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Dong, John Qi; Yang, Chia-Han

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Information technology and organizational learning in knowledge alliances and networks: Evidence from U.S. pharmaceutical industry

John Qi Dong^{a,*}, Chia-Han Yang^b

^a Faculty of Economics and Business, University of Groningen, 9747 AE Groningen, The Netherlands

^b Institute of Creative Industries Design, National Cheng Kung University, Tainan City 701, Taiwan

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ABSTRACT

Recent years have witnessed a change in firms' innovation patterns, from closed to open, in which information technology (IT) has played an important role. This paper aims to open up the black box of IT-enabled absorptive capacity by theorizing and testing the role of IT in two organizational learning processes, which are either interactive with partners in the knowledge alliance or non-interactive with others in the knowledge network. In particular, we formulate a model explaining how a firm's IT investment moderates its organizational learning processes in knowledge alliances and networks, which sheds light on the role of IT as an enabler of absorptive capacity. Using a panel data set from the U.S. pharmaceutical industry, the results show the moderating role of IT in strengthening the organizational learning processes from knowledge alliance experience to coinvented knowledge and from knowledge network centrality to assimilated knowledge, which, in turn, improve firm competitiveness.

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1. Introduction

With the advances in information technology, access to external knowledge across firm boundaries is now a key source of innovation [22,56,98]. Innovation activities have thus moved from closed to open forms, with various stakeholders directly or indirectly exchanging knowledge in shared physical or social contexts [18,32]. The growing literature on innovation has raised the interest of firms in tapping into external resources, and researchers have also begun to examine innovation dynamics from inter-organizational and network-based perspectives [39,44,60, 82,107]. Such studies focus on outside-in knowledge flows and show that firms have to develop their *absorptive capacity* to learn from external sources of knowledge [48,65,104].

In Cohen and Levinthal's [22] original concept, absorptive capacity is defined as a firm's ability to assimilate and utilize external knowledge for commercial ends and thus a new way to view organizational learning and innovation. The subsequent absorptive

capacity literature has drawn on a process-oriented perspective and conceptualized absorptive capacity as a set of different organizational learning processes [60,61,66,115]. Consistent with the prior literature, *this study defines absorptive capacity as the externally oriented organizational learning processes of a firm that are carried out to obtain and create knowledge across its boundaries* [22,100,112]. In these externally oriented organizational learning processes, visible knowledge alliances with partners and invisible knowledge networks among firms have been recognized as important external knowledge sources that can aid innovation (e.g., [48,104]).

The recent IS literature increasingly suggests that one of the most critical enablers of absorptive capacity is information technology (IT; [53,86]), and IT is also seen as a catalyst of organizational learning [103] and innovation [19,6,33,34,56, 98,113]. Although the notion of IT-enabled absorptive capacity has been widely used in IS research, the understanding of how IT enables absorptive capacity with regard to various different externally oriented organizational learning processes is still limited. In other words, little is known about what happens inside the black box of IT-enabled absorptive capacity.

The current study aims to fill this gap in the literature by explaining how IT strengthens the externally oriented organizational learning processes in knowledge alliances and networks and thus how it can enhance a firm's absorptive capacity. The research

* Corresponding author at: Department of Innovation Management and Strategy, Faculty of Economics and Business, University of Groningen, 9747 AE Groningen, The Netherlands. Tel.: +31 50 363 4839.

E-mail address: john.dong@rug.nl (J.Q. Dong).

question addressed in this paper is how IT facilitates organizational learning processes in knowledge alliances and networks, two contexts that have been highlighted in the literature. These two contexts represent organizational learning processes that are interactive with visible alliance partners (e.g., [60]) or interactive with other firms in an invisible network of knowledge flows (e.g., [104,2]). Because no prior study in the literature attempts to simultaneously consider the organizational learning processes that occur in knowledge alliances and networks, this work aims to provide a more holistic picture by taking into account both of these contexts simultaneously.

We formulate a conceptual model that connects knowledge alliance experience and knowledge network centrality to the corresponding organizational learning outcomes as coinvented knowledge and assimilated knowledge, respectively. IT investment is theorized as a key moderator that enhances these organizational learning processes. Our model differs from prior studies by reconceptualizing alliance-based, interactive, network-based, non-interactive, externally oriented organizational learning processes as a firm's absorptive capacity. Furthermore, the model highlights IT's role as an enabler of absorptive capacity by facilitating these processes. By doing so, this work is able to offer a novel understanding to the IS literature as to what IT-enabled absorptive capacity is and how IT enables absorptive capacity.

Compared to the extant IS literature, this paper contributes an insightful theory of IT-enabled absorptive capacity by theorizing the role of IT in alliance- and network-based organizational learning processes. These processes lead to coinvented knowledge based on prior successful experiences of knowledge exchange in alliances, or the knowledge that is assimilated from the intangible networks among firms in an industry. Given that recent studies in the pharmaceutical industry reflect the importance of alliances and open innovation due to the distributed nature of knowledge [17,20,23,83], we focus on empirically testing our theory based on a sample of firms from the U.S. pharmaceutical industry.

The empirical results based on a panel data set from the U.S. pharmaceutical industry reveal that IT plays a significant moderating role in strengthening the organizational learning processes that occur in knowledge alliances and networks. The findings further show that these organizational learning processes enabled by IT can improve firm competitiveness by generating learning outcomes such as coinvented and assimilated knowledge. Therefore, simply getting access to external resources in a knowledge alliance or network does not automatically lead to desirable innovation outcomes, unless a firm is able to leverage its strategic resources, such as IT investments, to facilitate organizational learning. IT-enabled absorptive capacity can thus lead to more effective organizational learning processes; thus, it is critical for innovation and the creation of a competitive advantage.

The rest of paper is organized as follows. Section 2 reviews the relevant literature and summarizes the theoretical background. The hypotheses and conceptual model are presented in Section 3. Data and measures are introduced in Section 4, and Section 5 then reports the empirical results. The main findings are discussed in Section 6, and the conclusion and implications are presented in Section 7.

2. Theoretical background

2.1. Open innovation and absorptive capacity theory

Since Schumpeter [92] first proposed that innovation is a path to economic growth, the conventional definition of innovation has been widely investigated in the hope of establishing a sequential model based on the characteristics of closed innovation activities within an organization. However, with innovation activities dynamically evolving, the innovation process has advanced from

a sequential, closed form to an open process. In this open process, various specialized participants absorb, emit and exchange knowledge inputs in shared physical or social contexts [32,102]. As researchers have begun to understand innovation activities as a series of knowledge exchanges and spillovers [51,58,105], a more dynamic conception of innovation is required to capture how knowledge can be acquired from external sources, such as knowledge alliances and networks [3,48,73,104].

A number of studies have been conducted regarding the growing relevance of external sources of innovation rather than a reliance on internal R&D, resulting in the notion of “open innovation” [15,16]. Open innovation describes the situation in which many innovative firms have shifted to an open model for their activities, using a wide range of external knowledge sources to help them achieve their goals. It highlights the use of purposive inflows and outflows of knowledge to accelerate innovation. This paradigm thus proposes that firms in an open innovation process should aim to acquire and use external knowledge.

Open innovation can shed light on absorptive capacity theory, which emphasizes externally oriented organizational learning [108]. Research on organizational learning has existed at least since the work of Cyert and March [29] and Cangelosi and Dill [14], and the literature has grown dramatically in recent years. Organizational learning occurs when the organization exploits internal experience or assimilates external knowledge. Because open innovation is essentially externally oriented learning processes that occur by reusing and recombining existing elements of knowledge [69,75], absorptive capacity theory is a powerful lens through which to understand how a focal firm can generate innovation and build competitiveness by working with external partners or assimilating knowledge spillovers. Because firms do not automatically appropriate the value of open innovation, their absorptive capacity becomes critical in enabling them to benefit from external sources of knowledge [91]. Therefore, the degree to which a firm can obtain desirable outcomes from its open innovation activities depends on how it carries out externally oriented organizational learning processes and thus on its absorptive capacity. For instance, Powell et al. [82] claim that the development of absorptive capacity by pharmaceutical firms, with regard to how they manage organizational learning in knowledge alliances, is an important source of innovation in this industry.

2.2. Absorptive capacity as externally oriented organizational learning

In Cohen and Levinthal's [22] original work, absorptive capacity is defined as a firm's ability to recognize the value of external information, assimilate it, and apply it to commercial ends. They thus propose absorptive capacity theory as a new way to understand the learning and innovation carried out by organizations. Subsequent scholars have drawn on a process-oriented perspective and conceptualized absorptive capacity as different externally oriented organizational learning processes [60,61,66,115]. This study pays attention to two particular externally oriented organizational learning processes, rooted in visible knowledge alliances and the invisible knowledge networks among firms.

Past studies proposed that externally oriented organizational learning is an assimilating and transforming process [27], which is based on the degree of “interaction” among firms within a specific industry [109,5]. These works suggest that externally oriented organizational learning occurs in a context composed of the organization itself and the environment in which it is embedded. As a result, two types of externally oriented organizational learning processes are commonly seen, those that entail direct interaction with others in a formal knowledge alliance and those without

direct interaction with others, in invisible knowledge networks [18,62,2].

As noted above, alliance-based and network-based organizational learning processes are particularly important for open innovation in the pharmaceutical industry [49]. Knowledge alliances are widely used in the U.S. pharmaceutical industry, where the scale benefits of such relationships can help firms to launch blockbuster drugs, make technology bets, accelerate clinical trials, and increase the desirability for licensing partners. Such companies can cover the entire value chain, from discovery to product testing, by engaging in knowledge alliances, due to the critical nature of innovation in this industry [43,52,82,99]. However, the rise of biotechnology and its interdisciplinary requirements necessitates knowledge assimilation from different external sources, further impeding any single firm's closed innovation activities [20,52]. This has led to a new approach of organizational learning that occurs without direct interactions with other firms and instead relies on an invisible knowledge network among pharmaceutical firms [17,36,57].

2.3. IT-enabled absorptive capacity

There is growing interest in the role of IT in enabling absorptive capacity or organizational learning. Alavi and Leidner [1] show that IT can enhance firms' assimilation of external knowledge by creating organizational memory in the form of electronic repositories. Tippins and Sohi [103] reveal that firms can accumulate valuable external knowledge that is stored and preserved for future use by IT and thus aid organizational learning. Subramani [97] finds that supply chain management (SCM) systems can be used to transfer domain-specific knowledge between a focal firm and its partners. Malhotra et al. [67] explain why standard IT interfaces are useful to configure absorptive capacity and thus assimilate marketing-facing knowledge from supply chain partners. Similarly, Malhotra et al. [68] suggest that standard IT interfaces facilitate mutual knowledge creation with supply chain partners. Saraf et al. [89] reveal that IT applications support knowledge sharing between a focal firm and its customers or distribution channel partners. Song et al. [94] similarly suggest that communication technologies help to foster knowledge sharing. Joshi et al. [53] develop the concept of IT-enabled absorptive capacity and find that it is associated with innovation outcomes, treating it as an exogenous black box in their model. Chi et al. [19] further suggest that IT-enabled absorptive capacity leads to the development of innovation in pharmaceutical alliances. Roberts et al. [86] systematically review the literature on IT and absorptive capacity and suggest that it is important to deepen our understanding of the mechanisms through which the former enables the latter. Frank et al. [40] also provide an overview regarding IT as one of the critical factors influencing the performance of knowledge transfer across different organizations.

These earlier studies explicitly or implicitly reveal that IT helps support the acquisition and assimilation of external knowledge in the form of IT-enabled absorptive capacity. Moving one step beyond this, a new IS perspective for understanding IT-enabled absorptive capacity that is addressed in this study will be how IT can be used to enable absorptive capacity in relation to organizational learning in specific contexts, such as knowledge alliances and networks.

3. Hypotheses development

3.1. Organizational learning in knowledge alliances and networks

As researchers have begun to understand innovation activities as a series of inter-organizational interactions between a focal firm and external knowledge providers [51,105], it has become

apparent that a more open and interactive conception of collaborative alliances is required [3]. These studies pointed to the growing relevance of knowledge alliances rather than a reliance on internal R&D, meaning that organizational learning can be regarded as resulting from distributed inter-organizational knowledge alliances or partnerships rather than from a single firm [24,82]. The notion of knowledge alliances was originally raised in a discussion on the history of trans-organizational innovation at the firm level [70], and since then, knowledge alliances, one approach to open innovation, have been identified as a useful means by which a firm's strategic flexibility can be increased to access external knowledge [42,80,81].

The cumulative successful experiences from prior knowledge alliances can enhance a firm's future collaborations with external knowledge providers [4,35,93]. In addition, several studies have noted that a firm's general alliance experience can positively affect its subsequent alliance performance [48,54,116]. We thus argue that a firm's successful experience of a knowledge alliance will be useful with regard to knowledge coinvention with its subsequent partners. This is because working to codify knowledge and create systems to efficiently coordinate and disseminate information with knowledge alliance partners is a possible mechanism for the development of a firm's ability to successfully manage collaborative knowledge coinvention efforts, which can then be leveraged in subsequent alliances [48]. For example, in the product development that occurs in the pharmaceutical industry, Rothaemel and Deeds [88] find that a beneficial biotech-product development path will depend on the effects of experiences from prior exploration alliances in "research" on subsequent exploitation alliances focusing on "development". Thus, we hypothesize the following:

H1. The knowledge alliance experience of a firm is positively associated with its subsequent coinvented knowledge.

A network perspective emphasizes the importance of knowledge spillover, which is how knowledge can be learned from external sources without direct interactions in a knowledge network [72,104]. Researchers have suggested that an innovative firm can receive intensive knowledge flows and learn more from external sources by getting access to other firms' knowledge. Such linkages of knowledge flows among firms form an invisible knowledge network in an industry, enabling a firm to assimilate knowledge flows or cross-cite external knowledge sources in the form of spillovers. In particular, in a field of rapid technological development such as pharmaceuticals, the locus of innovation is found within the knowledge networks that sustain a fluid and evolving community of industry professionals [82]. Drawing on a network perspective, the position of a firm in the knowledge network of its industry is particularly important. Several decades of research have shown that the degree to which a firm is able to access external knowledge is characterized by its network position [41,106,50] and that a firm can enjoy better learning outcomes and produce more innovation outputs if it occupies a central network position that offers access to external knowledge developed by other firms in the industry [26,105].

By occupying a central network position, a firm is more likely to access useful knowledge from other participants in knowledge network. As a result, the proportion of external knowledge elements in the resultant recombined knowledge created by the focal firm is significantly increased by its greater centrality in the knowledge network due to the greater amount opportunities for assimilating external knowledge from other firms [82,104]. Thus, we hypothesize the following:

H2. The knowledge network centrality of a firm is positively associated with its subsequent assimilated knowledge.

3.2. The moderating role of information technology

While discussing open innovation, a number of studies show that one of the most important drivers of this process is IT (e.g., [33,34,40,56,98,113]). Conventionally, the division of labor, task specialization, and coordination costs shape the composition of an innovation team, whereas the innovation outputs of a team are determined by the number of collaborators and partners, their skill levels, and the division of specialized labor [8]. Although prior studies only generally propose the existence of IT-enabled absorptive capacity [53,86], the current work suggests that investment in IT enables a firm's absorptive capacity through facilitating externally oriented organizational learning processes across various contexts.

As the scale of collaboration increases, knowledge alliances require greater investment in IT to lower coordination costs and enhance organizational learning, thus making positive results more likely. For example, IT can facilitate access to codified knowledge by lowering the costs of accessing shared knowledge in a collaborative alliance [28,38]. IT can also facilitate the development of more efficient processes for managing alliances, such as when a partner-specific alliance sets up an online mechanism for accessing knowledge and enabling the mutual creation of knowledge [31,68]. In addition, IT enhances organizational memory and thus the ability to store, retrieve, and share prior successful experiences of knowledge alliances [103], which can then be passed on to subsequent collaborations. Therefore, when knowledge alliance participation is enabled by IT, organizational learning can be strengthened by the more effective ways of collaboration this allows and the learning that can occur based on previous successful experiences. This should then lead to better outcomes with regard to knowledge coinvention. In a specific industry context, it has been revealed that IT-based knowledge sharing in pharmaceutical alliances, where the implementation of digital platforms enables the sharing of knowledge between the virtual communities of drug discovery project teams, can result in a more productive innovation process [74,114]. We thus propose that greater IT investment is likely to strengthen the link between knowledge alliance experience and subsequent coinvented knowledge, suggesting a positive moderating role of IT in the organizational learning processes that occur in knowledge alliances. Based on this, the following hypothesis is presented.

H3. IT investment strengthens the positive relationship between a firm's knowledge alliance experience and subsequent coinvented knowledge.

Although a growing number of IS studies have examined how IT can enhance absorptive capacity and innovation [53,67,86], few works explore the effect of a company's position in the network of knowledge flows among firms and how IT investment affects the link between knowledge network position and organizational learning outcomes. This study proposes a positive moderating role for IT in enabling a firm to assimilate external knowledge in its knowledge network. For example, IT can encourage the acquisition and assimilation of external knowledge by supporting information exchanges and sharing among firms [7,84,89]. The wide exchange of information has been found to enable organizational learning and innovation in supply chains [33,97]. In general, IT supports the acquisition, dissemination, and interpretation of external knowledge; it enhances organizational memory and thus the ability to store and retrieve the assimilated knowledge [1,103]. Therefore, based on the knowledge search routines enabled by IT, organizational learning will be strengthened by broadening the search for knowledge elements from others to be used in knowledge recombination projects. It is then expected that the outcomes of knowledge assimilation in a knowledge network will be enhanced.

In a specific industry context, some empirical works show that IT infrastructure (network and communication technologies, in particular) allows distributed pharmaceutical companies to get access to each other's knowledge and thus improve the overall efficiency of the innovation process [38,56,101]. Therefore, we further propose that greater IT investment is likely to strengthen the link between knowledge network centrality and subsequent assimilated knowledge, suggesting a positive moderating role of IT in the organizational learning processes that occur in a knowledge network. Based on this, the following hypothesis is presented.

H4. IT investment strengthens the positive relationship between a firm's knowledge network centrality and subsequent assimilated knowledge.

3.3. Learning outcomes and competitive advantage

IT is causing a revolution in knowledge alliances and networks with regard to organizational learning from external parties, which, in turn, can lead to the development of a sustainable competitive advantage [53,56,77,98]. In more detail, the externally oriented organizational learning processes that take place in a knowledge alliance or knowledge network can enhance the integration of diversified knowledge flows by facilitating inter-organizational collaboration or knowledge exchange. Open innovation processes, such as coinvented and assimilated knowledge, can upgrade a firm's competitiveness by enabling superior organizational learning outcomes [16,111].

Coinvented and assimilated knowledge can enhance a firm's competitive advantage [63,75,78,79]. Research has shown that collaborative R&D can lead to better learning outcomes in patent coinvention due to the use of diversified sources of knowledge and problem-solving mechanisms [12]. Similarly, the assimilation of external knowledge can result in high-quality knowledge recombination due to the variety of knowledge sources applied [22,82,115]. Such high quality innovation outcomes can lead to a greater competitive advantage, manifested by a larger market share [75,92]. For example, Hughes and Wareham [49] focus on the open innovation patterns of pharmaceutical firms and find that both building collaborative partnerships and extending existing knowledge networks can increase the value captured by firms, thus enhancing competitiveness. This leads to the final hypotheses, as follows.

H5a. The coinvented knowledge of a firm is positively associated with its competitiveness.

H5b. The assimilated knowledge of a firm is positively associated with its competitiveness.

Fig. 1 presents a conceptual model that links organizational learning processes in knowledge alliances and networks to firm competitiveness through the learning outcomes of coinvented and assimilated knowledge and using IT investment as a moderator to explain how IT facilitates a focal firm's externally oriented organizational learning processes via IT-enabled absorptive capacity.

4. Methodology

4.1. Data

This study uses four independent sources to construct a panel data set to test the hypotheses. The empirical analysis focuses on the U.S. pharmaceutical industry (SIC code: 2834) from 2003 to 2005. The U.S. pharmaceutical industry is noted for its activity with regard to alliance formation, organizational learning, and

Fig. 1. Research model.

innovation (e.g., [19,48,82,88,90]) and thus provides an ideal research context for this study. Moreover, IT plays an important role in facilitating organizational learning and knowledge creation in this industry [74,56,101,114]. In addition, focusing on a single industry can also control for numerous confounding factors related to industry characteristics.

To construct the sample, we first obtained the data for all U.S. public firms in the pharmaceutical industry with a SIC code 2834 from Standard and Poor's Compustat database. Financial data for R&D investment, financial leverage, firm size, and market share were obtained. Second, the Compustat data were matched with an alliance data set based on company name. This alliance data set was collected by coding all new drug approval files from the U.S. Food and Drug Administration (FDA) since 2003. Because this study is interested in successful knowledge alliance experiences, knowledge alliances that led to the approval of new drugs were examined. Third, the data were matched to the National Bureau of Economic Research's (NBER) Patent Citations database containing all U.S. patent citations from 1976 to 2006 by firm GVKEY [46] to construct the knowledge network of pharmaceutical industry and knowledge-related measures. Finally, IT data were obtained from the Harte Hanks' Computer Intelligence (CI) database in 2003–2005 and were merged with the other data by company name. These procedures resulted in a final sample of 24 distinct drug companies for the years 2003–2005, with a total of 68 firm-year observations. This sample size is comparable to that used in past research on firm alliances and networks ([104]: $n = 60$).¹

4.2. Measures

4.2.1. Knowledge alliance experience

Knowledge alliance experience was measured by two alternative measures—alliance count and alliance intensity—to capture both the absolute and relative experience of a firm's successful participation in such alliances. For each year, the alliance count was measured by the number of successful knowledge alliances in which a focal firm participated, which were those that successfully developed approved drugs [48]. Alliance intensity was measured by the number of successful knowledge alliances divided by the total number of new drugs approved by the FDA in the focal year.

4.2.2. Knowledge network centrality

The knowledge networks of firms were constructed based on the patent citation pairs made by *all* public firms in the U.S. pharmaceutical industry in a specific year. Patent citation pairs can indicate knowledge flows among firms [55,110], which were aggregated to the firm level and weighted by the number of citations made by the focal firm. Network centrality has long been suggested to reflect external knowledge access in a network [11,41]. Because different centrality measures have been used in prior studies, this work incorporated four widely used alternative measures to capture the centrality of a focal firm in the knowledge network.

Specifically, degree centrality, closeness centrality, betweenness centrality, and eigenvector centrality were calculated for each firm in a specific year [76]. Stata 12.1 was used for the network analysis. The command "netsis" was used to calculate centrality measures [71], and the command "netplot" was used to visualize the network [25].² Figs. 2–4 show the resulting knowledge network of the U.S. pharmaceutical industry from 2003 to 2005. It is worth noting that although the sample consists of 68 firm-year observations, we included *all* public firms in the U.S. pharmaceutical industry in the network analysis to calculate reliable and valid centrality measures.

Degree centrality was calculated by the number of ties that a focal firm i had in a specific year t , shown by the following formula:

$$\text{Degree}_{it} = \frac{\text{No. of ties}_{it}}{\text{No. of firms}_t} \quad (1)$$

Closeness centrality was calculated by the inverse of the average shortest distance between a focal firm i and other firms in a specific year t , shown by the following formula:

$$\text{Closeness}_{it} = \frac{\text{No. of firms}_t - 1}{\sum \text{No. of ties as shortest distance}_{it}} \quad (2)$$

Betweenness centrality was calculated by the number of times that a focal firm i was on the shortest path between a pair of other firms (m and n) in a specific year t , as follows:

$$\text{Betweenness}_{it} = \sum \frac{\text{No. of shortest paths of } m \text{ and } n \text{ via } i_{it}}{\text{No. of shortest paths of } m \text{ and } n_{it}} \cdot \frac{1}{1/2((\text{No. of firms}_t - 1)(\text{No. of firms}_t - 2))} \quad (3)$$

¹ It is worth noting that small sample does not affect the internal validity of this study. This is because a small sample size actually reduces the statistical power and increases the difficulty of detecting significant effects. If we are nonetheless able to observe any significant effects, however, it provides more convincing statistical evidence with a lower risk of type I errors.

² The Stata program "netsis" was developed by Hirotaka Miura at the Department of Mathematics, Columbia University in the U.S. The Stata program "netplot" was developed by Rense Corten at the Department of Sociology, Utrecht University in the Netherlands.

Fig. 2. Knowledge network of U.S. Pharmaceutical Industry in 2003.

Fig. 4. Knowledge network of U.S. Pharmaceutical Industry in 2005.

Fig. 3. Knowledge network of U.S. Pharmaceutical Industry in 2004.

Eigenvector centrality was calculated by the following steps. Let $A = a_{ij}$ be the adjacency matrix of the knowledge network (value = 1 if there is a tie, value = 0 otherwise) in a specific year t , x_i denote the score of the i th node in a row, and x_j denote the score of the j th node in a column. We thus have:

$$x_{it} = \frac{1}{\gamma} \sum a_{ijt} x_{jt} \quad (4)$$

In vector notation, Eq. (4) can be rewritten as:

$$X = \frac{1}{\gamma} AX \text{ or } AX = \gamma X \quad (5)$$

Finally, eigenvector centrality is the greatest eigenvector solution γ with all positive entries, as follows:

$$\text{Eigenvector}_{it} = \max(\gamma) \quad (6)$$

Intuitively, degree centrality captures a focal firm's number of knowledge sources compared to the size of the knowledge network. It indicates the degree to which a firm can get access to a variety of knowledge sources in the network. Closeness centrality represents the average distance between a focal firm and other firms in the rest of the knowledge network. Therefore, this measure reflects how close a firm is to other firms in the network. Betweenness centrality reflects the number of times a focal firm is on the shortest path of knowledge flows between other firms in the knowledge network. It captures the importance of a firm in the network in terms of bridging knowledge flows among others. Eigenvector centrality is proportional to the sum of centralities of a focal firm's neighbor firms in the knowledge network. This measure thus indicates the importance of a firm in the network in terms of other firms with whom it exchanges knowledge.

4.2.3. Coinvented knowledge

Patent outputs have been widely used as the measure of knowledge outputs [19,53,56]. Two *alternative* measures were created for coinvented knowledge, which are the number of coinventors (i.e., other assignees sharing the ownership of a patent with the focal firm) and the number of coinventions (i.e., patents assigned to two or more assignees, including the focal firm) in a specific year. Natural logarithms were used to reduce the skewedness of these two measures.

4.2.4. Assimilated knowledge

Patent citations represent the degree to which a novel knowledge invention has recombined existing knowledge elements [37,55].

Table 1

Descriptive statistics and correlations.

	Mean	SD	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Market share	0.06	0.08														
Logged number of coinventors	0.69	1.08	0.58													
Logged number of coinventions	0.68	1.05	0.59	1.00												
Logged number cross-citations	3.42	3.31	0.69	0.74	0.74											
Cross-citation ratio	0.51	0.44	0.46	0.49	0.49	0.82										
Alliance count	0.09	0.33	0.15	0.30	0.31	0.20	0.08									
Alliance intensity	0.06	0.22	0.08	0.23	0.23	0.21	0.09	0.92								
Degree centrality	0.91	1.73	0.57	0.58	0.58	0.68	0.39	0.25	0.30							
Closeness centrality	0.20	0.15	0.49	0.53	0.53	0.78	0.68	0.14	0.16	0.45						
Betweenness centrality	0.05	0.08	0.67	0.57	0.57	0.76	0.46	0.30	0.33	0.95	0.56					
Eigenvector centrality	0.06	0.15	0.42	0.43	0.43	0.56	0.30	0.18	0.26	0.96	0.35	0.88				
IT	0.01	0.02	−0.24	−0.26	−0.26	−0.26	−0.26	−0.11	−0.11	−0.21	−0.32	−0.24	−0.17			
R&D	0.08	0.07	0.05	0.08	0.08	0.12	0.09	0.04	0.07	0.14	0.03	0.13	0.14	−0.01		
Financial leverage	0.18	0.16	−0.19	−0.06	−0.06	0.07	0.30	−0.11	−0.07	−0.08	0.18	−0.10	−0.07	−0.13	0.33	
Size	6.32	0.90	0.54	0.50	0.50	0.55	0.29	0.15	0.14	0.42	0.35	0.52	0.31	0.05	0.30	0.00

Note: Values in bold are significant correlations with $p < 0.05$.

Cross-citations reflect the degree to which a firm assimilates and utilizes external knowledge elements from other firms in its own knowledge recombination processes [87,110]. We therefore used two *alternative* cross-citation measures to capture the level and degree of assimilated knowledge [110]. Specifically, the number of cross-citations a focal firm made and the ratio of cross-citations over the total citations a firm made in a specific year were calculated. The natural logarithm was used to reduce the skewedness in the number of cross-citations.

4.2.5. IT investment

This study followed a recent operationalization of IT investment that combines different prevailing approaches [113]. Specifically, the Hedonic method was used to derive the price indices for a list of IT hardware components, including IBM mainframe, non-IBM mainframe, mini-computer, PC, LAN, mainframe tape drive, mainframe disk drive, and dumb terminal [21]. Multiplying the counts of a firm's IT hardware components by these corresponding prices generated the level of IT hardware investment. Using the Hedonic method improves on the traditional estimation of IT hardware investment, which relies exclusively on the mainframe price index to account for all types of IT hardware (e.g., [47]).

Second, IT hardware investment was deflated by the PC price index and the price index for “Computers and Peripheral Equipment” from the U.S. Bureau of Economic Analysis (BEA) to account for the changes in the quality of IT hardware. Third, the average compensation of IT personnel at the industry level was obtained from the U.S. Bureau of Labor Statistics (BLS), and the industry-specific compensation was multiplied by the number of IT personnel in each firm, generating the estimation of IT labor investment. Fourth, IT labor investment was deflated by the price index for the “Total Compensation Cost” from BLS.

Finally, a well-established procedure was used to calculate total IT investment as the sum of IT hardware investment plus *three times* the IT labor investment (e.g., [30,47,113]). Total IT investment was normalized as the ratio of total IT investment over the total assets of a firm derived from the Compustat database. Although the IT data do not include software investment, it has been suggested that this is proportional to IT labor investment and can be proxied by two times the figure for it [47]. Therefore, the measure of IT investment consists of a firm's investment in IT hardware, software and labor.

4.2.6. Firm competitiveness

Because this study is particularly interested in firm competitiveness, as manifested by the market share of firms that resulted

from firm adaptation in organizational learning processes [75], market share was used to measure the competitiveness of a firm in the marketplace. Specifically, this work followed Bharadwaj et al. [9] to compute the weighted market share based on the sales of all U.S. pharmaceutical firms in the Compustat database with SIC code 2834.

4.2.7. Control variables

Several important firm characteristics were controlled for in the analysis. First, R&D investment was controlled for, as measured by R&D spending over total sales [22]. Second, financial leverage was also controlled for, as measured long-term debt over total assets, which reflects a firm's capital structure and slack resources [13].³ Third, firm size was controlled for and proxied by the natural logarithm of total sales. Finally, year dummies were included to control for time fixed effects. Descriptive statistics and correlations are presented in Table 1.

5. Results

Ordinary least squares (OLS) regression was used to analyze the data. Before conducting the regression analysis, we checked the distribution of the variables and found that they met the OLS assumptions. Because the data have a panel structure, clustered robust standard errors were used in all analyses to address the issues of nested structure and heteroscedasticity. Multicollinearity was also examined by checking the variance inflation factors (VIFs) in the regression analysis. The results showed that the VIFs were always below the threshold of 10, suggesting that multicollinearity was not a serious problem in our analysis. To avoid reverse causality, *one-year lagged* dependent variables were used in all regression models.

Tables 2 and 3 report the regression results for testing H1 and H3, with alternative measures for coinvented knowledge as the dependent variables. Both count and intensity measures of knowledge alliance experience had significant and positive effects on coinvented knowledge, as measured by the logged number of coinventors or coinventions in the subsequent year, supporting H1. In addition, the interaction terms between knowledge alliance experience and IT investment demonstrated significant and positive effects on subsequent coinvented knowledge, supporting H3.

Tables 4 and 5 report the regression results for testing H2 and H4, with alternative measures for assimilated knowledge as the

³ Financial leverage is negatively related to slack resources: The higher a firm's financial leverage, the more difficult it is to get access to external funds.

Table 2

Regression results for coinvented knowledge (logged number of coinventors).

	(1)	(2)	(3)	(4)	(5)
Alliance count		0.798*** (0.285)		−0.135 (0.260)	
Alliance intensity			0.866** (0.372)		−0.197 (0.393)
Alliance count × IT				370.832** (146.201)	
Alliance intensity × IT					455.403** (164.334)
IT				−12.681** (4.964)	−13.095** (5.248)
R&D	−1.022 (2.534)	−1.400 (2.345)	−1.288 (2.397)	−1.110 (2.076)	−1.092 (2.105)
Financial leverage	−0.282 (0.844)	−0.055 (0.792)	−0.177 (0.837)	−0.359 (0.710)	−0.428 (0.761)
Size	0.638*** (0.205)	0.610*** (0.196)	0.620*** (0.203)	0.606*** (0.189)	0.624*** (0.198)
Year dummies	Yes	Yes	Yes	Yes	Yes
R ²	0.267	0.321	0.294	0.398	0.373
Adj. R ²	0.207	0.254	0.225	0.317	0.288
F	2.33*	4.49***	4.86***	3.48***	6.45***

Note: $n=68$. Clustered robust standard errors are in parentheses. Dependent variable is one-year lagged log of number of coinventors.

* $p < 0.1$.** $p < 0.05$.*** $p < 0.01$.

dependent variables. All measures of knowledge network centrality had significant and positive effects on assimilated knowledge, measured by the logged number of cross-citations or cross-citation ratio in the subsequent year, supporting H2. The interaction terms between two out of four centrality measures (i.e., degree centrality and eigenvector centrality) and IT investment demonstrated significant and positive effects on the subsequent number of cross-citations. Moreover, the interaction terms between three out of four centrality measures (i.e., degree centrality, betweenness centrality, and eigenvector centrality) and IT investment showed significant and positive effects on the subsequent cross-citation ratio. These results largely support H4.

Table 6 reports the regression results for testing H5a and H5b.⁴ Because there are multiple *alternative* measures for coinvented and assimilated knowledge, these highly correlated variables were added into the regression model separately to avoid the problem of multicollinearity. The results showed that coinvented knowledge and assimilated knowledge had significant and positive effects on firm competitiveness, as measured by market share one year later. These results are robust across alternative measures and thus support H5a and H5b.

6. Discussion

This study reconceptualizes absorptive capacity as alliance-based, interactive, network-based, non-interactive, organizational learning processes. The role of IT is theorized as facilitating these externally oriented organizational learning processes rooted in the visible knowledge alliances and invisible knowledge networks among firms. Although prior alliance experience has been recognized as a source of organizational learning [48], this study suggests that firms also search for external knowledge in invisible knowledge networks that only consist of knowledge flows. These two organizational learning processes are both important for the creation of new knowledge, which, in turn, jointly contribute to firm competitiveness.

⁴ We lost three observations due to missing values for the variables in this analysis.

Table 3

Regression results for coinvented knowledge (logged number of coinventions).

	(1)	(2)	(3)	(4)	(5)
Alliance count		0.814*** (0.280)		−0.117 (0.253)	
Alliance intensity			0.891** (0.367)		−0.176 (0.383)
Alliance count × IT				371.620** (145.664)	
Alliance intensity × IT					460.172*** (163.116)
IT				−12.377** (4.819)	−12.795** (5.112)
R&D	−0.971 (2.491)	−1.357 (2.298)	−1.246 (2.350)	−1.071 (2.036)	−1.053 (2.064)
Financial leverage	−0.311 (0.829)	−0.080 (0.776)	−0.203 (0.821)	−0.377 (0.698)	−0.448 (0.750)
Size	0.626*** (0.201)	0.597*** (0.191)	0.607*** (0.199)	0.593*** (0.184)	0.611*** (0.193)
Year dummies	Yes	Yes	Yes	Yes	Yes
R ²	0.268	0.327	0.299	0.405	0.378
Adj. R ²	0.209	0.261	0.230	0.325	0.294
F	2.34*	4.56***	4.90***	3.55***	6.83***

Note: $n=68$. Clustered robust standard errors are in parentheses. Dependent variable is one-year lagged log of number of coinventions.

* $p < 0.1$.** $p < 0.05$.*** $p < 0.01$.

By using a panel dataset from U.S. pharmaceutical firms in recent years, the results showed that IT plays an important moderating role in facilitating alliance-based and network-based organizational learning processes, which is consistent with our explanation of how IT enables a firm's absorptive capacity. The IT resources invested by a firm enable its absorptive capacity by strengthening the organizational learning processes in relation to alliance experience and network position, thus leading to the coinvention and assimilation of knowledge. Specifically, a firm's prior experience of engaging in successful knowledge alliances was found to be associated with its subsequent coinvented knowledge with partners, and the centrality of a firm in the industry knowledge network was found to be related to its subsequent assimilation performance. More importantly, IT investment played a significant moderating role in these relationships by strengthening the links from experience to coinvented knowledge and from centrality to assimilated knowledge. In turn, coinvented and assimilated knowledge was found to positively affect firm competitiveness. Furthermore, the results showed that IT investment does not moderate the relationship between closeness centrality and assimilated knowledge. This finding may indicate the boundary condition of the proposed theory. Recall that closeness centrality reflects the average distance between a focal firm and other firms in the knowledge network. Therefore, for firms that already have access to others' knowledge, IT does not provide much assistance in organizational learning processes.

Our study contributes to recent IS research on IT-enabled absorptive capacity [53,67,86] by revealing the mechanisms through which IT is used to facilitate the organizational learning processes constituting absorptive capacity. This study examined the mechanisms in two different contexts under which a focal firm explicitly learns from external partners in visible knowledge alliances or implicitly learns from other firms in invisible knowledge networks. However, knowledge alliances and networks do not automatically lead to coinvented or assimilated knowledge at the embedded firms. This is because firms vary in their investments in IT, which facilitates or hinders their organizational learning processes in knowledge alliances and networks.

Table 4

Regression results for assimilated knowledge (logged number of cross-citations).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Degree centrality		1.059*** (0.334)				0.546*** (0.110)			
Closeness centrality			14.994*** (1.995)				14.432*** (2.244)		
Betweenness centrality				28.658*** (6.554)				22.839*** (5.142)	
Eigenvector centrality					9.606*** (2.958)				4.648*** (1.369)
Degree centrality × IT						374.552*** (133.945)			
Closeness centrality × IT							−2.415 (66.234)		
Betweenness centrality × IT								2221.174 (1328.191)	
Eigenvector centrality × IT									3675.912** (1561.624)
IT						−22.742** (9.340)	−10.521 (8.660)	−15.981 (11.474)	−26.737* (14.297)
R&D	−4.708 (10.408)	−5.752 (6.904)	1.166 (4.065)	−5.088 (5.715)	−6.655 (8.032)	−6.191 (4.944)	1.055 (4.212)	−4.837 (5.199)	−6.867 (7.098)
Financial leverage	1.942 (2.903)	3.092 (2.393)	−1.218 (1.601)	3.520 (2.220)	2.879 (2.610)	2.871 (2.035)	−1.272 (1.580)	2.794 (2.079)	3.234 (2.669)
Size	2.200*** (0.465)	1.318*** (0.432)	1.130** (0.416)	0.895* (0.435)	1.718*** (0.442)	1.014** (0.365)	1.175** (0.432)	0.870* (0.434)	1.606*** (0.420)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R ²	0.328	0.574	0.699	0.645	0.497	0.679	0.704	0.671	0.575
Adj. R ²	0.274	0.532	0.670	0.610	0.447	0.635	0.664	0.626	0.517
F	5.90***	10.39***	20.13***	15.95***	8.33***	23.81***	23.98***	16.39***	23.08***

Note: $n = 68$. Clustered robust standard errors are in parentheses. Dependent variable is one-year lagged log of number of cross-citations.* $p < 0.1$.** $p < 0.05$.*** $p < 0.01$.**Table 5**

Regression results for assimilated knowledge (cross-citation ratio).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Degree centrality		0.088* (0.045)				0.021 (0.015)			
Closeness centrality			1.777*** (0.330)				1.677*** (0.396)		
Betweenness centrality				2.616** (1.015)				1.679** (0.772)	
Eigenvector centrality					0.724* (0.390)				0.074 (0.165)
Degree centrality × IT						48.674*** (16.089)			
Closeness centrality × IT							5.037 (7.637)		
Betweenness centrality × IT								366.673** (172.843)	
Eigenvector centrality × IT									485.871** (184.671)
IT						−3.093** (1.180)	−1.272 (1.312)	−2.418 (1.494)	−3.348* (1.736)
R&D	−0.744 (1.449)	−0.831 (1.194)	−0.048 (0.622)	−0.778 (1.064)	−0.890 (1.303)	−0.886 (0.960)	−0.114 (0.666)	−0.739 (0.981)	−0.921 (1.199)
Financial leverage	0.908** (0.363)	1.003*** (0.320)	0.533* (0.259)	1.052*** (0.297)	0.978*** (0.343)	0.972*** (0.277)	0.505* (0.265)	0.937*** (0.281)	1.029*** (0.339)
Size	0.167*** (0.059)	0.094 (0.064)	0.040 (0.040)	0.048 (0.063)	0.131*** (0.061)	0.055 (0.052)	0.048 (0.044)	0.043 (0.058)	0.116* (0.057)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R ²	0.206	0.304	0.507	0.358	0.261	0.408	0.509	0.397	0.336
Adj. R ²	0.142	0.236	0.458	0.295	0.188	0.328	0.443	0.315	0.246
F	6.30***	6.05***	29.64***	7.00***	5.76***	16.27***	38.29***	11.78***	13.07***

Note: $n = 68$. Clustered robust standard errors are in parentheses. Dependent variable is one-year lagged cross-citation ratio.* $p < 0.1$.** $p < 0.05$.*** $p < 0.01$.

Table 6
Regression results for firm competitiveness (market share).

	(1)	(2)	(3)	(4)	(5)
<i>Coinvented knowledge</i>					
Logged number of coinventors		0.030 [*] (0.015)			
Logged number of coinventions			0.032 ^{**} (0.015)		
<i>Assimilated knowledge</i>					
Logged number cross-citations				0.015 ^{***} (0.004)	
Cross-citation ratio					0.093 ^{***} (0.030)
R&D	0.021 (0.190)	0.010 (0.147)	0.009 (0.146)	−0.033 (0.135)	0.059 (0.173)
Financial leverage	−0.128 (0.078)	−0.110 (0.073)	−0.108 (0.073)	−0.140 ^{**} (0.066)	−0.215 ^{**} (0.083)
Size	0.056 ^{***} (0.019)	0.036 (0.024)	0.036 (0.024)	0.025 [*] (0.014)	0.044 ^{***} (0.014)
Year dummies	Yes	Yes	Yes	Yes	Yes
R ²	0.320	0.435	0.439	0.556	0.503
Adj. R ²	0.263	0.377	0.381	0.510	0.451
F	2.19 [*]	4.21 ^{***}	4.33 ^{***}	3.33 ^{**}	2.83 ^{***}

Note: $n=65$. Clustered robust standard errors are in parentheses. Dependent variable is one-year lagged market share.

^{*} $p < 0.1$.

^{**} $p < 0.05$.

^{***} $p < 0.01$.

7. Conclusion

The paper contributes to a better understanding of how IT enables absorptive capacity by moderating externally oriented organizational learning processes that involve interactive learning from knowledge alliance partners and non-interactive learning in industry knowledge networks. A panel data set from the U.S. pharmaceutical industry is used to validate this study's model of IT-enabled absorptive capacity. The empirical findings reveal that IT investment can strengthen the links between knowledge alliance experience and coinvented knowledge and between knowledge network centrality and assimilated knowledge, which, in turn, improve firm competitiveness. This study finds the mechanisms through which IT enables absorptive capacity and opens up the black box of IT-enabled absorptive capacity. Not only does this work reconceptualize absorptive capacity as alliance-based and network-based organizational learning processes; it also provides solid evidence on IT's role as a key catalyst of these processes that enable absorptive capacity.

Our study has several limitations, as follows. First, departing from prior empirical efforts of directly operationalizing IT-enabled absorptive capacity (e.g., [53]), this study tries to uncover the mechanisms through which IT is used to enable absorptive capacity. Therefore, it is necessary to separate the measures of IT and absorptive capacity that consist of different organizational learning processes. This study examines two particular organizational learning processes that constitute absorptive capacity, those in knowledge alliances and networks. Future research may adopt alternative typologies to conceptualize other specific externally oriented organizational learning processes to extend our understanding of IT's role in enabling absorptive capacity.

Second, the sample was derived from firms in the U.S. pharmaceutical industry, which is characterized by the frequency of innovation activities that are carried out in knowledge alliances and networks [19,48,82]. Although we construct a panel data set from multiple sources, the sample size is relatively small due to the availability of firm-level IT data. This sample size is comparable to prior studies on firm alliances and networks (e.g., [104]: $n = 60$), and the results based on a small sample should be seen as having

good internal validity (because the smaller statistical power leads to more conservative significance tests). However, external validity is a concern when generalizing the current findings. Future studies may collect larger samples from the U.S. pharmaceutical industry or other industries to examine the present findings and thus obtain complementary evidence on IT-enabled absorptive capacity.

The empirical findings of this work reveal the importance of IT in facilitating organizational learning processes in the U.S. pharmaceutical industry, which has some important managerial implications. Conventionally, IT is used for the sharing and reuse of knowledge throughout an enterprise [64]. Corporate IP-based networks, telecommunications, and delivery systems all facilitate the transfer of knowledge across firm boundaries. These technologies also offer the infrastructure to facilitate virtual, interpersonal interactions among R&D teams that ensure the transfer of explicit and tacit knowledge [64,85].

Externally oriented organizational learning processes rely on IT to create digital connections and online access or databases for the discovery and sharing of the knowledge that can be incorporated into new pharmaceutical products [114]. The role of IT in the pharmaceutical industry is not only to support communication systems but also to provide a digital platform for the sharing of knowledge between a virtual community of drug discovery projects, resulting in more productive innovation processes, such as “blockbuster” innovation [45,74]. Some work practices in pharmaceutical firms, such as those related to open source biotechnology [10,59] and open source biotech software [96,95], show the importance of IT for enabling organizational learning and absorptive capacity. Notably, we found that IT investment does not strengthen the benefits of closeness centrality with regard to the assimilation of knowledge. This shows that IT will not strongly influence organizational learning if a pharmaceutical firm already has access to external knowledge sources in a knowledge network.

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John Qi Dong is an Assistant Professor of Strategy and Organization at Faculty of Economics and Business, University of Groningen in the Netherlands. He holds a PhD degree in information systems from Hong Kong University of Science and Technology. He also received a master degree and a bachelor degree, both in management, from Renmin University of China. His research interests include technology and innovation management, information technology and innovation, and business value of information technology. His work has been published or forthcoming in *Journal of Management* and *Information and Management*, among others.

Chia-Han Yang is an Assistant Professor at Institute of Creative Industries Design, National Cheng Kung University in Taiwan. He holds a PhD degree and a master degree, both in management of technology, from National Chiao Tung University. He also received a master degree in mechanic engineering from National Taiwan University and a bachelor degree in power mechanic engineering from National Tsing Hua University. His research interests include technology and innovation management, creative industry analysis, and service design. His work has been published or forthcoming in *Technological Forecasting and Social Change*, *Information and Management*, and *Energy Policy*, among others.