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e-Commerce Metrics for Net-Enhanced Organizations: Assessing the Value of e-Commerce to Firm Performance in the Manufacturing Sector

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In this study, we developed a set of constructs to measure e-commerce capability in Internet-enhanced organizations. The e-commerce capability metrics consist of four dimensions: information, transaction, customization, and supplier connection. These measures were empirically validated for reliability, content, and construct validity. Then we examined the nomological validity of these e-commerce metrics in terms of their relationships to firm performance, with data from 260 manufacturing companies divided into high IT-intensity and low IT-intensity sectors. Grounded in the dynamic capabilities perspective and the resource-based theory of the firm, a series of hypotheses were developed. After controlling for variations of industry effects and firm size, our empirical analysis found a significant relationship between e-commerce capability and some measures of firm performance (e.g., inventory turnover), indicating that the proposed metrics have demonstrated value for capturing e-commerce effects. However, our analysis showed that e-commerce tends to be associated with the *increased* cost of goods sold for traditional manufacturing companies, but there is an opposite relationship for technology companies. This result seems to highlight the role of *resource complementarity* for the business value of e-commerce—traditional companies need enhanced alignment between e-commerce capability and their existing IT infrastructure to reap the benefits of e-commerce.
(*Electronic Commerce*; *IT Intensity*; *e-Commerce Metrics*; *Measurement*; *Validation*; *Firm Performance*; *Net-Enhanced Organizations*)

1. Introduction

Despite controversies surrounding electronic commerce (e-commerce or EC) and the burst of the "dot com" bubble, many large companies continue to deploy e-commerce extensively in their enterprise value chains and develop Internet-enabled initiatives to manage inventory using electronic links to suppliers, to strengthen online integration with distributors and business partners, to design and customize products and services, and to attempt to serve customers more effectively.[1] As indicated by a recent survey, "connecting to customers and suppliers electronically" is

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[1]In our study, e-commerce is defined as business activities conducted over the Internet. Net-enhanced organizations are traditional, "brick and mortar" firms that are using the Internet to *enhance* their existing businesses (Straub et al. 2002).

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one of the top-ranked information technology (IT) management issues (Computer Sciences Corp. 2001).

While sizeable investments in e-commerce are being made, researchers and practitioners are struggling to determine whether and how these expenditures improve the business performance of firms, or even how to measure the Internet-based, e-commerce initiatives in the first place. There has been much speculation but very little empirical data to gauge the scale and characteristics of the Internet-based initiatives and their impact on firm performance, especially of large manufacturing companies. Because of the difficulty of determining what data to collect and of actually collecting them, most of the existing evidence regarding such issues tends to be either anecdotal or qualitative in nature. Case studies on companies such as Dell and Cisco provided insights into business use and benefits of e-commerce, but are the findings of these case studies specific to a few "leading edge" firms, or are the lessons more widely applicable? At the same time, there are also cases where many firms, concerned about falling behind on the technology curve, engage in e-commerce initiatives without deriving any benefits. Thus, we still know relatively little about the impacts of e-commerce on most firms. To answer this question, we need evidence from large-sample statistical analysis. Such studies cannot be undertaken until we have found a set of metrics that will reveal relevant relationships.

Key research questions that motivate our work are: What are the relevant metrics for studying e-commerce? How are these e-commerce metrics related to the business performance of a firm in terms of profitability, cost reduction, and operational efficiency? Are the relationships between EC metrics and firm performance different for various types of companies? What are the determinants that explain cross-sectional variations? What kind of relationship (substitute or complement) exists between Internet systems and pre-Internet IT infrastructure?

To answer these questions, we proposed a set of e-commerce metrics for EC capabilities related to customers and suppliers. We then collected data to validate these metrics and examined their nomological efficacy in terms of relationships to firm performance, and the strength of the relationships. Grounded in a resource-based theory of the firm (also known as RBV or resource-based view of the firm), a series of hypotheses were developed to test the presence (or absence) of the EC effects in terms of whether e-commerce capabilities, in conjunction with a firm's IT infrastructure, are associated with performance measures such as profit margin, cost reduction, and supply chain efficiency. This will help provide empirical evidence as to which of the proposed metrics have value for studying the scale, characteristics, and impacts of e-commerce on firm performance.

Placed in the larger context of information system (IS) literature, this study can be considered to be an extension of the IT-productivity research stream into the Internet domain, motivated by the shift from pre-Internet IT infrastructure to Internet-based systems that enable e-commerce capabilities. E-commerce capability is modeled as a new type of technological resource that, combined with firm IT infrastructure, may have certain relationships to firm performance. These relationships are empirically tested with data from the manufacturing sector.

2. Theory and Hypotheses

Because most large firms are still in the early stage of positioning themselves to exploit the business opportunities enabled by the Internet, it is difficult to know how best to measure e-commerce capability. This points to the need for a theoretical framework that may offer some guidance. In this section, we review the relevant theoretical perspectives in conjunction with the existing information systems (IS) and e-commerce literature.

2.1. Business Value of Information Technology

The literature in IT productivity and business value can be classified into two categories: (1) the production-economics-based approach and (2) the process-oriented approach (Barua and Mukhopadhyay 2000). The *production-economics-based approach* uses production functions to study the relationship between output measures and production inputs such as IT and non-IT capital and labor. After many years' debate on the "productivity paradox," several researchers have estimated production functions and found a positive relationship between IT and productivity. Their results were corroborated by several other studies and triggered a large stream of literature in this area, which is extensively reviewed elsewhere (cf. Chan 2000, Dewan and Min 1997, Brynjolfsson and Yang 1996). As Hitt and Brynjolfsson (1996) point out, while the theory of production predicts that lower prices for IT will create benefits in the form of lower production costs for a given level of output, it is silent on the question of whether firms will gain performance advantages in terms of supra-normal firm profitability.

The *process-oriented approach* attempts to explain the process through which IT investments improve intermediate operational performance, which in turn may affect higher levels of financial performance (Barua et al. 1995). Among other studies, Mukhopadhyay et al. (1995) assessed the business value of electronic data interchange (EDI) in a manufacturing setting. They found that EDI enabled effective use of information to coordinate material movements between the manufacturer and its suppliers, which resulted in significant cost savings and inventory reduction. As an interorganizational information system, EDI has some features in common with the Internet-based initiatives, but it also exhibits significant differences as EDI is typically a more expensive, proprietary technology controlled by one large manufacturer or supplier. In contrast, Internet technologies may induce large-scale transformations within an organization as well as in its relationships with customers and suppliers. Thus, while there is some evidence of economic impacts from IT such as EDI, it is not clear whether this can be directly extended to the Internet-based electronic business.

Because most of these studies were conducted before the widespread use of the Internet, they naturally did not include variables associated with Internet initiatives and e-commerce capabilities. Given the shift to Internet-based systems as a new IT architecture, we seek to extend the IT value literature to the Internet domain. Our goal is to gauge the recent Internet-based, e-commerce initiatives and their links to performance measures, with *the focus moving away from pre-Internet IT infrastructure and legacy systems toward Internet and e-commerce capabilities*. This should complement and extend the existing literature. To achieve this, we need a new theoretical framework that goes beyond the production-economics and business-process approaches in the mainstream IT literature.

2.2. Resource-Based Theory for Net-Enhanced Organizations

A potential framework for augmenting the theoretical basis of e-commerce value is the *resource-based view* of the firm, which links firm performance to organizational resources and capabilities. Firms create performance advantages by assembling resources that work together to create organizational capabilities (Penrose 1959, Wernerfelt 1984, Peteraf 1993). To create sustainable advantages, these resources, or resource combinations, would have to be economically valuable, relatively scarce, difficult to imitate, or imperfectly mobile across firms (Barney 1991). Resources can be combined and integrated into unique clusters that enable distinctive abilities within a firm (Teece et al. 1997). RBV has been widely accepted in strategic management literature.

In the IS literature, the resource-based view has been used to explain how firms can create competitive value from IT assets, and how sustainability resides more in the organization's skills to leverage IT than in the technology itself. IT payoffs depend heavily on "fitting the pieces together," i.e., on exploiting relationships among complementary resources.[2] Computers, databases, technical platforms, and communication networks form the core of a firm's overall IT infrastructure resources. Although the individual components that go into the IT infrastructure are commodity-like, the process of integrating the components to develop an integrative infrastructure tailored to a firm's strategic context is complex and imperfectly understood (Milgrom and Roberts 1990, Weill and Broadbent 1998).

The resource-based view has been extended with the dynamic capabilities perspective (DCP) to address the realities of high-velocity markets and rapid technological change. DCP refers to the ability of a firm to

[2]See, e.g., Clemons and Row (1991), Ross et al. (1996), Jarvenpaa and Leidner (1998), Mata et al. (1995), and Bharadwaj (2000). Resources examined in these studies included managerial skills, IT expertise, organizational skills, and intangible assets. All of these studies were conducted before the Internet; e-commerce has not yet been studied from a resource-based perspective.

achieve new forms of competitive advantage by renewing technological, organizational, and managerial resources to achieve congruence with the changing business environment (Teece et al. 1997, Eisenhardt and Martin 2000). In this environment, capabilities that enable rapid and purposeful reconfiguration of a firm's resources are the means through which both industry position and timely, unique resources can be obtained. This model suggests that dynamic capabilities are essentially change-oriented capabilities that help firms reconfigure their resource base to meet evolving customer demands and competitor strategies. The ability to foresee technological change and adopt the appropriate strategies may create a trajectory of growth that would create a performance advantage (Teece et al. 1997).

Capabilities are dynamic because the firm must continually build, adapt, and reconfigure internal and external competences to achieve congruence with the changing business environment when the rate of technological change is rapid, time-to-market is critical, and the nature of future competition and markets are difficult to determine (Teece et al. 1997). Dynamic capabilities create resource configurations that generate value-creating strategies (Eisenhardt and Martin 2000).

As digital networks provide business processes with capabilities for speed, strategy is fast becoming a dynamic process of recreating and executing innovation options to gain competitive advantage (Teece et al. 1997). Applying the dynamic capabilities theory for understanding a firm's ability to create value through the business use of digital networks, Wheeler (2002) proposes the Net-enabled Business Innovation Cycle (NeBIC), which identifies that Net-enabled business innovations require timely and ongoing reconfiguration of firm resources. Zahra and George's 2002 article reinforces its appropriateness in the IS context.

Consistent with DCP, e-commerce can be considered to be a dynamic capability. Net-enhanced organizations continually reconfigure their internal and external resources to employ digital networks to exploit business opportunities. Thus, Net-enhanced organizations exemplify the characteristics of dynamic capabilities as they engage routines, prior and emergent knowledge, analytic processes, and simple rules to turn IT into customer value (Wheeler 2002, Bharadwaj et al. 2000, Sambamurthy et al. 2001).

Because this study seeks to extend the IT value literature to the domain of Internet-enabled e-business initiatives, it is natural to ask if Internet initiatives are different from pre-Internet technologies (e.g., PC, mainframe, legacy systems). In fact, the economic characteristics of the Internet are significantly different from those of pre-Internet computer technologies. The Internet is unique in terms of *connectivity*, *interactivity*, and open-standard *network integration* (Shapiro and Varian 1999, Kauffman et al. 2001). These characteristics have very different impacts on customer reach and richness of information. Prior to the Internet, firms often used stand-alone, proprietary systems to communicate limited data. It was difficult or costly for a firm to connect to its customers, suppliers, and business partners. In contrast, the Internet enables a two-way, real-time information exchange between a firm and its customers and suppliers (Straub et al. 2002).

Given these unique characteristics of the Internet, many organizations have embraced e-commerce. Yet, the way that e-commerce is embedded in business processes differs. In fact, it is how firms leverage their investments to create unique Internet-enabled resources and firm-specific capabilities that determines a firm's overall EC effectiveness.[3] Firms benefit from the Internet when they embed e-commerce capability in their organizational fabric in a way that produces sustainable resource complementarity.

Complementarity represents an enhancement of resource value and arises when a resource produces greater returns in the presence of another resource than it does alone. For example, the integration of e-commerce capability and IT infrastructure may improve connectivity, compatibility, and responsiveness of firm information systems, which leads to greater efficiency and lower costs. Information systems can embody rigidity and incompatibility, especially when they are based on proprietary pre-Internet platforms

[3]Straub and Klein (2001) apply the RBV perspective to the Internet space in their arguments that Net-enablement conveys to the firm a resource that cannot be substituted for or imitated (such as customer proprietary data, shared information). Exploitation of these resources, they assert, will lead to sustainable competitive advantage for Net-enabled organizations.

for software and hardware. "Islands of automation" (McKenney and McFarlan 1982) are often seen in the manufacturing industry, where various stages of manufacturing might be highly automated because of the use of CAD, CAM, and CIM technologies in the last two decades. Yet many of such systems are isolated from each other and not integrated internally with other parts of the corporate information systems or externally with suppliers and business partners. Data reentry is often needed to be done manually, increasing costs and errors. The business processes captured in such systems can become easily outdated.

The connectivity and open-standard data exchange of the Internet may help remove incompatibility of the legacy information systems. A mainframe-based legacy IT system (such as EDI) that only marginally improves performance under ordinary conditions may produce substantial advantages when combined with the Internet—its greater connectivity allows more direct interaction with customers and tighter data sharing with suppliers. Internet-based e-commerce can be utilized to enhance traditional IT systems in many ways. For example, using Web-based, graphical interface to improve the user-friendliness of ERP systems, implementing Internet-based middleware to make EDI-connections more flexible and affordable for smaller businesses, connecting various legacy databases by common Internet protocol and open standard, using XML-based communication to increase the ability of exchanging invoice and payment documents online between companies, and analyzing online data to better understand customer demand.

For these reasons, it is important to focus on resource complementarity as a feasible path to e-commerce effectiveness. The resource-based view provides a solid theoretical foundation for studying the contexts and conditions under which EC may produce performance gains. Particularly, it points toward a more balanced perspective, one that acknowledges the commodity view of the technology per se, while allowing the possibility of performance associations arising from combining EC capabilities with IT infrastructure and other complementary resources.

The above discussion also suggests that a study of e-commerce has to develop appropriate metrics of EC capability, IT infrastructure, and firm performance. We need measures to capture the characteristics of Internet functionalities and integration that can help build customer and supplier relationships across the value chain. It is a complex task to measure this kind of integration. Nonetheless, e-commerce functionalities may serve as a proxy. As discussed in §3, e-commerce functionalities represent the level of integration with customers and suppliers, upstream and downstream of the value chain.

Throughout this paper, we use three related terms: EC initiatives, EC capabilities, and EC functionalities. EC initiatives taken by firms result in EC capabilities, which are reflected by EC functionality indicators. EC capabilities are the main theoretical metrics of interest. Specifically, e-commerce capabilities reflect a company's strategic initiatives to use the Internet to share information, facilitate transactions, improve customer services, and strengthen supplier integration. To a certain extent, these EC capabilities should be reflected in the functionalities of the company's Web site, because the Web site serves as a gateway for dealing with customers and business partners in the Internet age (Fortune 2000). E-commerce functionalities may range from static information to online order tracking and from digital product catalogues to integration with suppliers' databases. These functionalities exhibit various levels of sophistication, which can be measured.

2.3. Hypothesis Development

The theoretical perspectives discussed above lead us to believe that e-commerce capabilities can combine with IT infrastructure and produce complementarities that contribute to firm performance. The testing of the relationships in the theoretical model may be thought of as a form of nomological validity. Nomological validity examines linkages that are specified in theory. If these linkages are found to be significant, particularly in spite of variants in measurement (Boudreau et al. 2001), then the instrumentation may be said to be nomologically validated (Campbell 1960, Bagozzi 1980). The hypotheses developed below allow us to explore these predicted relationships and to verify our metrics through this means.

With respect to Hypothesis 1, prior IT investment is critical to enabling e-commerce capabilities. Given this complementary nature between IT and EC, our first hypothesis is that EC capabilities, combined with IT infrastructure, create resource complementarities that explain performance variance across firms.

HYPOTHESIS 1. *EC capability and IT intensity exhibit a significant reinforcing interaction effect. That is, the interaction effect will be more significant than the main effects of either IT or EC alone.*

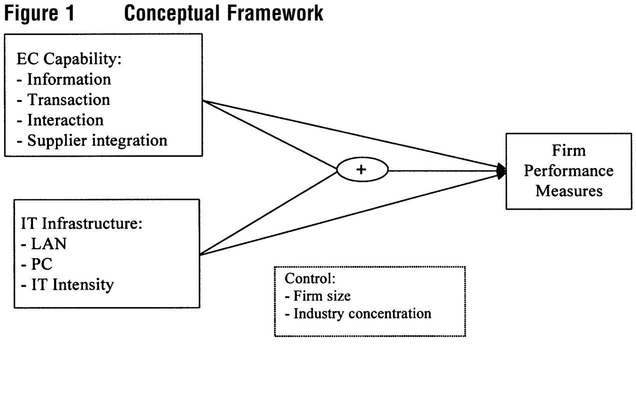
This is illustrated by the conceptual framework shown in Figure 1. In this framework, two sets of independent variables—EC capability and IT intensity—are jointly associated with performance measures. As discussed later in greater detail, *EC capability* is a composite index generated from a set of specific variables measuring EC functionalities related to customers and suppliers. IT infrastructure is represented by an index termed *IT intensity*, which is equal to a firm's total value of IT stock divided by the number of employees. *Interaction effect* is calculated by the product of the two variables—EC capability and IT intensity.

As discussed above in the theoretical section, the use of e-commerce may improve information flow and reduce transaction costs and inefficiencies. Firms' e-commerce initiatives will result in varying degrees of EC capability, and we might assume that the more developed this capability, the greater the positive relationship to the firm's profitability, and the greater the negative relationship to cost measures of the firm (cost reduction). Therefore, we have the following two hypotheses:

HYPOTHESIS 2. *Greater EC capability, in conjunction with IT intensity, is associated with lower cost measures.*

HYPOTHESIS 3. *Greater EC capability, in conjunction with IT intensity, is associated with higher profitability measures.*

Figure 1 Conceptual Framework



Notice that the hypotheses represent multiplicative propositions, reflecting the interaction effect between EC and IT. As discussed earlier, EC capability alone may be insufficient to impact performance measures; rather it may have to be integrated with the firm's existing IT infrastructure. The IT infrastructure provides the platform to launch innovative EC applications faster or more effectively than the competition.

Another area which should benefit from Internet-based e-commerce initiatives is inventory management. As documented in the supply chain literature, the poor quality of information exchange among suppliers and manufactures led to inventory buffer buildup along the supply chain, a phenomenon termed as the "bullwhip effect."[4] The use of Internet-based initiatives should improve the flow of information. Better information flow along the supply chain will make material flow more efficient. This is the notion of replacing inventory with information (Milgrom and Roberts 1988). This is important for the manufacturing industry as a whole, but it seems to be particularly relevant for high-tech manufacturing firms, where inventories anywhere along the supply chain can become obsolete in a matter of months. Hence, by improving the quality of information exchange through establishing electronic information linkages, the average inventory turnover rate should increase as the inventory stock decreases along the supply chain. This leads to our next hypothesis.

HYPOTHESIS 4. *Greater EC capability, in conjunction with IT intensity, is associated with improved supply chain efficiency.*

The latter three hypotheses explore the relationships of e-commerce to cost reduction, profit generation, and inventory management. Yet, these relationships might be different for different types of companies (e.g., high-tech vs. traditional manufacturing), because of the varying nature of resource bases and IT infrastructure.

High-tech companies and traditional manufacturing

[4]The bullwhip effect is defined as the artificial amplification of volatility in supply chains due to information distortion and demand uncertainties (Lee et al. 1997).

companies have different experience paths and resource bases in their IT infrastructure and Internet usage. Viewed from the resource-based perspective, firm IT infrastructure is an important business resource; its unique characteristics can enable firms to implement the right applications at the right time. The IT infrastructure underpins a firm's competitive position by enabling initiatives such as Internet-based electronic integration of supply chains. "It is the IT platform that determines the business degrees of freedom a firm enjoys in its business plans," as noted by Keen (1991, p. 184). On the other hand, a nonintegrated IT infrastructure dominated by system incompatibilities severely restricts an organization's business choices.

Hence, existing IT infrastructure and legacy information systems can be either advantages or liabilities. This is related to the dual nature of resources: Current capabilities may both propel and constrain future investment activity. For example, information systems can embody rigidities, especially when they are based on proprietary platforms for software and hardware (which is observed more often in traditional manufacturing companies than in technology companies). The business processes captured in such software and hardware could become outdated easily. Such incompatibility may hinder firm ability to exploit the value of a new technology such as the Internet.

As elaborated later, high-tech firms, relative to traditional manufacturing, tend to have a more intensive and flexible IT infrastructure, which may make their e-commerce initiatives more effective. Hence, our final hypothesis tests the possible differential effects of e-commerce on two types of firms: high IT-intensity vs. low IT-intensity manufacturing firms.

HYPOTHESIS 5. *E-commerce metrics may exhibit stronger association with firm performance in high IT-intensity firms than in low IT-intensity firms.*

3. Research Method

Measurement characteristics and nomological validity were tested for 260 manufacturing companies using primary data and secondary data from public databases and Web sites. Coding of the secondary data was supplemented by a primary data collection via a field study/survey for certain key variables. Data were collected and analyzed for a two-year study period.

3.1. Metrics Design

E-commerce metrics yield information about key attributes in e-commerce initiatives in a Net-enhanced organization. As articulated by Straub et al. (2002), metrics are important because they provide comparability and a rigorous research procedure. "Good metrics earn credence and subsequently relieve researchers from repeated efforts at construct and instrumentation development. Metrics enable research to accumulate in a subject area as direct comparisons become possible between persons, time periods, industries, cultures, or geographic regions" (Straub et al. 2002).

The variables used for this study fall into three main categories: dependent, independent, and control variables. Their relationships are illustrated in the conceptual framework shown above in Figure 1, where each set of variables is represented in a box. We describe these variables in turn below.

3.1.1. Dependent Variables—Performance Metrics. To assess the value of e-commerce capability, we employed multiple financial measures of firm performance, as we believe that the business value of Internet-enabled initiatives is best measured by gains in financial performance (Porter 2001). Specifically, for each company, we measured performance along three dimensions: profitability, cost reduction, and inventory efficiency. Four major variables were used to operationalize these three dimensions; they also served as dependent variables in the regression analysis. As defined in Appendix Table A1, the four performance metrics are as follows: (1) Two profitability metrics are sales per employee and gross margin. Ratios were used to normalize profits and account for size differences among firms. (2) Cost of goods sold (COGS) is a generally accepted accounting measure that indicates the cost side of a firm's operations. (3) Inventory turnover (INVX) was used to measure a firm's supply chain efficiency, as widely cited in supply chain management literature (Lee et al. 1997). Again, this variable was chosen because it was a ratio and hence corrected with firm size. All of these performance metrics are objective secondary data in the sense that they are reflected on firm financial filings to the Security and Exchange Commission (SEC).[5] These measures have been used in previous studies (e.g., Venkatraman 1989, Bharadwaj 2000, Mukhopadhyay et al. 1995).

3.1.2. Independent Variables. *(a) IT Infrastructure Metrics.* The first group of independent variables measures the IT infrastructure of each company, including PC, LAN, MIPS, and IT Stock, as defined in Appendix Table A2. These objective measures have been commonly utilized in the IT-productivity literature (e.g., Hitt and Brynjolfsson 1996). IT intensity, ITINT, is a derived variable created by dividing IT Stock by the number of employees, EMP. By revealing IT value in dollars per employee and controlling for size differences, IT intensity indicates the relative emphasis put on IT and computer systems in each organization.

(b) e-Commerce Capability Metrics. The second group of independent variables was e-commerce capabilities. Based on our detailed content analysis, 20 variables were used to characterize a company's EC capabilities. These variables are shown in Appendix Table A3. Together they are intended to measure EC capabilities along four dimensions:

• Information: useful information about products and services.

• Transaction: capabilities to facilitate transactions online.

• Interaction and Customization: capabilities that enable online interactions between the users and the company, and allow users to customize products according to their personal preferences.

• Supplier Connection: electronic linkages to integrate suppliers via information sharing.

We recognized that there might be some variations among companies in terms of the features of products, the needs of customers, and the nature of interactions with customers and business partners. This added extra challenge for the design of the measures. After going through several cycles of consultation with industry experts and e-commerce managers (some of them were sponsors of this project), we pretested the variables on 12 companies. We then consulted with a panel of academic experts to ensure all variables were on solid conceptual grounds. Based on the feedback from these academic and industry experts, we revised the variables, refined the definitions, interviewed users, and pilot-tested on 22 additional companies. Also, some EC measures that were considered to be biased in favor of high-tech firms were removed. This process resulted in the 20 variables that were used to characterize a firm's e-commerce capabilities (Table A3).

Manufacturers today are closer to their customers than ever before, partly because of the increasing connection enabled by information and communication technologies in general and the Internet in particular. Our design of measures reflects this trend. Pioneered by high-tech manufacturers like Dell and Cisco, the "go-direct" model allows manufacturers to interact with customers more directly (e.g., provide information, sell products, and receive feedback). While the high-tech firms are the forerunners on the e-business curve, traditional manufacturers are following suit. For example, cars are being made in modules that are simply snapped together in small assembly lines close to the consumer, where details can be adapted to customer preferences. This trend is being driven largely by the growing demand for customization (or "build-to-order") in the auto, appliance, and other industries, and is being influenced by earlier developments in the high-tech industry (see reports in Economist 2002, Fortune 2001). This reflects a key strength of the Internet technologies—the ability to provide informational, transactional, and interactive capabilities to customers and suppliers across time and space. Together with the supplier-related variables, the EC measures are believed to fairly closely represent a common set of e-commerce capabilities associated with typical businesses in an average company. Collectively, they can serve as a *proxy* of e-commerce capabilities.

In addition to the individual EC functionality indicators, a higher-level composite metric was created for each of the four dimensions of EC capabilities: Information, Transaction, Interaction (customization), and Supplier Connection. These composite metrics represent a more aggregated measure of the level of capability along these four dimensions. For example, the Supplier Connection index is an aggregation of all individual capability variables in this category. The

[5]Companies in our sample are public companies.

higher the score, the more capable EC capability a company has. By measuring the degree of electronic connectivity with suppliers and business partners, this metric reflects the networked connections that extend the firm to the outer world along the supply chain.

Finally, a total EC capability index was created by aggregating these four composite metrics. The use of these composite metrics transforms the binary variables of individual functionalities into continuous composite measures, which helps to alleviate some potential statistical issues associated with using a large number of binary variables as independent variables in the regression models.

3.1.3. Control Variables. Some of the cross-sectional variations in performance can be explained only if controls are appropriately applied. To control for firm-specific and industry effects, we employed two control variables to account for firm size and industry concentration. Controlling for firm size minimizes confounding effects from size. Among several possible measures of firm size, such as total assets and sales, we chose to use number of employees, EMP, as a firm size indicator, following the tradition of the IT literature.[6] The rationale to control for industry concentration comes from microeconomic theory, postulating that firm profitability is associated with the degree of competitiveness of the industry sector (Tirole 1988, Milgrom and Roberts 1990). For example, profit margins tend to be low in highly competitive sectors. To control for industry concentration, we used the Herfindahl-Herschmann Index (HHI) as a measure of the concentration level in each of the 4-digit SIC category.[7]

3.2. Sample Selection: Manufacturing Industry

We chose to focus on the manufacturing industry for several reasons. First, we believe that the key potential of e-commerce lies in efficiency gains and cost reduction for large traditional companies, rather than pure-play "dot com" companies. More importantly, concentrating on a single industry limits the scope of the project, but helps to minimize the differences of industry structure, business activity, and other effects that may confound the analysis (Steinfield et al. 2000).

We analyzed all manufacturing companies from the Fortune 1000 list. After eliminating those companies for which we were unable to obtain data on variables such as supplier connection, we generated a database of 260 companies; all of them belong to SIC Division 4 manufacturing. Data used in this study were obtained from both secondary data collection and public databases. First, data on e-commerce capabilities were collected through detailed content analysis on each company's Web site. These capabilities data were then matched with IT-infrastructure variables from the Harte-Hanks database of computer equipment (formerly the Computer Intelligence database), and financial-performance variables from Standard & Poor's Compustat database.

Based on our earlier discussions on RBV and dynamic capabilities theory, manufacturing companies in different sectors should have a different history of technology investment, and thus may have accumulated different resource bases and IT intensity. Such differences may affect the payoff of the more recent e-commerce initiatives. To examine the possible differential effects of e-commerce, we divided the original set of 260 manufacturing companies into two samples corresponding to two types of manufacturing companies: (1) technology-oriented, or "high-tech," companies, and (2) traditional manufacturing companies.

They were classified primarily on the basis of the four-digit SIC codes. The high-tech manufacturing group included companies in the following four-digit SIC codes: 3570 ~ 3579 (computer hardware), 3600 ~ 3691 (semiconductor and electronics), and 3825 ~ 3861 (instruments, etc.). This sample included such companies as Dell, Cisco, HP, Apple, Gateway, Lucent, Nortel, and Honeywell. The traditional manufacturing group included companies in the following four-digit SIC codes: 2000 ~ 3490 (appliance, packaged goods, apparel, furniture and chemicals), 3510 (engines and turbines), 3523 (farm machinery), 3537 (industrial

[6]For example, Brynjolfsson et al. (1994) used number of employees as a control for firm size. Our data showed a high correlation among these various size indicators.

[7]The Herfindahl-Herschmann Index is a truncated index and is calculated by squaring the concentration ratio for each of the top 50 companies or the entire sector (whichever is lower), and summing those squares to a cumulative total. The higher the index, the more concentrated the industry sector is at the top (Tirole 1988, p. 221).

trucks and tractors), and 3714 (automobiles and parts). This sample included companies such as Ford, Goodyear, Case, Mattel, Otis, and Whirlpool.

As supported by the descriptive statistics, technology-oriented companies tended to be high IT-intensity firms, and traditional manufacturing companies tend to be low IT-intensity firms. The former category is mainly IT-producing firms, while the latter category is mainly IT-using firms. This division is consistent with the literature (e.g., Stiroh 2001).

3.3. Coding Procedure

To code the data from both secondary data collection and public databases, data on e-commerce capabilities on the company Web site were subjected to detailed content analysis. These capabilities data were then matched with IT-infrastructure variables from the Harte-Hanks database of computer equipment (formerly the Computer Intelligence database), and financial-performance variables from Standard & Poor's Compustat database.

Coding for e-commerce capability turned out to be the most time-consuming part of the data collection and creation effort, as this type of data was not readily available because of the lack of publicly accessible measures for each company. As discussed above, after going through several cycles of consultation, interview, pilot-testing, and revising, a coding system with a standard coding form and the definitions of variables were finalized. Through a series of intensive sessions, three groups of coders were trained to code the EC functionalities according to the coding system. They performed content analysis and examined each Web site of the companies on our list, filling out a standard data form. Each EC functionality attribute was coded using a binary variable, representing whether or not a Web site had the particular functionality, where one was "yes," zero was "no," and undefined variables were considered missing values. A random sample of 34 Web sites was used for reliability testing. Two groups of the coders analyzed the full Web sites. The third group reviewed the items, on which disagreement occurred, and a majority rule was used to determine the coding. Intercoder reliability was then calculated by using the per item agreement method suggested in the literature (Kassarjian 1977). Overall intercoder reliability of 0.92 was achieved.

While this method worked well for customer-oriented functionalities, we encountered difficulty in collecting data on supplier-related functionalities. Some companies used extranets or EDI to conduct businesses with their suppliers, which might not be observable from the Web site. To collect data on supplier connection and backend systems, we designed a survey of IT executives and e-business managers, asking six specific questions as to whether their companies have the six supplier functionalities (shown at the bottom of Appendix Table A3). Each of these items was reviewed for its content, scope and purpose (content validity). To increase response rate, the survey was kept brief and specific. The execution of the survey was managed by a professional survey firm. After we received the data, we checked for consistency and validity. The responses were then incorporated into the coding of EC capabilities.

The data collection procedure described above was repeated twice for two years. The functionality data were then matched to IT variables from the Harte-Hanks database and financial data from the Compustat database for the same time period.

3.4. Validity of the Instrumentation

According to the guidelines for validation provided by Straub (1989) and Boudreau et al. (2001), we performed multiple tests on construct validity and reliability. Confirmatory factor analysis (CFA) was conducted to examine the validity of the constructs and to justify the e-commerce index categorization, in which 20 indicators were grouped into four latent variables. A software package, AMOS 4.0, was used to implement the CFA. The results and statistical measures are provided in Table 1.

3.4.1. Reliability. Reliability is an indication of measurement accuracy, that is, the extent to which instrumentation produces consistent or error-free results. Cronbach's α reliabilities in the test ranged from 0.65 to 0.93, hence *internal consistency* appeared to be high, as shown in Table 1. Factor loadings were all positive, significant, and above the cutoff value of 0.4 (Gefen et al. 2000). Further, construct reliability was evaluated in two ways: composite reliability and variance extracted. Both measures were above 0.7 for all

Table 1 e-Commerce Capability Constructs

		High-Tech Sample			Traditional Sample		
Constructs	Indicators	Factor Loading	Convergent Validity	Cronbach Alpha	Factor Loading	Convergent Validity	Cronbach Alpha
Information	Product information	0.588	3.119***	0.657	0.407	3.086***	0.673
	Search capability	0.572	2.723***		0.750	4.070***	
	Product review	0.464	1.952*		0.446	1.936*	
	Product update	0.458	—		0.452	—	
Transaction	Buy capability	0.982	12.816***	0.929	0.907	11.912***	0.904
	Online order tracking	0.898	14.849***		0.945	17.060***	
	Account management	0.922	16.369***		0.856	14.650***	
	Return	0.419	—		0.408	—	
	Security	0.417	4.037***		0.405	4.987***	
Interaction	Configuration capability	0.446	4.041***	0.842	0.452	3.262***	0.802
	Customer registration	0.721	3.878***		0.794	6.056***	
	Online recommendation	0.475	—		0.468	—	
	Content personalization	0.508	2.918**		0.507	4.680***	
	Real-time support	0.526	4.554***		0.509	4.119***	
Supplier Connection	Online procurement	0.452	2.453**	0.703	0.443	1.847*	0.651
	EDI	0.652	2.652**		0.614	2.916***	
	Integrat. to backend IS	0.454	2.372**		0.438	1.905*	
	Fulfillment	0.412	—		0.561	—	
	Inventory data sharing	0.750	3.784***		0.593	2.772**	

Note. Significance levels: $***p \leq 0.01$; $**0.01 < p \leq 0.05$; $*\ 0.05 < p \leq 0.10$.

four EC capability constructs (information, transaction, interaction, and supplier connection), based on which we may conclude that the reliability for these constructs is adequate (Straub 1989).

3.4.2. Content and Construct Validity. Validating one's instrumentation includes content and construct validity. *Content validity* is the degree to which items in an instrument reflect the content universe to which the instrument will be generalized (Boudreau et al. 2001). This validity was verified by checking the various indicators' managerial meanings and by a careful literature review. The items used in this study were based on strong theoretical grounds and distilled from extensive research interviews and literature review. Our carefully designed instrumentation followed by checks, pretests, and balances imposed during and after the data collection added to the confidence we felt we could place in the content validity of our data set.

Construct validity is the extent to which an operationalization measures the concepts that it purports to measure (Straub 1989). It has two components: convergent and discriminant validity.[8] Convergent validity was verified through the *t* statistic for each factor loading. Only one indicator, supplier virtual community, had an insignificant contribution to the supplier connection construct. After dropping this variable, all loadings were significant, as reported in the middle column of Table 1. Hence, we may conclude an acceptable convergent validity for both samples. By comparing construct variance extracted with correlations among constructs, using the conceptual discrimination process articulated originally by Campbell and Fiske (1959), discriminant validity was found to be acceptable as well. In their evaluative procedure, items in constructs should correlate more highly with items in

[8]We treat nomological validation separately in later sections.

the same construct than with items thought to be theoretically distinct constructs. By this logic, the instrumentation demonstrated good measurement properties.

3.4.3. Overall Model Fit Table 2 listed several goodness-of-fit statistics to assess how well the specified model explains the observed data from three aspects: absolute fit, incremental fit, and model parsimony. The two insignificant p-values ($p = 0.281$ and 0.168) for the chi-square statistics imply good absolute fit. Five incremental fit indices are all above 0.9, the conventional cut-off point as suggested by Gefen et al. (2000) and Hair et al. (1998), indicating an excellent model fit comparing to a baseline null model. Each of these indices is briefly discussed below:

• Tucker-Lewis Index (TLI) combines a measure of parsimony into a relative index between the proposed and null models, resulting in values ranging from zero to one. This measure can also be used for comparing between alternative models by substituting the alternative model for the null model.

• Normed Fit Index (NFI) represents the proportion of total covariance among observed variables explained by a target model when using the null model as a baseline model. Similar to TLI, it is a relative comparison of the proposed model to the null model, ranging from zero (no fit at all) to one (perfect fit).

Table 2 Validity Statistics

Goodness-of-Fit Indices	High-Tech Sample	Traditional Sample
Absolute Fit		
Chi-Square	85.830	88.233
p value	0.281	0.168
Incremental Fit		
Normed Fit Index (NFI)	0.950	0.959
Relative Fit Index (RFI)	0.924	0.932
Incremental Fit Index (IFI)	0.996	0.993
Tucker-Lewis Index (TLI)	0.994	0.988
Comparative Fit Index (CFI)	0.996	0.992
Parsimonious Fit		
Normed Chi-Square	1.086	1.209
Root Mean Square Error of Approximation (RMSEA)	0.032	0.033
RMSEA Lower Bound	0.000	0.000
RMSEA Upper Bound	0.071	0.055

• Relative Fit Index (RFI): The difference between RFI and NFI is that RFI is derived by adjusting the discrepancy (chi-square) of the proposed and baseline models by their respective degrees of freedom. RFI values close to one indicate a good fit.

• Incremental Fit Index (IFI) is the ratio of the difference between discrepancy (chi-square) of the proposed and baseline models over the difference of the respective degrees of freedom. It also serves as a comparison of two models, with values close to one being a good fit.

• Comparative Fit Index (CFI) estimates each noncentrality parameter by the difference between its t statistic and the corresponding degrees of freedom.

As to the parsimonious fit, the normed chi-square is the ratio of the chi-square divided by the degrees of freedom, such that the chi-square is adjusted by the degrees of freedom to assess model fit for various models. The root mean square error of approximation (RMSEA) is the square root of the mean of the population discrepancy per degree of freedom. Small RMSEA values mean low residual variance and, therefore, a good fitting model. As shown in Table 2, the normed chi-square is well below two, the upper threshold suggested by Carmines et al. (1981). RMSEA is below the cutoff value 0.08 suggested by Browne et al. (1993). Hence, both samples satisfied these recommended criteria.

In conclusion, based on these tests for validity and reliability, we felt that the data and constructs have been adequately validated. The overall fit statistics, validity, and reliability measures lend substantial support for confirmation of the proposed model. This also reflects the fact that the items have been pretested and refined over several rounds of data collection.

3.5. Descriptive Statistics

The summary statistics offered several interesting characteristics about the sample, as shown in Table 3. First, the two samples, technology and traditional manufacturing, show a considerable difference in IT intensity. While an average traditional manufacturer has 6.2 million dollars of IT stock, an average technology firm has 3.5 times more IT stock. Consequently, IT intensity is substantially higher for the technology sample. Similarly, an average technology company tends to have 50% more PCs per employee than its traditional counterpart. Further, the total index of EC capability is much higher for the technology sample than the traditional manufacturing sample.

The above comparison indicates that the two samples are distinctive in terms of IT intensity and EC capability, and hence provides some justification to our sample split of the "high-tech" and "traditional" manufacturing.[9] Based on the descriptive statistics, the technology companies can be considered as "leaders" of e-commerce adoption in terms of the degree of sophistication of EC capability, which is built on a more IT-intensive technology infrastructure than the traditional manufacturing group. The two groups show substantial differences in their technological resources as manifested by their differences in IT intensity and PCs. These resource differences are a key area to consider in examining firm performance as suggested by the resource-based theory.

Table 3 Descriptive Statistics

		High-Tech Sample $N = 64$		Traditional Sample $N = 196$	
	Variables	Mean	Std. Dev.	Mean	Std. Dev.
IT Metrics	IT stock	21.6	36.5	6.2	11.9
	IT intensity	946	2,322	302	271
	LAN	28	46	26	32
	PC per employee	0.31	0.26	0.20	0.15
EC Metrics	EC capability index	14.3	9.4	10.1	7.9
	Supplier connection	4.2	3.2	3.1	2.2
Performance Metrics	Inventory turnover	17.5	23.4	10.0	8.4
	Profit margin (%)	33	16	31	19
	COGS	6,905	10,546	5,804	15,366

Note. IT Stock and COGS are in millions of dollars; IT Intensity is in 1,000 per employee.

4. Empirical Results

Our primary goal was to establish a set of e-commerce metrics and collect data to validate these metrics. Having discussed this task and established their validity, we can now advance to the next phase of the research, focusing on empirical assessment of the research model and testing each of the hypotheses proposed earlier.

The model specifies the relationship between firm performance measures and a set of explanatory variables, including e-commerce capability and IT intensity for a given sample, while controlling for firm size and industry-specific effects. The theoretical discussions in §2 point to the importance of interaction effect between IT intensity and EC capability, two types of complementary resources. Hence the basic econometric relationship may be specified as follows:

$$DV = f(EC, IT, EC{*}IT, \varepsilon \ldots), \qquad (1)$$

where *EC* stands for e-commerce capability, *IT* denotes IT Intensity, and *EC*IT* represents the interaction effect. *DV* (dependent variable) denotes the performance metrics that will be replaced in turn by each of the four performance variables. For example, the regression equation for inventory turnover, INVX, is

$$INVX = \alpha + \sum \beta_i EC_i + \beta_5 IT + \beta_6 EC{*}IT + (controls) + \varepsilon, \qquad (2)$$

where $EC_i (i = 1, \ldots, 4)$ represent the four *EC* composite metrics identified earlier, β_i's are the coefficients, α is the constant, and ε is the residual term that captures the net effect of all unspecified factors. The model suggests that a correlational relationship exists between the *DV* and the independent variables. Before we proceed to regression analysis, two statistical issues need to be addressed, namely multicollinearity and heteroscedasticity.

Multicollinearity. To test for multicollinearity, we created a correlation matrix for all the independent variables, and discovered that the following variables possessed a correlation coefficient of over 0.70 (the threshold for possible multicollinearity): IT intensity (ITINT) and MIPS as well as IT Stock. As a result, MIPS and IT Stock were dropped from all subsequent regressions. After the corrections, we also followed the

[9]To test whether these two samples are sufficiently distinct, we performed *t* test (mean), Mann-Whitney *U* test (median), and Bartlett test (variance). The results demonstrated that profit margins and COGS do not have different means and medians, but they do exhibit significantly different variance. All other variables have different mean, median, and variance.

approach of Belsley et al. (1980) and found that all BKW conditional indices were below the threshold level of 30.

Heteroscedasticity. With our cross-sectional data, variance of disturbances may not be constant among observations because of differing factors related to specific firms. This may increase the possibility of heteroscedasticity. To account for this possible problem, many of the variables used in our analysis were normalized for the size of the firm, by expressing them as ratios rather than raw numbers.[10] To check for heteroskedasticity, we performed the White test (White 1980); heteroskedasticity was detected, at the 5% level, in the regressions using INVX (both samples), COGS (traditional sample), and profit margins (traditional sample). Heteroskedasticity was not significant in other regressions. The White heteroskedasticity-consistent standard errors were used for all cases if the White heteroskedasticity test statistic was significant at 5% level.

Table 4 Regression Results on COGS

	High-Tech Sample		Traditional Sample	
Overall Model:				
R^2 Adj.	0.321**	0.421**	0.301***	0.343***
Significance	0.016	0.049	0.001	0.0001
EC Capability:				
Overall Index	−2352.318**		1574.869**	
Information		913.013		4088.288
Transaction		1608.062		−2431.250
Interaction		−2341.265*		1468.520
Supplier Connection		−568.446*		−481.778*
IT Intensity	76.812*	76.707	58.90*	−55.670
Interaction Effect:				
EC*IT	−2710.342**	−2757.996*	1077.00**	992.808**

Note. Under each sample, two regressions are reported—The first one used the overall EC capability index, while the second one replaced it with the four EC capability constructs in the regression. Entries reported above are coefficients. Significance levels: ***$p \leq 0.01$; **$0.01 < p \leq 0.05$; *$0.05 < p \leq 0.10$.

4.1. Cost Measures

To test Hypothesis 2, the regression model is specified as follows:

$$COGS = \alpha + \sum \beta_i EC_i + \beta_5\, IT + \beta_6\, EC{*}IT + (controls) + \varepsilon. \quad (3)$$

As shown in Table 4, the adjusted R^2 is consistently associated with significant p values, indicating a reasonably good fit of the overall model. As shown by its negative coefficient and significance level, higher overall EC capability tends to be associated with lower COGS for the high-tech sample. The IT intensity is marginally significant with a positive coefficient. The *interaction effect* is found to be statistically significant, but showed opposite relationships on the two samples: a negative coefficient for the high-tech sample and a positive coefficient for the traditional sample. This implies that the interaction effect tends to be associated with *decreased* COGS for the technology companies, but *increased* COGS for their traditional counterparts. This is a surprise in the sense that the use of e-commerce, together with IT investment, is associated with increased COGS for the traditional manufacturing companies.[11]

It is possible that these companies have not yet reached a level of IT infrastructure, as well as experience and learning curve, where costs would be decreased. Higher costs might reflect learning cost, adjustment costs, IT infrastructure misalignment and inefficiencies (e.g., legacy information systems and data platforms), and the costs of integrating such IT systems with existing organizational and business processes. Perhaps our data did not capture enough details of the differences in the nature of EC and IT resources between traditional and technology companies, but we learned from field interviews and case studies that the *level* of integration is greater in technology companies (Mendelson 1999, Kraemer and

[10]Ratios were used in many areas of our analysis. For instance, IT Stock was divided by number of employees (EMP) to normalize the IT infrastructure variable into a single ratio (ITINT). The same method was used to normalize differences in revenues and profitability. Sales (SALE) was divided by EMP to get a normalized measure of per-person productivity, while gross margin was divided by SALE.

[11]Even though the theory does not predict this opposite relationship, this finding shows that something other than IT alone affects the relationship. In this sense, it is consistent with RBV.

Table 5 Regression Results on INVX

	High-Tech Sample		Traditional Sample	
Overall Model:				
R^2 Adj.	0.412**	0.556***	0.221**	0.348**
Significance	0.040	0.002	0.019	0.018
EC Capability:				
Overall Index	0.458*		0.022*	
Information		0.029		0.014
Transaction		0.097*		−0.003
Interaction		−0.104		0.006
Supplier Connection		0.272**		0.004*
IT Intensity	−0.125*	−0.137*	−0.017	−0.016
Interaction Effect:				
EC*IT	0.025***	0.027***	0.004**	0.003*

Note. Under each sample, two regressions are reported—The first one used the overall EC capability index, while the second one replaced it with the four EC capability constructs in the regression. Entries reported above are coefficients. Significance levels: $***p \le 0.01$; $**0.01 < p \le 0.05$; $*0.05 < p \le 0.10$.

Dedrick 2002). That is, the technology resource base is richer, more extensive, interconnected and responsive. Also, it is based on larger investment, considerable learning and expertise that comes from being a high-tech vs. traditional manufacturing company. In contrast, traditional manufacturing companies suffer from incompatible legacy systems in their IT infrastructure. As discussed in §2, resource-based theory suggests that these differences lead to differences in firm performance.

4.2. Profitability Measures

To test Hypothesis 3, we regressed gross margin against the same set of independent variables as above. For the traditional manufacturing sample, the adjusted R^2 is 0.069 with p value $= 0.285$, hence we cannot reject the null hypothesis. For the technology sample, the adjusted R^2 is 0.16 with p value $= 0.14$. We cannot reject the null hypothesis either, even though the result improved slightly. A similar weak result was obtained when sales per employee was used as the dependent variable. These weak results indicate that overall aggregate measures of firm performance such as total sales and profit margins appear to be too "remote" to be significantly associated with e-commerce capability. It is also possible that a time lag exists between the use and consequence of e-commerce initiatives. Given the short history of e-commerce, it may be too early to observe its effects on overall aggregate measures of firm performance.

4.3. Inventory Turnover

Using INVX as the dependent variable as proposed in Hypothesis 4, the regression results were mixed. As shown in Table 5, regression on the technology sample generated reasonably good adjusted R^2 with significant p values, leading us to reject the null hypothesis. The overall EC capability index, as well as the Transaction and Supply Connection subindices, was found to be significant, indicating a positive association of these EC capabilities to INVX. The result for the traditional manufacturing sample turned out to be relatively weaker than that of the high-tech sample, but still statistically significant (as indicated by the p values).[12]

These results provide empirical evidence on the positive association of e-commerce with inventory management and supply chain efficiency, consistent with the theoretical predictions we made in §2. The result also seems to support the theoretical argument that better information flow along the supply chain can substitute for physical inventory (Milgrom and Roberts 1988).

4.4. Interaction Effects Between IT and EC

We have noticed that the *interaction effect* is statistically significant for COGS, though it showed opposite relationships on the two samples. For INVX, the interaction effect is found to be statistically significant for both samples. It is stronger in the high-tech sample than in the traditional sample, as indicated by the significance levels and the relative magnitude of the coefficients in Table 5. Putting together these results demonstrates the importance of the interaction effect, which has been proposed as our main hypothesis in §2.3.

[12]The two control variables, EMP and HHI, were found to be statistically insignificant, and hence were not reported to avoid crowding the table.

Figure 2 Interaction Effect of IT Intensity and EC Capability

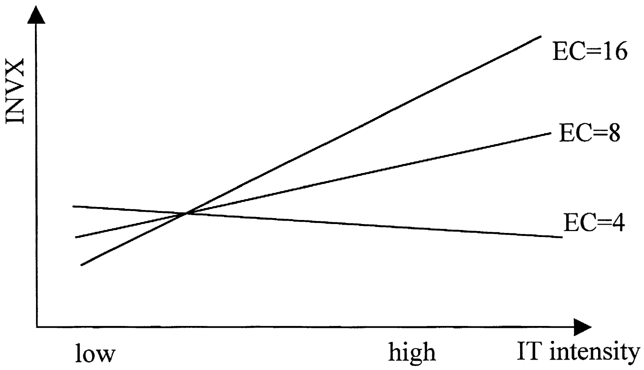


Figure 2 depicts the nature of the interaction between EC capability and IT intensity for INVX. For low IT intensity firms, more e-commerce use did not lead to improvement of INVX. However, for high IT intensity firms, greater EC capability was positively associated with higher INVX. This makes sense, in that, when the IT infrastructure was not there, merely building a fancy Web site would not help firm performance. The failures of many dot com firms have testified to this. Only when the firm has an intensive IT infrastructure, e-commerce initiatives become capable of improving firm performance. Further, as shown in Figure 2, the lines with higher EC have a positive, steeper slope (i.e., higher first derivative). This means that higher levels EC capability tend to make IT infrastructure more valuable. Once again, this suggests the complementarity of EC and IT, as theorized in §2.2.

4.5. Differential Relationships: High-Tech vs. Traditional Companies

Comparing the two samples, we noticed that the technology sample exhibited stronger links between e-commerce metrics and firm performance measures. The model was statistically stronger in terms of higher R^2 and more significant coefficients. The interaction effect was stronger as well for both INVX and COGS, as we discussed above. Together, these results supported Hypothesis 5.

Among other possible explanations, the differential resource base might imply an *experience curve* or adjustment cost that has to be overcome before realizing cost savings. Based on the complementarity concept of resource-based theory, traditional manufacturing companies may need significantly enhanced alignment with their existing IT infrastructure in order to reap the benefits of Internet-based initiatives. A reasonable networked communication and information infrastructure, replacing the rigid legacy systems, may need to be in place before e-business benefits can be harvested by these organizations.

These findings indicate that the high-tech and traditional samples exhibit distinctive characteristics in terms of EC capability and IT infrastructure, which lead to differential relationships to firm performance. This shows that the high-tech vs. traditional manufacturing classification scheme has value for studying differential effects of e-commerce initiatives.

5. Discussion

By examining substantive relationships of the e-commerce measures to firm performance in the above section, we were empirically testing to see if the measures are consistent with theory. Such empirical assessment helps to establish nomological validity of the constructs. One must consider the relationship of the concept under investigation to other concepts in an overall context of a theoretical network. "This is an important component of the construct assessment since it moves the logic of assessment from statistical domain of intercorrelations among the multiple indicators designed to capture the underlying trait (i.e., reliability, convergent, and discriminant validity) towards the substantive domain focusing on relationships that are best interpreted in the light of the received theory" (Venkatraman 1989, p. 954).

Together with the validity and reliability statistics discussed in §3.4, we believe that we have validated our e-commerce constructs. They can be used for future studies or further refinements by other IS researchers who wish to measure these constructs more extensively. They can also be used as starting points to investigate the various research issues related to Net-enabled organizations as articulated by Straub and Watson (2001).

In addition, we have shown that the theories of RBV and dynamic capabilities offer a relevant framework to study the value of e-commerce. Firms differ in terms of their ability to adapt to changes induced by digital technologies (Christensen 1997). Net-enabled organizations, such as high-tech firms, are likely to be more agile and capable of competing in dynamic markets than traditional manufacturing companies. These traditional manufacturing firms have to build their dynamic capabilities needed to exploit new IT resources. Success in this process depends on the firm's reserves of relevant knowledge, managerial commitment to adopting the new technologies, and the entrepreneurial process that pervades the firm's operations (Teece et al. 1997, Wheeler 2002). As shown by our study, high-tech firms are adept at developing systems and processes that create and expand their dynamic capabilities, while traditional manufacturing companies are struggling to benefit from digitally induced transformations. Future research should examine the processes that firms use to develop and renew their dynamic capabilities.

Many limitations of the study could be cited, but we focus on key limitations here. First, in our empirical analysis, we compared high-tech vs. traditional manufacturing companies to examine the differences and similarities of the role of EC capability metrics on these companies. However, our sample may not be fully representative of the true population of high-tech and traditional sectors due to possible bias of sample selection. Despite this possibility, we felt that the use of a sample of *Fortune* 1000 manufacturing firms was suitable as a proxy for our research purpose. Second, while we took steps to reduce bias in the data collection process, noise is inevitable. The content analysis alone may underestimate some EC capabilities related to business-to-business interactions, especially for some companies that relied on extranet, EDI, or private networks for dealing with suppliers. Nonetheless, we believe that the survey data on supplier connection helped to alleviate this problem.

Our study has numerous implications for managers. Increasing levels of e-commerce capabilities by technology companies over time have been accompanied by complementary investments in IT infrastructure and business processes, as well as a steady "digitization" and "informatization" of production and supply chain management. All of this serves to enhance the effectiveness of the more recent investments in Internet-based e-commerce initiatives. By the same token, one explanation for the less significant estimated relationship of e-commerce metrics and firm performance in the traditional manufacturing sector is the relatively low level of IT intensity, a key EC-enhancing complementary resource.

It is possible that there is path dependence such that companies must invest in complementary resources and transform their old accumulated resources (such as technical platforms, databases, and legacy information systems) to the Internet before investment in this relatively new technology becomes productive.[13] Compared to high-tech companies, traditional companies suffer from the lack of complementary digitization in their value chains, as suggested by the differences in EC capability and IT intensity shown in the data.

Hence, for managers, positioning e-commerce to leverage other complementary resources such as IT infrastructure and connectivity with suppliers should be a necessary condition for those companies to benefit from e-commerce. In addition, the success of the Internet initiatives of a firm depends not only on its own efforts to digitize its value chain, but also on the readiness of its customers, suppliers, and business partners to simultaneously engage in electronic interactions and transactions. While it is conventional to think of this readiness as something external to the firm, our study points to the need to consider it as a driver that requires a proactive commitment of resources.

6. Conclusion

This study, through successive stages of testing and refinement, has arrived at a set of e-commerce measures that satisfied necessary measurement properties. The result is a parsimonious, 20-item instrument and instrumentation procedure. The four scales demonstrate acceptable levels of reliability and validity, as empirically verified. We categorized the major metrics

[13]Such practices have been shown effective in many high-tech companies such as Cisco, Dell, Sun, and Gateway.

into: (1) e-commerce capability metrics (information, transaction, customization, supplier connection, and the overall EC capability index), (2) IT intensity metrics, and (3) performance metrics. The EC capability constructs developed in our study are specific to the Internet, and have no precedence in the IS literature. As we have demonstrated, this method of instrumentation can be used to investigate the relationships of e-commerce to firm performance. The items can also serve as a foundation in other studies for theory testing as well as further extensions or refinements.

More broadly, this study offers several contributions: (1) It develops a theoretical framework for assessing the value of e-commerce to firm performance grounded on the resource-based theory, (2) it empirically quantifies the relationship of the EC metrics to performance measures, and (3) it offers interpretations consistent with the theories of RBV and dynamic capabilities. Further, the analysis highlights key areas that may require managerial attention and further research. As far as we are aware, this is one of the first studies to provide an empirical test of this complementary relationship, and it is the first time that a rich database on a large number of manufacturing companies has been assembled for assessing e-commerce value.

Putting together our results for the high IT-intensity and low IT-intensity companies highlights the notion of *resource complementarity* for e-commerce investments, wherein companies must first build the necessary resources and adjust the business processes before e-commerce initiatives become productive. Traditional manufacturers would have to go through a costly learning curve. These companies adopting new Internet initiatives must have the complementary IT infrastructure and have the right alignment with other complementary organizational resources. Finally, the Internet is fundamentally about connectivity. E-commerce may necessitate more tight integration with customers and suppliers, up and down the supply chain, which goes well beyond the walls of an individual organization.

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Appendix. Construction of Variables and Measures

Table A1. Performance Metrics

Variable	Description	Definition
REVPEREMP	Revenue Per Employee	It is calculated by dividing revenues (SALES) by the total number of employees (EMP) in each firm. This figure measures the productivity per employee in the firm.
GRMGNPCT	Profit Margin (%)	It is equal to the difference of SALES and COGS divided by SALES. It is an indicator of a firm's profitability.
COGS	Cost of Goods Sold	The item represents all costs directly allocated by the company to production, such as direct materials and supplies, direct labor, and overhead (not included in XSGA).
INVX	Inventory Turnover	The inventory turnover rate is calculated by COGS, divided by the average inventory level, INVT, (i.e., the average of the current year's total inventories and the prior year's total inventories). It represents the number of times the average inventory of a firm is sold over a given time period (typically a year). It is an indicator of a firm's operational efficiency along its supply chain.

Table A2. IT Infrastructure Metrics

Variable	Description	Definition
PC	Number of PCs	PC is the total number of personal computers (including laptops) in the company.
LAN	Total Number of Local Area Networks	LAN represents the total number of installed local area networks in an organization, which denotes the extent of the connectivity of the organization's IT infrastructure. In general, LANs are measured by "bridges."
MIPS	Total Installed MIPS	MIPS is the total level of installed processing power, measured in millions of instructions per second (excluding personal computers).
IT Stock	Total Purchase Value of Systems	It is the total purchase value of all computer systems in the organization, which was calculated by CI and was based on the current value of the installed base.
IT Intensity	Intensity of IT Investment	It is created during this study by dividing IT Stock by the number of employees, EMP. By revealing IT value in dollars per employee, IT intensity indicates the relative emphasis put on IT and computer systems in each organization.

Table A3. e-Commerce Capability Indicators

Category		Description	Definition
Information	ec1	Product Information Online	This signifies whether a product catalog or other product availability information is available online.
	ec2	Search Capability	This indicates whether the Web site offers attribute-based search capability. It assists customers in finding a specifically needed product quickly.
	ec3	Product Review	Information provided to potential customers about product quality, usability, and reliability (e.g., through third-party reviews or customer ratings).
	ec4	Product Update	Indicates whether a Web site posts product updates, maintenance and repair FAQs, e-mail based support or other pre- and post-sale support.
Transaction	ec5	Buy Capability	This enables the customer to place the order through the Web site.
	ec6	Online Order Tracking	This enables the customer to log on the Web site to view the status of the order. It helps the buyer to become aware of product movement in the order processing cycle.
	ec7	Account Management	A simplified procedure to complete transactions for registered users.
	ec8	Return	Information, procedure, and mechanism to facilitate returns.
	ec9	Security	Indications about the security of transactions and customers' sensitive data.
Interaction and Customization	ec10	Configuration Capability	This enables the user to configure product features via the Web site. This functionality allows products to be "built-to-order" on the basis of the customer's preference.
	ec11	Customer Registration	A feature where users can register with the Web site to gain access to personalized accounts or private messages.
	ec12	Online Recommendation	Describes the use of dynamic real-time online product recommendations
	ec13	Content Personalization	A functionality allowing online visitors to customize the content viewed on the Web site.
	ec14	Real-Time Support	Online technical support handled by live representatives through either Web-enabled voice communication or instant messaging based communication.
Supplier Connection	ec15	Online Procurement	This corresponds to Internet-enabled procurement of raw materials, supplies and parts by the manufacturer (including placing orders and tracking orders online).
	ec16	EDI Links	Whether the company uses electronic data interchange or extranet for supply chain management.
	ec17	Supplier Virtual Community	Whether the company offers an online community dedicated to suppliers (e.g., discussion forms, chat rooms, message boards, online FAQ's . . .).
	ec18	Integration to Backend Info. Systems	An indication of online integration with databases and backend information systems with suppliers.
	Ec19	Fulfillment and Logistics	A functionality to facilitate shipment and logistics management with suppliers and distributors via the Internet.
	ec20	Inventory Data Sharing	Whether inventory information is updated and shared online with suppliers and business partners through electronic links.

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