Product Differentiation and the Use of Information Technology: New Evidence from the Trucking Industry

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Since the mid-1980s many authors have investigated the influence of information technology (IT) on productivity. Until recently there has been no clear evidence that productivity increases as a result of IT spending. This productivity paradox is partly due to the difficulty in correctly identifying outputs, particularly in the service sector such as the trucking industry. Products are often differentiated by quality attributes of the service provided, rather than merely the physical content of the good delivered by motor carriers. A carrier's primary marketing objective, e.g. on-time-performance vs. lowest rate carrier, are precisely what differentiates a trucking firm's service. This paper uses cross-sectional data to show that the use of increasingly sophisticated IT by trucking firms varies depending upon marketing objectives. Our empirical results imply that in order to measure the impact of IT on productivity it is crucial to account for how the firm differentiates its product. We conclude that the productivity paradox can be alleviated if measures of output incorporate firms' marketing objectives.

1. Introduction

Did a university's 1980 investment in new Vax computer help faculty and students be more productive? Does investment in a satellite communications network improve the productivity of UPS workers? The answers ten years ago to similar questions were either "maybe," or "no," and this productivity paradox of information technology (IT) fueled a large literature.[1]

Brynjolfsson and Hitt (1998) summarize the key reasons for the productivity paradox with the following humorous passage:

> Productivity is a simple concept. It is the amount of output produced
> per unit of input [yet productivity] is notoriously difficult to
> measure...In particular, there are two aspects of productivity that have
> increasingly defied precise measurement: output and input.

More recently, better data and a clearer understanding of how to measure both outputs and inputs have begun to reveal that use of technology may in fact improve productivity. Using cross-sectional data this paper finds that the use of increasingly sophisticated IT by trucking firms depends on marketing objectives. Marketing objectives are defined by a firm's competitive strategy, and these objectives are met by product differentiation. Our empirical results imply that in order to measure output precisely, it is crucial to account for how the firm differentiates its product.

Evidence of a connection between a firm's use of IT and its marketing objectives would suggest that these traditionally intangible variables add a new dimension to the firm's measured output. If this is true, then productivity studies (even at the firm level) may need to include the firm's objectives to identify output correctly. Measured output can no longer be limited to simply counting widgets.

Measures of productivity--defined as the effect of IT on output--must incorporate a firm's competitive strategies. This connection of IT with competitive strategy is important for

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[1] Brynjolfsson (1993) and Wilson (1993) survey the literature that investigates the impact of information technology on productivity.

understanding one of many reasons the productivity paradox initially existed. Suppose two

trucking firms provide the (seemingly) exact same service: the delivery of heavy machinery. Yet

one firm has on-time performance as its most important objective, while the other firm markets

itself as having the lowest freight rate. Each firm uses IT differently depending upon how each

markets its service, even though both may deliver one machine per day. If output is measured as

the number of machines delivered, the relationship between productivity and IT use will be

mismeasured. The on-time performer delivering an asphalt spreader to a construction site two

hours late can count its output as zero. The lowest-rate carrier moves that same spreader when it is

idle from one storage site to another. If that delivery is a few hours late it is still a productive day.

The on-time performer will differentiate its service--timely delivery of the spreader--by using

sophisticated IT. The lowest-rate firm has little need for the same technology. Production studies

that aggregate over all firms delivering heavy machinery will not accurately gauge the true impact

of IT.

The difficulty of measuring output in the face of accelerating use of technology is clearly

important in the modern economy, yet the existing empirical literature is in its early stages. Until

now, data sets containing both detailed output and financial characteristics, as well as particular

types of firm-specific technologies, have been hard to find. Even with the recent availability of

firm-level data explored by Brynjolfsson and Hitt (1996), and detailed truck-level data explored by

Hubbard (1998), still the issue of how to measure output precisely has not been fully explored.

We do not attempt to measure productivity in this paper, but we do uncover evidence indicating

that given the use of IT to differentiate a firm's product, marketing objectives must be taken into

account when measuring output.

We use a new data set that contains information about firms' objectives, detailed

technology use, and financial and operating characteristics. Our probit and ordered probit

estimations explain the use of three levels of technological sophistication. The groups of

technology that reflect intensity are intuitively straightforward. The categories are 1) no

technology, 2) two-way radios or cell phones, or pagers, and 3) automatic vehicle location (AVL), or on-board-computers, or satellite communications.[2] We test whether IT use responds to truckers' haul characteristics differently depending upon the firm's primary marketing objective.[3] The empirical models control for key variables, including complementary technologies, operating characteristics, financial attributes, and industry-wide organizational structure.[4]

Our results show that a firm's marketing objective is a key factor in determining the patterns of IT use. Haul characteristics have a statistically significant influence on IT use for firms with a primary marketing objective of on-time performance. For those firms not concerned with on-time performance, this is not the case. We infer from these results that two firms could be delivering the same product, yet be using different levels of technology owing to the particular market niche they have carved. A firm's choice to use sophisticated IT depends more upon the way a product is delivered (e.g., on-time versus lowest freight rate) rather than *what* product is delivered. Moreover, the patterns of IT use that we observe suggest that the number of products delivered is not the only component of the measured output. We take these results as evidence that output measures should incorporate the firm-specific objective that reflects the customer's perception of a successfully delivered good.

After a summary of the related literature and a brief description of the trucking industry in section 2, section 3 presents the empirical implementation. Section 4 describes the data, section 5 the results and implications and section 6 offers concluding remarks.**2.**

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[2] The probit model simply collapses the first two categories of the ordered probit into one category.
[3] The haul characteristics in our model include the time-sensitivity of the goods, and the route variability of the haul.
[4] Our models distinguish between information-gathering technologies (dependent variable) and information-processing technologies (explanatory variable). Please see the variable descriptions and expected coefficients in the data section below for a detailed explanation of the distinction.

Literature Review and the Trucking Industry

Porter (1985a,b,c) lays the groundwork for understanding the complex relationship between a firm's use of IT and the nature of that firm's output. Firms *must* adopt some forms of IT just to survive in a quickly changing environment. Technology changes industry structure, creates competitive advantage, spawns completely new businesses, and literally transforms industries by actuating new approaches to competitive behavior. Firms are increasingly able to customize products to serve small market niches--thus IT enhances a company's ability to differentiate itself. Products have been reshaped by the use of IT, and the product's definition must now include multidimensional quality characteristics such as, in the motor carrier industry, whether the truck delivers the product on time or at the lowest freight rate.

Porter recognized early that the influence of IT on the modern economy would make it difficult to pin down a precise definition of the firm's output. Indeed a "productivity paradox" emerged in the 1980s literature, and this paradox in no small part reflected Porter's observations that output, transformed by IT, would be difficult to measure for many reasons. Roach (1987) and Solow (1987) first recognized this paradox--no clear evidence of productivity increases as a result of IT spending. Their premature conclusions, summarized by Solow's statement that "we see the computer age everywhere except in the productivity statistics," were based on early and aggregate data. As Porter implicitly predicted, it was too early for the data to reveal the true long-term benefits of IT--production processes don't change overnight. Also, even if the IT benefits existed, they were washed out in the aggregate data.

The ensuing research that investigates the influence of IT on firms' performance is large, and is reviewed by Brynjolfsson (1993) and Wilson (1993). The results from these studies are mixed, suggesting positive, negative, and zero effects of the use of technology on productivity. The assorted results can be only partly explained by problems stemming from the use of aggregate data (Morrison and Berndt 1990), small sample size of firm-level data (Loveman 1994), unreliable data (Siegel and Griliches 1991), or misspecifications, such as using profits as performance

measures (Dos Santos et al. 1993). More recently, examinations of large firm-level time-series data by Brynjolfsson and Hitt (1995, 1996), Lichtenberg (1995), and Dewan and Min (1997) indicate that IT might enhance productivity.

Even after careful investigation of representative microdata, a nagging question remains-- what reflects the true output of the firm? In today's highly specialized economy, particularly in the service sector, output is certainly more than merely the number of widgets produced. Instead, to measure output one must take into account the value provided to the customer. Brynjolfsson and Hitt (1996) acknowledge that there is "an inherent difficulty of measuring the benefits of IT investment." Recognizing this, they queried managers to determine their justifications for investing in IT. The most important reasons were customer service, cost savings, timeliness, and quality. Indeed, Brynjolfsson and Hitt (1995) suggest that future research examine subsamples of IT data based on organizational form and management strategy. Our paper does precisely that by exploring how the use of IT varies in response to the manager's perception of what is important-- such as timeliness.

A clear illustration of the difficulty in defining output as a result of IT can be found in the motor carrier industry. Trucking offers a prime test case since as in any service, several nonphysical components compose the firm's output. Also the industry has recently become technologically intensive, and technology use is heterogeneous.

Deregulation (1978-79) stimulated competition among previously unrelated trucking firms. The Interstate Commerce Commission (ICC) eased its strict entry policy by granting operating certificates at an accelerated rate. Because of this open-door policy along with more flexible carrier rates, the industry experienced a drastic restructuring and reorganization (Zingales 1998, Hubbard 1998, Swan 1997). Truckers could now haul goods, relatively unfettered by previously constraining regulations. The availability and proliferation of IT throughout the trucking industry coincided with this deregulation. New and existing firms needed to carve out niches, i.e.,

differentiate their products by offering services related to their "core competence" or comparative advantage.

Zingales (1998) finds that both the fittest (economically efficient) as well as the fattest (substantially liquid) trucking firms survived the deregulation. IT such as cellular phones and electronic data interchange (EDI), coupled with deregulation played an important role at this time by enabling entry into otherwise untouchable markets. Smaller (or newly entering) firms that perhaps did not have the financial ability to buy sophisticated technology were forced to be the fittest and specialize along a different path than the larger firms. Firms with the ability to borrow more easily, or with more cash availability (the fattest), could more quickly adopt the sophisticated and expensive technologies, such as satellite communications.

Porter's insight that IT use would make output difficult to measure is particularly important in the trucking industry and is highlighted by the findings of Swan (1997) and Zingales (1998). Swan shows that trucking firms that change their operating routines will experience decreased productivity and face an increased risk of failure. Zingales investigates the increased risk of bankruptcy in the post-deregulation trucking industry. Surviving firms were among the fittest and the fattest and were precisely those who adjusted their operating routines to the changing needs of the industry. The adjustment of operating routines was often associated with the adoption of IT to gain a market niche and exploit the firm's core competence. This dynamic market made it *increasingly* difficult to measure output and consequently, the productivity resulting from IT investment.

Hubbard (1998) investigates where and why IT is valuable in the trucking industry. He uses truck-level data to explore how the use of two types of on-board computers are influenced by detailed carrier, shipper, and haul information. He finds that trip recorders, a technology that enables incentive benefits, are more common on trucks operating far from home, making fewer stops, within private fleets, and on trucks that are under longer-term use agreements. Electronic vehicle management systems (EVMS) (associated with coordination benefits) are more common as

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haul-length increases, within for-hire fleets, and on trucks that are under longer-term use agreements.

Our investigation is similar to Hubbard (1998) in that both papers explore the determinants of IT use. Yet we ask a different question, owing to our access to information about the firm's marketing objectives, more detailed technology data, and the firm's financial characteristics. Hubbard's finding that both incentive- and coordination-related benefits make IT valuable complement our finding that IT use depends upon the firm's marketing objectives. For example, the goal of being an on-time performer (a key variable in our investigation) is certainly closely related to *both* incentive- and coordination-related benefits of IT. Hubbard did not explicitly consider how his results related to productivity, yet those results support our conclusion. The firm needs to be concerned with *both* incentive- and coordination-related benefits of IT in order to meet its objective of being on time.

The Empirical Model

We observe the use of IT in discrete amounts. For example, either trucking firm uses cell phones or it does not. Yet the need for technology in production is truly a continuous, unobserved (latent) variable. This variable--the sophistication of IT use--is determined by a firm's operational characteristics and marketing objectives. We model this latent variable in two ways. The latent variable has either one observed threshold (a probit model) or two observed thresholds (an ordered probit model). Each threshold denotes the transition from one set of technologies to another. As the firm crosses a higher threshold, more sophisticated technologies are used. Our goal is to identify empirically both these thresholds and the firms' characteristics that affect the observed use of technology.

Our first specification, the probit model, captures a simplistic view of adopting IT. In this world the firms are either high- or low-technology users. High technologies are state-of-the-art information-gathering technologies that include satellite communications (SATCOM), on-board

computers (OBC), or automatic vehicle location and tracking devices (AVL).[5] Low technologies are basic communication technologies that include two-way radios, cell phones, or pagers. The low-technology group in this specification also includes firms using none of the above communication technologies. These firms perhaps depend upon local telephone networks.

Our second approach, the ordered probit, recognizes that firms using no communication technologies whatsoever may have very different operational characteristics than their counterparts using even the most basic gadgets. Hubbard (1998) investigates a problem similar to ours and uses a multinomial logit. His three categories distinguish firms with no technology from those with trip recorders and those with EVMS. We have grouped and ordered our six information-gathering technologies according to their sophistication. For example, a satellite communications network gathers more information than a two-way radio and is in the high-technology category. Using an ordered probit helps us to capture this inherent ordering of the sophistication of IT use.

Both of our empirical specifications are summarized here. The probit model simply collapses the first two categories of the ordered probit, presented below, into one category.

$$t_i = \beta\, X_i\, +\, \varepsilon$$
$$y = 1 \text{ if no IT is used i.e., } t_i \quad 0$$
$$y = 2 \text{ if only CELL or CB or PAGER, i.e. } t_i \quad \mu_1$$
$$y = 3 \text{ if OBC or AVL or SATCOM, i.e. } t_i \quad \mu_2$$

Here, t_i is assumed to be the unobserved intensity of IT use, while X_i denotes a vector of firm-specific characteristics that may influence the probability of using more sophisticated technologies. The latent variable, t_i, determines the use of a more sophisticated group of technologies for the ith trucking firm. The vector X_i contains the time-sensitivity of the route, route variability, average load, average haul, total equipment, debt to equity ratio, net profit margin and the sum of five additional information-processing (complementary) technologies. The cumulative distribution of ε

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[5] Please see the data section and the appendix below for a detailed description of technologies.

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is assumed to be normal. The unobserved index t_i is assumed to have two thresholds, μ_1 and μ_2.

Crossing each threshold is associated with a transition to using a new set of technologies. The

variable y denotes three sets of observed technologies, which are grouped in order of increasing

sophistication described above. Maximum likelihood estimates of μ and β are obtained to

investigate the impact of haul characteristics on IT use.

4. Data

Empirical evidence about the influence of a firm's objectives on IT use is scarce, because

this type of data is rarely collected. Recently a data set containing detailed information on

marketing objectives as well as IT use has become available. This data is the Motor Carrier Safety,

Operations, and Technology (MCSOT) Survey, conducted by the American Trucking Association

(ATA). The survey contains a special module in which respondents report the use of various types

of information-gathering and information-processing (complementary) technologies. In addition to

being the unique source of detailed IT data, the survey contains other information (e.g., a firm's

ranking of marketing objectives, and operational characteristics) relevant to testing the hypothesis

outlined above. The survey information used below was collected in June 1998 and the data for

technology use covers both 1996 and 1998.

Our empirical investigation also uses data drawn from a second source, the US Department

of Transportation's Bureau of Transportation Statistics (DOT). The bureau queries 2800 class 1

and class 2 for-hire trucking firms ($3 million revenue) that are engaged in interstate commerce.[6]

Owing to nonresponses, the final 1996 survey contains information on 1800 firms. The DOT data

contains the name of each firm as well as other detailed information (e.g., full income statement,

balance sheet, labor force information, equipment data, and operating statistics). These data

(specific variables described below) provide control variables for our empirical model.[7]

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[6] For-hire trucks are those that are not part of a private fleet. For example the hypothetical firm Acme Retailers employs a for-hire trucking company to deliver goods to its retail outlets--Acme doesn't maintain its own private fleet.

[7] Both the Transportation Technical Services Company (Blue Book database) and the ATA (Financial and Operating Statistics) organize and summarize the DOT data into machine readable form. We use variables from both sources.

The ATA's MCSOT survey was sent to the 1800 firms contained in the DOT data, and 755 of these responded. Ignoring missing values (n=26), extreme values for firm size (n=8), and firms that report owning no trucks (n=18) leaves our final merged data sample at 703 firms.

Variable Descriptions and Expected Coefficients

A.   Marketing Objectives and Commodities Hauled

Table 1 describes the firms' primary marketing objectives according to the industry's conventional organizational structure--truckload (TL) and less-than-truckload (LTL).[8] For a detailed description of these categorizations, see Swan (1997). Briefly stated, TL carriers are point-to-point operators--single trucks hauling their load directly from origin to destination-- typically carrying more than 10,000 pounds. LTL carriers use an airline-type hub-and-spoke system with shipments of less than 10,000 pounds. The table shows the vast majority of the firms market themselves as on-time performers (OTP-72%); 85% of the LTL firms are OTP while only 77% of the TL firms are OTP.

Table 2 describes the percentage of firms that haul each commodity.[9] The patterns of this table seem reasonable. More firms haul goods that are normally associated with timely deliveries whose primary marketing objective is on-time performance versus non-on-time performers. For example, parcels, processed food, and retail goods are hauled by more on-timers than non-on-timers (see columns 3 and 4). On the other hand, more non -on-time performers haul nonperishable goods, such as dump-trucking and mineral ores. More firms whose objective is to provide specialized and dedicated equipment (see column 7) haul hazardous chemicals and heavy machinery. A notable overall pattern is that various firms represented by varying marketing objectives haul virtually all products. For example, 13% of on-time performers haul heavy machinery while 13% of firms offering the lowest freight rate also haul heavy machinery.

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[8] Our entire sample (*un*censored) includes 703 firms. Only 611 firms (table 1, column 2--all firms censored) could unambiguously categorize their marketing objective.

[9] Since each firm might haul many different products, the columns do not add to 100.

B.   Technologies

Our empirical specification emphasizes the distinction between information-gathering and information-processing (complementary) technologies. Following Hubbard (1998), we say that an information-gathering technology is one that resides on the truck. The question we examine--what determines technology use--refers to information-gathering technologies. For example, we categorize satellite communications as a gathering technology. One of its functions is to provide the driver and dispatchers information about the location of the truck. An example of a technology that processes information is computer-aided dispatching. Sometimes a gathering technology cannot be used without a processing technology, whereas in other cases they can be used independently.

We acknowledge that there are many gray areas in categorizing these technologies, and that it is difficult to create clear partitions. We assume the following reasonable, intuitive categories. The information-gathering technologies--used to create our dependent variable--are cell phones, two-way radios, and pagers (low technology), and automatic vehicle location systems, satellite communications, and on-board computers (high technology). The information-processing technologies are electronic data interchange, computer-aided routing, computer-aided dispatching, the internet, and maintenance-tracking software. We use the information-gathering technologies to construct our limited dependent variable describing technology use. The sum of the five processing technologies is used as a control variable.[10]

Table 3 contains descriptive statistics for the use of each technology. The incidence of technology use is as expected. Among the gathering technologies for all firms (column 2), the low technologies--cellphones and pagers--are used by the largest percentage of the firms, 61% and 56% respectively. Fewer firms (automatic vehicle location systems (23%), satellite

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[10] Hubbard (1998) emphasizes the importance of processing technologies in explaining the use of information-gathering technology. He labels the processing technologies "backoffice" technologies. His data does not contain information on these backoffice technologies, and he takes special care to empirically confirm that his model has no bias owing to the exclusion of this type of technology.

communications (32%), and on-board computers (7%) use the more sophisticated and more expensive gathering technologies (high technologies). Two-way radios are both low technology and inexpensive, yet are used by a relatively small percentage of firms (31%). Perhaps the usefulness of two-way radios in improving productivity has been overshadowed by cell phones and pagers. Finally, it seems reasonable that very few firms (5%) use no technology at all.

Reasonable patterns of technology use emerge by comparing on-time performers (OTPs, column 3) with firms offering the lowest freight rate (LFR--column 4), and with all firms that are *non*-OTP. The sophisticated technologies (e.g., automatic vehicle location systems) are used by more OTP firms (compared to LFR or *non*-OTP) whereas the low technologies (e.g., cellphones) are used by more LFR and *non*-OTP firms (than by OTP firms.) The OTP firms also use more information-processing technologies (e.g., computer aided routing and dispatching) than their LFR counterparts. It seems that the OTP firms use the higher technologies to meet their marketing objective, even though these technologies are generally more expensive.

C.   Explanatory Variables

The empirical model described above contains a vector of control variables X_i that are assumed to influence the probability of using more highly sophisticated information-gathering technologies. Table 4 contains sample means of these variables.

One of our two key explanatory variables describes the percentage of the firm's dispatches that are time-sensitive or perishable (row 1). The variable ranges from 1 to 5, 1 indicating that none of the dispatches is time-sensitive, 2 indicating that 1-25% are time-sensitive, etc. The 3.9 average for time-sensitivity in table 4 indicates that for the average firm, between 26 and 50% of their dispatches are time-sensitive. As expected those who market themselves as on-time performers haul more time-sensitive goods than do non-on-timers. We expect that the probability of using more sophisticated technology will increase as the proportion of time-sensitive hauls increases *if the firm markets itself as an on-time performer.*

Our second key explanatory variable describes the variability of the company's routes (row 2). It ranges from 1 to 4, 1 indicating not at all variable, and 4--indicating extremely variable. The probability of using sophisticated technology should rise as the route variability rises, *only with firms for which the variability of the route may preclude them from obtaining their objective*. For example, an on-time performer that hauls mostly within the hub-and-spoke system (LTL hauler) should be expected to use more sophisticated technology in response to an increase in route variability. In contrast, a point-to-point hauler (TL hauler) is not expected to use high technology gadgets in response to more variable routes. Their objectives are different. The incentive to use information-gathering technology should, then, be clearly related to how the production activity is organized.

Both time-sensitivity and route-variability are firm-specific haul characteristics. We expect that these characteristics will influence the use of IT differently, depending upon how firms market themselves to their customers. Our data include a variable that ranks each firm's marketing objectives among five items--providing the lowest freight rates, on-time performance, short turn-around, safety of performance, and availability of specialized equipment. We assume that if a firm ranks on-time performance as its most important marketing objective, then being on time is a key component of that firm's output. With this in mind, we run separate regressions on firms with different marketing objectives.

Grimm et al. (1989), McMullen (1987), and McMullen and Tanaka (1995) explain costs in the motor carrier industry and include output attributes as explanatory variables to help capture the heterogeneity of output. Our investigation of IT use has the same concern--to reduce heterogeneity in our sample as much as possible--so that the impact of marketing objectives can be more clearly examined. The output attributes we include to reduce heterogeneity are the average load and the average haul. The average load indicates the number of tons transported by each unit dispatched. The average haul length measures how far the average unit travels each time it is dispatched.

A low average load indicates that the trucks operate more frequently, reflecting higher quality service. Trucks with lighter loads are more often LTL carriers where operating costs are typically higher for many reasons. Coupled with the need for more advanced hub-and-spoke infrastructure, an LTL carrier should find more sophisticated technology useful for coordination purposes (Hubbard 1998). We expect that trucks with a smaller average load will use more sophisticated technology--a negative coefficient on average load.

A longer average haul length indicates the need for more sophisticated technology such as satellite communications and automatic vehicle location systems. The further the truck is from home, the less cost-effective is a cell phone or a pager. We expect a positive coefficient on average haul. Columns 3 and 4 in Table 4 reveal that on-time performers have a lower average load and a lower average haul than their counterparts that offer the lowest freight rate. This makes sense, since absent the need to be on time, firms offering the lowest freight rate concentrate on reducing average costs by making sure their trucks are fuller (higher average load) and travel longer distances (higher average haul).

Total equipment is defined as the number of trucks plus tractors plus trailers. This variable controls for the size of the firm's operation. On-time performers operate more units than LFR firms (Table 4). Firms offering the lowest freight rate as their specialty don't need the larger fleets to ensure on-time delivery. We also include the net profit margin (net income as a percent of gross revenue) as a control variable to ensure that our results are not driven by the firm's financial well-being.

Zingales (1998) explains the survival of *post*-deregulation trucking firms with the level of *pre*-deregulation leverage. He finds that highly leveraged firms are less likely to survive. We include the debt-to-equity ratio to control for the firm's leverage and are uncertain about this variable's coefficient. More highly leveraged firms may be indicative of the ability to borrow to acquire sophisticated IT, but it may also indicate that the firm has already exhausted its borrowing capacity. If the firm is unable to borrow it is less capable of adopting sophisticated technology.

5. Results

Main Findings

Our estimation strategy investigates the impact of haul characteristics on the use of information technology. The question to be examined is: Does the impact of haul characteristics on IT use vary depending upon the firm's marketing strategy? If the answer is yes, then two firms may seem to offer identical services yet in fact offer different services as a result of disparate marketing strategies and varying IT usage. Outputs might then be grouped incorrectly in productivity studies, and the impact of IT on productivity may be mismeasured.

We investigate the variation in IT use with two separate specifications. In the first specification, we categorize information-gathering technologies used on the truck as either high-tech or low-tech. These two groups serve to define our dependent variable for probit estimates (table 5). In our second specification we create three groups of IT use, in order of increasing sophistication. These ordered probit estimates are presented in tables 6 and 7. A list of variable means for all explanatory variables is presented in table 4. Table 5, specification 1 predicts the use of IT for the entire sample (n=703). Specifications 2 and 3 partition the sample according to whether or not the firm's primary marketing objective is to be an on-time performer.[11]

The evidence indicates that a firm's use of increasingly sophisticated IT varies considerably depending upon its marketing strategy. For those firms that market themselves as on-time performers (table 5, specification 2), the estimated probit coefficients for both the proportion of time-sensitive hauls and for the firm's route variability are positive and significant at the five-percent level. For firms with marketing objectives *other than* on-time performance, the coefficients for those same key haul characteristics are statistically insignificant (specification 3).

For on-time performers (specification 2) at sample means, a 25% rise in the number of time-sensitive hauls increases the probability of using sophisticated IT by 5%. For *non-* on-time

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[11] The number of observations for on-timers (439) plus non-on-timers (172) does not sum to 703 because we dropped 92 firms that reported more than one primary marketing objective.

performers, the same 25% rise in time-sensitive hauls has a statistically insignificant impact on technology use. The impact of time-sensitive hauls on technology use is 50% higher for on-timers compared to the entire sample.

The impact of route variability on the use of information-gathering technology follows the same pattern as the impact of time-sensitive hauls. On-time performers use more sophisticated technology as routes become more variable, while for *non*-on-timers route variability has no impact. For on-time performers, a 25% rise in route variability increases the probability of using sophisticated technology by 7%. The impact of route variability on technology use is 100% higher for on-timers compared to the entire sample.

The sharp difference between the estimates for on-timers versus non-on-timers supports the hypothesis that a firm's measured output must incorporate information about service-oriented firm-specific goals. Productivity studies that aggregate over all firms producing the same physical good are likely to misrepresent the true output of the firm. Firms with different customer-oriented goals (e.g., on-time performers vs. non-on-time performers) use different technologies in response to variations in the *same haul characteristics*. The services, and therefore the output, that the on-time performer produces are clearly different.

The remaining estimates in table 5 for on-timers (specification 2) accord with several of our predictions outlined in the data section above. A notable (overall) result is that the combined explanatory variables perform better at explaining technology use within a particular marketing objective (on-timers) than for the sample that includes all other marketing objectives combined (non-on-timers).

To reduce sample heterogeneity we included average load and average haul as output attributes. Trucks with a smaller average load use more sophisticated IT, possibly owing to the need for more coordination. The significantly positive impact of average haul indicates that trucks traveling longer distances are more likely to use sophisticated IT.

The total equipment coefficient suggests that larger operations find the more sophisticated technologies useful, perhaps again for coordination purposes. Yet the insignificant coefficient on net profit margin raises doubts about firms buying IT simply because they have the cash.

Firms use significantly higher levels of information technology as they become more leveraged. It may be that they are borrowing to acquire some of the more expensive technologies such as satellite communications. Finally, it makes sense that firms with more highly sophisticated gathering technologies will be more likely to have more processing (complementary) technologies.

Additional Findings

We address possible objections to our above specification by splitting our sample in a more traditional manner (TL and LTL), and by using an alternate (ordered) categorization of the technologies contained in the dependent variable. Our additional findings indicate that our main results are robust.

One alternative for creating our dependent variable is to use a categorization of technologies that reflects an order of sophistication that includes no technologies, some low-level gadgets, and highly sophisticated gadgets. Grouping together firms that use no technologies with those using low-level yet highly effective technologies such as cell phones may raise questions regarding the validity of our result. To address this potential concern we re-estimate the table 5 specifications using the ordered probit model described in the empirical specification section above. Our results, presented in table 6, still indicate that firms choose more sophisticated technologies differently depending upon their marketing objective.

Second, our results may be questioned since we neglect to control for the highly heterogeneous organizational structure in the motor carrier industry. As mentioned earlier, TL and LTL carriers operate differently along many dimensions. We partition our sample along the TL/LTL lines, yet we find that this categorization is not the main concern when estimating IT use. Specifications 1 and 2 in Table 7 indicate that for all firms neither time-sensitivity nor route

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variability has a statistically significant impact on technology use. This split does little to resolve the problem that occurs owing to aggregating over heterogeneous competitive strategies.[12]

      Specifications 3, 4, and 5 in table 7 support our previous conclusion: the important categorization in explaining variation in IT use is the firm's primary objective for quality customer service. There is a notable difference in results between TL and LTL firms for on-timers. Specification 4 (LTL firms only) reveals that route variability has a significantly positive influence on IT adoption. This statistically significant effect is not present for only TL firms (specification 3). For on-timers, the time-sensitivity of hauls has a statistically significant positive impact on technology use. This result holds for both TL and LTL firms (specifications 3 and 4). For TL firms that are not concerned with on-time performance (specification 5), these haul characteristics have no impact.[13] A notable difference in results between TL and LTL firms for on-timers is that the route-variability coefficient is much larger for the LTL firms. Firms in both categories may have equivalently variable routes yet associate different uncertainties with that variation. The uncertainty is likely to be higher for the LTL firms, and therefore, the more sophisticated technology would be more useful for them.

6. Conclusion

      The estimates presented above indicate that marketing objectives are a pivotal factor in determining the use of information technology. We find that sophisticated IT is used differently by firms with similar haul characteristics yet different marketing strategies. Firms that market themselves as on-time performers use IT differently than do firms that have other marketing criteria. This finding is important because marketing strategies can add distinct quality dimensions to a good or service. Previous research has found that a primary reason for the productivity paradox is the incorrect measuring of outputs. Our results indicate that output cannot be measured correctly until the impact of marketing objectives--the quality dimension of the good--is recognized. Even in firm-level productivity studies, precise measurement of the influence of IT on

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[12] In table 7, all firms (columns 2 plus 3--325 firms) excludes specialized carriers. The censored sample (columns 4 through 6--283 firms) also excludes firms that listed more than one primary marketing objective.

productivity should control for the quality dimension of the good. One way to accomplish this might be to group firms producing similar goods and services according to their primary marketing objectives.

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Table 1

Distribution of Primary Marketing Objectives

Firm's Primary Marketing Objective	Organizational Structure of the Market			
	All Firms (Censored)[*]	Only TL	Only LTL	Specialized
On-Time Performance	439 (71.85%)	184 (77.31%)	45 (84.91%)	210 (77.19%)
Lowest Freight Rate	61 (9.98%)	18 (7.56%)	6 (11.32%)	37 (11.56%)
Safety	32 (5.24%)	12 (5.04%)	0	20 (14.06)
Specialized/Dedicated Equipment	66 (10.80%)	19 (7.98%)	2 (3.77%)	45 (3.77%)
Short Turn-Around on Customers Request	13 (2.13%)	5 (2.10%)	0	8 (2.50)
Non-On-Timers (Rows 3 through 6)	172 (28.15%)	54 (22.69%)	8 (15.09%)	110 (22.91%)
Sample Size	611	238	53	320

* The entire sample (all firms *un*censored) is 703 firms. The censored sample of 611 (column 2) excludes 92 firms that listed more than one primary marketing objective.

Table 2

Percentage of Firms Hauling Each Commodity

Goods Hauled	Firm's Primary Marketing Objective						
	All Firms[*]	On-Time Performance	Non-On-Time Performers (Cols. 4-7)	Lowest Freight Rate	Safety	Specialized Equipment	Short Turn Around
Auto Parts or Vehicles	0.16	0.16	0.12	0.08	0.19	0.11	0.23
Raw Petroleum Products	0.04	0.03	0.08	0.11	0.03	0.06	0.08
Mine Ores	0.03	0.02	0.05	0.03	0.09	0.06	0.00
Processed Food	0.24	0.27	0.17	0.18	0.09	0.17	0.31
Parcels	0.05	0.06	0.01	0.02	0.00	0.02	0.00
Heavy Machinery	0.15	0.13	0.19	0.13	0.25	0.23	0.15
Refined Petroleum Products	0.11	0.10	0.13	0.13	0.03	0.17	0.15
Forest Products	0.15	0.15	0.18	0.11	0.09	0.29	0.15
Farm Fresh Products	0.14	0.14	0.12	0.15	0.06	0.14	0.08
Refuse	0.02	0.02	0.005	0.00	0.00	0.00	0.08
Household Goods	0.06	0.05	0.06	0.10	0.03	0.05	0.00
Dump Trucking	0.10	0.07	0.17	0.16	0.13	0.20	0.23
Retail	0.14	0.15	0.10	0.11	0.09	0.12	0.00
Building Materials	0.24	0.23	0.26	0.21	0.28	0.32	0.15
Hazardous Chemicals	0.15	0.15	0.19	0.20	0.06	0.27	0.08
Sample Size	703	439	172	61	32	66	13

Notes: The percentages for each column do not add to 100% because most trucking firms haul more than one commodity.
 * The entire sample (column 2--all firms *un*censored) is 703 firms. The censored sample (columns 3 plus 4) of 611
   excludes 92 firms that listed more than one primary marketing objective.

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Table 3

Sample Means of Technology Use

Information Technology Use	Firm's Primary Marketing Objective			
	All Firms[*]	On-Time Performance	Lowest Freight Rate	Non-On-Time Perfomers
Low Technology--Information Gathering				
Cellphone 1998	0.61	0.60	0.69	0.67
Pager 1998	0.56	0.52	0.64	0.66
Two-way Radio 1998	0.31	0.31	0.43	0.34
High Technology--Information Gathering				
Auto Vehicle Location 1998	0.23	0.25	0.10	0.20
On Board Computers 1998	0.07	0.07	0.03	0.06
Satellite Comm. 1998	0.32	0.32	0.21	0.30
Information Processing				
Computer Aided Dispatching 1996	0.29	0.31	0.18	0.28
Computer Aided Routing 1996	0.22	0.23	0.15	0.24
Electronic Data Interchange 1996	0.29	0.32	0.26	0.28
Internet 1996	0.10	0.10	0.08	0.09
Maintenance Tracking Software 1996	0.17	0.19	0.15	0.16
Others				
No IT use	0.05	0.06	0.08	0.03
No Info Gathering Technology 1998	0.11	0.13	0.11	0.08
No Info Processing Technology 1996	0.47	0.45	0.59	0.45
Sample Size	703	439	61	172

* The entire sample (column 2--all firms *un*censored) is 703 firms. The censored sample (columns 3 plus 5) of 611 excludes 92 firms that listed more than one primary marketing objective.

Table 4

Sample Means of Explanatory Variables

Firm Characteristics	Most Important Marketing Objective			
	All Firms[*]	On-Time Performance	Lowest Freight Rate	Non-On-Time Performers
Time-Sensitive Hauls (Scale:1-5)	3.90	3.98	3.85	3.80
Route Variability (Scale:1-4)	3.20	3.15	3.28	3.29
Average Load (Tons)	14.93	14.64	15.26	16.52
Average Haul (Miles)	554.06	521.64	751.15	637.42
Total Equipment (Power Units and Trailers)	414.48	437.55	260.85	356.12
Leverage (Debt/Equity)	0.56	0.57	0.49	0.53
Net Profit Margin (Net Income/Gross Rev.)	1.58	1.59	1.32	1.83
Information Processing Technology (Scale: 0-5)	1.08	1.15	0.82	1.04
Sample Size	703	439	61	172

* The entire sample (column 2--all firms *un*censored) is 703 firms. The censored sample (columns 3 plus 5) of 611 excludes 92 firms that listed more than one primary marketing objective.

Table 5

Probit Estimates – Impact of Haul Characteristics on IT Use

Variable	Estimated Coefficient (Standard Error)		
	All Firms[a]	On-Timers	Non On-Timers
Time Sensitive Hauls	0.082 (0.042)**	0.125 (0.056)**	-0.003 (0.083)
Route Variability	0.083 (0.068)	0.175 (0.089)**	-0.130 (0.142)
Average Load (Tons)	-0.0174 (0.0071)**	-0.021 (0.0100)**	-0.0007 (0.0136)
Average Haul (Miles)	0.0002 (0.0001)**	0.0003 (0.0001)**	0.0005 (0.0002)**
Total Equipment (Power Units and Trailers)	0.0002 (0.00006)***	0.0001 (0.00006)*	0.00122 (0.00031)***
Leverage (Debt/Equity)	0.750 (0.208)***	0.818 (0.260)***	0.023 (0.455)
Net Profit Margin (Net Income/Gross Rev.)	0.020 (0.013)	0.022 (0.017)	0.001 (0.025)
Information-Processing Technology (Scale: 0-5)	0.203 (0.040)***	0.201 (0.049)***	0.252 (0.091)***
Log Likelihood	-416.23	-260.84	-86.56
Dependent Variable Mean	0.36	0.36	0.47
Sample Size	703	439	172

Notes: Dependent variable is 1 if the firm uses Satellite Communication or On-board Computers or Automated Vehicle Locators. Dependent variable is zero other wise. *, **, *** indicate 90%, 95% and 99% level of significance respectively.
[a] The entire sample (column 2--all firms *un*censored) is 703 firms. The censored sample (columns 3 plus 4) of 611 excludes 92 firms that listed more than one primary marketing objective.

Table 6

Ordered Probit Estimates –Impact of Haul Characteristics on IT Use

Variable	Estimated Coefficient (Standard Error)		
	All Firms[a]	On-Timers	Non On-Timers
Time-Sensitive Hauls	0.059 (0.035)*	0.109 (0.047)**	-0.035 (0.070)
Route Variability	0.043 (0.057)	0.064 (0.074)	-0.015 (0.120)
Average Load	-0.014 (0.0059)**	-0.0184 (0.0082)**	0.0032 (0.0111)
Average Haul	0.0001 (0.0001)	0.0002 (0.0001)	0.0002 (0.0002)
Total Equipment (Power Units and Trailers)	0.00019 (0.00006)***	0.00009 (0.00006)	0.00126 (0.0003)***
Leverage (Debt/Equity)	0.584 (0.178)***	0.631 (0.223)***	0.086 (0.383)
Net Profit Margin (Net Income/Gross Rev.)	0.020 (0.011)	0.022 (0.014)	0.005 (0.020)
Information-Processing Technology (Scale: 0-5)	0.164 (0.036)***	0.161 (0.044)***	0.216 (0.082)***
Cut 1[b]	-0.444 (0.273)*	-0.134 (0.352)	-0.907 (0.565)
Cut 2[b]	1.219 (0.275)***	1.430 (0.356)***	1.181 (0.568)**
Log Likelihood	-634.17	-407.17	-130.09
Sample Size	703	439	172

   Notes: Dependent variable is 1 if the firm does not use any information-gathering technologies. Dependent variable is 2 if the firm only uses low technologies--Cellphones or Pagers or Two-Way Radios. Dependent variable is 3 if the firm uses high technologies--Satellite Communications or On-board Computers or Automated Vehicle Locators. Dependent variable is zero other wise. *, **, *** indicate 90%, 95% and 99% level of significance respectively.
   [a] The entire sample (column 2--all firms *un*censored) is 703 firms. The censored sample (columns 3 plus 4) of 611 excludes 92 firms that listed more than one primary marketing objective.
   [b] The estimated thresholds (Cut1 and Cut2) are significantly different from each other at 99% level of significance.

Table 7

Ordered Probit Estimates –Impact of Haul Characteristics on IT Use
by
Marketing Objectives and Industry Structure

Variable	Estimated Coefficients				
	All Firms[a]		On-Timers		Non-On-Timers
	TL	LTL	TL	LTL	TL
Time-Sensitive Hauls	0.072	0.192	0.131	0.457	-0.123
	(0.062)	(0.165)	(0.075)*	(0.232)***	(0.162)
Route Variability	-0.069	0.239	0.021	0.497	-0.355
	(0.099)	(0.205)	(0.122)	(0.257)*	(0.239)
Average Load	-0.0063	0.0289	-0.0167	0.0346	0.0359
	(0.0102)	(0.0361)	(0.0127)	(0.0412)	(0.0258)
Average Haul	0.0003	-0.0003	0.0004	-0.0001	0.0005
	(0.0001)**	(0.0007)	(0.0002)**	(0.0009)	(0.0003)
Total Equipment (Power Units and Trailers)	0.00051	0.00002	0.00037	-0.00005	0.00181
	(0.00015)***	(0.00010)	(0.00017)**	(0.00011)	(0.00075)**
Leverage (Debt/Equity)	0.349	1.071	0.437	1.282	-0.118
	(0.302)	(0.811)	(0.356)	(0.978)	(0.716)
Net Profit Margin (Net Income/Gross Rev.)	0.007	0.013	0.007	0.039	0.009
	(0.018)	(0.063)	(0.025)	(0.070)	(0.034)
Information-Processing Technology (Scale: 0-5)	0.141	0.243	0.146	0.311	0.053
	(0.057)**	(0.141)*	(0.065)**	(0.171)*	(0.162)
Cut 1[b]	-0.461	0.372	0.071	2.396	-1.521
	(0.474)	(0.966)	(0.553)	(1.344)*	(1.280)
Cut 2[b]	0.972	3.125	1.452	5.239	0.086
	(0.475)**	(1.056)***	(0.559)***	(1.566)***	(1.262)
Log Likelihood	-245.55	-38.21	-173.92	-27.97	-45.06
Sample Size	266	59	184	45	54

Notes: Dependent variable is 1 if the firm does not use any information-gathering technologies. Dependent variable is 2 if the firm only uses low technologies--Cellphones or Pagers or Two-Way Radios. Dependent variable is 3 if the firm uses high technologies--Satellite Communications or On-board Computers or Automated Vehicle Locators. Dependent variable is zero other wise. *, **, *** indicate 90%, 95% and 99% level of significance respectively.

[a] All firms (columns 2 plus 3--325 firms) excludes specialized carriers. The censored sample (columns 4 through 6--283 firms) also excludes firms that listed more than one primary marketing objective.

[b] The estimated thresholds (Cut1 and Cut2) are significantly different from each other at 99% level of significance.

Appendix: Description of Technologies[14]

This appendix provides brief descriptions of each of the eleven technologies listed in the paper. These technologies are used for fleet management, and to enhance the competitive advantage of the industry and of individual trucking companies by improving the efficiency of goods movements through real-time information exchange and communications, and by providing customers with up-to-the-minute information regarding the location and timing of shipments and deliveries.

Low technology communications and information gathering

1.   Cellular phones

Voice and data are transmitted by these mobile communication devises. While this technology is common, service areas are limited and "dead zones" exist in less populated areas, mountainous areas, tunnels, or anywhere transmitters are sparse.

2.   Two-way radios

Voice conversations are transmitted via these proprietary radio systems. The ranges of two-way radios can extent to 50 miles with the appropriate transmitter.

3.   Pagers

One-way text messages are transmitted to a small receiver via a number of paging networks. The range is only constrained by the type of supporting technology.

High technology for information gathering

4, 5.   Automatic Vehicle Location (AVL), and Satellite Communications (SATCOM)

AVL is a broad descriptive category of technologies to track the location of transponders. It is possible to pinpoint the location of a vehicle using ground-based or satellite technologies. When combined with on-board computers and routing and dispatching software, these systems allow for real-time optimization of fleet routing and dispatching. Drivers, dispatchers, shippers, and receivers can track a truck from pickup to delivery, perform just-in-time deliveries, coordinate intermodal shipments, and provide improved customer service. Satellite communications provide AVL capabilities and also communications between the vehicle and dispatcher. With an on-board computer, two-way text or voice communications can allow for dynamic routing and dispatching, as well as the real-time monitoring of vehicle operating parameters (speed, RPMs, etc.). Satellite systems are less effective in urban areas, because their radio-navigation signals are reflected and distorted by buildings, bridges, power lines, and other structures. Ground-based AVL are more reliable in urban areas which may make this technology more attractive to short-haul motor

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[14] We wish to thank Bob Pritchard for his contribution to this footnote. Parts of this appendix draws heavily, and reproduces portions of information exactly from Commercial Vehicle Fleet Management and Information Systems, Technical Memorandum 3, ITS Fleet Management Technology Resource Guide, prepared by Cambridge Systematics, Inc., in cooperation with ATA Foundation Private Fleet Management Institute. The memorandum was prepared for the Federal Highway Administration, May 1996.

carriers. Since sufficient antenna coverage for ground based systems does not exist throughout the US, satellite systems that have global coverage, can be used more effectively by long-haul carriers.

6.   On-board computers (OBCs)

OBCs are either vehicle based or hand-held computers used to capture information from the vehicle, or by the driver. OBCs are sometimes used as trip recorders, for monitoring vehicle performance measures such as speed, fuel consumption and drivers' hours of service. Information stored in OBCs can be uploaded to the dispatch center using mobile communication systems, or downloaded to a system when the truck returns to its domicile. OBCs are often used as a platform for two way text communications, and sometimes in conjunction with routing and dispatching systems as well as with maintenance-scheduling software. OBCs can provide the following functions:

•   Business Transactions: Registers delivery times, state line crossings, and customer signatures for proof-of-delivery; transmits delivery notifications.
•   Driver Log: Enables drivers to input records of fuel consumption and hours of service using a keyboard and display screen.
•   Vehicle Location Information: Deciphers AVL system transmissions.
•   Vehicle performance data collection: Engine idling, braking, shifting, and acceleration patterns, as well as data from diagnostic systems for ancillary equipment such as refrigeration units can be captured. OBCs can allow for remote diagnostics prior to a malfunction in order to improve the safety performance of vehicles.

Technology for information processing

7.   Electronic data interchange (EDI)

A series of standardized messages comprises the umbrella concept of EDI and allows for computer to computer data transmission. The transmissions can occur between trucking companies and shippers, or between any two trading partners. EDI allows for automatic scheduling, billing, receipt of load acknowledgment, etc.

8, 9.   Computer-aided routing, and dispatching (CAR and CAD):

Routing and dispatching software provides decision support for route selection in order to minimize the time and cost of moving freight. Systems are used to schedule trucks and drivers subject to availability of parameters such as allowable driving hours, size of load, origin and destination. Static systems allow for preplanning. More sophisticated dynamic systems allow routing and dispatch decisions based on real-time truck locations, generate route maps, estimate delivery times and distances, and help improve cost estimates. These software provide the following benefits:

•   Improved dispatcher productivity: Companies report that routing procedures, which previously took staff eight hours with a manual system, now can be finished in one hour.
•   Reduced client inventory costs: With the reliable delivery provided by CAR and CAD systems, "just-in-time" inventory systems can be more commonly used and

"manufacture on demand" is also made feasible. With these software firms no longer need to keep extensive inventories at manufacturing plants.

- Improved communication efficiency: With a computerized system, load information to drivers can be relayed instantaneously.
- Reduced labor costs: Companies do not need to employ logistics experts to operate these systems. Simple user interfaces make it possible for employees without specialized training to operate the system. Shippers can make their routing and dispatching information available on the internet so that receivers can track shipments in real-time thus reducing dispatchers' workloads.

10.	Maintenance tracking software (MTS)

This software optimizes many areas of vehicle maintenance. For example, MTS can track and reorder parts in a repair department or do real-time vehicle diagnostic via satellite communications. As real-time information becomes available about the performance of trucks, MTS is used to continuously improve the performance of vehicles and schedule preventive and emergency repairs as needed in the most cost-effective manner.

11.	Internet

The Internet provides a variety of communications opportunities. Its current most common application allows for low-cost computer to computer messaging and data sharing. EDI is viable via the Internet, replacing the higher cost proprietary telecommunications networks.