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Hierarchical business value of information technology: Toward a digital innovation value chain

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ABSTRACT

Information technology (IT) increasingly changes the ways through which firms develop and commercialize innovation. Prior studies have mainly focused on the direct effect of IT use on innovation performance, while little is known about how IT use for different purposes in the innovation processes leads to innovation performance at the organizational level. Drawing on the routine-based absorptive capacity (AC) framework, we conceptualize IT use for knowledge search and relational search as IT-enabled internal and external AC routines and unveil the hierarchical benefits resulting from IT use for innovation. We propose a model in which firms need to purposefully use IT to search for knowledge in the new product development process or search for relationships in the collaborative innovation process, leading to first-order benefits (i.e., internal innovation benefits and open innovation benefits) and, in turn, second-order benefits (i.e., innovation performance). By using a unique data set from 1028 German firms between 2003 and 2007, we find that IT use for knowledge search enhances internal innovation benefits, whereas IT use for relational search increases open innovation benefits. More importantly, internal and open innovation benefits mediate the relationships between IT use for knowledge and relational search and various innovation performance measures. Taken together, our findings shed light on a deeper understanding of the digital innovation value chain.

1. Introduction

Recent years have witnessed a rapid change in how firms innovate, as information technology (IT) plays an increasingly central role in creating innovation opportunities and outcomes [1–3]. There is a growing research interest in *whether* firms' use of IT leads to innovation performance (e.g., [4–16]). Most prior studies focus on the direct effect of IT use on innovation performance without looking into multiple intermediate mechanisms through which this direct effect is established. As a result, *how* IT use generates different types of benefits at the process level which, in turn, affect innovation performance at the organizational level remains, until now, unclear. Only a paucity of studies — [17,18] and, more recently, [19] — looked into the impact of IT on the innovation process, with a single focus on the internal innovation process without considering the open innovation process. This is a surprising gap as in the relevant literature on business value of IT, such a deep understanding of the hierarchical benefits stemming from IT use for financial performance has been well developed (e.g., [20–23]). Hence, there is a need to deepen our understanding of the hierarchical

benefits from IT use for innovation. Furthermore, the conceptualization of IT use often remains a black box in prior work — that is, aggregated IT investment or use is used — which offers little insight into how IT is used for different purposes in the innovation processes.

To address these gaps in literature, we draw on the concept of absorptive capacity (AC) — defined as a firm's ability to recognize the value of external knowledge, assimilate it, and utilize it for commercial ends [24] — to explain how different process-level benefits from IT use for distinct purposes will affect innovation performance. AC is an important organizational learning capability and has been widely recognized as a key determinant of innovation [24–26]. Moreover, research has shown that IT use, in general, helps develop AC [10,27,28]. We draw on and, more importantly, extend a routine-based model of AC [25] and conceptualize IT use as the IT-enabled AC routines in internal and external innovation processes. Such fine-grained theorizing of IT-enabled AC routines in different innovation processes has not been developed in the past. We further uncover the internal and external benefits from these IT-enabled AC routines that can lead to innovation performance. Knowing hierarchical benefits that are derived from IT

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use can deepen our understanding about the role of IT in internal and external innovation processes that ultimately influence innovation performance.

By decomposing the *internal* and *external* AC routines that are enabled by IT use, we develop a dual-channeling perspective to theorize the digital innovation value chain from IT use to *internal* and *external* innovation benefits at the process level to innovation performance at the organizational level. Lewin et al. [25] proposed that important internal AC routines consist of knowledge management practices across organizations, which are often conceptualized as search processes for knowledge [29] or relationships [30]. Likewise, important external AC routines consist of partnering with and learning from a diverse set of innovation partners [25].

In the digital innovation literature, IT use is considered as a key enabler for knowledge management [10,31] and knowledge search in particular [15,32]. In the routine-based AC framework, Lewin et al. [25] identified one type of internal AC routine that is particularly relevant to IT use: “IT-based knowledge codification system to store and manage knowledge, and retrieve it for future needs” (p. 87). Accordingly, by drawing on the routine-based AC framework, we theorize *IT use for knowledge search* — that is, a firm’s internal use of IT for gathering and sharing scientific or market knowledge — as an IT-enabled internal AC routine.

IT use has also been considered as a key enabler for open innovation initiatives in which a focal firm is collaborating with external innovation partners [7,9,27] and creating relational value [13,33,34]. In the routine-based AC framework, Lewin et al. [25] also emphasized that co-development relationships and R&D partnerships for collaboration with suppliers, customers, competitors, universities, and research institutions are the key learning practices for external AC routines (see Table 2 p. 90). In the same line, we theorize *IT use for relational search* — that is, a firm’s use of IT for identifying and establishing relationships with innovation partners — as an IT-enabled external AC routine.

The routine-based AC framework suggests that internal and external AC routines can lead to innovation performance (see Fig. 2 in [25], p. 92), without explaining how this link is realized. Research on business value of IT points to the hierarchical benefits from IT use as first-order benefits at the process level and second-order benefits at the organizational level [20,22,23]. In light of internal and external AC routines, we synthesize this hierarchical view with the digital innovation literature and propose that firms can derive internal innovation benefits from IT use in the new product development process¹ [4,10,14,17] and open innovation benefits from IT in the collaborative innovation process [7,9,27,32]. We define *internal innovation benefits* as a firm’s completion of its new product design and commercialization and *open innovation benefits* as a firm’s realization of its collaboration with different types of innovation partners. These two first-order benefits from IT use in internal and external innovation processes are the process-level antecedents of second-order benefits as innovation performance at the organizational level [1,2].

Consequently, we propose a two-stage model explaining the digital innovation value chain, consisting of both first- and second-order benefits for innovation. In the first stage of our model, we aim to explore the effect of IT use for knowledge search on internal innovation benefits and the effect of IT use for relational search on open innovation benefits. In the second stage of our model, we investigate how internal and open innovation benefits lead to innovation performance. To test our model and associated hypotheses, we use a large-scale data set from 1028 German firms by merging three waves of survey conducted between 2003 and 2007. The empirical findings corroborate our model and provide novel insight into the mediating paths from IT use for knowledge search to internal innovation benefits to innovation performance, and from IT use for relational search to open innovation

benefits to innovation performance. Importantly, IT use for knowledge and relational search does not directly influence innovation performance and their impacts must be carried over by creating first-order benefit in internal and external innovation processes.

The rest of the paper is organized as follows. In the next section, we introduce the theoretical background and review relevant literature. Then, hypotheses are developed. Subsequently, data and measures are reported, followed by the results. Finally, we discuss the main findings, the implications for theory and practice, and the limitations and directions for future research.

2. Theoretical background

2.1. IT use for internal and external AC routines

Since the introduction of the AC concept by Cohen and Levinthal [24], this concept has been widely studied as a key antecedent of organizational learning and innovation. For example, AC is conceptualized as a dynamic capability of processing knowledge that enhances innovation performance [26,46]. Zahra and George [26] refined this concept as a set of knowledge capabilities, including acquisition, assimilation, transformation, and exploitation, while potential AC consists of knowledge acquisition and assimilation, and realized AC consists of knowledge transformation and exploitation. More recently, Lane et al. [46] highlighted major shortcomings of the AC literature. They noted that little attention has been paid to the routines underlying AC, limiting our understanding of the micro-foundations of AC. In other words, there is a lack of direct observation of AC in practices, and a need to deepen our understanding of the AC routines. Another limitation of extant AC literature is that, though AC is a dynamic capability of learning from external knowledge, prior studies often overlooked the internal dimension of AC [25]. Namely, prior literature has mainly focused on the assimilation and exploration of knowledge in the external environment while neglecting the role of the internal dimension of AC.

Consequently, Lewin et al. [25] systematically introduced a routine-based AC framework, entailing *internal* and *external* AC routines. They explicitly identified the micro-foundations of internal and external AC as the meta-routines underlying AC and their expression in the form practiced routines, allowing scholars to conceptualize and operationalize AC routines in both internal and external dimensions. Routines (e.g., repetitive activities, decision rules, processes, standard operating programs, and procedures) comprise the building blocks of organizational capabilities [47,48] and evolve over time as a result of search and learning [49]. Routines also serve as the “organizational memory”, because they support in building the stock of explicit and tacit knowledge in organizations (e.g., [50–52]). In their framework, Lewin et al. [25] suggested that important *internal AC routines* consist of knowledge management practices across organizations on the one hand, and important *external AC routines* consist of learning from and with a diverse set of partners on the other.

In the IS literature, scholars have conceptualized IT use as IT-enabled absorptive capacity (see [28] for a literature review). For example, Joshi et al. [10] theorized and operationalized IT-enabled potential and realized absorptive capacity by firms’ use of different IT systems. In the routine-based AC framework, Lewin et al. [25] identified one type of internal AC routine that is particularly relevant to IT use — “sharing knowledge and superior practices across the organization” (p. 87). For example, “IT-based knowledge codification system to store and manage knowledge, and retrieve it for future needs” ([25], p. 87). Accordingly, we theorize *IT use for knowledge search* as an IT-enabled internal AC routine, referring to a firm’s internal use of IT for gathering and sharing scientific or market knowledge. Such an IT-enabled internal AC routine offers firms effective digital means (e.g., databases and knowledge portals), to access and share scientific and market knowledge from disparate sources.

¹ We use new products as a generic term referring to new products or services.

IT use can also enable open innovation initiatives by facilitating a focal firm's collaboration with innovation partners [7,9,27]. In the routine-based AC framework, Lewin et al. [25] also emphasized "learning from and with partners, suppliers, customers, competitors, and consultants" (p. 90). Examples include "co-development relationships, collaborating with 'lead users', collaborating with suppliers, R&D partnerships, networking with outside organizations, universities, and research institutions in particular" ([25], p. 90). In the same line, we theorize *IT use for relational search* as an IT-enabled external AC routine, referring to a firm's use of IT for identifying and establishing relationships with innovation partners. Such an IT-enabled external AC routine could be carried out by developing relationships via digital means (e.g., other organizations' central and departmental websites).

2.2. First-order and second-order benefits from IT use

Past research on business value of IT has documented that firms' use of IT has the potential to create direct, first-order benefits and indirect, second-order benefits, manifested by a two-stage model (e.g., [20,22,23]). Essentially, first-order benefits refer to the benefits for business processes (e.g., internal and external innovation processes), whereas second-order benefits are commercial outcomes in the external environment (e.g., innovation performance in the marketplace). Drawing on the digital innovation literature and the routine-based AC framework, we identify two major types of first-order benefits from IT use at the process level, leading to innovation performance at the organizational level.

First, in the internal innovation process (i.e., new product development process), internal AC routines can bring *internal innovation benefits* (e.g., [4,10,14,17]), defined as a firm's completion of its new product design and commercialization. For example, internal innovation benefits arise when 3M seeks for market signals to make decisions whether they should continue with new product development, entering a new market, or terminate specific innovation activities [25]. Similarly, IDEO receives internal innovation benefits by comparing the performance of their newly developed products to available products in the market [53,54].

Second, in the external innovation process (i.e., collaborative innovation process), external AC routines can bring *open innovation benefits* (e.g., [7–9,32]), defined as a firm's realization of its collaboration with different types of innovation partners. For example, a focal firm can establish co-development relationships [35,37] and R&D partnerships [55] by collaborating with suppliers, customers, competitors, universities, and research institutions [36,38,39].

Traditionally, the innovation process occurred internally, within the boundary of a firm, in the form of R&D projects. However, open innovation has emerged when firms became aware of the knowledge inputs and shared resources they could use externally with other firms [56]. Different types of partners with different knowledge and resources are required for developing and delivering sophisticated new products and services [57,58]. For example, innovation can be accomplished by collaborating with science-based innovation partners, such as universities and research institutions with a large pool of scientific knowledge [55,59]. In addition, innovation can be jointly developed and commercialized with market-based partners, through collaborating with suppliers to improve input quality and reduce production costs [60], collecting new and valuable ideas from customers [61], and sharing production and marketing resources with competitors [62].

Next to the benefits of open innovation, there are also disadvantages. A variety of collaborators might create an attention problem [32,39]. Therefore, firms should also rely on their new product development process and keep a balance between internal and external innovation processes [39,63,64]. Success in innovation is expected to require more and possibly more ambidextrous, internal and external AC routines [25]. Therefore, both internal innovation benefits and open innovation benefits are important for achieving superior innovation

Fig. 1. Research Model.

performance at the organizational level. Fig. 1 presents our research model and we develop associated hypotheses, which is explained in the next section.

3. Hypotheses Development

3.1. The hierarchical benefits from IT use for knowledge search

There are two major phases of the new product development process — new product design and commercialization [65,66]. In the same line, Joshi et al. [10] distinguished the ideated and commercialized innovation as two-stage outcomes of a firm's innovation process. IT use for knowledge search allows a firm to gather and share knowledge through the organization. We propose that IT use for knowledge search can enhance a firm's internal innovation benefits in the new product development process for two reasons.

First, IT use for knowledge search can enhance a firm's ability to design new products. IT use can enhance a firm's ability to acquire and share scientific knowledge in databases and knowledge repositories for scientific literature and patents [31], which benefits the design of new product features. Owing to the use of IT, firms can enhance the quality of a new product design [17], save development costs [4], and shorten the development cycle time [14], thereby supporting the completion of a new product design — a key internal innovation benefit.

Second, IT use for knowledge search strengthens a firm's ability to commercialize a new product. Besides scientific knowledge, IT can also be used to search for market knowledge that is beneficial for the introduction of a new product in the marketplace [10]. For example, Procter & Gamble uses IT to forge closer links between market information and product features to satisfy customers' fast-changing needs [67]. Moreover, knowledge portals contain best practices from prior commercialization projects and allow new projects to retrieve useful knowledge and learn from past success [68–70]. Shared knowledge portals can also serve as "boundary objects" to reduce misunderstanding and encourage consensus [71,72] when commercializing new products, where cross-functional teams consisting of professionals from different areas such as R&D and marketing are often involved. In summary, IT use for knowledge search can enhance the commercialization of new products — another key internal innovation benefit. Thus, we propose the following hypothesis:

H1. IT use for knowledge search has a positive relationship with internal innovation benefits.

IT use does not automatically generate superior innovation performance at the organizational level, unless it is used for knowledge search that supports gathering and sharing scientific or market knowledge for internal innovation purposes. To achieve good innovation performance, firms need to use IT in the innovation processes, such as an internal new product development process [17], to develop better products and win market competition. IT use in the internal new product development process results in internal innovation benefits, such as the completion of

a new product design and commercialization at the process level. In turn, these internal innovation benefits result in developing and introducing competitive new products in the marketplace, leading to superior innovation performance at the organizational level [1,2]. Given the hierarchy of first- and second-order benefits, we argue that the impact of IT use for knowledge search on (second-order) innovation performance is channeled by (first-order) internal innovation benefits. Thus, we propose the following mediation hypothesis:

H2. Internal innovation benefits mediate the positive relationship between IT use for knowledge search and innovation performance.

3.2. The hierarchical benefits from IT use for relational search

Besides the internal innovation process, firms also open up their innovation activity to benefit from the collaboration with innovation partners [73]. Collaborating with different types of innovation partners increases the likelihood to be exposed to different new ideas from partners [74,75]. For example, firms that collaborate with science-based partners such as universities and research institutions are exposed to a wider “R&D horizon” [76]. Firms can also collaborate with market-based partners such as suppliers, customers, and competitors, providing them access to a broader range of market information and complementary resources that benefit co-development of new products [39,77]. IT use for relational search can identify and establish external relationships with innovation partners. We propose that IT use for relational search can generate open innovation benefits in the collaborative innovation process for two reasons.

First, IT use for relational search supports the identification of different types of innovation partners. Internet technologies become a key driver of increasing R&D collaboration [78]. The use of online websites, for instance, helps firms to easily search for numerous organizations and their R&D departments and identify potential innovation partners that possess complementary knowledge and resources. By using online websites for relational search, firms are able to find a variety of potential innovation partners, including suppliers, customers, competitors, universities, and research institutions, for jointly developing new products [7,9].

Second, IT use for relational search supports the establishment of external relationships with different types of innovation partners. Once potential innovation partners are identified, communication starts with the contact information on the websites, leading to R&D partnerships and co-development relationships [7,78]. Subsequently, a focal firm may leverage the online portals embedded in innovation partners’ websites to collaborate with them via digital connections [9,79]. IT use, therefore, provides the focal firm new opportunities to develop external relationships for innovation collaboration [33,80]. In summary, IT use for relational search could bring open innovation benefits, leading to the following hypothesis:

H3. IT use for relational search has a positive relationship with open innovation benefits.

IT use does not directly imply that firms can use IT to generate superior innovation performance at the organizational level, unless it is used for relational search that enables identifying and establishing relationships with innovation partners. To achieve superior innovation performance, firms need to use IT in the innovation processes, such as external collaborative innovation process [9], to co-develop better products and win market competition. Such a process leads to open innovation benefits with a variety of complementary knowledge and resources, which create synergies when co-developing innovation with partners at the process level. In turn, these open innovation benefits result in developing and introducing competitive new products in the marketplace, leading to superior innovation performance at the organizational level [1,2]. Given the hierarchy of first- and second-order benefits, we argue that the impact of IT use for relational search on

(second-order) innovation performance is channeled by (first-order) open innovation benefits. Finally, we have the following mediation hypothesis:

H4. Open innovation benefits mediate the positive relationship between IT use for relational search and innovation performance.

4. Methods

4.1. Data

To test our hypotheses, we construct a unique data set between 2003 and 2007 from the Center for European Economic Research (ZEW)’s Mannheim Innovation Panel (MIP) database². This database consists of survey data based on a large, representative sample of firms from all manufacturing and service industries in Germany³ [81]. For policy and research purposes, ZEW conducts the innovation survey annually since 1993, which is the German part of the European Commission’s Community Innovation Survey (CIS). CIS is the primary firm-level data source [82] for innovation research (e.g., [32,38,39,83,84]). The survey questionnaire is designed based on the Organization for Economic Cooperation and Development’s (OECD) Oslo Manual [85], which provides well-grounded and established guidelines to guarantee the understandability, reliability, and validity of questions across countries. To develop and improve the Oslo Manual, extensive pilot tests were conducted in each European country [84]. ZEW has conducted a non-response analysis and assessed common method bias confirming the high quality of data.

Although MIP database has a panel structure, the survey questions change over time. In particular, the questions about IT use were asked only in 2003. To avoid reverse causality and common method bias, we adopt a time-separated design by choosing the dependent variables measured later than the independent variables. As the questions about internal and open innovation benefits are available for 2005, but not for 2004, we can only use two-year time lag in the empirical analysis⁴. We thus merged two waves of survey in 2003 and 2005 to examine the impacts of IT use for knowledge and relational search on internal and open innovation benefits. To be consistent in the choice of time lag, we further augmented our data with most innovation performance measures in 2007. We also obtained a number of control variables, including IT investment, R&D investment, firm size, firm age, mergers and acquisitions (M&As), and location, from the survey in 2003. Our final sample comprises 1028 firms with a few missing values in some variables. Table 1 describes the sample distribution by industries based on NACE Rev. 1 two-digit codes.

4.2. Measures

4.2.1. IT use for knowledge search

We rely on two binary questions from the survey in 2003 to capture IT use for knowledge search as 1) whether a firm uses scientific literature and patent databases and 2) whether a firm uses knowledge portals (0 = no use; 1 = use). We take the summative index approach that has been widely used in prior research (e.g., [10,13]) to aggregate multiple binary measurement items and measure IT use for knowledge

² Available on <http://doi.org/10.7806/zew.mip.2013.v1.suf>.

³ In 2007, Germany was following the U.S. and ranked No. 2 in the Global Innovation Index [108].

⁴ One may argue that first- and second-order benefits from IT use might not take place immediately within two years or might fade away after two years. If the effects of IT use last for less or more than two years, it is less likely that we can observe any significant effects in our conservative results. But if we are still able to observe any significant effects, it actually indicates that the effects are very strong. Thus, if we observe any significant effects, such a concern can only make our results more conservative, rather than threatening their validity.

Table 1
Sample Distribution by Industries.

NACE code	Industry	Obs.	Percentage (%)
10–14	Mining and quarrying	17	1.7
15, 16	Manufacture of food products and tobacco	32	3.1
17–19	Textiles, clothing, and leather products	30	2.9
20–22	Wood, paper, and printing	43	4.2
23, 24	Refining petroleum, code manufacture, and chemical products	31	3.0
25	Manufacture of rubber and plastic products	43	4.2
26	Glass, ceramics, other non-metallic mineral products	28	2.7
27, 28	Manufacture of basic metals and fabricated metal products	94	9.1
29	Manufacture of machinery, weapons and ammunition, and domestic appliances	67	6.5
30–32	Manufacture of office machinery and computers, electrical machinery, and television and communication equipment	39	3.8
33	Manufacture of medical, precision, and optical instruments	51	5.0
34, 35	Manufacture of motor vehicles, other transport equipment, and aircraft and spacecraft	17	1.7
36	Manufacture of furniture, jewelry, musical instruments, sports equipment, games, and toys	21	2.0
51	Wholesale and commission trade, with the exception of motor vehicles and motorcycles	42	4.1
50, 52	Retail trade, and repair of motor vehicles and motorcycles	36	3.5
60–63, 641	Land transport, water transport, and air transport	92	8.9
65–67	Banking, insurance	33	3.2
72, 642	Computer-related activities, IT, telecommunications	57	5.5
73, 742, 743	Scientific and technical services	107	10.4
741, 744	Business-related services	49	4.8
745–748, 90	Other services	58	5.6
70, 71	Real estate activities and renting of machinery equipment and household goods	41	4.0
Total		1028	100

Table 2
Description of Measures.

Variable	Measurements	Scale	References
IT use for knowledge search	Whether a firm uses scientific literature and patent databases; Whether a firm uses knowledge portals	0 = no; 1 = moderate; 2 = high	Alavi and Leidner [31], Dong and Netten [32], Joshi et al. [10], Lewin et al. [25], Trantopoulos et al. [15]
IT use for relational search	Whether a firm uses other organizations' central websites to develop relationships for innovation collaboration; Whether a firm uses other organizations' R&D departmental websites to develop relationships for innovation collaboration	0 = no; 1 = moderate; 2 = high	Cui et al. [7], Dong and Yang [27], Lewin et al. [25], Rai et al. [33], Saldanha et al. [13], Saraf et al. [34]
Internal innovation benefits	Whether a firm designs new products; Whether a firm commercializes new products	0 = no; 1 = moderate; 2 = high	Banker et al. [4], Joshi et al. [10], Pavlou and El Sawy [17], Tambe et al. [14]
Open innovation benefits	The number of different types of organizations that a firm collaborates with for innovation: suppliers, customers, competitors, universities, and research institutions	0–5	Cui et al. [7], Dong and Netten [32], Dong and Wu [8], Dyer and Singh [35], Gómez et al. [9], Koch and Strotmann [36], Koza and Lewin [37]
Invention success	Whether a firm successfully generated new patents	0 = no; 1 = yes	Joshi et al. [10]
Innovation success	Whether a firm successfully introduced new products or services in the past three years	0 = no; 1 = yes	Leiponen and Helfat [38]
Innovation new to the market	Sales from products new to the market scaled by total sales	Ratio	Laursen and Salter [39]
Innovation new to the firm	Sales from products new to the firm scaled by total sales	Ratio	Laursen and Salter [39]
Innovation significantly improved	Sales from significantly improved products scaled by total sales	Ratio	Laursen and Salter [39]
IT investment	IT expenditure in hardware, software, services and personnel scaled by total sales	Ratio	Bardhan et al. [5], Han and Mithas [40], Mithas et al. [41]
R&D investment	R&D expenditure scaled by total sales	Ratio	Cohen and Levinthal [24], Shimizutani and Todo [42],
Size	The natural logarithm of total sales	Continuous	Dong [43], Dong and Yang [44]
Age	Whether a firm is a new startup established in the last three years	0 = no; 1 = yes	Laursen and Salter [39]
M&As	Whether a firm has any M&As in the last three years	0 = no; 1 = yes	Valentini [45]
Location	Whether a firm is located in East or West Germany	0 = West; 1 = East	Dong and Netten [32]

search⁵. Specifically, we summed up the two binary items to measure

the level of IT use for knowledge search, varying from 0 to 2.

⁵ We also conducted a factor analysis by using rotated principle component analysis to assess the validity of measurement items that are used to measure IT use for knowledge search, IT use for relational search, internal innovation benefits, and open innovation benefits. All items significantly loaded on the construct that they are intent on measuring but did not significantly load on the construct that they are not intent on measuring (see Appendix A), confirming the convergent and discriminant validity of our measurements. We further checked the average variance extracted (AVE) for these measurement times. All constructs had the AVEs above 0.5, suggesting good convergent validity. The square roots of AVE were greater than inter-construct correlations (see Table 3), indicating good discriminant validity.

4.2.2. IT use for relational search

We rely on two binary questions from the survey conducted in 2003, to capture IT use for relational search: 1) whether a firm uses other organizations' central websites to develop relationships for innovation collaboration and 2) whether a firm uses other organizations' R&D departmental websites to develop relationships for innovation collaboration (0 = no use; 1 = use). Again, we created a summative index by summing up the two binary items to measure to the level of IT use for relational search, varying from 0 to 2.

Table 3
Descriptive Statistics and Correlations.

	Obs.	Mean	SD	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
(1) Invention success	1028	0.42	0.49														
(2) Innovation success	934	0.20	0.40	0.31													
(3) Innovation new to the market	801	0.04	0.12	0.31	0.35												
(4) Innovation new to the firm	799	0.04	0.12	0.21	0.41	0.51											
(5) Innovation significantly improved	794	0.20	0.18	0.19	0.47	0.58	0.51										
(6) Internal innovation benefits	1028	0.59	0.80	0.37	0.46	0.29	0.28	0.33									
(7) Open innovation benefits	1028	0.40	1.01	0.37	0.30	0.28	0.30	0.28	0.37								
(8) IT use for knowledge search	799	0.36	0.66	0.35	0.27	0.19	0.21	0.19	0.35	0.39							
(9) IT use for relational search	791	0.24	0.53	0.22	0.22	0.10	0.09	0.15	0.25	0.33	0.47						
(10) IT investment	766	0.02	0.08	−0.05	−0.04	0.00	0.00	0.02	−0.03	0.02	0.07	−0.01					
(11) R&D investment	974	0.02	0.04	0.41	0.32	0.40	0.28	0.36	0.40	0.47	0.43	0.27	0.01				
(12) M&As	926	0.06	0.24	0.04	0.06	0.04	0.06	0.02	0.10	0.10	0.11	0.02	0.03	0.08			
(13) Size	1028	2.15	1.55	0.21	0.14	0.07	0.06	0.04	0.19	0.14	0.21	0.12	−0.07	−0.06	0.13		
(14) Age	952	0.03	0.17	0.11	0.05	0.22	0.18	0.16	0.07	0.08	0.05	0.05	0.07	0.21	0.14	0.00	
(15) Location	1027	0.41	0.49	−0.05	−0.03	−0.04	0.04	0.00	0.00	0.09	0.02	0.04	−0.01	0.07	−0.03	−0.19	0.02

Notes: Correlations in bold are significant at $p < 0.05$. Figures in diagonal are the square roots of AVE based on original multiple items.

4.2.3. Internal innovation benefits

We measure internal innovation benefits in the new product development process by relying on two binary questions from the survey in 2005 as 1) whether a firm has technically designed new products and 2) whether a firm has commercialized its new products (0 = no; 1 = yes). We created a summative index by summing up the two binary items to measure the level of internal innovation benefits, varying from 0 to 2.

4.2.4. Open innovation benefits

The open innovation literature suggests that the openness of a firm in its innovation activity is often captured by counting the number of different types of innovation partners [38,39,75]. We follow this approach to measure open innovation benefits in the collaborative innovation process by counting the number of a firm's different types of innovation partners in 2005, including 1) suppliers [86], 2) customers [62], 3) competitors [87], 4) universities [74], and 5) research institutions [74]. Thus, the measure of open innovation benefits varies from 0 to 5, where 0 indicates that the focal firm had no innovation partners and 5 indicates that the focal firm collaborated with all five types of innovation partners.

4.2.5. Innovation performance

We have a comprehensive approach to measure innovation performance based on measures that are used in past research with similar data sources [38,39]. Specifically, we include five alternative measures for innovation performance. First, we measure *invention success* by using a binary variable, which indicates whether a firm successfully generated new patents in 2005 (0 = no, 1 = yes) [10]. Second, we measure *innovation success* by using another binary variable, which indicates whether a firm successfully introduced new products or services in the past three years by 2007 (0 = no, 1 = yes) [38]. Third, we measure *innovation new to the market*, reflecting the radicalness of a firm's new products [39], by a firm's sales from products or services that are new in the marketplace in 2007 scaled by its total sales. Fourth, we include *innovation new to the firm* as an indicator of incremental innovation performance, measured by a firm's sales from new products or services that are new to the firm but may exist in the marketplace in 2007 scaled by total sales [39]. Finally, we include *innovation significantly improved* as an alternative measure of incremental innovation performance, by a firm's sales from significantly improved products or services in 2007 scaled by total sales [39].

In line with our aim to measure second-order benefits, our innovation performance measures not only capture patents, but more importantly, also capture the financial performance of new products or services in the marketplace. New product measures are superior to

patents for several reasons. First, many patents owned by a firm may not be useful for developing new products [88]. Second, new product measures reflect not only developmental outcomes but also financial performance, which cannot be known by looking into patents [39]. Finally, there are huge differences in the patenting propensity across industries and firms in the service sectors rarely apply for patents. For example, 50% of our sample was derived from firms in service industries (see Table 1), requiring innovation performance measures that are applicable across different industries.

4.3. Control variables

A number of variables from the survey conducted in 2003, which might influence first- and second-order benefits from IT use, are controlled in this study. First, we control *IT investment* as a firm's total expenditure in IT hardware, software, services and labor, scaled by total sales [5,40,41]. Next, we include *R&D investment*, measured by a firm's R&D expenditure scaled by its total sales [24,42]. Third, *firm size* is controlled by the natural logarithm of total sales [43,44]. Fourth, *firm age* is controlled by a binary variable, separating new startups within 3 years from more mature firms (0 = more than 3 years old; 1 = within 3 years old) [39]. Fifth, we control for *mergers and acquisitions (M&As)* that may significantly change a firm's resources and capabilities for innovation [45], by including a binary variable indicating whether a firm was involved in any M&As between 2001 and 2003 (0 = no; 1 = yes). Sixth, a *firm's location* is also controlled by a binary variable indicating whether a firm is in West or East Germany (0 = West; 1 = East) [32], as there are big differences between West and East Germany in economic development [89]. Finally, we include a number of *industry dummies* based on NACE Rev. 1 two-digit codes to control for unobservable industry heterogeneities. Table 2 provides a description of our measures and Table 3 shows the descriptive statistics and correlations of our variables. It is worth noting that IT investment is not significantly correlated with IT use for knowledge and relational search, suggesting that firms that invest more in IT may not always use IT for knowledge and relational search in the innovation processes.

5. Results

5.1. Regression analysis

Since all our constructs are measured by a single variable, there is no need to use structural equation modeling (SEM) to estimate a measurement model. We, therefore, use ordinary least squares (OLS) regression, which is essentially equivalent to estimating a structural model in SEM. Before conducting the regression analysis, we did several

Table 4
OLS Regression Results for Internal Innovation Benefits.

	(1)	(2)
IT use for knowledge search		0.155** (0.056)
IT use for relational search		0.090 (0.061)
IT investment	−0.091 (0.343)	−0.220 (0.368)
R&D investment	6.136*** (0.708)	4.760*** (0.837)
M&As	0.165 (0.121)	0.216 (0.133)
Size	0.084*** (0.020)	0.047* (0.022)
Age	−0.124 (0.166)	−0.086 (0.180)
Location	0.071 (0.055)	0.059 (0.060)
Industry dummies	Yes	Yes
Constant	0.670** (0.214)	−0.066 (0.238)
R ²	0.280	0.294
Adj. R ²	0.252	0.257
F	10.170***	8.041***
n	708	570

Notes: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. Standard errors are in parentheses. Dependent variable is internal innovation benefits.

diagnostic tests. We found that the distributions of our variables meet the OLS assumptions. Multicollinearity was also examined by checking the variance inflation factors (VIFs), which were all below the threshold of 10.

Table 4 presents OLS regression results for internal innovation benefits. First, the control model was estimated and then IT use for knowledge search and IT use for relational search were added to estimate a full model. In the control model, it was found that larger firms with higher R&D investment have stronger internal innovation benefits. The full model showed that IT use for knowledge search has a statistically significant and positive effect on internal innovation benefits ($\beta = 0.155$, $p < 0.01$). Thus, H1 was supported. Consistent with our research model, however, we did not observe a statistically significant effect of IT use for relational search on internal innovation benefits.

Table 5 presents OLS regression results for open innovation benefits. Again, the control model was estimated first and then the full model with IT use for knowledge search and IT use for relational search. In the control model, it was again found that larger firms with higher R&D investment have greater open innovation benefits. Firms in East Germany demonstrate a higher level of open innovation benefits than firms in West Germany. In the full model, IT use for relational search has a statistically significant and positive effect on open innovation benefits ($\beta = 0.214$, $p < 0.01$). Thus, H3 was supported. Consistent with our research model, however, IT use for knowledge search does not have a statistically significant effect on open innovation benefits.

Table 6 reports the logistic regression results for invention success, given its binary scale. We first estimated the control model, then both IT use for knowledge search and IT use for relational search were added to the control model, and finally internal innovation benefits and open innovation benefits. In the control model, it was found that larger firms with higher R&D investment are more likely to produce patent inventions. In the partial model, IT use for knowledge search has a statistically significant and positive effect on the likelihood of invention success ($\beta = 0.579$, $p < 0.05$). It seems that scientific literature and patent databases are particularly useful for the success of developing patent inventions. However, IT use for relational search does not have a statistically significant effect on the likelihood of invention success ($\beta = 0.211$, $p > 0.05$). In the full model, internal innovation benefits have a statistically significant and positive effect on the likelihood of

Table 5
OLS Regression Results for Open Innovation Benefits.

	(1)	(2)
IT use for knowledge search		0.135 (0.074)
IT use for relational search		0.214** (0.080)
IT investment	0.482 (0.451)	0.285 (0.487)
R&D investment	9.609*** (0.932)	7.793*** (1.105)
M&As	0.234 (0.159)	0.260 (0.176)
Size	0.157*** (0.026)	0.132*** (0.029)
Age	−0.308 (0.218)	−0.331 (0.238)
Location	0.206** (0.072)	0.215** (0.080)
Industry dummies	Yes	Yes
Constant	−0.097 (0.282)	−0.430 (0.311)
R ²	0.286	0.312
Adj. R ²	0.259	0.276
F	10.508***	8.750***
n	708	570

Notes: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. Standard errors are in parentheses. Dependent variable is open innovation benefits.

Table 6
Logistic Regression Results for Invention Success.

	(1)	(2)	(3)
Internal innovation benefits			0.534** (0.183)
Open innovation benefits			0.358** (0.127)
IT use for knowledge search		0.579* (0.232)	0.508* (0.236)
IT use for relational search		0.211 (0.265)	0.084 (0.276)
IT investment	−1.363 (3.045)	−2.129 (3.384)	−3.655 (3.655)
R&D investment	23.073*** (2.962)	21.498*** (3.667)	17.224*** (3.821)
M&As	−0.433 (0.517)	−0.441 (0.585)	−0.722 (0.602)
Size	0.447*** (0.088)	0.429*** (0.105)	0.337** (0.111)
Age	0.232 (0.632)	−0.012 (0.690)	0.270 (0.669)
Location	0.061 (0.256)	0.028 (0.297)	−0.164 (0.311)
Industry dummies	Yes	Yes	Yes
Constant	−4.513*** (1.114)	−4.788*** (1.097)	−4.641*** (1.094)
Chi ²	193.729	169.275	186.175
n	644	504	504

Notes: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. Standard errors are in parentheses. Dependent variable is invention success.

invention success ($\beta = 0.534$, $p < 0.01$). Open innovation benefits also have a statistically significant and positive effect on the likelihood of invention success ($\beta = 0.358$, $p < 0.01$).

Table 7 reports the logistic regression results for innovation success. We first estimated the control model, then both IT use for knowledge search and IT use for relational search were added to the control model, and finally internal innovation benefits and open innovation benefits. In the control model, it was found that larger firms with higher R&D investment are more likely to successfully introduce new products in the past three years. In the partial model, IT use for knowledge search and IT use for relational search do not have statistically significant effects

Table 7
Logistic Regression Results for Innovation Success.

	(1)	(2)	(3)
Internal innovation benefits			1.064*** (0.154)
Open innovation benefits			0.350** (0.133)
IT use for knowledge search		0.116 (0.187)	−0.054 (0.203)
IT use for relational search		0.220 (0.204)	0.038 (0.227)
IT investment	−1.700 (2.004)	−1.147 (1.944)	−1.349 (2.405)
R&D investment	13.149*** (2.496)	12.539*** (3.063)	6.001 (3.417)
M&As	0.293 (0.396)	0.017 (0.458)	−0.406 (0.506)
Size	0.201** (0.066)	0.169* (0.076)	0.086 (0.083)
Age	−0.717 (0.561)	−1.192 (0.650)	−1.085 (0.650)
Location	−0.109 (0.182)	−0.080 (0.205)	−0.230 (0.222)
Industry dummies	Yes	Yes	Yes
Constant	−1.982*** (0.548)	−2.129** (0.683)	−2.075** (0.704)
Chi ²	162.081	134.619	198.466
n	708	570	570

Notes: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. Standard errors are in parentheses. Dependent variable is innovation success.

on the likelihood of innovation success ($\beta = 0.116$, $p > 0.05$; $\beta = 0.220$, $p > 0.05$). In the full model, however, internal innovation benefits and open innovation benefits have statistically significant and positive effects on the likelihood of innovation success ($\beta = 1.064$, $p < 0.001$; $\beta = 0.350$, $p < 0.01$).

Table 8 reports OLS regression results for innovation new to the market. We first estimated the control model, then both IT use for knowledge search and IT use for relational search were added, and

Table 8
OLS Regression Results for Innovation New to the Market.

	(1)	(2)	(3)
Internal innovation benefits			0.031*** (0.007)
Open innovation benefits			0.007 (0.005)
IT use for knowledge search		−0.002 (0.009)	−0.009 (0.009)
IT use for relational search		−0.014 (0.010)	−0.017 (0.010)
IT investment	0.023 (0.052)	0.049 (0.057)	0.054 (0.056)
R&D investment	1.000*** (0.115)	1.017*** (0.135)	0.811*** (0.140)
M&As	0.001 (0.020)	0.001 (0.021)	−0.004 (0.021)
Size	0.005 (0.003)	0.007 (0.004)	0.004 (0.004)
Age	0.032 (0.027)	−0.019 (0.031)	−0.022 (0.030)
Location	−0.010 (0.009)	−0.013 (0.010)	−0.015 (0.009)
Industry dummies	Yes	Yes	Yes
Constant	0.014 (0.049)	−0.015 (0.056)	−0.049 (0.055)
R ²	0.215	0.237	0.281
Adj. R ²	0.176	0.185	0.228
F	5.544	4.562	5.344
n	553	441	441

Notes: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. Standard errors are in parentheses. Dependent variable is innovation new to the market.

Table 9
OLS Regression Results for Innovation New to the Firm.

	(1)	(2)	(3)
Internal innovation benefits			0.016* (0.007)
Open innovation benefits			0.014* (0.006)
IT use for knowledge search		0.009 (0.010)	0.003 (0.010)
IT use for relational search		−0.016 (0.011)	−0.019 (0.011)
IT investment	0.001 (0.058)	0.035 (0.063)	0.035 (0.062)
R&D investment	0.822*** (0.124)	0.700*** (0.147)	0.516*** (0.154)
M&As	−0.006 (0.022)	0.004 (0.024)	0.002 (0.023)
Size	0.006 (0.004)	0.005 (0.004)	0.003 (0.004)
Age	0.050 (0.030)	−0.006 (0.034)	−0.006 (0.033)
Location	0.001 (0.010)	0.006 (0.011)	0.004 (0.011)
Industry dummies	Yes	Yes	Yes
Constant	−0.033 (0.041)	−0.008 (0.061)	−0.023 (0.061)
R ²	0.158	0.167	0.190
Adj. R ²	0.116	0.110	0.131
F	3.804	2.945	3.215
n	555	441	441

Notes: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. Standard errors are in parentheses. Dependent variable is innovation new to the firm.

finally internal innovation benefits and open innovation benefits. In the control model, we found that firms with higher R&D investment have greater revenue from innovation new to the market. In the partial model, IT use for knowledge search and IT use for relational search do not have statistically significant effects on innovation new to the market ($\beta = -0.002$, $p > 0.05$; $\beta = -0.014$, $p > 0.05$). In the full model, however, internal innovation benefits have a statistically significant and positive effect on innovation new to the market ($\beta = 0.031$, $p < 0.001$). Open innovation benefits do not have a statistically significant effect on innovation new to the market ($\beta = 0.007$, $p > 0.05$). This surprising result might be explained by the value appropriation risks that are particularly high for breakthrough innovation in the collaborative innovation process — the open innovation benefits are likely to be appropriated by a firm's innovation partners, making its innovation performance unchanged [74,90].

Table 9 reports OLS regression results for innovation new to the firm. We first estimated the control model, then both IT use for knowledge search and IT use for relational search were added, and finally internal innovation benefits and open innovation benefits. In the control model, we found that firms with higher R&D investment have greater revenue from innovation new to the firm. In the partial model, IT use for knowledge search and IT use for relational search do not have statistically significant effects on innovation new to the firm ($\beta = 0.009$, $p > 0.05$; $\beta = -0.016$, $p > 0.05$). In the full model, however, internal innovation benefits and open innovation benefits have statistically significant and positive effects on innovation new to the firm ($\beta = 0.016$, $p < 0.05$; $\beta = 0.014$, $p < 0.05$).

Table 10 reports that OLS regression results for innovation significantly improved. We first estimated the control model, then both IT use for knowledge search and IT use for relational search were added to the control model, and finally internal innovation benefits and open innovation benefits. In the control model, we found that firms with higher R&D investment have greater revenue from innovation significantly improved. In the partial model, IT use for knowledge search and IT use for relational search do not have statistically significant effects on innovation significantly improved ($\beta = -0.001$, $p > 0.05$;

Table 10
OLS Regression Results for Innovation Significantly Improved.

	(1)	(2)	(3)
Internal innovation benefits			0.047*** (0.011)
Open innovation benefits			0.019* (0.008)
IT use for knowledge search		−0.001 (0.015)	−0.014 (0.015)
IT use for relational search		0.004 (0.016)	−0.003 (0.016)
IT investment	−0.009 (0.083)	0.017 (0.094)	0.023 (0.091)
R&D investment	1.263*** (0.179)	1.119*** (0.220)	0.759*** (0.227)
M&As	−0.026 (0.031)	−0.015 (0.035)	−0.024 (0.034)
Size	0.006 (0.005)	0.004 (0.006)	−0.001 (0.006)
Age	0.085 (0.043)	0.025 (0.050)	0.023 (0.049)
Location	0.002 (0.014)	−0.000 (0.016)	−0.003 (0.015)
Industry dummies	Yes	Yes	Yes
Constant	0.102 (0.069)	0.114 (0.079)	0.067 (0.078)
R ²	0.194	0.179	0.226
Adj. R ²	0.154	0.123	0.169
F	4.866	3.192	3.983
n	553	440	440

Notes: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. Standard errors are in parentheses. Dependent variable is innovation significantly improved.

$\beta = 0.004$, $p > 0.05$). In the full model, however, internal innovation benefits and open innovation benefits have statistically significant and positive effects on innovation significantly improved ($\beta = 0.047$, $p < 0.001$; $\beta = 0.019$, $p < 0.05$).

5.2. Mediation analysis

To test H2 and H4, we conducted a mediation analysis. Traditionally, the Baron and Kenny [91] approach could be used to establish mediation. However, recent literature documented that this approach is neither necessary nor sufficient to test mediation, and particularly the independent variable does not have to demonstrate a direct effect on the dependent variable [92]. Alternatively, a Sobel test can be used to examine the significance of mediation [93], which however makes strong assumptions about the distribution of standard errors for the mediating effects. Through simulation research, it has been found that a bootstrapping approach outperforms a Sobel test [94], guiding us to conduct a mediation analysis based on bootstrapping.

Stata 14.0 was used for the mediation analysis, and specifically we ran the command “medeff” with 1000 times resampling [95]⁶. However, our original model could not be estimated by the bootstrapping algorithm due to the large number of industry dummies included. Therefore, we reduced the number of industry dummies by aggregating them to a macro level. Based on NACE Rev. 1 two-digit codes, we followed the literature (e.g., [32,96]) to create a new binary variable indicating if a firm belongs to manufacturing or service sector. We found that internal innovation benefits significantly mediate the relationship between IT use for knowledge search and invention success (mean = 0.007, 95% confidence interval = [0.001, 0.017]), the relationship between IT use for knowledge search and innovation success

(mean = 0.024, 95% confidence interval = [0.004, 0.048]), the relationship between IT use for knowledge search and innovation new to the market (mean = 0.004, 95% confidence interval = [0.001, 0.010]), the relationship between IT use for knowledge search and innovation new to the firm (mean = 0.003, 95% confidence interval = [0.001, 0.007]), and the relationship between IT use for knowledge search and innovation significantly improved (mean = 0.008, 95% confidence interval = [0.001, 0.016]). Thus, H2 was supported.

We also found that open innovation benefits significantly mediate the relationship between IT use for relational search and invention success (mean = 0.009, 95% confidence interval = [0.002, 0.020]), the relationship between IT use for relational search and innovation success (mean = 0.016, 95% confidence interval = [0.004, 0.034]), the relationship between IT use for knowledge search and innovation new to the firm (mean = 0.003, 95% confidence interval = [0.001, 0.007]), and the relationship between IT use for knowledge search and innovation significantly improved (mean = 0.004, 95% confidence interval = [0.001, 0.010]). Consistent with OLS regression results in which open innovation benefits do not have a significant effect on innovation new to the market, we found that open innovation benefits do not significantly mediate the relationship between IT use for relational search and innovation new to the market (mean = 0.001, 95% confidence interval = [0.000, 0.004]). Overall, H4 was largely supported, as the mediating effects of open innovation benefits were significant for four out of five innovation performance measures.

5.3. Post hoc analysis

In a post hoc analysis, we further analyzed the interdependence between open innovation benefits and internal innovation benefits as one may affect the other⁷. Given our research design in which both first-order benefits (i.e., internal innovation benefits and open innovation benefits) are measured at the same time, we cannot really test the causal relationship between them. However, we empirically explore their interdependence in a post-hoc analysis. Collaboration with diverse innovation partners increases the likelihood to be exposed to new ideas and useful resources, facilitating internal design and commercialization of new products. Therefore, we explored the relationship between open innovation benefits and internal innovation benefits.

Consequently, Table 11 reports the OLS regression results for internal innovation benefits. We first estimated the control model, then both IT use for knowledge search and IT use for relational search were added, and finally open innovation benefits were added. In the control model, we found that firms with higher R&D investment have greater internal innovation benefits. Consistent with our results reported earlier, IT use for knowledge search has a statistically significant and positive effect on internal innovation benefits ($\beta = 0.155$, $p < 0.01$), whereas IT use for relational search does not have a statistically significant effect on internal innovation benefits ($\beta = 0.090$, $p > 0.05$). In the full model, open innovation benefits have a statistically significant and positive effect on internal innovation benefits ($\beta = 0.069$, $p < 0.05$).

6. Discussion and conclusion

6.1. Main findings

This study investigates how IT use for knowledge and relational search influences innovation benefits at the process level and innovation performance at the organizational level by building on and extending the routine-based AC framework [25]. In light of the internal and external AC routines, we conceptualize IT use for knowledge search as an IT-enabled internal AC routine leading to internal innovation

⁶ The Stata program “mediation” was developed by Raymond Hicks at Niehaus Center for Globalization and Governance, Princeton University and Dustin Tingley at Department of Government, Harvard University in the U.S.

⁷ We thank one anonymous reviewer who suggested this point.

Table 11
OLS Regression Results for Internal Innovation Benefits.

	(1)	(2)	(3)
Open innovation benefits			0.069* (0.032)
IT use for knowledge search		0.155** (0.056)	0.146** (0.056)
IT use for relational search		0.090 (0.061)	0.075 (0.061)
IT investment	−0.091 (0.343)	−0.220 (0.368)	−0.240 (0.367)
R&D investment	6.136*** (0.708)	4.760*** (0.837)	4.222*** (0.872)
M&As	0.165 (0.121)	0.216 (0.133)	0.198 (0.133)
Size	0.084*** (0.020)	0.047* (0.022)	0.038 (0.023)
Age	−0.124 (0.166)	−0.086 (0.180)	−0.063 (0.180)
Location	0.071 (0.055)	0.059 (0.060)	0.045 (0.060)
Industry dummies	Yes	Yes	Yes
Constant	0.670** (0.214)	−0.044 (0.235)	−0.015 (0.235)
R ²	0.280	0.294	0.300
Adj. R ²	0.252	0.257	0.262
F	10.170	8.041	7.971
n	708	570	570

Notes: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$. Standard errors are in parentheses. Dependent variable is internal innovation benefits.

benefits and IT use for relational search as an IT-enabled external AC routine leading to open innovation benefits. Internal and external innovation benefits at the process level, ultimately, increase innovation performance at the organizational level. By conducting regression and mediation analysis based on a large-scale data set from German firms between 2003 and 2007, our results corroborate our theory.

We find that IT use for knowledge search has a positive effect on internal innovation benefits. Consistent with past research indicating that IT use plays an important role in the new product development process (e.g., [4,17]), our results show that IT use for knowledge search is a key enabler of internal innovation benefits. We empirically demonstrate that IT use for knowledge search facilitates design and commercialization of new products. More importantly, our results indicate that internal innovation benefits mediate the relationship between IT use for knowledge search and innovation performance. In line with our research model, IT use for knowledge search does not directly influence innovation performance of new products (rather than patent inventions). This finding is consistent with our theoretical arguments that a firm's IT use for knowledge search strengthens internal innovation benefits, which, in turn, lead to an improvement of innovation performance.

In addition, we find that IT use for relational search has a positive effect on open innovation benefits. This is aligned with prior findings showing that IT use is critical for open innovation (e.g., [7,9,32]). We empirically demonstrate that IT use for relational search leads to identification of and collaboration with different types of innovation partners. Our results further indicate that open innovation benefits mediate the relationship between IT use for relational search and innovation performance. In line with our research model, IT use for relational search does not directly influence innovation performance. This finding is consistent with our theoretical arguments that a firm's IT use for relational search strengthens open innovation benefits, which, in turn, lead to an improvement of innovation performance.

6.2. Theoretical implications

This study provides a more holistic picture about the hierarchical

benefits from IT use for innovation. Along a digital innovation value chain, IT use generates first-order benefits at the process level and then second-order benefits at the organizational level. By conducting a literature review on the digital innovation literature (see Appendix B), we find that our study departs from prior work in several notable aspects. In particular, we surprisingly find that none of prior studies has explicitly distinguished IT use for knowledge and relational search, and none of them considered both internal and external innovation benefits, which are found to be key intermediate mechanisms explaining the IT-innovation relationship. Our study is also the most comprehensive to cover all innovation performance measures. Table 12 provides an overview of innovation studies in the IS literature. Specifically, this study offers three major implications for research.

First, this study opens up the black box of IT use in digital innovation research, where IT use is often represented by aggregate investment or usage for any purposes. Easily accessible IT investment data offer little insight into different types of IT that are used by firms in different innovation processes [103], although firms' use of different types of IT may result in distinct outcomes [104]. As Table 12 shows, most prior studies conceptualized IT use in a generic manner, without a clear distinction of different innovation purposes. We contribute a more fine-grained conceptualization of two IT artifacts for innovation — IT use for knowledge search (that is, a firm's internal use of IT for gathering and sharing scientific or market knowledge) and IT use for relational search (that is, a firm's use of IT for identifying and establishing relationships with innovation partners). Consistent with prior findings (e.g., [104]), our results show that IT investment does not have a significant impact on either first- or second-order benefits for innovation. However, IT use for knowledge and relational search can generate various benefits for innovation. These findings suggest that simply using IT investment may not be sufficient to unveil the nuanced IT-innovation relationship, as the value creation of IT resides in the actual usage in business processes [21,105]. Instead, future research needs to develop rich, granular conceptualization of IT use to deepen our understanding of the IT-innovation relationship.

Second, we go beyond a direct relationship between IT and innovation in past digital innovation research by examining the hierarchical benefits from IT use for innovation. As Table 12 shows, prior studies often adopted a single focus on either internal innovation benefits or open innovation benefits from IT use to explain a limited set of innovation performance measures. This study reveals the intermediate mechanisms through which IT use affects a comprehensive set of measures for innovation performance. The first-order internal and open innovation benefits fully mediate the impacts of IT use on innovation performance. These findings contribute a novel insight into the digital innovation value chain, allowing us to zoom in internal and external value-creating mechanisms leading to the IT-innovation relationship. These underpinnings in the digital innovation value chain provide in-depth theoretical foundation for future research.

Finally, more broadly, this study extends the routine-based AC framework [25] by conceptualizing internal and external AC routines in the digital context. In this framework, important internal AC routines consist of knowledge management and superior practices across organizations, while important external AC routines consist of learning from and with a diverse set of partners. In the digital context, we identify IT use for knowledge search and IT use for relational as two key internal and external AC routines. Furthermore, we contribute a more in-depth understanding to the routine-based AC framework about the missing link between internal and external AC routines and innovation performance. Our study uncovers the missing link of internal and external innovation benefits at the process level, which, in turn, lead to innovation performance at the organizational level. Future research based on the routine-based AC framework needs to take a hierarchical perspective to understand how internal and external AC routines generate innovation performance through internal and external innovation processes.

Table 12
A Summary of Innovation Studies in the IS Literature.

Reference	IT artifacts			First-order benefits		Second-order benefits					
	IT investment	IT use	IT use for knowledge search	IT use for relational search	Internal innovation benefits	Open innovation benefits	Invention success	Innovation success	Innovation new to the market	Innovation new to the firm	Innovation significantly improved
Pavlou and El Sawy [17]	✓				✓			✓			
Banker et al. [4]	✓				✓			✓			
Pavlou and El Sawy [18]	✓				✓			✓			
Joshi et al. [10]		✓					✓				
Kleis et al. [11]	✓						✓				
Xue et al. [16]	✓						✓				
Tang et al. [97]		✓				✓			✓	✓	✓
Chen et al. [6]		✓			✓			✓	✓	✓	
Cui et al. [7]				✓							
Limaj et al. [98]			✓		✓						
Gómez et al. [9]	✓						✓		✓	✓	
Ravichandran et al. [12]	✓						✓				
Saldanha et al. [13]			✓				✓				
Trantopoulos et al. [15]	✓					✓		✓			
Benitez et al. [99]	✓	✓					✓				
Cui et al. [100]		✓				✓			✓	✓	
Ravichandran [101]	✓	✓			✓						
Tarafdar and Tanriverdi [102]		✓									
Dong and Yang [19]	✓		✓	✓	✓		✓	✓	✓	✓	✓
This study	✓			✓		✓					

6.3. Managerial implications

Our findings also induce important practical implications, which help managers to make strategic decisions to invest in IT for innovation. We suggest that, to reap full benefits from IT use for innovation, managers need to understand and be aware of the fact that IT use can only promote innovation performance through deployment in internal and external innovation activity. To achieve superior innovation performance, firms can use IT to internally search knowledge on the one hand, or search for external innovation partners on the other. The first approach improves innovation performance by enhancing the new product development process, while the second approach is by collaborating with a variety of innovation partners with complementary knowledge and resources. In either way, firms can use IT to facilitate its internal or external innovation process, which will eventually produce competitive new products with superior innovation performance in the marketplace. Finally, managers who want to raise innovation performance may consider developing ambidextrous IT use for both knowledge and relational search.

6.4. Limitations and future research

This study has some limitations that deserve discussion. First, owing to data constraints, we can only use a two-year time lag in our research design. Though it does not affect the validity of our analysis and is even likely to make our result more conservative (an inappropriate time lag makes it more difficult to observe any significant effects), future study

may try other time lags to examine our results. Second, we conceptualize and operationalize two new constructs for IT use. While we try our best to operationalize these constructs based on archival data, our measures are imperfect and need to be refined. In particular, we can only capture whether a firm uses IT for specific innovation purpose and are not able to take into account the effectiveness of usage. Future study may develop more fine-grained measures (e.g., effective use) for these constructs to better test our theory. Last but not least, our large sample covers firms from both manufacturing and service industries in Germany between 2003 and 2007. Thus, it should be cautious when generalizing our findings to firms in other national contexts. While our theory is not specific to the German context, future study may collect data from other countries, especially from less innovative or developing countries, to test our findings. Moreover, future research may gather more recent data to replicate our study, as firms' use of IT for innovation are changing rapidly nowadays.

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Appendix A. Loadings and cross-loadings

	IT use for knowledge search (ITKS)	IT use for relational search (ITRS)	Internal innovation benefits (INT)	Open innovation benefits (OPEN)
ITKS1	0.735	0.240	0.184	0.292
ITKS2	0.878	0.097	0.123	0.019
ITRS1	0.359	0.600	0.023	0.289
ITRS2	0.118	0.894	0.125	0.020
INT1	0.094	0.103	0.869	0.102
INT2	0.160	0.064	0.844	0.174
OPEN1	0.040	0.005	0.135	0.714
OPEN2	0.092	0.172	0.129	0.801
OPEN3	−0.013	0.101	0.044	0.689
OPEN4	0.256	0.034	0.240	0.715

Appendix B. Literature review procedures

We conducted a scoping literature review on the digital innovation literature, with the objective to compare this study with previous innovation studies in the IS field. A scoping review simply provides an initial indication of the potential size and nature of the available literature on a particular topic, instead of providing in-depth discussion on prior findings [106]. We searched relevant articles based on the EBSCO Host database by using “innovation” as the keyword. We focus on scholarly articles published in the Association for Information Systems (AIS) senior scholars' basket of eight journals (*European Journal of Information Systems*, *Information Systems Journal*, *Information Systems Research*, *Journal of the Association for Information Systems*, *Journal of Information Technology*, *Journal of Management Information Systems*, *Journal of Strategic Information Systems*, and *MIS Quarterly*), *Decision Support Systems* and *Information and Management*, which are widely considered as the leading IS journals publishing the most important research findings in the field [107].

An initial set of articles published in a 20 year period between 2000 and 2019 in the selected journals was found after the keyword was entered in the search engine of the EBSCO Host database. A final set of 19 articles was selected by analyzing both titles and abstracts and, if necessary, the methods and results, to identify relevant articles with any form of IT artifacts and innovation measures at the firm level. Each paper was then analyzed and coded in terms of the key IT artifacts and innovation measures that are studied. Two authors coded all the 19 articles independently with a high agreement (Cohen's kappa = 0.859). Differences were reconciled and consensus was achieved after a discussion.

The main findings from this literature review are summarized in Table 12. Six studies use IT investment as the independent variable, which is controlled in this study. Nine studies have the independent variable as IT use in general. Four studies investigate IT use for knowledge search as the independent variable, while only one study explicitly theorizes IT use for relational search. For innovation measures, four studies investigate internal innovation benefits and five studies investigate external innovation benefits. However, none of prior studies consider both internal and external innovation benefits. Similarly, none of prior studies cover all the five innovation performance measures.

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