Information technology, knowledge processes, and innovation success

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Abstract

Despite the obvious linkage between information technologies (IT) and knowledge processes and the apparent strategic importance of both, little research has done to explicitly examine how, if at all, IT and knowledge processes affect firm outcomes. The purpose of this study is to bridge this important gap and investigate whether knowledge processes mediate the relationship between IT and performance. An empirical test of research hypotheses involves collecting data from 277 high-technology firms. The results support our proposed mediating model, which provides a more complete understanding than heretofore of the IT-performance process. Our study concludes with a discussion of its implications for both IT design and knowledge management.

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Introduction

Hoping to improve performance, modern corporations have made a tremendous investment in information technology (IT). For corporate America alone, IT investment in 1995 was estimated at approximately $505 billion (Strassmann 1997). Between 1996 and 2000, IT investment has been steadily increasing worldwide at an average annual rate of 10% (Willcocks and Lester 1999).

Whether and to what extent IT's promised value will materialize, however, remains to be an open question. Researchers have extensively studied the link between IT and performance, investigating a direct causal link (e.g., Loveman 1988; Morrison and Berndt 1990; Weill 1992), contingency models (e.g., Banker, Kauffman, and Morey 1990), models differentiating between intermediate and higher level output variables (e.g., Barua, Kriebel, and Mukhopadhyay 1995; Mukhopadhyay and Cooper 1992, 1993; Rai, Patnayakuni, and Patnayakuni 1996), and even econometrics models (Brynjolfsson and Hitt 1996). Given the pervasiveness of IT and our relative ignorance about this complex process, the relationship between IT and performance has been and will continue to be a subject of steadfast interest.

A firm's knowledge is determined by such processes as knowledge generation, dissemination, and application. The knowledge-based theory of the firm suggests that knowledge is the core source of competitive advantage (Spender and Grant 1996), because tangible inputs such as labor, capital, and technology, are important only for their ability to render *services*, in Penrose's language (1959: 25), which is a function of the knowledge applied to them (Tsoukas 1996). In other words, it is not so much the resources *per se* that are important as the *services* they render, and knowledge plays a key role in determining the level of *services*. Consequently, one can expect that processes aimed at enhancing a firm's knowledge are crucial to efficient use of firm resources and eventual performance.

To our knowledge, no research has done to address how IT and knowledge processes together influence business performance. This is surprising given the importance of IT and knowledge management in both management and IT literatures. The purpose of this article is to fill this gap by investigating how, if at all, IT and knowledge processes affect firm outcomes. Among various outcome measures, we have selected innovation success for two reasons. First, innovation success is critical to ultimate firm performance: innovation returns reportedly account for 50% or more of corporate revenue (Kotler 1991). It is even more important for high-technology industries, on which our data are based. Second, innovation success measures performance associated with one particular application system – innovation. Barua, Kriebel, and Mukhopadhyay (1995) and others have explicitly suggested measuring IT value through performance associated with application activities, rather than aggregate firm performance. We further concentrate on the strategic business unit (SBU) as the unit of analysis, in accordance with the IT literature, which warns against an aggregate analysis at the enterprise level and advises using lower levels of analysis (e.g., Banker, Kauffman, and Morey 1990; Barua, Kriebel, and Mukhopadhyay 1995; Weill and Olson 1989).

Examining the "IT-knowledge processes-innovation" chain is useful on both conceptual and strategic grounds. On one hand, despite the widely presumed value of IT, the discordant findings on the IT-performance relationship, known as the "IT-productivity paradox", have somewhat confused scholars and practitioners (see Brynjolfsson 1993 for a review). If the inclusion of knowledge processes can help identify empirical regularities or reconcile irregularities in the supposed IT-performance relationship, our understanding of the effect of IT on performance would be advanced. On the other hand, both IT and knowledge processes are believed to be crucial in the "information age" and are intuitively related. Yet the issue of whether IT facilitates an organization's knowledge processes has not been addressed explicitly in the literature. If it does, then one important manifestation of IT is the improvement of knowledge processes leading to innovation success. Identification of this generative mechanism will aid in IT design and use.

We begin by defining the major concepts used in the study; then we develop a series of research hypotheses. We then describe the research design and report the empirical findings. Finally, we discuss the implications of our findings and suggest directions for future research.

Conceptual Development

Information Technology (IT)

A considerable number of IT studies use aggregate IT measures. However, such measures are problematic for at least two reasons. First, they mix all kinds of technologies together, ignoring the fact that various types of IT work best for various purposes (Huber 1990). Weill (1990), for example, reports the various impacts of various IT types. This type of aggregation may contribute to the IT-productivity paradox. Second, the results of such aggregate study offer limited managerial implications because realistic IT selection, investment and management decisions are always associated with specific types of IT. Therefore, our study begins by classifying general IT into various groups and then focuses on specific types.

The literature lacks an explicit and unified classification of IT because there is large variation in IT research questions and scope. Typically, researchers classify IT by technological functions (Kendall 1997). Huber (1990) defines advanced IT to include computer-assisted communication technologies (e.g., email, video conferencing, electronic bulletin boards, and computer conferencing) and computer-assisted decision-aiding technologies (e.g., decision-support systems, expert systems, and executive information systems). This classification has received broad acknowledgment, for it captures the core functions of different IT and provides a good conceptual theory for conducting empirical work. From a broader view of IT, Kendall (1997) proposes a classification that includes production-oriented technologies, coordination-oriented technologies (cooperative and control), and organizational-oriented technologies. This system of classification provides comprehensive coverage of a wide range of technologies.

The current study concentrates on two types of IT: communication technologies (IT_c) and decision-aiding technologies (IT_d). IT_c in our study is equivalent to the communication technologies defined by both Kendall (1997) and Huber (1990), which aim to increase, intensify, and expand interactions among users. IT_d extends Huber's decision-aiding IT to include some of the production-oriented technologies listed in Kendal's classification, such as GUI, CASE, Expert systems, and Hypertext. These "production" technologies are included because they are designed to improve decision-making and information retrieval (Kendall 1997). These two types of IT are widely used and have been extensively discussed by researchers; therefore our findings concerning them should have satisfying comparability to existing studies and practices.

IT_c supports and enhances the communication-related activities of team members. It helps to overcome space and time constraints in communication, increase the range and depth of information access, target groups more precisely, and ultimately enable knowledge to be shared more rapidly, more conveniently, and yet less expensively (e.g., Warkentin, Sayeed, and Hightower 1997; Lucas 1998).

IT_d, on the other hand, helps individuals or organizations create models and develop alternatives and solutions for their tasks. Advancement in IT_d has expanded "decision aiding" to include not only decision-making but also planning, idea generation, conflict resolution, and negotiation (Williams and Wilson 1997). Whereas IT_c is concerned with communication, IT_d is concerned with tasks. Functions of IT_d generally include “storing and retrieving large amounts of information rapidly; more accurately combining and reconfiguring information so as to create new information; and more compactly using the inputs and models developed by experts” (Huber 1990).

A common feature of both IT_c and IT_d is their value, because of their unique digital component, in contributing to higher levels of *basic characteristics* such as data storage capacity, transmission capacity, and processing capacity (Huber 1990). Over time IT has grown more sophisticated, so that new communication technologies feature an increase in speed, a dramatic reduction in costs, a sharp rise in communication bandwidth, vastly expanded connectivity, and better integration of communication with computing technologies (Fulk and DeSanctis 1995). Group support systems have gained capacity and been adapted for highly complex tasks (DeJean 1988). IT is increasingly regarded as a “package”: IT *per se* does not assure benefit (Kraemer and King 1988), unless integrated into a package with organization ware and people. A deficiency in any part will prevent IT from working properly (Kraemer and King 1988).

Recognizing that the dynamics of IT and the fact of its availability alone do not guarantee its use (Madhavan and Grover 1998), we treat it as a multidimensional concept, which varies in intensity (relative to industrial standard), availability, innovativeness, ease of use, and quality of service.

Knowledge Processes

“In an economy where the only certainty is uncertainty, the one sure source of lasting competitive advantage is knowledge” (Nonaka 1991). It has been widely accepted that knowledge processes are critical to firm success. The unique knowledge processes of such high-profile Japanese companies as Honda, Canon, Matsushita, NEC, and Kao are generally acclaimed as the secret to their success over western competitors (Nonaka 1991; Nonaka and Takeuchi 1995).

So what is knowledge? This question has intrigued some of the world's greatest thinkers from Plato to Popper, but no clear consensus has emerged. In this study, we mainly follow the epistemological tradition that defines knowledge as "justified true belief" (Audi 1995). Knowledge here is understood as information that has been validated by experience, which has entered human belief systems as rules for guiding actions, and, in the case of business, that has proved beneficial to firm performance. Given our focus on high-technology firms, we are particularly interested in technological knowledge, that is, knowledge generated in response to major technological shifts.

Knowledge alone, however, is a static term. To achieve lasting competitive advantage, practitioners do not simply use knowledge in an instrumental fashion; they must continuously create new knowledge and make the best use of it (Nonaka and Takeuchi 1995). The knowledge-creation process includes "creating new knowledge, disseminating it widely throughout the organization, and quickly embodying it in new technology and products" (Nonaka 1991: 96). In this study, we focus on these three key knowledge processes in organizations (i.e., knowledge generation, dissemination and application). This classification is also consistent with the literature (e.g., Coombs and Hull 1998; Meyer and Zack 1996; Nonaka 1994; Zack 1999). For instance, Coombs and Hull (1998) explicitly define knowledge creation as knowledge generation, transfer and use.

Following the literature, this study focuses on three components of the knowledge creation processes: knowledge generation, knowledge dissemination, and knowledge application. Knowledge generation refers to the organization-wide generation of new knowledge pertaining to current and future technology needs. Knowledge dissemination refers to interactions (within or across departments) in which new knowledge is disseminated. Knowledge application refers to the use of knowledge in organizational practices to achieve superior performance.

The Effects of IT on Knowledge Processes

Figure 1 presents our conceptual model. Because a particular type of IT works best for a particular case (Huber 1990), we examine two types of IT (IT_c and IT_d) in this study. We conjecture that both IT types are positively related to the three components of knowledge creation processes and innovation success. Furthermore, knowledge generation, knowledge dissemination, and knowledge application are hypothesized to be positively related to innovation success. We develop our research hypotheses below.

[insert Figure 1 about here]

We conjecture that IT_c is positively related to the level of knowledge generation. IT_c (e.g., Electronic Data Interchange (EDI) and technologies designed specially for linking the firm with consumers and industrial resources) exposes the firm to useful information about markets, industries, and suppliers. As a result of this increased acquisition and storage of information, and the development of computer-enhanced organizational memories, "organizational intelligence is likely to be more accurate, comprehensive, timely, and available" (Huber 1990:63). This then lays a sound base for better knowledge generation. Moreover, considering that IT_c leads to knowledge dissemination, and knowledge dissemination to new knowledge generation, IT_c promotes knowledge generation also by this means.

IT_c is also expected to foster knowledge dissemination by efficiently alleviating factors leading to "internal stickiness". First, according to Szulanski (1996), such factors include temporal constraints, recipients' lack of absorptive capacity, and arduous relationships among functions. Evidence from various studies suggests that IT_c may overcome or reduce the impact of these problems. For instance, numerous studies (e.g., Rice and Bair 1984; Chidambaram and

Jones 1993; Warkentin, Sayeed and Hightower 1997; Lucas 1998; Culnan and Markus 1987) have shown that advances in electronic communication obviate the need in coordination and information sharing for the physical proximity of nodes. Second, IT_c is found to flatten business structure, hence allowing faster communication across vertical boundaries (Davidow and Malone 1992). Third, IT_c also promises to improve the absorptive capacity of recipients by reducing the burden of language and world-view difference among different functions. Lea and Spears (1992) find that experienced email users are significantly less likely to make critical judgments about the senders from their words and grammar than are users of traditional paper documents. Where email is accepted as a very informal medium for communications between people who know each other, this tolerance appears to be even stronger (Yates and Orlikowski 1992). Lucas (1998) further claims that "email continues to carry with it social norms that permit senders to relax the formal rules of written business communications" (p. 20). Finally, IT_c promotes positive relational communication and coordination between people (Walther 1995; Chidambaram 1996), thus hopefully easing the "arduous relationships" that may prevent effective knowledge dissemination. Moreover, IT_c can foster knowledge dissemination by creating new relationships within organization members through "weak ties" (Constant, Sproull, and Kiesler 1996; Lucas 1998).

As for knowledge application, IT_c's benefit mainly stems from the fact that it leads to clear communication of decisions and thus to organization-wide understanding about knowledge application. In addition, its basic characteristics speed up the process of involving people in knowledge application. For example, the broadcast feature of email enables the sender to spread information at once to a number of people rapidly and reliably at a very low cost (Lucas 1998).

Less noticed but equally important is the potential psychological impact of IT_c on knowledge management processes. As mentioned earlier, the use of IT_c leads to increased external and internal information. This in turn leads top management to perceive a lower level of uncertainty and thus a lower level of risk, and therefore to have a high level of confidence and tolerance for risk, and to offer more support to new knowledge creation. We therefore hypothesize:

H_{1a}: (1) IT_c is positively related to the level of knowledge generation;
(2) IT_c is positively related to the level of knowledge dissemination;
(3) IT_c is positively related to the level of knowledge application.

As to tasks and content, IT_d is intentionally designed to help the individuals or organizations in such tasks as decision making, planning, idea generation, conflict resolution, and negotiation (Williams and Wilson 1997). IT_d therefore promises to contribute to the three knowledge processes. According to the broad DSS literature, IT_d provides decision-makers with the capability to extend their bounds of rationality (Todd and Benbasat 1999). Specifically, IT_d may assist the three knowledge creation processes through at least three functions: (1) a rationalized/optimized module of decision making, (2) organizational memory, and (3) anonymity (e.g., Kraemer and King 1988; Nunamaker et al. 1991).

First, a structured module built on complex procedures and agreed assumptions usually focuses decision attention on the key issues, and encourages the use of objective data and criteria (Kraemer and King 1988). This helps overcome decision-makers' cognitive limitations and leads to better decisions. In addition, IT_d is often designed to provide many alternatives, thereby promoting idea/option generation. As to knowledge dissemination, IT_d usually requires standard forms of input and produces standard reports that are readily understandable to users. In addition, graphic display functions in many IT_d programs replace text and tables with charts and graphs, which further facilitates knowledge sharing among different departments who often use different functional languages (Griffin and Hauser 1996). With respect to knowledge application, the normative models given by IT_d promote a standard practice of implementation. The standardization and associated clear guidance make the application process easy to control and monitor. IT_d therefore promotes the efficiency (but not necessary effectiveness) of knowledge application.

Second, one common obstacle to decision making and knowledge creation is that problems are not fully explored and alternative solutions not sufficiently considered (Huber 1982). The organizational memory function of IT_d helps remove this kind of obstacle by allowing users to retrieve information previously processed. IT_d builds an "information center" for organization members to store, share, and retrieve information (Kraemer and King 1988; Torgler 1983). This helps generate more options and therefore new knowledge (Nunamaker et al. 1991). The same accessibility to stored information also enhances knowledge dissemination.

Finally, the anonymity associated with general IT_d allows users to participate freely in discussion without considering status and personality, thus alleviating common problems such as conformity of thought. The increased diversity of opinion often leads to generation of new knowledge (Robbins 1997). These arguments lead us to posit:

H_{1b}: (1) IT_d is positively related to the level of knowledge generation;
(2) IT_d is positively related to the level of knowledge dissemination;
(3) IT_d is positively related to the level of knowledge application.

The Effects of IT on Innovation Success

Innovation is risky and complex. It takes time, costs money, requires quality products or services, and demands effective collaboration of cross-functional and cross-regional teams. The success of innovation directly hinges on effective management of all these issues; and in many regards, IT promises to help for several reasons. First, IT has been found to speed up new product development processes. For example, Novell's Group Wise division uses a group support system to schedule meetings among developers, documenters, testers, and marketers for the review and approval process. They report that the new product development cycle time has gone from 48 months to 18 months (Grantham, Carr, and Coleman 1997). This increase in speed is due mainly to larger and smoother information exchange, unrestricted by human limitation and regional separation.

Second, IT helps reduce innovation cost. It helps reduce paper waste and the need for a large staff. New product development (NPD) often involves multiple individuals and groups. This can lead to redundancies if the communication among them is not effective. By establishing an "information center" and providing a convenient communication channel, both IT_c and IT_d allow innovation/NPD members to retrieve data, track software problems, and exchange information easily and quickly, and thereby save time and significantly reduce redundancies. Additionally, IT_c can notably reduce travel and communication costs. For example, the "Digital Nervous System" of British Petroleum (BP) saves the company more than $25 million in annual travel expenses (Newing 1998).

Third, prior studies have documented the necessity of cross-functional integration in the innovation processes (e.g., Moenaert and Souder 1996; Xie, Song, and Stringfellow 1998). We conjecture that IT, including both IT_c and IT_d, can greatly enhance cross-functional integration in the presence of various integration barriers such as physical separation, goal incongruity and cultural difference. Successful NPD also requires the involvement of customers and business partners in the new product process. IT_c such as EDI and meeting systems can timely incorporate their views into new product design and later tests. For example, in designing new computers, IBM uses electronic meeting systems to hold strategic listening sessions with customers in both Europe and US. Similarly, Lotus uses IT to get assistance from its 12,000 business partners in designing, customizing, and implementing its products. In addition, efficient use of IT in supply chain management ensures high quality purchasing of materials and timely distribution of new products.

Finally, innovation success ultimately results from delivery of a differentiated product with unique benefits and superior value for its users. In practice, IT has been used to improve new products and related services directly. An obvious way is through quickly capturing, and incorporating into new product design, information about customer needs and industrial change. Another way is through support for superior post-purchase services. For example, Sun Microsystems introduced an IT-based 24-hour global support system that allows its customers worldwide to place a service request. Since the system's introduction Sun has been able to settle over 70% of customer problems within two days, whereas before the number was only 54% (Lipnack and Stamps 1997). Therefore, we hypothesize that,

H_2: IT, including both IT_c and IT_d, is positively related to the level of innovation success.

The Effects of Knowledge Processes on Innovation Success

The knowledge-based theory suggests that knowledge is the principle source of economic rent (Grant 1996). This theory holds that "the strategic actions which reposition the firm require it to possess very specific resources, competencies and capabilities" (Spender 1996: 46). By definition, those leading to competitive advantage must be scarce, valuable, and reasonably durable (Barney 1991). Since the origin of all tangible resources lies outside the firm, it follows that competitive advantage must arise from intangible firm-specific knowledge. Thus "it is the firm's knowledge, and its ability to generate knowledge, that lies at the core of a more epistemologically sound theory of the firm" (Spender 1996: 46). The value of knowledge and knowledge processes has been conceptually, descriptively and empirically proved along a variety of performance measures (e.g., DeCarolis and Deeds 1999; Nonaka 1991, 1994; Drucker 1993; Toffler 1990; Quinn 1992; Vekstein 1998).

A great deal of research has indicated that innovation success is likely to be influenced by a range of firm knowledge/information systems and processes. Specifically, Day (1991) points out that various market sensing information processes are crucial to innovation in learning firms. Hutt, Reingen, and Ronchetto (1988) find that effective innovation typically involve continuous knowledge sharing and use. Clark and Fujimoto (1991) explicitly describe NPD processes as “total information/knowledge systems”.

A positive relationship between knowledge processes and innovation success can therefore be hypothesized on various grounds. First, a high level of knowledge generation normally results in better and newer technological ideas. These better ideas tend to increase firm adaptation and adaptability (Huber 1991), which then allow the firm to more efficiently differentiate from and compete against competitors, and thereby, we would expect, to increase sales and/or profitability. Second, efficient knowledge dissemination and application reduces the time required for the development and launch of new products. Time has recently become a key factor in innovation because products have a greatly shortened life cycle. By improving the timeliness and speed of innovation, knowledge creation improves innovation performance. Finally, effective knowledge creation activities are expected to reinforce a firm’s culture of and commitment to innovation, thus making a long-term impact on innovation. Formally, we hypothesize:

H_3: (1) Knowledge generation is positively related to the level of innovation success;
(2) Knowledge dissemination is positively related to the level of innovation success;
(3) Knowledge application is positively related to the level of innovation success.

Methodology

Research Instrument Development Procedure

We used existing scales wherever possible and undertook the following six steps to develop the new scales. First, we conducted a literature review and identified a pool of items for each of the three constructs from the existing literature. We tried to generate items that tap the domain of each construct as closely as possible (Churchill 1979).

Second, we conducted in-depth interviews in seven knowledge-intensive organizations (IBM, Philips, Microsoft, Motorola, Sony, Intel, and Merck). The purpose of these field researches was to build an understanding of the knowledge management process and to develop appropriate measurement items. A total number of 32 senior executives, IT officers, and R&D experts were interviewed during this research stage. The interviews followed a standard protocol and they consisted of three parts. The first part of the interviews was designed to elicit salient constructs and definitions of those constructs. Participants were first asked their opinions regarding important issues in the knowledge creation process. The second part of the interviews focused on eliciting team member evaluations of the theoretical model to describe their own experiences. The third part of the interviews addressed perceptions of the relevance and completeness of scale items drawn from our literature review and earlier case studies.

Third, we carried out desk research by examining company documents regarding their knowledge management process and reviewing the relevant literature. We then performed a content analysis using the procedure recommended by Kassarjian (1977). The aim was to standardize the outcomes of the different interviews from the different companies. All measurement items generated from the above two steps were given a unique code. Five researchers with adequate knowledge in the field of knowledge management independently verified for all issues how they could be positioned in the developed research instrument. Four researchers compared their outcomes and discussed any differences. In cases where consensus could not be reached, the fifth researcher served as a referee and determined the final positioning. The referee had to intervene in only one of the measurement items.

Fourth, using the measurement items generated, we developed the first draft of our research instrument. We discussed this first draft with a representative panel of experienced IT officers and R&D managers from the companies. This helped us to refine a number of the items included in the first draft of our research instrument. We then followed the recommendations of Churchill (1979) and identified subsets of items that were unique and possessed "different shades of meaning" to informants. We submitted a list of constructs and corresponding measurement items to a panel of academic “experts” for critical evaluation and suggestions. We constructed a questionnaire based on those items judged to have high consistency and face validity.

Fifth, we pretested the survey for clarity and appropriateness using the participants of the case studies. The participants were asked to indicate any ambiguity or difficulties they experienced in responding to the items. Based on the feedbacks from the participants, we eliminated some items and modified other items which managers either had difficulties with or found them to be ambiguous.

Sixth, the final research instruments were subjected to additional pretests involving personal interviews with six executives in Motorola, Microsoft, and IBM. We ask these executives to complete the survey as they applied to their business unit. At this stage, this pretest resulted only minor refinements on two measurement items.

Measures

We used two items to assess innovation success and one item to measure overall performance: percentage of sales generated by the new products (NPsales), percentage of profit generated by new products (NPprofits), and return on investment (ROI). These variables have been used extensively in both the management and marketing literature (see Griffin and Page 1993 for a review of innovation success measures).

IT_c is equivalent to the communication technologies defined by both Kendall (1997) and Huber (1990), which aim to increase, intensify, and expand interactions among users. We used the following definition: the information technology (IT_c) provides ways to enable, intensify, or expand the interactions of multiple agents (e.g., organizational members, departments, etc.) in the execution of a planning, design, decision, or implementation task (Kendall 1997; Huber 1990). IT_d extends Huber's decision-aiding IT to include some of the production-oriented technologies listed in Kendal's classification, such as GUI, CASE, Expert systems, and Hypertext. It was defined as the information technology which provides ways to increase the capacity of an individual, organization, or team to effectively create models, develop alternatives and solutions, and/or make more effective decisions (Kendall 1997). These two types of IT are widely used and have been extensively discussed by researchers in IT literature (see Kendall 1997; Huber 1990).

Both IT_c *and* IT_d were measured by a 5-items scale which measures the level of the investment in the IT relative to the industry norm/standard (0=much lower than the industry norm/standard; 10= much higher than the industry norm/standard); the availability of the IT systems (0=available to only a few people; 10=available to everyone); the level of state-of-the-art technology in the IT systems (0=much worse than the industry norm/standard; 10=much better than the industry norm/standard); the level of easiness to use the IT systems (0=very difficult to use; 10=very easy to use); and the quality of the service of the IT systems (0=not dependable; 10=highly dependable). These measures were adopted from Sethi and King (1994).

Scales for the *Knowledge generation, knowledge dissemination, and knowledge application* were developed using the research instrument development procedure discussed in the earlier section. *Knowledge generation* was defined as the organization-wide generation of new knowledge pertaining to current and future technology needs. The 4-items scale measures: to what extent does the firm conduct in-house knowledge generation? how much intelligence on the competitors' technological development do several departments in the organization generate independently? what level does the company constantly monitor technology changes in the industry? and how often does the firm meet with customers to find out what products or technologies they will need in the future?

Knowledge dissemination refers to interactions (within or across departments) in which new knowledge is disseminated across the organization. A 3-item scale measures the level of informal "hall talk" concerning technology development tactics or strategies within the organization; the level of dissemination of the data on technology development in the company on a regular basis; and the extent in which the company periodically circulates documents (e.g., reports, newsletters) that provide information regarding new knowledge created.

Knowledge application refers to the use of knowledge in organizational practices to achieve superior performance. A 3-item scale measures the level of knowledge application as standard practice in the company; the degree of periodically reviews of the product development efforts to ensure that the company applies the knowledge it creates; and the speed of looking for applications of the new knowledge through new product research and development.

We also collect industry control variables using Michael Portor's five competitive force measures: the extent to which the customers of the firm are able to negotiate lower prices from it (0=very low; 10= very high); the extent to which the firm is able to negotiate lower prices from its suppliers (0=very low; 10= very high); the likelihood of a new competitor being able to earn satisfactory profits in the firm's principal served market segment within three years after entry (0=very low; 10= very high); the extent to which other competitive products can perform the same function as the product of the industry (0=very low; 10= very high); and the level of rivalry among existing competitors in the primary served markets (0=very low; 10= very high).

Data Collection

The data on the measures of IT_c and IT_d were collected from the corporate IT officers; the data on the level of knowledge generation, knowledge dissemination, and knowledge application were provided by SBU managers; and the performance measures were collected (as part of a another concurrent research project) from secondary sources, annual reports, company records, and/or personal interviews. The collection of the data from different informants/sources was designed to reduce potential common-method bias.

The sampling frame consisted of the companies listed in the *High-Technology Industries Directory*, all of which were sent a mailing. After initial contacts to identify appropriate informants, we narrowed the original list to 686 firms that had valid contact information for the final survey. Phone calls were made to verify the contact information. In administering each of the mail surveys, we followed the total design method for survey research (Dillman 1978). The first mailing packet included a personalized letter, an express postage-paid envelope with individually typed return-address label, and the questionnaires. We sent out three follow-up letters. We re-sent the questionnaire, together with a reminder letter, to each firm that did not respond after three weeks. To increase the response rate, we supplemented our extensive personal contacts and networking efforts with numerous incentives. From the 686 firms, we collected complete data from 277 firms (a 40% response rate). These companies are operating in the following businesses: telecommunications equipment; semiconductors and computer related products; software related products; Internet related services and equipments; instruments and related products; electronic and electrical equipment; pharmaceutical, drugs, & medicines; industrial machinery & equipment.

To test for possible non-response bias, we compared early (first wave of mailing) with late responses on knowledge intensity of the firm. The results indicated no significant differences at a 95% confidence interval. We also collected additional financial data from secondary sources such as CompuStat and company annual reports to compare respondent with non-respondent firms on annual sales and number of employees. The results indicated that there were no significant differences between the responding and non-responding firms at a 95% confidence interval. Thus, we conclude that there is no non-response bias and that the results may be generalized to the firms that did not respond.

Results

Factor Analysis and Scale Reliability

We performed a factor analysis using Varimax rotation. The factor loadings are reported in Table 1. For the five factors, all the corresponding measures have acceptable loadings, ranging from 0.57 to 0.93. These loadings suggest a high level of validity for all the five constructs. The total variance explained by the five factors is 77%. The reliability of all the measures (reported on the diagonal in Table 2) is found to surpass the 0.70 thresholds recommended by Nunnally (1978), hence implying a high level of scale reliability. In Table 2, we also present the descriptive statistics.

[insert Tables 1 & 2 about here]

Model Specification and Results

The hypotheses were examined in the following five regression models. Follow-up coefficient tests were performed to determine the relative importance of knowledge processes to innovation success. We included the five industry competitive force variables as control variables in the performance equations. We performed collinearity diagnostics and found no significant problems with multicollinearity.

(1) $KG = f(IT_c, IT_d)$; $KD = f(IT_c, IT_d)$; $KA = f(IT_c, IT_d)$;

(2) Innovation Performance = f (IT_c, IT_d, control variables); and

(3) Innovation Performance = f (IT_c, IT_d, KG, KD, KA, control variables).

The above regression models also allow testing of the potential mediators. Although not formally hypothesized, the central assumption here is that knowledge processes mediate the relationship between IT and innovation success. According to Judd and Kenny (1981) and Baron and Kenny (1986), three conditions must all be met in order to establish mediation using these groups of equations. First, the independent variables (IT_c, IT_d) must be shown to affect the mediators (KG, KD, and KA) in the first equation; second, the independent variables must be shown to affect the dependent variable (innovation performance) in the second equation; and third, the presumed mediator must be shown to affect the dependent variable in the third equation. If all these conditions hold in the predicted direction and the mediating effects are true, the effects of the independent variables on the dependent variable should be less in the third equation than in the second. If the independent variable(s) no longer have significant effects when the mediators are controlled, then perfect mediation holds. Otherwise, the mediation is imperfect, as evidenced by the smaller but non-zero coefficient.

Ordinary least squares technique was employed for estimating model parameters. Results for the three regressions are presented in Table 3. Overall, the findings provide strong support for the posited mediating model and support most of the hypotheses.

[insert Table 3 about here]

Specifically, in equation 1 (Table 3a), IT_c is found to be positively related to the level of all three knowledge creation processes at the 0.01 confident level. IT_d is found to be positively related to the level of knowledge dissemination and the level of knowledge application. Therefore, all hypotheses in H_1 except for H_{1b} (1) are supported. Furthermore, the first condition of a mediating model holds.

In equation 2 (Table 3b), both IT_c and IT_d are significantly and positively related to all the three innovation success measures at 0.01 confidence level, supporting hypothesis H2. Furthermore, the second condition of a mediating model is also supported.

In equation 3 (Table 3c), all three components of the knowledge processes are positively related to the three performance measures, thus supporting H_3. Furthermore, the results also reveal that coefficients of IT on innovation performance are reduced to a much lower level. Thus, we find support for the third condition of a mediating model.

Since all the three conditions of the mediating model testing are met, our conjecture that knowledge processes mediate the direct relationship between IT and innovation success is supported. Notably, the observed mediation effects of knowledge processes differ between the two types of IT. IT_d no longer shows a significant impact on all the three output measures, hence indicating perfect mediation by knowledge processes. IT_c's impact is reduced to a surprising negative level.

Discussion

From IT to Performance – Any Missing Links?

This study examines the role of knowledge processes in the relationship between IT and innovation performance. The central assumption here is that knowledge processes mediate what has been previously supposed as a direct relationship. If true, these knowledge processes act as a generative mechanism through which IT is able to influence innovation performance. That is, IT facilitates knowledge processes that lead to innovation success. This mediating relationship is one step forward in providing a more complete understanding of the perplexing IT-performance process.

The empirical findings strongly support the assumption that IT is able to influence performance through mediators. On the basis of the current data, we find a mediating role of IT_d and IT_c. Our identification of the mediator between IT and performance offers valuable insights into IT design and use. IT (both IT_c and IT_d) should be designed explicitly to improve knowledge generation, dissemination and application. Past research in IT design has largely focused on the technical issues such as speed, accuracy and capacity. This study highlights the importance of strategic issues, such as the alignment of IT with an organization's particular knowledge management process. The reasoning is straightforward. IT that helps link the firm with customers should enhance the firm's knowledge generation. New ideas that better represent customer needs will increase the level of success. Our findings reinforce Cortada's recommendation that firms should align IT with various business strategies to get the most from their IT investment (Cortada 1998).

IT plays a complex role in organizations; we hope that more efforts will be made to find the potential missing links between IT and business outcomes. Our study is among the few studies that are beginning to engage this issue (among others are Barua, Kriebel, and

Mukhopadhyay 1995; Mukhopadhyay and Cooper 1992, 1993; Rai, Patnayakuni, and Patnayakuni 1996). Exploration of these intermediate mechanisms will advance our understanding of the IT value both conceptually and strategically. In the meantime, identification of these mechanisms may result in more specific suggestions for IT design and use in firms.

Importance of Balanced Knowledge Processes

As one of the few empirical studies, perhaps the only one, on knowledge management, this study also promises to add significantly to the knowledge management literature. Existing research in this field is generally restricted to normative conclusions based on case studies, anecdotes and conceptual frameworks. This study offers a timely empirical test of the current theory. To avoid a vague discussion of knowledge management, we look into three key components of the knowledge management processes identified in the literature.

As we expected, the results suggest that all the three components are critical to innovation success. Follow-up analyses of their relative importance (see Table 3d) found significant difference between knowledge generation and knowledge application, and between knowledge dissemination and knowledge application, whereas knowledge generation and dissemination appear to have an equal impact. These findings underscore the importance of taking a balanced approach to knowledge processes. That is, firms must deploy resources in a balanced way to different knowledge processes in order to obtain optimal return.

The results also highlight the particular importance of knowledge application, the effect of which on innovation performance is significantly larger than that of the other two components. Surprisingly, knowledge application has received the least notice among the three components in the literature. Evidence shows that although firms are enthusiastic about acquiring and transferring best practices among their units, surprising performance differences are unequivocally observed among these units (Chew, Bresnahan, and Clark 1990). This indicates the need to improve knowledge application in reality.

Potential Pitfalls of Communication IT

An intriguing finding of this study is the negative impact of IT_c on innovation success after the mediators (knowledge processes) are controlled. The implication of this is that IT_c does not influence firm performance directly. Instead, IT_c affects innovation both positively (e.g., through facilitating knowledge processes) and negatively (through potential pitfalls). Given the mixed pattern, the current widespread frenzy of digitalization should be viewed and embraced with caution. When evaluating the IT value and making investment decisions, managers must avoid over-optimism. Potential pitfalls of IT should be thoroughly probed.

There are far fewer studies of IT_c's potential pitfalls than of its benefits. One among these few has to do with information richness, "the ability of information to change understanding within a time interval" (Daft and Lengel 1986). Using social presence theory (Short, Williams, and Christie 1976), the lack of social context cues hypothesis (Sproull and Kiesler 1986), and media richness theory (Daft and Lengel 1986), researchers have criticized IT_c as a "lean" medium that lacks the many social cues and warmth of traditional face-to-face meetings. This media "leanness" may be particularly harmful to innovation, where uncertainty is extremely high and many cues are not easily observable or communicable in the digital network. Another potential pitfall of IT_c may arise from information overload, which can distract firms from making timely decisions and thus lead them to miss innovation opportunities. Another relatively little discussed problem of IT_c is organizational control and monitoring of telecommuters who substitute "telecommunications for physical travel to the organization" (Kurland and Egan 1999). Remote supervision of these workers presents monitoring challenges, and their physical isolation may impede their involvement in valued organizational outcomes. A keen understanding of the potential pitfalls of IT would guide IT investors to avoid or handle those problems and make the most of their tremendous IT spending.

Limitations and Future Research

Ample areas exist for future research. In addition to those mentioned above, several arise from the limitations of this study. First, the outcome variables used here are all financial measures. Non-financial outcomes should be explored. Creativity, quality, flexibility, and customer satisfaction, for example, are all critical to firm competitive advantage.

Second, this study examines only a short-term outcome within a one-year period. Since innovation often takes more than a year to fully realize value, longitudinal studies using panel data would help reveal the dynamics of time and information hidden from a static single-period study.

Finally, general business research has found that environmental contingencies often affect many strategic linkages (e.g., Fry and Slocum 1984). Further research may therefore investigate the role of environmental contingencies in mediation. Presumably, the patterns identified here (i.e., the alignment of IT with knowledge processes and the relative importance of knowledge processes) would not be found in stable and low technology industries.

Figure 1
Conceptual Model

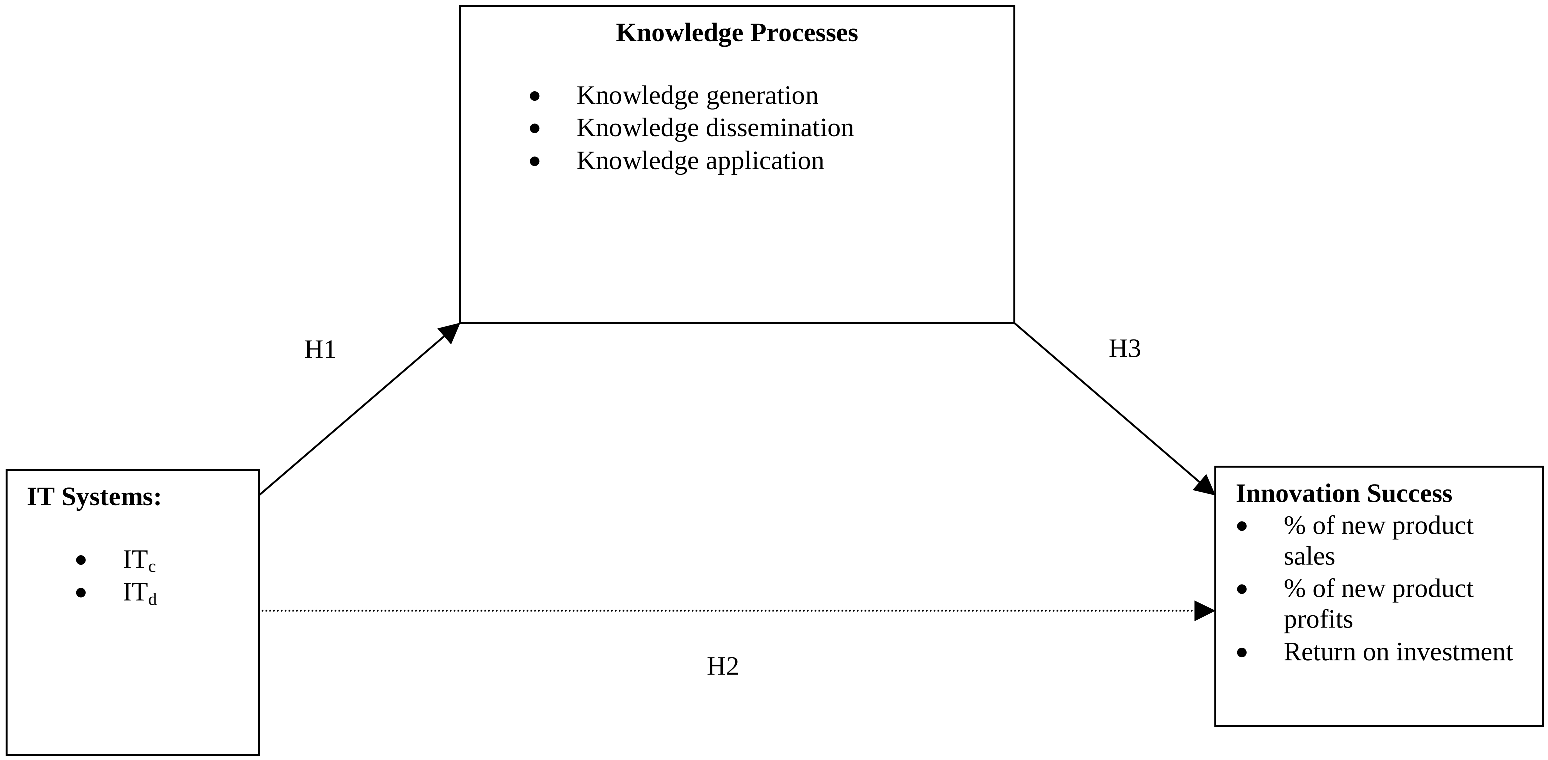

Table 1
Factor Loadings with Varimax Rotation

	Factor Loadings*				
Items	**F1**	**F2**	**F3**	**F4**	**F5**
itc2	0.93	0.20	0.12	0.19	0.15
itc1	0.90	0.03	0.01	0.14	0.11
itc4	0.89	0.08	0.09	0.18	0.16
itc3	0.88	0.24	0.07	0.13	0.06
itc5	0.86	0.25	0.13	0.17	0.11
itd1	0.20	0.85	0.10	0.12	0.23
itd2	-0.04	0.84	0.07	0.10	0.05
itd3	0.19	0.80	0.05	0.07	0.03
itd4	0.12	0.80	-0.05	0.15	0.03
itd5	0.18	0.69	-0.04	-0.02	0.04
KG2	0.10	-0.03	0.93	0.09	0.02
KG1	0.08	-0.08	0.92	0.08	-0.02
KG4	0.07	0.12	0.89	-0.02	0.19
KG3	0.05	0.09	0.89	-0.06	0.18
KD3	0.20	0.06	-0.06	0.83	0.07
KD1	0.25	0.40	0.07	0.62	0.19
KD2	0.38	0.12	0.13	0.61	0.25
KA3	0.07	0.02	0.28	0.38	0.70
KA2	0.38	0.34	-0.02	0.00	0.66
KA1	0.33	0.10	0.40	0.30	0.57
Variance Explained	.3697	.1690	.1261	.0687	.0382

*Item identified as five factors:
- $F1=IT_c$;
- $F2=IT_d$;
- F3=knowledge generation (KG);
- F4=knowledge dissemination (KD); and
- F5=knowledge application (KA).

Note: numbers in boxes indicate items that load highly for each of the five factors.

Table 2
Descriptive Statistics

	Mean	S.D.	IT_c	IT_d	KG	KD	KA	ROI	NPS	NPP	BPOW	SPOW	RIVAL	SUBS	ENTRY
Computer-assisted communication technologies (IT_c)	4.11	2.60	***(0.87)***												
Decision-Aid Information Technologies (IT_d)	6.43	2.38	0.35	***(0.96)***											
Knowledge Generation (KG)	6.51	2.32	0.19	0.07	***(0.94)***										
Knowledge Dissemination (KD)	5.39	2.38	0.54	0.37	0.14	***(0.73)***									
Knowledge Application (KA)	5.47	2.16	0.59	0.46	0.35	0.55	***(0.72)***								
Return on Investment (ROI)	6.93	9.98	0.28	0.27	0.29	0.44	0.56	***NA***							
Percentage of new product sales (NPSales)	20.96	12.19	0.30	0.28	0.40	0.48	0.60	0.79	***NA***						
Percentage of new product profits (NPProfits)	22.07	8.85	0.30	0.28	0.29	0.44	0.56	0.76	0.75	***NA***					
Buyer Power (BPOW)	4.99	1.92	-0.01	-0.02	0.02	0.08	-0.01	-0.08	-0.05	0.00	***NA***				
supplier Power (SPOW)	4.95	2.02	0.07	-0.03	0.01	0.00	0.05	0.01	0.04	0.00	-0.14	***NA***			
Rivalry of Competition (RIVAL)	4.84	1.93	-0.07	-0.04	0.01	-0.10	-0.10	-0.15	-0.13	-0.14	0.08	0.00	***NA***		
Threat of Substitution (SUBS)	4.76	1.88	-0.05	-0.07	-0.04	0.06	-0.04	-0.02	-0.02	-0.05	-0.05	0.01	-0.10	***NA***	
Threat of Entry (ENTRY)	5.16	1.88	0.00	-0.08	0.03	-0.01	0.02	-0.01	0.01	0.02	-0.01	0.01	0.11	-0.02	***NA***

* Note: The Cronbach Coefficient Alpha for each measure is on the diagonal (and in italics and bold);
The correlations among the measures are on the off-diagonal.

Table 3
Hypotheses Tests

a. OLS estimates of Equation 1: Dependent variables are knowledge generation (KG), knowledge dissemination (KD), and knowledge application (KA)

	KG		KD		KA	
	Parameter Estimate	**Std. Error**	**Parameter Estimate**	**Std. Error**	**Parameter Estimate**	**Std. Error**
Intercept	5.79***	0.41	2.31***	0.35	2.14***	0.30
ITc	0.16**	0.06	0.42***	0.05	0.40***	0.04
ITd	0.01	0.06	0.21***	0.05	0.26***	0.04
Adj. R-square	.0273		.3223		.4103	

*p<0.05; **p<0.01; ***p<0.001.

b. OLS estimates of Equation 2: Dependent variables are return on investment (ROI), new product sales as percentage of the total revenue, percentage of profits generated from new products

	ROI		NPSales (%)		NPProfits (%)	
	Parameter Estimate	**Std. Error**	**Parameter Estimate**	**Std. Error**	**Parameter Estimate**	**Std. Error**
Intercept	3.65	3.89	12.36**	4.72	16.40***	3.43
ITc	0.78***	0.23	1.02***	0.28	0.72***	0.21
ITd	0.80**	0.26	1.05***	0.31	0.77***	0.23
bpow	-0.35	0.30	-0.20	0.36	0.06	0.26
spow	-0.06	0.28	0.18	0.35	-0.02	0.25
rival	-0.64*	0.30	-0.71	0.36	-0.60*	0.26
subs	-0.06	0.30	-0.05	0.37	-0.15	0.27
entry	0.08	0.30	0.27	0.37	0.23	0.27
Adj. R-square	.1090		.1202		.1205	

*p<0.05; **p<0.01; ***p<0.001.

Table 3 (Continued)
Hypotheses Tests

c. OLS estimates of Equation 3: Dependent variables are return on investment (ROI), new product sales as percentage of the total revenue, percentage of profits generated from new products

	ROI		**NPSales (%)**		**NPProfits (%)**	
	Parameter Estimate	**Std. Error**	**Parameter Estimate**	**Std. Error**	**Parameter Estimate**	**Std. Error**
Intercept	-5.33	3.51	-2.07	3.99	8.71**	3.16
ITc	-0.61*	0.24	-0.81**	0.28	-0.44*	0.22
ITd	-0.00	0.23	0.06	0.27	0.11	0.21
KG	0.52*	0.22	1.25***	0.25	0.47**	0.20
KD	1.06***	0.26	1.50***	0.30	0.88**	0.23
KA	2.16***	0.32	2.50***	0.36	1.78***	0.29
bpow	-0.50	0.26	-0.42	0.29	-0.07	0.23
spow	-0.09	0.24	0.15	0.27	-0.04	0.22
rival	-0.42	0.25	-0.44	0.29	-0.42	0.23
subs	-0.17	0.26	-0.18	0.29	-0.24	0.23
entry	-0.06	0.26	0.08	0.29	0.11	0.23
Adj. R-square	.3621		.4479		.3451	

*p<0.05; **p<0.01; ***p<0.001.

d. Coefficient tests for Equation 3

	H_0: KG=KD		**H_0: KG=KA**		**H_0: KD=KA**	
Dependent variables	**F-value**	**Pr > F**	**F-value**	**Pr > F**	**F-value**	**Pr > F**
ROI	2.60	0.1083	13.74	0.0003	5.59	0.0188
NPSales (%)	0.43	0.5131	6.13	0.0139	3.55	0.0608
NPProfits (%)	1.82	0.1785	10.77	0.0012	4.62	0.0326

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