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Does IT Impact Firm Innovativeness: An Empirical Examination of Complementary and Direct Effects

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ABSTRACT

In this study we investigate the relationship between IT investment and firm innovation outcome. We theorize about the relationships between IT and the innovation processes and identify complementary and direct effects of IT on firm innovation outcomes. We test our theory using data compiled from secondary sources. Using Negative Binomial regression models we find that the interaction between IT investment and R&D expenditure significantly impacts firm innovation measured using patent counts and that IT investments do not have a direct effect on innovation outcomes. We interpret and discuss our results in the paper.

Keywords

Information technology, innovativeness, patent, complementarity, open innovation

INTRODUCTION

Innovation has been considered a critical source of competitive advantage (Teece, Pisano, and Shuen 1997) and an important competence (Prahalad and Hamel 1990) firms have to develop to be successful in today's business environment (Linder, Jarvenpaa, and Davenport 2003). Innovation has also been recognized as a primary means of corporate renewal (Dougherty 1992; Bowen et al. 1994), since the growth and development of a firm depend on its ability to introduce new products and processes over time (Dougherty and Hardy 1996; Penrose 1959). The importance of innovation is especially relevant in a rapidly-changing environment since organizations need to continuously renew themselves to survive and prosper in dynamic environments (Danneels 2002). Furthermore, with a wide range of business processes, from manufacturing, back office operations to logistics and customer service, being outsourced, innovation has become the core of business of most large and small firms.

Information systems scholars have long been interested in the effects of IT on firm performance and have examined the relationship between IT stock and a myriad of firm performance indicators such as productivity, profitability, competitive advantage and consumer surplus. With innovation becoming the core mission of firms today, it is only appropriate that IS research expands in scope to include innovation as an indicator of firm performance. Firms in their endeavor to enhance their innovation capabilities have sought to use IT in every aspect of the innovation process. Broadband connection and video conferencing have facilitated the coordination between geographically distributed R&D centers. In drug discovery, pattern discovery and molecular modeling supported by advanced processing capacity of information technology have significantly accelerated the R&D process (Augen 2002). Automakers, by leveraging 3-D virtual-reality modeling software, have dramatically cut the time it takes to build a car from 40 months to less than 18 months (InformationWeek Sept. 22, 2003). These examples illustrate how IT investments can complement and enhance the innovation processes in a firm. In this study we theorize about the complementarities between IT investments and other factor inputs to the innovation process and empirically examine the effects of these complementarities on innovation outcomes.

Besides harnessing the internal innovation capabilities, firms are seeking to source innovation externally. Procter & Gamble Co. has created the position of director of external innovation and expects half of its new product ideas to be generated from outside by 2010, compared to 20% now (Business Week, Mar.21, 2005). The outsourcing of technological knowledge through licensing, R&D partnerships, research contract and agreements, has become more common than in the past, and markets for technology have emerged in several industries (Arora et al. 2001). Use of advanced information technology enables organizations to leverage these external innovation sources such as virtual open innovation markets. InnoCentive, a virtual open innovation marketplace has enabled Eli Lilly to access specialists worldwide and contract with them to collect and filter

innovative ideas. In this case, use of information technology contributes to firm innovativeness through enhancing its capabilities to source innovation externally.

In summary, we propose that information technology contributes to firm innovation outcome by complementing internal innovation capabilities and enhancing its external innovation sourcing capabilities. Both effects will be empirically examined using a knowledge production function model. In contrast to past IT value studies that have used the standard Cobb-Douglas production function, we use the knowledge production function which is more appropriate when the research focus is on innovation outcomes and not efficiency and cost reduction.

The rest of the paper is organized as follows: the next two sections highlight the impact of IT on both internal innovation capabilities and external innovation sourcing capabilities. Following this, we describe the data and the econometrics methods employed to test our research model. The following section discusses the results, followed by a discussion of the implications of the study future research and practice.

COMPLEMENTARY EFFECTS OF IT ON FIRM INNOVATION CAPABILITIES

Innovation is a knowledge driven process that is affected by factor inputs such as investments in research and development and the prior knowledge stocks of a firm (Griliches 1979, 1998). However, this link is not automatic and studies have found significant variation in innovation outcomes across firms with similar levels of R&D investments (Henderson and Cockburn 1994). Research in new product development and R&D management have identified factors such as coordination effectiveness (Allen 1964, 1977, 1980), number of weak ties (Pickering and King 1996; Quarterman 1990), ability to harness dispersed knowledge resources to be important in understand variance in innovation outcomes of firms. Collectively this body of research has argued that complementarities between R&D activities and other firm resources have to be understood in examining innovation outcome of firms. Synthesizing their findings, this paper argues that IT complements internal innovative capability by increasing coordination efficiency, enabling weak ties, actualizing organizational memory and providing advanced computation capability.

Coordination Efficiency

Inputs from multiple scientific disciplines are typically required for an innovation. For instance, modern drug discovery requires the input of scientists skilled in a very wide range of disciplines, including molecular biology, physiology, biochemistry, analytic and medicinal chemistry, crystallography and pharmacology (Henderson and Cockburn 1994) In fact, linking technologies in unexpected ways is at the heart of innovation. Hence, it has been proposed that patent output is determined not only by R&D expenditure but also by effective coordination within a R&D group. An overwhelming body of research indicates that the most direct route to increasing research and development productivity is through developing good technical communication within the R&D organization (Allen 1964, 1977, 1980; Baker et al. 1967; Goldbar et al. 1979). Clark and Fujimoto (1991), Hauser and Clausing (1988) found that high performance in product development is associated with the use of organizational mechanisms that actively encourage the exchange of information across “component” boundaries within the firm. Henderson and Cockburn (1994) found that frequent change of information across disciplinary or disease areas have a significant positive relationship with patent count.

One of the most significant influences of information technology is to facilitate communication and coordination (Allen 1968; DeSanctis and Monge 1999). Information technology improves coordination in two ways: by providing a common language and embedding organization routines into information systems.

Although both researchers and practitioners have been aware of the communication need in R&D activities, the real challenge resides in how to realize it. Cross-functional teams are not so difficult to set up, however, the challenge is for the team to access and integrate the knowledge of the team members (Grant 1996). Demsetz (1991) identifies the prerequisite for communication between different specialists as the presence of common knowledge between them. The more common language shared between specialists, the more efficient the communication process. Virtual product design provided by computer-aided-design tools enables a common language when engineers from different fields communicate. Boeing benefits from its virtual product design platform by successfully integrating knowledge from electronics to new materials. Even for the specialists sharing the same technical knowledge, when they reside in different geographic locations, virtual design that changes real time improves their communication efficiency.

Technology can support coordination by embedding the organizational routines into information systems (Alavi and Leidner 2001). Organizational routines refer to the development of task performance and coordination patterns, interaction protocols,

and process specifications that allow individuals to apply and integrate their specialized knowledge without the need to articulate and communicate what they know to others (Alavi and Leidner 2001). Information systems can codify and automate organizational routines so that the need for communication and coordination is reduced. Some communication between specialists can be replaced by integration between information systems. For instance, in the R&D department of a construction materials manufacturer, the color formula was manually forwarded to the engineers. After systems integration between two design groups, the formula is automatically transferred and the process becomes more error-proof. The efficiency of coordination is improved by IT in this case because the need of communication is decreased.

Enabling Weak Ties

Social ties are the links that bind individuals to other individuals, as manifested in the frequency and nature of communication among individuals. Granovetter (1973) differentiated between strong ties and weak ties on four dimensions: time, emotional intensity, mutual confidence and reciprocity. Weak ties are maintained through less frequent and less emotionally intense communication, in relationships that do not require or encourage sharing of confidences or establishment of strong reciprocities. Strong ties are generally in place for reasons not affected by marginal changes in communication costs. That is to say, strong ties will seldom be weakened by lack of communication technology access. On the contrary, the establishment of weak ties among people in the same organization or from different organization is greatly influenced by the ease and cost of communication and hence will be impacted by the use of information and communication technology.

Number of weak ties impacts the innovation capacity in two ways. First, weak ties between organizational specialists and external scientific community keep firms updated with the state-of-the-art knowledge. Secondly, weak ties within the R&D department provide novel information and reduce search time for knowledge in innovation activities, both of which in turn improve innovation capabilities of the firm (Hensen 1999).

Feldman (1987) has argued that participation in electronic news groups facilitate establishing weak ties between an organization member and his or her external professional community and that such ties have typically been used to gather information in problems solving (Quarterman 1990, Pickering and King 1996). Henderson and Cockburn (1994) found that keeping R&D specialists connected to external science community is positively associated with higher patenting activity in the pharmaceutical industry.

Besides the weak ties to external scientific community, information technology, like intranet and bulletin broadcasting within the firm increases the number of weak ties among R&D personnel within the organization. According to the social network theory, weak ties are efficient for knowledge sharing because they provide access to novel information by bridging otherwise disconnected groups and individuals in an organization. A significant part of innovation ideas occur during the interaction of distant sources of knowledge. P&G describes their innovation strength as linking the most impossible knowledge together (Sakkab 2002). They achieve the strength by using an internal website called "InnovationNet" that acts as the global "lunchroom" where researchers throughout the world can trade information and make connections across the company (Sakkab 2002). Moreover, weak ties between specialists from different disciplines reduce the time to search for knowledge, thus speed up the innovation process.

Actualizing Organizational Memory

The ability to store and retrieve technological knowledge is critical to access and integrate knowledge across time and space. Marsh and Stock (2003) proposed that the inter-temporal integration, defined as "the process of collecting, interpreting, and internalizing technological and marketing capabilities from past new product development projects and incorporating that knowledge...into the development of future new product", increases innovation success and long-term competitive advantage. Empirical studies have also shown that while organizations create knowledge and learn, they also forget, because of, for example, change of personnel. Maintaining the stock of prior knowledge is greatly facilitated by information technology.

Advanced computer storage technology and sophisticated retrieval techniques, such as query languages, multimedia databases, and database management systems, can be effective tools in enhancing storage/retrieval of knowledge (Alavi and Leidner 2001). A project memory system at DEC (Digital Equipment Corporation) combines such information as bulletin board postings, product release statement, service manuals, and e-mail messages to keep a comprehensive record of the technology and product data and to enable rapid access to the information. Document management technology allows knowledge to be effectively stored and made accessible, even when it is dispersed among a variety of geographic locations (Stein and Zwass 1995). Merck accelerates its drug discovery process by sharing experimental procedures and findings between its various research labs (Beierly and Chakrabarti, 1996; Ross, Beath, and Goodhue, 1996). These examples

illustrate how IT capabilities today enable firms to actualize organizational memory through repositories and thereby make available these knowledge resources firm wide.

Advanced Computational Capability

The computational capacity need for certain R&D, such as for drug discovery and automobile design is extremely high. The use of information technology in chemical structure prediction, pattern discovery, and systems and molecular modeling has expedited drug discovery process tremendously. For example, using traditional drug development techniques it took nearly 40 years to capitalize on a base understanding of a cholesterol biosynthesis pathway to develop statin drugs. On the contrary, in silico molecular modeling and access to databases containing genomic and proteomic information, a molecular-level understanding of the role of the HER-2 receptor in breast cancer led to the development of the chemotherapeutic agent within only three years (Augen 2002).

In automobile and aircraft industry, the design of a part might involve thousands of components making physical prototyping time consuming and costly. Advance design software allows firms today to use virtual design models which in turn have cut down the design costs and time. More importantly, these models allow iterative evolution of design alternatives easily there by improving the quality of the design as well and allowing for more creative design outcomes to emerge. Automating product development has been expanding to include simulated crash testing. Now GM can electronically design a vehicle and then put that virtual car through a series of simulated crash tests using digital vehicle data to help build safer cars (InformationWeek Sept. 22, 2003). In industries where R&D and product development requires significant computational capabilities, appropriate IT platforms become a necessity.

DIRECT EFFECTS OF IT ON INNOVATION SOURCING CAPABILITIES

Companies are no longer limited by ideas generated from internal R&D resources (Chesbrough 2003). Instead they have opened themselves to external R&D resources outside, such as start-ups, universities, research consortia, and other outside organizations. As a matter of fact, the outsourcing of technological knowledge through licensing, R&D joint ventures, research contract and agreements, R&D partnerships, has become more common than in the past, and markets for technology have emerged in several industries (Arora et al. 2001). For example, most of the drugs that are currently in Pfizer's pipeline originated outside the company. It is posited that complementing internal R&D with external technology sourcing leads to faster pace of innovation, faster access to knowledge, and the availability of good technology (Sakkab 2002). By buying design from Asian technology suppliers, HP claims that it takes 60% less time to get a new concept to market (Business Week, Mar.21, 2005).

The literature focusing on the "make-or-buy dilemma" of technology has shown that due to the tacit nature of technological knowledge and high uncertainty involved in technological contract, the transaction cost for sourcing technology from the market is so high that companies choose to build their own in-house R&D capabilities. However, Cesaroni (2004) shows that when technology markets emerge, transaction costs become less severe, and technology outsourcing becomes a more attractive option which companies might decide to exploit. In relative terms, the advantages of in-house technology development reduce if markets for technology operate efficiently. Likewise, since advanced information technology reduces the searching cost and coordination cost in buying technology, the use of IT could also make technology sourcing more attractive.

IT reduces the searching cost in technology sourcing by connecting the focal firm to globally available technology resources. Firms like Eli Lilly and P&G have used virtual open innovation markets to solve technological problem. The virtual market connects several resources such as a retired Nobel laureate, a professor in Europe, and a professional in China. The technological problem is sent to community members; and then proposal to solve the problem will be sent back from interested members and selected by the firm. By doing that, traditional "R&D" has changed to "C&D" (Connect and Development) now. Eli Lilly and Co. has founded InnoCentive, which claims to be the "largest virtual laboratory in the world." It posts scientific problems from its 30 "seeker" members to a proprietary network of 70,000 registered "solvers" around the world. Each posting includes a promised cash award for the solution (Anthes 2004). The virtual technology market relies mostly on the use of telecommunication network as an enabler.

Furthermore, cutting-edge search technologies are another enabler of the "connect and develop" approach. Success of virtual open technology market place depends on their ability to get high-quality responses, which in turn depends on their ability to identify the right problem solvers. Sophisticated search algorithms are used to build the right mailing list comprised of potential problem solvers. For instance, NineSigma Inc. helps its 50 or so clients prepare technical briefs describing projects or problems they are trying to solve and then sends the briefs — without identifying the originating companies — to thousands of researchers around the world. NineSigma creates a unique database of potential respondents for every client

request. The databases are said to be generated through a variety of searching techniques, some of which are proprietary. For each problem, NineSigma sends out 6,000 bid requests on average and receives 10 to 100 responses. InnoCentive claims that proprietary algorithms are used to identify with a higher probability the researchers on the mailing list most likely to participate in the challenge.

RESEARCH MODEL

Based on the arguments presented above we posit that IT impacts innovation outcomes both directly and indirectly. By increasing coordination efficiency and enabling weak ties, actualizing organizational memory and advancing computational capabilities, information technology complements the internal innovation capabilities of a firm by achieving higher outcome from existing R&D investment. That is, a higher level of IT investment could lead to higher R&D productivity of a firm. Hence, we propose that

H1: Information technology investment moderates the relationship between R&D expenditure and innovation outcome.

In addition to the complementary effects of IT on internal R&D activities, information technology enables firms to go beyond the internal innovation capabilities and take advantage of external sources of innovations. That is, information technology leads to higher innovation outcome directly in addition to complementing internal R&D investment. We propose that information technology investment enhances innovation sourcing capabilities of a firm. Hence,

H2: Information technology investment has a positive relationship with innovation outcome.

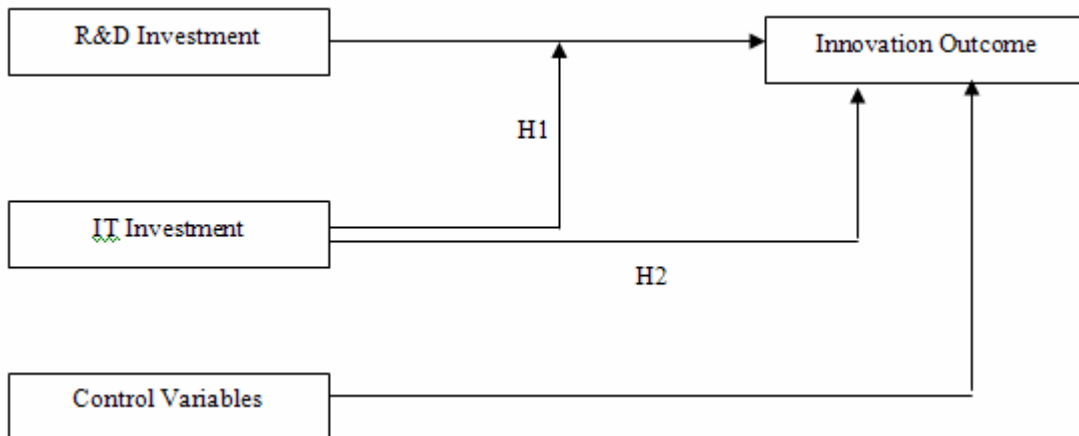


Figure 1: Research Model

RESEARCH METHODOLOGY

Data to test the research model was compiled from several secondary sources. IT investment data was obtained from a data set published by Information Week. Data about the R&D investments were obtained from Compustat. We matched the firms listed in InformationWeek with firms in Compustat database, and 963 observations remained after matching. After dropping observations for which R&D investment or diversification level data were not available, 583 observations remained. We further dropped firms in the services industry such as retail, wholesale, insurance and retained only product manufacturing firms resulting in a sample of 450 observations. This data pruning was necessary because the innovation and patenting behaviors could be very different across product manufacturing and services industries. Table 1 profiles data set in terms of the industry segments and the number of observations in each industry segment.

Industry Classification	First 2 sic code	Number of Observations
Food and kindred products	20	9
Apparel and other textile products	23	1
Lumber and wood products	24	3
Furniture and fixtures	25	11
Paper and allied products	26	27
Printing and publishing	27	2
Chemicals and allied products	28	88
Petroleum and coal products	29	17
Rubber and miscellaneous plastics products	30	10
Stone, clay, glass and concrete products	32	5
Primary metal industries	33	35
Fabricated metal industries	34	21
Industrial machinery and equipment	35	86
Electrical and electronic equipment	36	42
Transportation equipment	37	55
Instruments and related products	38	37
Miscellaneous manufacturing industries	39	1
Total		450

Table1: Distribution of Observations by Industry Segments

MEASURES

Annual patent count is used as the proxy for innovation outcome of the firm. Despite shortcomings, patent count data has been widely used as an indicator of innovation outcome (Ahuja 2000; Cincera 1997; Hall and Ziedonis 2001; Henderson and Cockburn 1994; Iwasa and Odagiri 2004; Flemming and Sorenson 2001; Lim 2004; Penner-Hahn and Shaver 2005). It is found that number of patents granted to a firm correlates with its sales from new products (Comanor and Scherer 1969) and the timing of new innovations (Basberg 1982). Nevertheless, the use of patent data for measuring innovation outcome is far from ideal (Griliches 1990). Some inventions may not be patented because the firm relies on secrecy or other means of protecting intellectual property (Basberg 1987). Since innovation is inherently difficult to measure and firms are reluctant to divulge sensitive internal metrics to outsiders, patent counts, although imperfect, are often the best measure available (Lim 2004). In this paper, we measure each firm's innovation outcome as the number of patents granted. Yearly number of patents granted to a firm during a period of 1994-1999 is calculated based on the patent database from USPTO (United States Patent and Trademark Office) compiled by hall, Jaffe and Trajtenberg (2001).

Annual information technology spending data utilized in this study is from the annual survey conducted by Informationweek (IW) during the period of 1991-1996. Every year since 1989, a list of 500 companies and their IT spending is published in a special issue of the magazine in September. The companies are drawn from the population of US firms with over \$1 billion in sales. IT spending data of a firm includes IT hardware and software investments in multiple categories (PCs, workstations, servers, mainframes, peripheral devices, software, local and wide area networks, and telecommunications). IW data has been used previously by Bharadwaj et al. (1999), Bharadwaj (2000), and Santhanam and Hartono (2003). It is also found to be highly correlated with IT investment data from other sources, such as Computerworld (Linchtenberg 1995) and has been recognized as an authoritative source of secondary data on firm level IT investment.

We compiled the R&D investment data from the Compustat database for the period of 1991 – 1996. Besides R&D investment, other factors may influence firm patent count. In our paper, firm size, previous knowledge stock, firm diversification level, industry dummies, and year dummies are controlled for. Previous knowledge has been considered an important determinant of new innovations. Following Argyres and Silverman (2004) and Henderson and Cockburn (1994), we calculated the total number of patent granted to the firm since 1963 as the proxy of the stock of previous knowledge. Nelson (1959) hypothesized that diversified firms may better appropriate the returns from R&D. We therefore constructed a firm-level diversification index based on the distribution of sales of the firm and used it as a control variable. Firm size is controlled by using the total assets of the firm. Industry dummies based on the first two sic code are also included in our model. The summary and descriptive of the variables in our model are shown in Table 2.

Variables	Unit	Mean	Std. Deviation	Minimum	Maximum
Patent Count	Number	95.26	186.19	0	1406
IT Investment	Million Dollars	198.62	335.82	0	3600
R&D Expenditure	Million Dollars	389.15	821.30	0.74	8900
Assets	Million Dollars	10213.91	23339.40	422.02	262867
Stock of Patents	Number	7147.96	12835.10	0	74526
Diversification	Ratio	0.59	0.26	0.1942	1

Table2: Descriptive Statistics of the Variables

ECONOMETRIC MODEL

We use the knowledge production function to test the research model. This production function first proposed by Griliches and further refined by his collaborators (Griliches 1979; Pakes and Griliches 1984; Jaffe 1986; Griliches 1998) has been extensively used in innovation research and has been found to be better suited for the study of knowledge work than the traditional production function. The output of knowledge production function is innovation, which is usually measured by number of patents. Typical input measures of the knowledge production function used in past studies are R&D expenditure, firm size, and previous knowledge. Besides these input variables, other factors of interest such as the location of R&D (Iwasa and Odagiri 2004), R&D organizational structure and diversification level of the firm (Argyres and Silverman 2004), integrative capabilities of a firm (Henderson and Cockburn 1994) have been incorporated in the knowledge production function.

We use a log-linear knowledge production with patent count as the output measure and R&D expenditure, IT investments, the interaction between IT investment and R&D expenditure, prior knowledge stock, firm size and firm diversification as the input measures. Because R&D expenditures take time to yield results in terms of patents and because of the time lags between patent application and patent granting it is important to incorporate time lags in the model. Moreover, the IS literature has also emphasized the lagged effects of IT investments. Consistent with past research in the product development and R&D literatures, we use a 3 year time lag in our model wherein the patent count numbers used for the period three years later than the year for R&D expenditure and for IT investments.

Consistent with recommended analytical practices for patent count data (Hausman, Hall and Griliches 1984), we used a negative binomial regression to obtain an unbiased estimate. Compared to Poisson regression, negative binomial regression accounts for over dispersion. Our patent data shows a mean value of 95.25 and a standard deviation of 186.19, suggesting that negative binomial regression is an appropriate method. Since we have an unbalanced panel data with 145 firms in the period from 1991 to 1996, we ran both the fixed-effect model and random effect model. Pooled ordinary least square model is not appropriate for our study since it is very likely that there exist unobserved firm specific effects (such as the propensity to patent) which are also correlated with our dependent variable (patent count). However, we cannot say for sure whether the firm specific effects are correlated with our independent variables or not, therefore, both fixed-effect and random-effect model are employed. As will be shown in next section, the results from both models are consistent.

RESULTS

The results from the fixed-effect negative binomial regression are presented in Table 3. We first introduce the explanatory variables typically used in a knowledge production function as a base model. In the second step, we add the IT investment

variable in the analysis to test hypothesis 2. In the third step, we introduce the interaction term of R&D and IT investment to test hypothesis 1.

In the base model, both R&D expenditure and stock of previous patents are significant at $p < 0.01$ level, which is consistent with previous studies. Model 1 includes IT investment into the set of variables in the base model. The coefficient of IT investment is positive but statistically not significant ($\beta = 0.0136$, t value = 0.33), which indicate that there is no direct association between IT investment and patent count of a firm. Hence, hypothesis 2 is rejected.

Fixed-effect negative binomial model (Dependent variable: patent count)

Independent Variables	Base Model	Model1 (Add IT investment)	Model 2 (Add R&D * IT)
Constant	1.0616 (0.9759)	1.1276 (.9978)	1.0865 (1.0139)
Log(R&D Expenditure)	0.5263*** (0.0902)	0.5226*** (0.0909)	0.4884*** (.09352)
Log(Stock of patents)	0.3786*** (0.0645)	0.3753*** (0.0651)	0.3671*** (0.0668)
Log(Asset)	-0.5356** (0.2296)	-0.5458 (0.2321)	-0.5237** (0.2343)
Diversification	0.0301 (0.2211)	0.02216 (0.2223)	-0.0068 (0.2235)
Log(IT Spending)		0.0136 (0.0412)	-0.0209 (0.0432)
Log(R&D Expenditure)*Log(IT Spending)			0.0472** (0.0239)
Year Dummies			
Log-likelihood chi-square	-927.059	-927.0038	-925.1217
N	309	309	309

Note: 1. *: $p < 0.1$; **: $p < 0.05$; ***: $p < 0.01$

2. Standard error in parentheses

3. Coefficients for year dummies not shown.

Table 3: Results of Fixed-Effect Negative Binomial Regression

Model 2 introduces the interaction term into the set of variables in model 1. The coefficient of IT investment is negative and statistically not significant ($\beta = -0.0209$, t value = -0.48), while that of the interaction term is positive and statistically significant at $p < 0.05$ level ($\beta = 0.0472$, $t = 1.98$). Hence, hypothesis 1 is supported. The significant interaction term in the model is interpreted as indicating that the relationship between R&D and patent count varies across different levels of IT investment (Cohen et. al 2002). In particular, it suggests that incremental R&D investment yields more innovation output at a higher level of IT investment. That is, firms with a higher level of IT investment can appropriate marginal R&D investment better than firms with a lower level of IT investment. The significant interaction term also suggests that incremental IT investments enhances innovation outcome at a high level of R&D investment, while incremental IT investment adversely affect innovation outcome at a low level of R&D investment. The complementarities between level of R&D investment and IT investment thus emerge as an important determinant of firm innovation outcome.

Table 4 shows the results of using random-effect negative binomial model. The difference between random and fixed effect model is that random effect model assumes that the unobserved firm specific effect is uncorrelated with existing independent variables. We are not sure whether this assumption holds in our model. Therefore, we used fixed-effect model as a safe and conservative choice. However, since random-effect model gives us more efficient estimation, we also ran our data using a random-effect model. As is shown in table 4, the results are consistent with that of the fixed-effect model and it gives us more efficient estimation (lower standard error for coefficient estimation).

Random-effect negative binomial model (Dependent variable: patent count)

Dependent variable	Base Model	Model1 (Add IT investment)	Model2 (Add R&D * IT)
Constant	-2.0612** (0.9697)	-2.147** (0.9726)	-2.1589** (0.9824)
Log(R&D Expenditure)	0.6444*** (0.0797)	0.3582*** (0.081)	0.3461*** (.08166)
Log(Stock of previous patents)	0.3786*** (0.0322)	0.6472*** (0.0326)	0.6501*** (0.0329)
Log(Asset)	-0.3355 (0.2095)	-0.3184 (0.21)	-0.3238 (0.2127)
Diversification	0.2716 (0.1728)	0.2883* (0.1746)	-0.2533 (0.1748)
Log(IT Spending)		-0.0251 (0.032)	-0.0552 (0.0341)
Log(R&D Expenditure)*Log(IT Spending)			0.037** (0.0178)
Year Dummies			
Industry Dummies			
Log-likelihood Chi-Square	-1538.0194	-1537.718	-1535.6355
N	450	450	450

Note: 1. *: p<0.1; **: p<0.05; ***: p<0.01

2. Standard error in parentheses

3. Coefficients for industry dummies and year dummies not shown.

Table 4: Results of Random-Effect Negative Binomial Regression

DISCUSSION AND CONCLUSION

In this paper we developed a theoretical model to examine the effects of IT on firm innovativeness and empirically tested the model. We proposed that IT has two types of effect on firm innovation. First, IT has an indirect effect by complementing existing R&D investment. Secondly, IT has a direct effect by enhancing a firm's external innovation sourcing capabilities. Using panel data of 150 large firms, we find empirical evidence that IT investments complement internal R&D capabilities and that these complementarities account for variance in firm innovativeness.

Past studies have examined the effects of IT on administrative processes and have found significant effects. Our results extend our knowledge about IT value by providing theoretical arguments and empirical evidence about the impacts of IT on the innovation processes of firms. This finding could be significant given the current trend where firms increasingly define innovation as the core activities they engage in. In such firms, the role of IT would decidedly be to support the innovation processes. This study by providing empirical evidence of the effects of IT on firm innovativeness highlights the potential value of IT in the current business environment.

Interesting, while innovation sourcing is on the rise, we did not find IT to be a significant enabler of a firms sourcing capabilities. One possible explanation of this result could be the time frame of this study, which is the early to mid 1990s. It could be argued that the open innovation phenomenon was at its early stages and not so prevalent.

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