is only available at ten year intervals, making time-series or panel-data analysis difficult.

Instead, we have studied annual data from the Bureau of Labor Statistics[12] which provide the annual number of people employed in each of several dozen occupational categories for the eight industry groups analyzed. (See table 2.) To measure the relative share of market coordinators, we constructed the dependent variable R as the ratio of salesworkers to managers.

The key explanatory variables were obtained from the Bureau of Economic Analysis and included the log of IT capital stock in constant dollars (*ITStock*) and the log of IT investments in constant dollars (*ITInvest*), again by industry on an annual basis (see table 3).

Because the types of coordination activity might vary systematically with industry size, we also included the log of total constant-dollar capital stock by industry (*TotStock*) and to account for varying scale economies, its square (*TotStock2*). The basic approach we used was of applying least squares regression to panel data with fixed effects between periods and between industries. Accordingly, we also included ten time dummy variables and seven industry dummies in the regression.

Model 1: The Unlagged Regression

Our first model included no lags in the impact of IT:

$$R = \beta_0 + \beta_1(\text{ITStock}) + \beta_2(\text{TotStock}) + \beta_3(\text{TotStock}^2) + \Sigma\beta_{i=4..21}\{\text{17 industry and year dummies}\} + e$$

In this simplest formulation of the hypothesis, we made the somewhat unrealistic assumption of no adjustment delay, that is, that firms immediately optimize to fully exploit the new IT investments and job titles adjust instantaneously to reflect new duties. Nonetheless, the results of this simple model were consistent with our hypothesis (table 4).

The sign on *ITStock* is positive as predicted by the theory, and with a Student's t-statistic of 1.83 it is significant at the 95% level. Its magnitude of 0.87 is large enough to indicate that changes in an industry's stock of IT can be important determinants of the ratio of salesworkers to managers in that industry: a one percent increase in IT stock is correlated with an almost one percent increase in the amount of market coordination in the period studied.

The sign on *TotStock* is positive and significant, indicating that salesworkers are added faster than managers for small levels of capital stock in an industry; the sign on its square is negative, however, indicating that for larger industries, hierarchical coordination begins to dominate. This is consistent with Stigler's lifecycle hypothesis on industry growth and integration enabled by scale economies (Stigler, 1962).

The interpretation of the industry dummies is complicated by the fact that the definitions of "salesworker" and especially "manager" can vary across industries. However, two predictions of Williamson's theory receive some support. Industries with significant transaction specific capital should tend to rely less on markets and indeed the transport and utilities category, with enormous transaction-specific investments has the lowest residual ratio of salesworkers by far. Secondly, firms which deal in intangibles often have difficulty using markets efficiently because of considerations of impacted information. The finance industry falls into this category and has the second lowest ratio of salesworkers. Not surprisingly, the agriculture industry, with its relatively homogeneous products, and the trade industry, which includes all retail establishments, score highest in amount of market coordination.

After controlling for IT stock, total capital stock and industry, a weak trend is apparent in the time dummies running counter to the trend in the raw data. The ratio of salesworkers to mangers is falling from 1976 to 1985 when the other variables are included. The time trend may indicate a missing variable which represents a factor in the economy towards more use of hierarchical coordination. One reasonable candidate for this missing factor is the degree to which the economy is increasingly based on knowledge and other intangibles which are difficult to contract upon in a traditional market because of information impactedness; the seller may not be able to describe what he is selling without in effect giving it away. Alternatively, this effect would be seen if increasing numbers of "knowledge" workers were simply labelled managers, even if they were not directly engaged in coordination. This is especially common in the increasing numbers of smaller organizations in which "managers" may even spend a substantial amount of time selling to individuals outside the firm. The "knowledge economy" hypothesis is explored in appendix I.

The resulting adjusted R-squared (0.63) and F-statistic (8.43) of the basic regression are well within the acceptable range for this type of regression.

Model 2: Effect of IT Stock after Three Years

With a rapidly changing technology like IT, it would be somewhat naive to assume that the effect would happen all at once. To account for adjustment costs which result in delays in learning to optimally apply the new technology, in reassigning workers and in reclassifying employment categories reported to the Bureau of Labor Statistics, we extended the model by allowing for a lag in the impact of IT stock. As the lag is increased, the impact of IT on the dependent variable also increased, peaking after 3 to 5 years. Model 2 presents the regression with IT lagged 3 years. With the addition of the lag, the magnitude (1.16) and significance (t-statistic of 2.11) of the coefficient on IT both increased. Most of the other results were qualitatively the same.

Model 3: An Adjustment Model

Clearly, one would expect that the changes in IT stock less than three years back should also affect R. Including all the lagged stock variables together would lead to multicollinearity given IT capital's average life of eight years. One solution is to include only the current year's IT *stock* variable and the IT *investments* for the previous years. The hypothesis holds that the sign on *ITStock* would be strongly positive as it embodies all of the useful capital stock that was purchased in previous years. However, because capital which was purchased more recently has not yet had as much of a chance to have an impact on employment, the expectation is that we would subtract some portion of more recent years' investments. In this way, the "net" effect of more recent years would be smaller and only gradually increase to the full effect after several years. Model 3 follows this approach.

The results of this model are consistent with our expectations: the coefficient on *ITStock* increases to 8.86 while the coefficients on the IT investment taper off from 1.45 to 0.597 when lagged from zero to five years. The other coefficients are qualitatively unchanged and the adjusted R-squared rises to 0.645.

Model 4: Fitting a "Learning Curve" to Adjustments to IT

The final model tested on R imposed more structure on the nature of the distributed lags. Inspection of the coefficients on *ITInvest* in model 3 suggested that an exponential decay in the amount of adjustment might best capture the effect seen in the data.[13] Accordingly, model 4, a non-linear least squares regression, was tested in which the coefficient on each lagged investment was restricted to be a constant times the previous years lag. The economic intuition is one of partial adjustment equilibrium: only a portion of the labor force turns over or can be retrained each year, so only a comparable portion can adjust to fully exploiting new technologies each year. In following years, a similar fraction of the remainder adjusts and so on (Kmenta(1986)). Exponential lags are also a natural way to model an organizational learning curve. This is plausible with IT because of the rapid pace of product innovation, necessitating significant learning-by-doing to implement efficient applications of the current technology (Gurbaxani (1987)).

The resulting NLS model is:

$$R = \beta_0 + \beta_1(ITStock) + \beta_2[ITInvest + \lambda(ITInvest(-1)) + \lambda^2(ITInvest(-2)) + \lambda^3(ITInvest(-3)) + \lambda^4(ITInvest(-4)) + \lambda^5(ITInvest(-5)) + \beta_3(TotStock) + \beta_4(TotStock2) + \Sigma\beta_{i=5...22}\{17 \text{ dummies}\} + e$$

We predict that the following inequalities would hold:

$$0 < \lambda < 1,$$
$$\beta_1 > 0,$$
$$\beta_2 < 0.$$

The coefficient λ can be thought of as representing the share of the labor force which does not fully adjust to added IT stock within one year. In model 3 this was unrestricted. We are now restricting it to be constant across time.

With this formulation, the results confirm our interpretation of the unrestricted regression. The coefficient on λ is estimated as 0.883 which is in the range expected, if somewhat high. Most of the other coefficients are approximately the same. However, the magnitude and significance of the coefficient on IT stock increase somewhat and the overall R-squared (0.66) is also better. Results of an F-test comparing the restricted and unrestricted regressions support this specification at the 99% level of significance.[14]

The Separate Effects on Salesworkers and Managers

When the dependent variable, *R*, is broken down into its constituent parts, salesworkers and managers, we see that the effect is not limited to one category alone but results from an apparent redistribution from the latter to the former following increases in IT stock. (table 5A and 5B) A number of studies dating back to Leavitt and Whisler have posited that the adoption of IT would result in a decrease in the number of managers. We find strong support for this hypothesis. More interestingly, IT is correlated with an increase in the number of salesworkers that is about as large as the decrease in managers, providing further confirmation of a shift to market-mediated coordination. The adjusted R-squared and F-statistic in each regression is generally even higher than in the *R* regression. Interestingly, changes in the total capital stock of industries seems to affect the number of salesworkers far more extensively than such changes affect managers' employment. This supports our interpretation of *TotStock* in the *R* regressions. Otherwise, the results are broadly analogous to those discussed above, with the obvious sign changes in the case of managers.

Discussion

Results of these regressions relating employment of two categories of "coordinators" to changes in the stock of information technology lend support to the hypothesis of increased reliance on markets with increased IT usage, ceteris paribus. However, many other changes were also happening in the US economy during the period in question so the assumption that all else was constant needs to be examined. The dummies and other variables should capture some of the other changes in the economy but we could conceivably be picking up effects of hidden variables which are collinear with IT investment.

One questionable assumption is that IT does not affect the relative productivity of salesworkers and managers since we are not measuring their outputs but only the numbers of individuals in each category. If IT increases the productivity of managers in comparison to the productivity of salesworkers, then the changes in employment distributions may simply reflect the fact that proportionately fewer managers are needed to do the same amount of coordination while proportionately more salesworkers are needed.

However, several studies have shown that, if anything, managers' productivity is often increased less by information technology than is the productivity of other workers such as salesworkers (Baily,1986; Loveman 1987; Roach, 1987). One explanation for this effect was provided as early as 1971 when it was noticed that the relatively unstructured tasks of middle and upper management were among the hardest to automate (Gorry and Scott-Morton (1971)). If these supposed productivity effects obtain, then our measure of relative employment categories may understate the net impact of IT in facilitating market-mediated coordination.

VI. Regressions on Firm Size

To help confirm our interpretation, we examined these same models with two different dependent variables, *Size1* and *Size2,* which we hypothesized would also be affected by changes in the balance between markets and hierarchies, but which would be less likely to be influenced in the same way by unexpected productivity changes or employment shifts. The hypothesis explored was that *if IT enables intrafirm transactions in a vertically integrated company to be replaced by interfirm transactions between a sequence of independent companies in the same production chain, then average firm size should decrease with IT stock.*

There are several potential ways to measure firm size: sales per firm, assets per firm, market valuation or employees per firm. We rejected the first measure because its sign was ambiguous under the tested hypothesis. The number of firms should go up but so should total sales as numerous intermediate sales are now counted which before would have been considered internal transfers and not counted. The second measure, assets per firm, is sensitive to changes in the nature of production. For instance, a service firm might require far fewer tangible assets (though perhaps more *human* capital) than a comparable manufacturing firm. This would bias our results if changes on the production side of the economy were occurring. Furthermore, this measure double counts IT-related assets. The third measure, market valuation, is notoriously volatile and responsive to financial conditions which are not easy to model. For instance, this measure would have shown a one quarter drop in average firm size on October 19, 1987. The final measure, employees per firm is vulnerable to shifts in the capital to labor ratio which may result from productivity changes caused by IT. However, we felt there was no reason to presume a priori that IT's impact on the productivity of capital would differ substantially from its impact on labor productivity. Of the four measures we felt that employees per firm would be least susceptible to these various biases and so the variables *Size1* and *Size2* are the log of the average number of employees per firm (or establishment) by industry by year. The appendix discusses results of an alternative measure (assets per firm) which supports the conclusions of this section, albeit with higher standard errors.

The variables *Size1* and *Size2* were derived from two different sets of data. Data for *Size1* was obtained from Compustat which only includes firms which are publicly traded. While these firms account for the majority of the economy's employment, there is a built in bias here towards medium- and large-sized firms, so changes among very small firms would not be picked up in these data. Data for *Size2* is from County Business Patterns and includes all establishments, thus eliminating the bias towards larger firms. However, the interpretation is complicated by the fact that "establishments" are not completely synonymous with "firms"; one firm may own several establishments. The data for the independent variables was unchanged.

We used a specification for the the models with *Size1* and *Size2* which was as close as possible to that which we used in the previous section. The only changes were that a) model 3 and model 4 were only lagged up to three years because greater lags proved insignificant, and b) the data for the farming industry was omitted from the *Size1* regressions because it included only two firms in the dependent variable, which we felt was insufficient to provide a reliable statistic.

The unlagged regression (model 1) was surprising relative to our hypothesis. *ITStock* had the wrong sign in the *Size1* regression and was not significantly different from zero in the *Size2* regression. (table 6 and table 7). We hypothesize that this is due not only to the learning lags discussed earlier but also because firms generally make most significant new investments in capital equipment such as IT in a year of growth. This is also when they are most likely to add to their labor force. Thus both *ITStock* and *Size1* will be positively correlated with a missing third variable having to do with growth. This effect apparently negates the inverse relationship we were expecting.

However, when three year lags are introduced (model 2), the impact of IT does indeed seem to be as expected. Furthermore, when the most recent years' IT investments are separated from the overall IT stock (model 3), the effect is quite pronounced. In this specification, *ITStock*, has the expected sign and is significant at the 99.9% and 99% level for *Size1* and *Size2*, respectively.

Interestingly, firms' size adjustments to IT investments seems to happen largely within the first 3 years. Structural shifts from managers to salesworkers in contrast took up to 5 years to work their way through the system. One explanation for this result is that opportunities for market coordination enabled by IT are first be exploited by new, small firms while the restructuring and relabelling of coordination within existing firms takes longer.

The non-linear least squares specification (model 4) which restricts the decay in the adjustment to an exponential form results in an excellent fit with the data. With the most recent years' investment fitted to this specification, the coefficients on *ITStock* are in the neighborhood of 0.3 or 0.4 and significant at over 99% in each regression. This suggests that each one percent increase in IT stock in an industry ultimately reduces average firm size by three to four tenths of a percent. The adjusted R-squared and F-statistics for this regression are not directly comparable to the model 4 with the other dependent variables, but do indicate that we have a very well-fitted model.

We estimate λ as about 0.7 in these formulations, somewhat lower than when *R* was the dependent variable, indicating a faster adjustment to IT. This is because λ is now capturing two distinct, additive effects: the adjustment/learning lags we saw earlier, plus the fading impact of the positive correlation of IT investment with contemporaneous firm growth. Given typical business cycles, this second effect can be expected to tail off quickly, exaggerating the apparent speed of adjustment.

Taken as a whole, this second series of regressions on firm size helps to confirm our interpretation of the first series on *R, salesworkers* and *managers*. We find substantial empirical support for the idea that information technology can lead to increased reliance on non-hierarchical modes of coordination, although the effect seems to take some time to reach its full magnitude.

VII. Conclusion

This paper continues research on the impact of information technology on organization structure in which a framework was developed which distinguishes coordination costs from production costs. One of the implications of this framework is that markets, with their relatively higher proportion of coordination costs would stand to benefit most from technologies that facilitated coordination. Previous research has traced the evolution of specific value chains (e.g. airline reservations) from hierarchical organization to market organization and shown that this transition was made easier, if not inevitable, because of advances in information technology (Malone, Yates and Benjamin (1987)).

In this paper, we have related the the impact of IT to one of the leading theories of organizational and market structure, Williamson's transaction cost analysis. We have also looked at broader trends in the economy through statistical analysis and for the first time found broad, clear empirical support for the hypothesis that market coordination is favored by the growth of IT. Information technology is not only correlated with a drop in the number of managers, but also with a commensurate increase in the number of salesworkers. Furthermore, the size of hierarchies, as measured by employees per firm, shows a substantial reduction following investments in IT.

As a secondary finding, we have also identified substantial adjustment lags (up to five years) in the use of IT. These lags may explain the surprisingly small or even insignificant impact of IT on productivity in studies which used shorter lags (e.g. Loveman, 1988) and suggest a way of resolving the paradox of seemingly negative value to IT investment.

Our empirical results were based on summary data from the entire United States economy from the early 1970s through 1985, a period when IT capital averaged less than 4% of total capital. If IT investment continues to grow at a rapid pace, the relationships found in the data may foreshadow a fairly dramatic restructuring of our economy in the coming decade.

Appendix I: Extensions

A. The Knowledge Economy Hypothesis

As discussed earlier, the pattern in the time dummies in the *R* regression suggested that, often all the other independent variables were controlled for, there was a residual trend toward increasing numbers of workers categorized as managers. If the importance of knowledge embodied in goods and services is increasing in our economy, then we would expect that not only might there be decreased reliance on markets (because information impactedness, characteristic of knowledge based products, makes markets inefficient) but also possibly an increase in white collar workers who handle information and are classified as managers, even if they do no coordination.

The log of U.S. research and development spending, (*R&D*), was used as a proxy for the importance of knowledge and other intangibles in the U.S. economy. Earlier studies (Caves (1984), Brynjolfsson (1984)) have shown that knowledge intensity as measured by R&D spending is a significant predictor of the degree of vertical integration. If research spending in the U.S. and thus knowledge is increasing over time, this would lead to decreased reliance on sales through markets in favor of managerial coordination. R&D entered with the expected negative sign and a fairly large magnitude. Interestingly, the trend in the time dummies disappears when R&D is introduced, supporting our use of it as a proxy for the growth in intangible and knowledge-intensive products.

When the time dummies were replaced outright by R&D, the new variable was significant at the 99.9% level, and the significance of ITStock, the adjusted R-Squared and the F-Statistic all increased markedly. The entire series of regressions, with R&D replacing the time dummies, is in appendix II.

These results on *R&D* coupled with the pattern in the industry dummies suggest that knowledge may be a fairly significant determinant of relative share of hierarchies in organizing economic activity. Because information technology facilitates not only coordination functions but also the storage and transmission of knowledge, it could be also expected to be highly correlated with transactions involving highly impacted information. As discussed earlier, these transactions are best handled through hierarchies, thus damping the relationship between IT and hierarchies found in the regressions. Ideally, we would like to see IT subdivided into two categories: one relating to coordination and the other relating to knowledge. This is in principle achievable, although our current data set does not permit such a distinction.

B. Generalized Least Squares

The industry groupings consisted of about ten related SIC codes each. While an attempt was made to keep the groups of equal size, there were some differences which could potentially lead to heteroskedasticity. Accordingly, a generalized least squares version of each of the non-linear models was run with each industry-year cell of the panel weighted by the square-root of the number of firms for the size regressions and the square-root of total capital stock for the *R* regression. The results were qualitatively unchanged in each case although the adjusted R-squared and F-statistics increased somewhat. As expected, the significance of *ITStock* decreased somewhat in each case although it remained significant at the 98% level.

C. Assets as a Measure of Firm Size

We mentioned earlier that the other measures of firm size were subject to a number of weaknesses. Nonetheless, we did test the final, non-linear version of the model on *lassiz*, the log of assets per firm, as an alternative definition of firm size. *ITStock* was still negatively correlated with firm size but its was reduced and standard error increased so it was no longer as significant at the 95% level in either the OLS or the GLS models. One obvious explanation for the reduced magnitude is that IT capital appears in both sides of the regression; IT can be a very significant portion of total capital assets in some firms. Furthermore, one would expect IT investment to be positively correlated with other capital assets, ceteris paribus, thereby, reducing the observed impact of IT.

D. Serial Correlation or General Partial Adjustments

We considered the hypothesis that the three to five year adjustment lags in the impacts of information technology result from its relative newness and unfamiliarity. Two reasonable alternative explanations for the lags we found are 1) that there is serial correlation in the true disturbance terms, perhaps because of missing variables in the model, or 2) that the dependent variables undergo only partial adjustment to all the independent variables, not just IT.

Exploring the first alternative hypothesis, in the current effects model with autocorrelation, we have:

$$y_t = \beta X_t + u_t$$

where

$$\beta X_t = \beta_0 + \beta_1(\text{ITStock}) + \beta_2(\text{R\&D}) + \beta_3(\text{TotStock}) + \beta_4(\text{TotStock2}) + \Sigma\beta_{i=5 \text{ to } 12}(\text{industry dummies})$$

and $u_t = ru_{t-1} + e_t$
with the e_t i.i.d.

Using the Koyck transfer (lag and multiply by **r**) we get:

$$ry_{t-1} = r\beta X_{t-1} + ru_{t-1}$$

Subtracting this from the original equation gives us:

$$y_t = ry_{t-1} + \beta X_t - \beta r X_{t-1} + e_t$$

Note that the disturbance terms are now serially uncorrelated. Furthermore, the third coefficient is equal to the opposite of the product of the first two.

Running this regression on *R* , we find that the coefficients on the lagged dependent variables *ITStock(-1)* and *TotStock(-1)* are 0.15 and 5.04, respectively. Clearly, these are substantially different from the values predicted by the autocorrelation model.[15] Similar results obtained for the regressions on firm size, so we accept our original hypothesis that the apparent significance of the lagged variables is caused by something other than, or in addition to, simple autocorrelation.

On the other hand, if *R* and *Size1* are subject to general partial adjustments, not just lags in adjusting to IT, we can write the model as follows:

$$y_t - y_{t-1} = \lambda(y_t^* - y_{t-1})$$

where $0 < \lambda < 1$

and y^* is the optimal level of the dependent variable if there were no lags:

$$y_t^* = \beta X_t$$

where X_t is defined as above.

Combining the equations yields:

$$y_t = (1-\lambda)y_{t-1} + \beta X_t$$

In this formulation, $\mathbf{X_{t-1}}$ is not a regressor.

When the lagged dependent variable is added to the regression, the t-statistics on most of the explanatory variables drops substantially. Griliches (1967) has noted that the estimates of the ß are often over stated when some serial correlation exists. Thus, it is unclear whether or not the X_{t-1} are in fact regressors. Their magnitudes are comparable to or greater than the unlagged variables, so one would be hesitant to eliminate the X_{t-1} without also eliminating the X_t. When the lagged dependent variables are added to the NLS regressions that imposed an exponential decay on IT adjustments (model 4), the coefficients on *ITStock* dropped in significance to the 90% level for the *R* regressions and to the 97% level for the *Size* regressions.

We conclude that there is some evidence that the dependent variables may adjust only partially each year to changes in all the independent variables. However, this model does not seem to yield as strong results as the original specifications, which only had partial adjustments to IT changes and which allowed for different effects long-term than contemporaneously. Nonetheless, the general partial adjustments model has a somewhat firmer theoretical basis and merits further examination.

Appendix II: Data sources

Unless otherwise noted, all data is by eight industry sectors (farming; mining; durable goods manufacturing; non-durable goods manufacturing; wholesale & retail trade; transport and utilities; finance, insurance and real estate; and services) and by year from 1975 to 1985.

Data for the number of salesworkers and managers were from the United States Bureau of Labor Statistics. The variable *R* was derived by dividing the number of salesworkers by the number of managers..

Data for information technology investments and total capital investments were from a study by the Bureau of Economic Analysis. A description of the data gathering methodology is available in Gorman et al. (1985) All data used were in constant dollars. Stocks were derived from flows by the authors using a modified Winfrey table based on average service lives as described in Gorman et al. (1985). The variables *ITStock*, *ITInvest*, and *TotStock* were derived by taking the logarithm of the respective data. *TotStock2* is the square of *TotStock*.

Data for average number of employees per firm and average assets per firm were derived by the authors from Compustat data by dividing total employment and total assets respectively per industry by total number of firms per industry. *Size1* and *Assiz* are the respective logarithms of this data.

Establishment size (*Size2*) was derived by taking the log of the number of employees per establishment from data in County Business Patterns. This data was only available from 1978 through 1985 so only these years were used in the regressions.

Total research and development spending (*R&D*) was aggregated on an economy-wide level from Compustat.

NOTES

[1] Source: BEA data. See data section for details.

[2] Real IT stock increased fivefold between 1970 and 1985 according to BEA data.

[3] The press reports market transactions intruding in all manner of aspects of the firm: temporary employment agencies offer executives for rent, brand names may be purchased and even the Goodyear blimp is not actually owned by its namesake company. (US News & World Report, 6/88)

[4] Williamson's analysis of these factors is most fully stated in his book (1975); a good summary can be found in Williamson (1981).

Williamson identifies four areas of potential "market failure" in which hierarchies would be beneficially employed. The first is in situations of complexity or uncertainty beyond that able to be handled by the bounded rationality of humans. The implications of the standard Arrow-Debreu analysis of markets require that all decision makers evaluate all possible decisions in all possible future states of nature (situations) before deciding what to do. They then seek to make complete contingent contracts with all interested parties. For situations of even moderate complexity or uncertainty, this can become an unimaginably large computational problem. Without a contingent contract, however, the decision-maker may be left open to the opportunism of others.

The alternative is to consider options only for situations that actually obtain as they occur. By organizing as a firm, all specific contingent contracts need not be specified in advance; rather, appropriate action is taken as each new state of the world is realized. This vastly economizes on computational needs and consequently provides an advantage over the pure market approach. Indeed, the firm has often been modelled as as primarily an information processing mechanism (Galbraith (1977); Grossman and Hart (1986); Cyert and March (1963)).

A second potential failure of markets is the opportunism occasioned by bargaining among a small number of participants. When each participant has a degree of monopoly power, he or she can extract value from the other bargainers even at the expense of total joint benefit. The market provides no incentive for participants to consider the interests of the whole and thus can lead to a loss of welfare. In contrast, within a firm, compensation is at least partially contingent on joint benefits and can be reallocated to provide incentives for maximizing group welfare.

A third and related market failure occurs when different parties to a transaction have different relevant information, or in Williamson's terminology, when information is "impacted". This creates an opportunity for misrepresentation at the expense of the other party. A hierarchy eliminates some of the incentive for gain at others expense since compensation is no longer solely (if at all) a function of individual performance versus others. Modelling the opportunistic transaction as a "prisoner's dilemma" provides an alternative lens to view this insight. A firm provides an environment of repeated transactions between pairs of actors and thus enhances the likelihood that cooperative (or non-opportunistic) behavior will evolve (Axelrod (1984); Brynjolfsson (1987)).

Arrow (1973) has made the related argument that the relative costs of intrafirm communication are often much lower than interfirm communication., even though he does not explicitly model why communication should be cheaper within a firm. Thus, applications which require significant communication may benefit from vertical integration.

Williamson argues that the fourth potential benefit of hierarchies over markets is less economic than sociological. Efficient operation of markets engenders a "cold", calculative atmosphere where each quid pro quo is carefully metered and tabulated. Hierarchies tend to work in a more loosely reciprocal, quasi-moral atmosphere. While this latter method of transacting may or may not be more efficient, many people find it intrinsically more satisfying and favor it when other considerations are nearly equal.

[5] In the language of Markus and Robey (1988), an organizational imperative is what drives the adoption of IT but we examine in this paper the subsequent "technological imperative" which leads an industry or economy to greater market coordination.

[6] Search costs are an example. Consider the simple rule suggested by Stigler (1961) of getting a price quote from n firms before deciding where to purchase. For a pure hierarchy, n=1 while a market has n > 1. Then the expected price paid, M_n, will be a decreasing function of n:

$$M_n = \int [1 - F(p)]^n \, dp$$

where F(p) is the distribution of prices, while the cost of searching increases linearly with n. The expected gain from searching one additional producer is decreasing with n so a firm should continue searching until this expected gain is just equal to the cost of searching. From this analysis it is clear that if the cost of searching decreases, then the amount of searching will increase and the expected price paid after searching will decrease, Consequently, we could expect to see more market mediated transactions. This effect has been recently analyzed by Bakos (1988)

[7] An interesting example of this is suggested by evolutionary biology. As individual neurons became better able to process information, the result was not organisms with fewer (or single) neurons, but rather organisms with more neurons adapted to ever more complex tasks.

[8] We found IT capital to be increasing in all industry groups, and new investments are at levels far beyond those needed to simply replenish current stock levels.

[9] Our data for investments in the separate categories of computers, telecommunications and photocopiers and related products all show the same, increasingly steep, upward slope.

[10] Two notes are in order: 1)the statistics pertain to a period during which these establishments accounted for just 27% and 54% of all establishments, respectively and 2) "establishments" do not necessarily coincide with "firms"-- one firm may own several establishments.

[11] Bureau of Labor Statistics as reported in the *Wall Street Journal*, 4/27/88; p. 29. Firms in intermediate size classes showed employment gains inversely proportional to their size.

[12] See appendix I for details on data sources and methodology.

[13] The authors are grateful to Ernst Berndt for this insight.

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[14] Assuming a normal error structure, we can calculate the statistic:

$$\frac{\dfrac{u^{*\prime}u^{*} - u'u}{c}}{\dfrac{u'u}{t-k}} \sim F(c,\ t\text{-}k)$$

In this case, u*'u* (the restricted sum of squared residuals) is 29.49; u'u (the unrestricted SSR) is 29.23; c (the number of restrictions) is 6; t-k (the degrees of freedom) is 55; and the statistic is 0.081. The critical value at 1% for the F-distribution is 0.141

[15] The calculations are: 0.83 x 0.05 x (-1) = -0.42 ≠ 0.15, and 0.83 x -2.61 x -1 = 2.17 ≠ 5.04, respectively.

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FIGURE 1

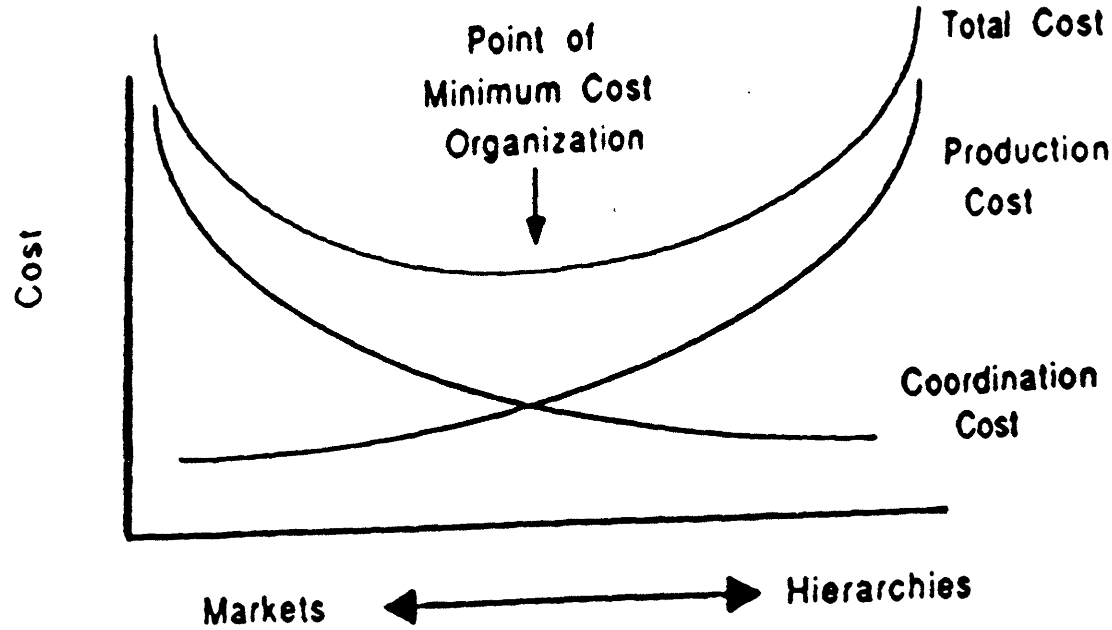

FIGURE 2

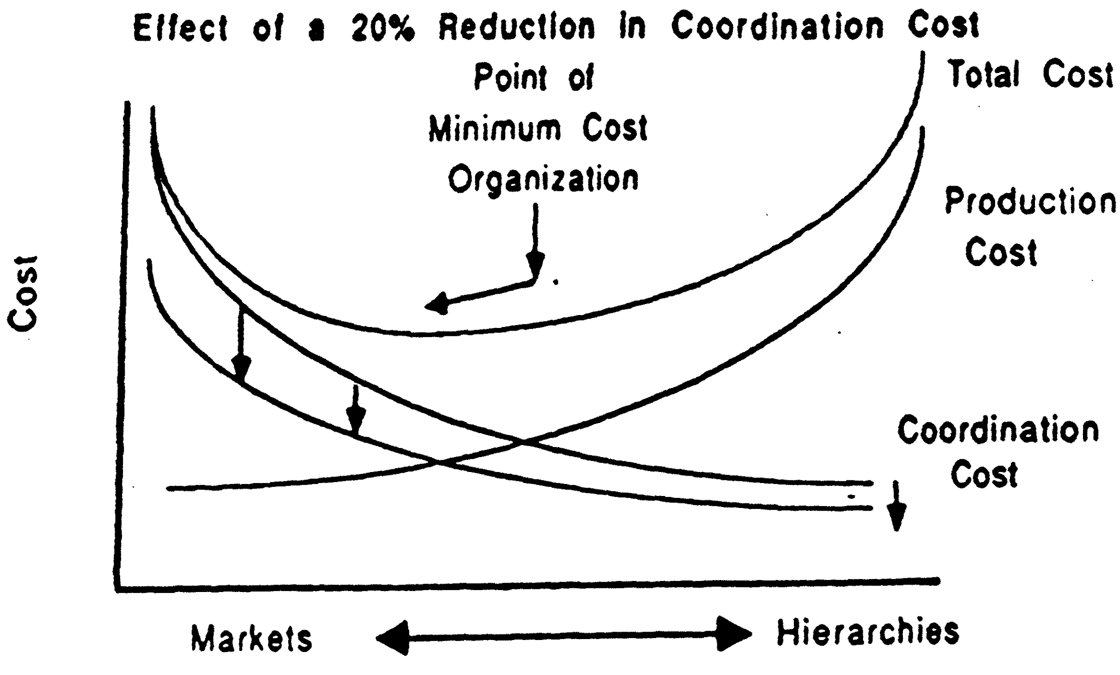

FIGURE 3

IT Stock as a Share of Total Capital Stock in the U.S. Economy

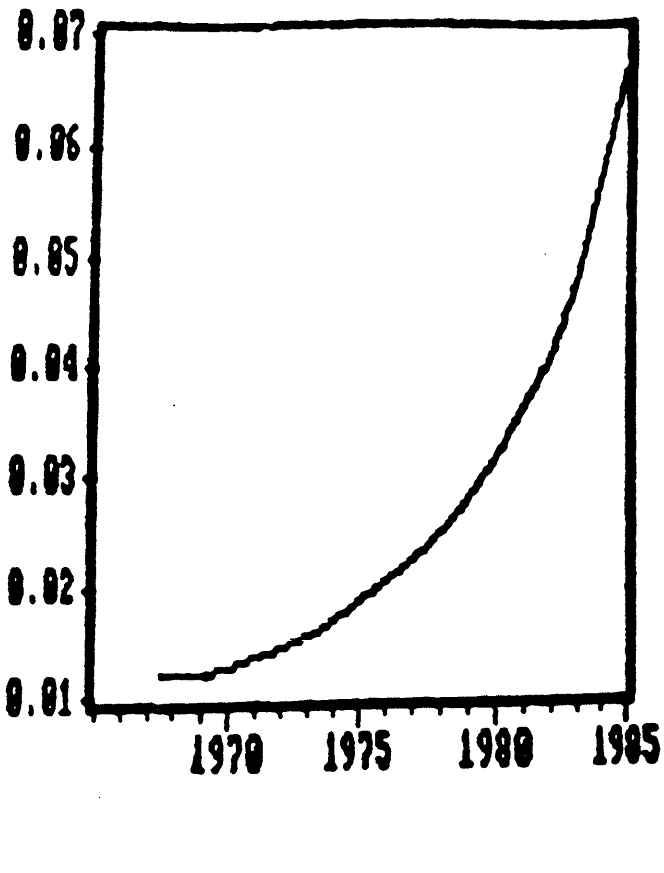

Table 1. Impact of IT on the Relative Efficiency of Markets and Hierarchies.

Source of Potential Market Failure	Impact of IT
Asset specificity	Facilitates Markets
Site Specificity	Facilitates Markets
Bounded Rationality	Uncertain
Information Impactedness	Facilitates Markets
Atmosphere	Uncertain
Difficult to Assign Residual Rights	Facilitates Markets

Table 2. Panel Data Format

INDUSTRY(i)	YEAR(t) 1974	. . .	1985
Farming	X_{it}	. . .	
Mining	.		
Durables	.		
Non-Durables	.		
Transport & Utilities			
Trade			
Finance			
Services			

Table 3. The Basic Variables and Models

Dependent Variables:

R: The Ratio of Salespersons to Managers.

Salespersons: Salespersons.

Managers: Managers.

Size1: The Log of Average Firm Size by Number of Employees, from Compustat.

Size2: The Log of Average Establishment Size by Number of Employees, from County Business Patterns.

Explanatory Variables, *ITStock* and *ITInvest*: The Log of the Constant Dollar Level of IT Capital Stock and IT Investment.

Control Variables: Variables to Control for Total Capital Investment, for Industry, and for Year.

Model 1: The unlagged regression

$$(\text{Dependent variable})_{it} = \beta_0 + \beta_1 * \text{ITStock}_{it} + \sum \beta_k * \text{Controls}_{itk}$$

Model 2: IT stock lagged three years

$$(\text{Dependent variable})_{it} = \beta_0 + \beta_1 * \text{ITStock}_{i(t-3)} + \sum \beta_k * \text{Controls}_{itk}$$

Model 3: Adjustment model, portion of recent IT investment separated from current IT stock

$$(\text{Dependent variable})_{it} = \beta_0 + \beta_1 * \text{ITStock}_{it} + \sum_{j=0..3} \partial_j * \text{ITInvest}_{i(t-j)} + \sum \beta_k * \text{Controls}_{itk}$$

Model 4: Non-linear least squares, learning speed explicitly modeled by λ

$$(\text{Dependent variable})_{it} = \beta_0 + \beta_1 * \text{ITStock}_i + \beta_2 * (\sum_{j=0..3} \lambda^j * \text{ITInvest}_{i(t-j)}) + \sum \beta_k * \text{Controls}_{itk}$$

Table 4. Regression Results on Dependent Variable *R*

VARIABLE	MODEL 1	MODEL 2	MODEL 3	MODEL 4
CONSTANT	-397.7*	-434.0**	-581.5**	-587.7***
	(168.1)	(179.0)	(189.2)	(185.9)
ITSTOCK	**0.874***		**8.86****	**9.187****
	(0.477)		**(3.25)**	**(3.13)**
ITSTOCK(-3)		**1.16***		
		(0.553)		
β_2				-1.68**
				(0.643)
λ				0.883***
				(0.043)
ITINVEST			-1.45*	
			(0.728)	
ITINVEST(-1)			-1.44*	
			(0.787)	
ITINVEST(-2)			-1.39*	
			(0.623)	
ITINVEST(-3)			-1.53*	
			(0.672)	
ITINVEST(-4)			-0.843	
			(0.591)	
ITINVEST(-5)			-0.596	
			(0.587)	
TOTSTOCK	53.6*	58.0*	77.7**	79.5**
	(25.5)	(27.4)	(28.7)	(28.2)
$TOTSTOCK^2$	-1.807*	-1.94*	-2.69**	-2.79**
	(0.975)	(1.05)	(1.11)	(1.09)

Standard Errors in Parentheses

* Significant at the 95% level
** Significant at the 99% level
*** Significant at the 99.9% level

Table 5a. Regression Results on Dependent Variable *Salesworkers*

VARIABLE	MODEL 1	MODEL 2	MODEL 3	MODEL 4
CONSTANT	-587806** (186877)	-625778** (200390)	-810210*** (208403)	-611082** (214073)
ITSTOCK	**1175*** **(530)**		**10774**** **(3585)**	**5061** **(3597)**
ITSTOCK(-3)		**1384*** **(618)**		
β_2				-751 (728)
λ				0.958*** (0.114)
ITINVEST			-1679* (801)	
ITINVEST(-1)			1789* (867)	
ITINVEST(-2)			-1619* (686)	
ITINVEST(-3)			-1873** (740)	
ITINVEST(-4)			-1033 (651)	
ITINVEST(-5)			-794 (646)	
TOTSTOCK	79184** (28411)	83697** (30696)	108843*** (31687)	85041** (32521)
$TOTSTOCK^2$	-2652** (1084)	-2782* (1181)	-3759** (1229)	-3011** (1259)

Standard Errors in Parentheses

* Significant at the 95% level
** Significant at the 99% level
*** Significant at the 99.9% level

Table 5b. Regression Results on Dependent Variable *Managers*

VARIABLE	MODEL 1	MODEL 2	MODEL 3	MODEL 4
CONSTANT	11425 (124506)	-15460 (123938)	133886 (128937)	16407 (127425)
ITSTOCK	**-629*** **(353)**		**-9214***** **(496)**	**-8706***** **(2143)**
ITSTOCK(-3)		**-1430***** **(382)**		
β_2				1828*** (441)
λ				0.833*** (.0335)
ITINVEST			1769*** (496)	
ITINVEST(-1)			1715*** (536)	
ITINVEST(-2)			1411*** (424)	
ITINVEST(-3)			1409** (458)	
ITINVEST(-4)			774* (403)	
ITINVEST(-5)			660 (399)	
TOTSTOCK	179 (18928)	7001 (18985)	-13194 (19604)	3980 (19353)
$TOTSTOCK^2$	-34.9 (722)	-364 (730)	395 (760)	-236 (749)

Standard Errors in Parentheses

* Significant at the 95% level
** Significant at the 99% level
*** Significant at the 99.9% level

Table 6. Regression Results on Dependent Variable *Size1*

VARIABLE	MODEL 1	MODEL 2	MODEL 3	MODEL 4
CONSTANT	-47.1** (16.6)	-45.0** (16.9)	-39.7** (13.4)	-39.0** (13.6)
ITSTOCK	**0.089 (0.045)**		**-0.398*** (0.118)**	**-0.430*** (0.117)**
ITSTOCK(-3)		**-0.059 (0.052)**		
β_2				0.161*** (0.029)
λ				0.731*** (0.107)
ITINVEST			0.117*** (0.036)	
ITINVEST(-1)			0.171*** (0.044)	
ITINVEST(-2)			0.0809* (0.038)	
ITINVEST(-3)			0.0280 (0.042)	
TOTSTOCK	6.68** (2.56)	6.56** (2.62)	6.34** (2.06)	6.14** (2.09)
$TOTSTOCK^2$	-0.225* (0.099)	-0.221* (0.102)	-0.235** (0.080)	-0.224** (0.081)

Standard Errors in Parentheses

* Significant at the 95% level
** Significant at the 99% level
*** Significant at the 99.9% level

Table 7. Regression Results on Dependent Variable *Size2*

VARIABLE	MODEL 1	MODEL 2	MODEL 3	MODEL 4
CONSTANT	-13.9 (16.8)	-9.39 (16.3)	-4.47 (17.4)	-3.82 (16.9)
ITSTOCK	**-0.00097** **(0.045)**		**-0.269**** **(0.107)**	**-0.262**** **(0.107)**
ITSTOCK(-3)		**-0.117**** **(0.047)**		
β_2				0.0788** (0.0298)
λ				0.689*** (0.179)
ITINVEST			0.061* (0.032)	
ITINVEST(-1)			0.093** (0.034)	
ITINVEST(-2)			0.010 (0.037)	
ITINVEST(-3)			0.031 (0.027)	
TOTSTOCK	2.25 (2.55)	1.83 (2.48)	1.10 (2.65)	1.00 (2.56)
TOTSTOCK^2	-0.075 (0.097)	-0.063 (0.094)	-0.037 (0.102)	-0.0339 (0.0980)

Standard Errors in Parentheses

* Significant at the 95% level
** Significant at the 99% level
*** Significant at the 99.9% level

APPENDIX III: REGRESSIONS WITH R&D INSTEAD OF TIME DUMMIES

Table A-4. Regression Results on Employment Categories With R&D

DEPENDENT VARIABLE: R

VARIABLE	MODEL 1	MODEL 2	MODEL 3	MODEL 4
CONSTANT	-335.7*	-383.7*	-479.7**	-440.5**
ITSTOCK	**0.968***		**5.91****	**6.16****
ITSTOCK(-3)		**1.17****		
β_2				-1.17*
λ				0.845***
ITINVEST			-1.10*	
ITINVEST(-1)			-0.899	
ITINVEST(-2)			-0.878	
ITINVEST(-3)			-0.785	
ITINVEST(-4)			-0.597	
ITINVEST(-5)			-0.323	
R&D	-2.9***	-3.26***	-3.66***	-3.53***
TOTSTOCK	50.0*	57.3*	71.1**	65.2*
$TOTSTOCK^2$	-1.66*	-1.92*	-2.44*	-2.23*
FARM	6.96**	8.40**	9.34***	9.27***
MINE	-0.854	-0.539	-0.171	-0.118
DURABLES	-1.85**	-1.67**	-1.73*	-1.60*
NONDUR	-0.813*	-0.734*	-0.774	-0.704
TRANS&UTIL	-4.00*	-3.96*	-3.56	-3.23
TRADE	1.63***	1.83***	1.77***	1.82***
FINANCE	-2.27**	-2.40**	-2.52**	-2.36**

* Significant at the 95% level
** Significant at the 99% level
*** Significant at the 99.9% level

Table A-5. Lagged Regression Results on Salespersons and Managers With R&D.

Model 2: IT lagged three years

DEPENDENT VARIABLE:	Salespersons	Managers
INDEPENDENT VARIABLE		
CONSTANT	-553307**	-22104
ITSTOCK(-3)	**1437****	**-885****
R&D	-4474***	2116**
TOTSTOCK	81981**	1914
$TOTSTOCK^2$	-2721*	-130

* Significant at the 95% level
** Significant at the 99% level
*** Significant at the 99.9% level

Table A-6. Regression Results on Firm Size With R&D.

DEPENDENT VARIABLE: SIZE1

VARIABLE	MODEL 1	MODEL 2	MODEL 3	MODEL 4
CONSTANT	-55.5**	-54.1**	-47.4**	-45.9**
ITSTOCK	**0.0122**		**-0.404*****	**-0.469*****
ITSTOCK(-3)		**-0.155*****		
β_2				0.198***
λ				0.591***
ITINVEST			0.153***	
ITINVEST(-1)			0.159***	
ITINVEST(-2)			0.0542	
ITINVEST(-3)			0.00296	
R&D	-0.0127	0.223*	0.185*	0.179*
TOTSTOCK	8.50**	8.02**	7.41***	7.16**
$TOTSTOCK^2$	-0.312**	-0.293**	-0.286**	-0.274**

* Significant at the 95% level
** Significant at the 99% level
*** Significant at the 99.9% level

Table A-7. Regression Results on Establishment Size With R&D.

DEPENDENT VARIABLE: SIZE2

VARIABLE	MODEL 1	MODEL 2	MODEL 3	MODEL 4
CONSTANT	-22.9	-11.0	2.90	-33.9
ITSTOCK	**-0.0801**		**-0.348****	**-0.396*****
ITSTOCK(-3)		**-0.203*****		
β_2				0.149***
λ				0.445**
ITINVEST			0.120**	
ITINVEST(-1)			0.111**	
ITINVEST(-2)			0.00376	
ITINVEST(-3)			-0.0199	
R&D	-0.0564	0.127	0.0654	0.0710
TOTSTOCK	3.99	2.02	0.0584	5.66
$TOTSTOCK^2$	-0.147	-0.0739	-0.00220	-0.215

* Significant at the 95% level
** Significant at the 99% level
*** Significant at the 99.9% level

APPENDIX IV: VALUES OF DUMMY VARIABLES IN REGRESSIONS

Table B-4. Dummy Variables for Regression on Dependent Variable *R*

VARIABLE	MODEL 1	MODEL 2	MODEL 3	MODEL 4
FARM	6.45 (2.64)	8.42 (3.28)	10.8 (3.27)	10.5 (3.18)
MINE	-1.13 (2.15)	-0.685 (2.12)	0.627 (2.63)	1.31 (2.54)
DURABLES	-1.87 (0.673)	-1.73 (0.705)	-1.62 (0.827)	-1.36 (0.782)
NONDUR	-0.821 (0.444)	-0.770 (0.457)	-0.680 (0.514)	-0.567 (0.494)
TRANS&UTIL	-4.043 (2.21)	-4.15 (2.28)	-3.13 (2.97)	-2.00 (2.78)
TRADE	1.63 (0.369)	1.80 (0.377)	1.83 (0.413)	1.90 (0.397)
FINANCE	-2.21 (0.868)	-2.48 (0.960)	-2.63 (1.08)	-2.23 (1.01)
1976	-0.352 (0.346)	-0.428 (0.383)	-0.387 (0.401)	-0.387 (0.374)
1977	-0.702 (0.382)	-0.868 (0.443)	-0.883 (0.470)	-0.729 (0.427)
1978	-1.12 (0.445)	-1.32 (0.530)	-1.59 (0.574)	-1.268 (0.502)
1979	-1.589 (0.534)	-1.81 (0.632)	-2.27 (0.676)	-1.94 (0.605)
1980	-1.98 (0.622)	-2.23 (0.737)	-2.85 (0.765)	-2.16 (0.727)
1981	-2.32 (0.707)	-2.65 (0.853)	-3.08 (0.871)	-2.83 (0.827)
1982	-1.94 (0.776)	-2.42 (0.972)	-2.68 (0.975)	-2.44 (0.927)
1983	-2.30 (0.858)	-2.85 (1.08)	-3.33 (1.10)	-2.964 (1.03)
1984	-2.63 (0.957)	-3.22 (1.19)	-4.01 (1.25)	-3.52 (1.15)
1985	-2.92 (1.05)	-3.53 (1.30)	-4.58 (1.37)	-4.04 (1.28)

Standard Errors in Parentheses

Table B-5a. Dummy Variables: Regression on Dependent Variable *Salesworker*

VARIABLE	MODEL 1	MODEL 2	MODEL 3	MODEL 4
FARM	8276	9882	10491	6460
	(2939)	(3672)	(3428)	(3672)
MINE	-2540	-2572	-1305	-822
	(2396)	(2375)	(2589)	(2926)
DURABLES	-3158	-3062	-2957	-2004
	(748)	(789)	(801)	(902)
NONDUR	-1828	-1794	-1717	-1136
	(493)	(511)	(518)	(571)
TRANS&UTIL	-6877	-7377	-6018	-3348
	(2462)	(2553)	(2772)	(322[illegible])
TRADE	4489	4694	4608	50[illegible]
	(410)	(422)	(425)	(45[illegible])
FINANCE	-3743	-4041	-3895	-2097
	(965)	(1074)	(1075)	(1173)
1976	-475	-560	-517	-244
	(385)	(429)	(441)	(431)
1977	-990	-1140	-1205	-493
	(424)	(495)	(513)	(496)
1978	-1563	-1757	-2073	-908
	(494)	(593)	(625)	(588)
1979	-2239	-2429	-2669	-1480
	(594)	(707)	(714)	(706)
1980	-2774	-2989	-3150	-1955
	(691)	(824)	(803)	(844)
1981	-3242	-3537	-3571	-2104
	(786)	(955)	(916)	(960)
1982	-2925	-3365	-3263	-1569
	(862)	(1087)	(1031)	(1076)
1983	-3288	-3796	-3872	-1835
	(953)	(1211)	(1178)	(1204)
1984	-3760	-4298	-4573	-2230
	(1063)	(1342)	(1314)	(1351)
1985	-4130	-4671	-5009	-2546
	(1172)	(1463)	(1425)	(1492)

Standard Errors in Parentheses

Table B-5b. Dummy Variables for Regression on Dependent Variable *Manager*

VARIABLE	MODEL 1	MODEL 2	MODEL 3	MODEL 4
FARM	-6116	-11185	-9568	-11028
	(1958)	(2271)	(2183)	(2177)
MINE	-3467	-5056	-3932	-4924
	(1596)	(1469)	(1649)	(1740)
DURABLES	-1419	-1502	-1329	-1664
	(498)	(487)	(510)	(534)
NONDUR	-1766	-1774	-1665	-1865
	(328)	(316)	(330)	(338)
TRANS&UTIL	-2254	-1934	-1552	-2307
	(1640)	(1579)	(1765)	(1903)
TRADE	600	498	548	374
	(273)	(261)	(270)	(272)
FINANCE	-691	102	39.3	-139
	(643)	(664)	(684)	(688)
1976	142	359	341	302
	(256)	(265)	(280)	(256)
1977	300	725	748	553
	(282)	(306)	(327)	(290)
1978	467	1089	1195	915
	(329)	(367)	(398)	(341)
1979	671	1428	1398	1380
	(395)	(437)	(454)	(412)
1980	817	1729	1589	1809
	(460)	(510)	(511)	(497)
1981	1019	2131	1901	2028
	(524)	(591)	(583)	(564)
1982	1012	2367	2055	2126
	(574)	(672)	(657)	(631)
1983	1232	2775	2541	2572
	(635)	(749)	(750)	(703)
1984	1416	3125	2951	3034
	(708)	(830)	(837)	(787)
1985	1618	3461	3262	3520
	(781)	(904)	(908)	(872)

Standard Errors in Parentheses

Table B-6. Dummy Variables for Regression on Dependent Variable *Size1*

VARIABLE	MODEL 1	MODEL 2	MODEL 3	MODEL 4
FARM				
MINE	-0.723 (0.262)	-1.24 (0.223)	-0.588 (0.215)	-0.658 (0.215)
DURABLES	0.306 (0.086)	0.254 (0.084)	0.408 (0.072)	0.377 (0.071)
NONDUR	0.480 (0.052)	0.460 (0.052)	0.551 (0.044)	0.536 (0.043)
TRANS&UTIL	-0.302 (0.309)	-0.580 (0.285)	0.128 (0.261)	0.021 (0.258)
TRADE	0.603 (0.039)	0.603 (0.040)	0.625 (0.032)	0.614 (0.032)
FINANCE	-1.00 (0.109)	-0.950 (0.120)	-0.759 (0.097)	-0.800 (0.096)
1976	-0.0006 (0.034)	0.020 (0.036)	0.057 (0.030)	0.038 (0.028)
1977	-0.017 (0.038)	0.025 (0.044)	0.082 (0.036)	0.062 (0.034)
1978	-0.028 (0.045)	0.035 (0.055)	0.128 (0.052)	0.081 (0.043)
1979	-0.023 (0.055)	0.065 (0.068)	0.128 (0.052)	0.106 (0.052)
1980	-0.077 (0.065)	0.034 (0.080)	0.094 (0.060)	0.074 (0.060)
1981	-0.101 (0.075)	0.034 (0.095)	0.112 (0.070)	0.085 (0.069)
1982	-0.183 (0.083)	-0.024 (0.109)	0.074 (0.079)	0.041 (0.079)
1983	-0.262 (0.092)	-0.079 (0.121)	0.046 (0.090)	0.004 (0.089)
1984	-0.238 (0.103)	-0.029 (0.137)	0.111 (0.102)	0.068 (0.101)
1985	-0.289 (0.115)	-0.057 (0.151)	0.088 (0.112)	0.051 21(0.112)

Standard Errors are in Parentheses

Table B-7. Dummy Variables for Regression on Dependent Variable *Size2*

VARIABLE	MODEL 1	MODEL 2	MODEL 3	MODEL 4
FARM	-0.690 (0.244)	-1.36 (0.282)	-1.12 (0.278)	-1.085 (0.276)
MINE	-0.329 (0.202)	-0.651 (0.172)	-0.454 (0.216)	-0.423 (0.202)
DURABLES	1.442 (0.059)	1.42 (0.057)	1.45 (0.061)	1.45 (0.590)
NONDUR	1.41 (0.037)	1.41 (0.036)	1.43 (0.039)	1.44 (0.0389)
TRANS&UTIL	0.436 (0.207)	0.330 (0.188)	0.435 (0.232)	0.456 (0.210)
TRADE	-0.095 (0.030)	-0.090 (0.028)	-0.084 (0.029)	-0.0848 (0.0294)
FINANCE	-0.158 (0.076)	-0.075 (0.081)	-0.077 (0.084)	-0.077 (0.081)
1978	0.040 (0.022)	0.057 (0.023)	0.055 (0.020)	0.0533 (0.024)
1979	0.040 (0.029)	0.077 (0.031)	0.060 (0.019)	0.0588 (0.0305)
1980	0.021 (0.037)	0.078 (0.039)	0.051 (0.021)	0.0519 (0.039)
1981	-0.016 (0.045)	0.063 (0.050)	0.034 (0.022)	0.032 (0.049)
1982	-0.154 (0.051)	-0.047 (0.060)	-0.080 (0.021)	-0.083 (0.058)
1983	-0.113 (0.059)	0.015 (0.070)	-0.015 (0.018)	-0.024 (0.067)
1984	-0.108 (0.068)	0.043 (0.811)	0.003 (0.107)	-0.0026 -(0.078)
1985				

Standard Errors are in Parentheses