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Standardization efforts: The relationship between knowledge dimensions, search processes and innovation outcomes

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ABSTRACT

We explore how a standardization effort (i.e., when a firm pursues standards to further innovation) involves different search processes for knowledge and innovation outcomes. Using an inductive case study of Vanke, a leading Chinese property developer, we show how varying degrees of knowledge complexity and codification combine to produce a typology of four types of search process: *active*, *integrative*, *decentralized* and *passive*, resulting in four types of innovation outcome: *modular*, *radical*, *incremental* and *architectural*. We argue that when the standardization effort in a firm involves highly codified knowledge, incremental and architectural innovation outcomes are fostered, while modular and radical innovations are hindered. We discuss how standardization efforts can result in a second-order innovation capability, and conclude by calling for comparative research in other settings to understand how standardization efforts can be suited to different types of search process in different industry contexts.

1. Introduction

This paper focuses on how a firm's standardization efforts impact its knowledge search processes, and the resulting innovation outcomes. Standardization is the process of developing and implementing specifications based on the consensus of the views of firms, users, interest groups and governments (Sherif, 2006; Saltzman et al., 2008). The resulting standards are intended to promote compatibility, interoperability and quality. An early example of standardization is the regulation of the sizes of the threads that we find on nuts, bolts and screws, which was achieved by the development of a screw-cutting lathe that could repeatedly produce these products to specific standards with universal applications.

Standards can be developed and governed by Standards Development Organizations (SDO) or independently, for example, by firms who have a first mover or dominant position in the market (Utterback, 1996). When a firm pursues a standard to produce an innovation outcome, this what we call a 'standardization effort'. More specifically, a standardization effort is when a firm pursues a leadership role in developing standards to further innovation. For example, Google followed a standardization effort when acquiring and developing the innovations for its mobile operating system, Android (Grøtnes, 2009).

Scholars have argued that standardization has a significant impact on the creation and diffusion of innovations (Dolfsma and Seo, 2013; Grøtnes, 2009; Lecocq and Demil, 2006; Tassey, 2000; Wrighta et al., 2012). However, prior research on the relationship between standardization and innovation remains inconsistent. For example, some studies have proposed a positive relationship (Rysman and Simcoe, 2008), where standardization fosters the diffusion of innovation (Hashem and Tann, 2007) and changes industrial structures (Lecocq and Demil, 2006), whereas others have argued that it constrains innovation, by inhibiting creativity (Hamel, 2006) and postponing the gestation period between invention and successful commercialization (Hill and Rothaermel, 2003). A number of studies have noted this unclear relationship between innovation and standardization (Gilson et al., 2005; Kano, 2000; Wrighta et al., 2012; Yoo et al., 2005). In one case, Damanpour (1991) argues that standardization can establish managerial control when implementing innovation in a

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Table 1
Standardization and innovation in management research.

Example study	Dimensions of knowledge embedded in a firm's standardization effort	Types of innovation outcome
Tassey (2000)	High codification, high complexity	Modular/architectural/incremental/radical
Kano (2000)	High or low codification, high complexity	Systematic/stand-alone
Tether et al. (2001)	High codification, high complexity	Service/process
Yoo et al. (2005)	High or low codification, high complexity	Diffusion/system/process
Rysman and Simcoe (2008)	High codification, high complexity	Diffusion/cumulative
Leiponen (2008)	High or low codification, high complexity	No classification
Grøtnes (2009)	High or low codification, high complexity	Outside-in/inside-out/coupled process
Viardot (2010)	High or low codification, high complexity	Incremental/radical
Wrighta et al. (2012)	High codification, high or low complexity	Incremental/radical management innovation
Narayanana and Chen (2012)	High or low codification, high complexity	Modular/architectural/incremental/radical/product/process/institutional/industrial/technological
Hytönen et al. (2013)	High or low codification, high complexity	No classification
Dolfsma and Seo (2013)	High codification, high complexity	Discrete/cumulative
Gao et al. (2014)	High or low codification, high complexity	Diffusion/capability
Groesser (2014)	High or low codification, high complexity	System/diffusion/incremental
Lopez-Berzosa and Gawer (2014)	High codification, high complexity	Collective innovation

manufacturing context, but it might also constrain the producer–client relationship in a service context. Given such inconsistencies, better understanding the inter-play and relationship between standardization and innovation is an important research opportunity.

In response, this study aims to improve our understanding of how the search for knowledge associated with a firm's standardization effort can result in more effective innovation management. According to Nelson and Winter (1982), understanding how firms search for knowledge helps to explain innovative behavior, a perspective that has since been widely applied within the innovation discourse (Chiang and Hung, 2010; Cillo and Verona, 2008; Fabrizio, 2009; Laursen and Salter, 2004; Mahdi, 2003). For example, Rosenkopf and Nerkar (2001) explored how a local search for solutions, using current knowledge, contrasts with distant search, or what Rosenkopf and Almeida (2003) call explorative learning. Katila and Ahuja (2002) focused on search depth (how deeply existing knowledge is reused) and search scope (how widely new knowledge is explored), while Greve (2003) investigated problematic search caused by low performance and slack search caused by excess resources.

In addition to how variations in search scope can impact innovation, studies have also highlighted the importance of different approaches to search. Broadcast search is suited to external solvers self-selecting themselves to create a solution (Jeppesen and Lakhani, 2010). In contrast 'pyramiding', a search process based upon the view that appropriate experts will know other appropriate experts, is used for identifying individuals who have more of a given attribute by "moving up to the pyramid" (Hippel et al., 2009:1398). Furthermore, search processes can vary in terms of the extent to which alliance partners jointly search for new knowledge across different knowledge domains (Zack, 1999) or use search processes to selectively target knowledge sources from product market, science and suppliers (McCarthy et al., 2006; Nicholson and Sahay, 2004).

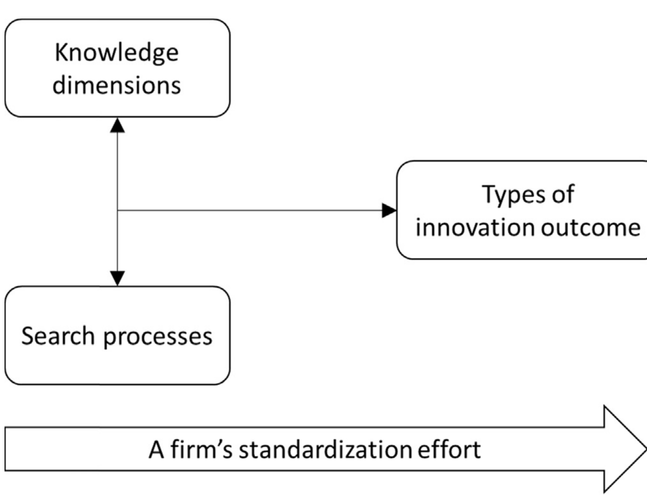

Fig. 1. Standardization efforts and the relationship between knowledge dimensions, search processes and innovation outcomes.

We present our arguments in four sections. First, we review the literature on standardization and innovation to identify how different dimensions of knowledge, embedded in the standardization effort, can impact different types of innovation outcome (see Fig. 1). We also examine and illustrate the potential relationships between the different dimensions of knowledge, search processes and innovation outcomes involved in a standardization effort. Second, to investigate and illustrate the relationships between these elements of a standardization effort, we present a case study on Vanke Co., Ltd. (Vanke), the largest residential property developer in China. For almost 16 years, Vanke has undertaken a standardization effort in housing design and construction. This resulted in standards and innovations for mass off-site fabrication (referred to as 'housing industrialization'), which have since been adopted by the Chinese construction industry and influenced related Chinese government policies. Third, we discuss the case findings and present a typology of four types of search process: active, integrative, decentralized and passive, along with four different types of innovation outcome: modular, radical, incremental and architectural. Finally, we conclude the paper by discussing theoretical and practical implications of our research.

2. Standardization and innovation in management research

Looking across the literature that explores the relationship between standardization and innovation, we identify two recurring main themes – knowledge embedded in standardization and types of innovation outcome (see Table 1). In this section we specifically discuss knowledge in the context of a firm's standardization effort. In addition, we discuss innovation from the perspective of searching for knowledge during a standardization effort. Although widely acknowledged as a key to understanding innovative behavior, search is only alluded to in the standardization discourse. The dearth of research in this area is reflected in its absence from our literature summary table (Table 1).

2.1. Knowledge embedded in a firm's standardization effort

Standardization is a deliberate attempt by an organization to develop, ratify and implement standards among stakeholders (Gao et al., 2014). Standardization can be led by a Standards Development Organization (SDO), such as the American Society of Mechanical Engineers (ASME) that oversees standards for mechanical components and devices. It can also be led by individual firms pursuing a standard for their products or processes and related innovations. This is called a 'standardization effort'. For example, Google developed the Android operating system for mobile telecommunication devices (Grøtnes, 2009), and management and accounting consultancies have, over time, developed standardized agendas and methods used within their industry (Wrighta et al., 2012).

Table 1 presents that research on standardization and innovation has employed two dimensions of knowledge to characterize the processes: codification and complexity. Codification refers to the extent to which knowledge can be documented, transferred or shared (Zack, 1999). The life cycles of standardization (Tether et al., 2001) and technological change (Anderson and Tushman, 1990) help explain how the level of knowledge codification can vary in standardization. Non-codified knowledge usually emerges at earlier stages of standardization when technological uncertainties, trials, and competition among various competing technologies are common. The early stage of a standardization effort can end with the emergence of, for example, a dominant design (Anderson and Tushman, 1990) and the non-codified knowledge partially transforms to codified knowledge when the industry standard becomes established.

Although studies define standardization and standards differently, they rarely emphasize this distinction, while some studies treat the two terms synonymously. For example, Tassey (2000:588) explains that "standardization represents a codification of an element of an industry's technology or simply some information relevant to the conduct of economic activity", while standards are "a set of specifications to which all elements of products, processes, formats, or procedures under its jurisdiction must conform". These definitions assume that standardization is a knowledge codification process, to assist understanding of the innovations and promote the efficiency of economic activity, especially in highly skilled settings (Bénézech et al., 2001).

We argue that merely focusing on codified knowledge underestimates the role of the capabilities and learning mechanisms accumulated from non-codified knowledge embedded in standardization. Such mechanisms can be developed as part of the process of developing and implementing a standard (Zollo and Winter, 2002), but tend to be neglected in the knowledge codification process of standardization. In technology industries, for example, the processes of standardization include providing compatible technology, creating a supportive network, developing a dominant brand name, going global, minimizing production cost and investing more than the competitors (Viardot, 2010). In our view, studies have tended to focus merely on the codified knowledge i.e., the process outcome, at the expense of non-codified knowledge that is embedded in the process of standardization. By 'embedded' we mean that the knowledge resides in the "organizing principles, routines and standard operating procedures" (Nicholson and Sahay, 2004:337) necessary for the standardization effort.

The second dimension of knowledge listed in Table 1 is knowledge complexity, which is the extent to which knowledge can flow and be used independently between people or subunits of firms (Teece, 1986; Winter, 1987). To be understood and used, knowledge with high complexity requires some other knowledge or additional processing. Knowledge with low complexity is stand-alone and can be more easily transferred and used. The literature emphasizes the importance of knowledge complexity in a firm's standardization effort, but fails to delineate how it impacts the type of innovation outcome that is produced.

Some studies suggest that high knowledge complexity is central to standardization (Rysman and Simcoe, 2008; Tassey, 2000; Tether et al., 2001). For example, Yoo et al. (2005) argue that the standardization and innovation in broadband mobile services is driven by the need to integrate complex and diverse technological knowledge. The literature moreover suggests that knowledge embedded in standardization may be composed of different degrees of complexity. For example, knowledge will likely be less complex when fewer stakeholders are involved, such as a 'bespoke (one-off, custom-made) service' (Tether et al., 2001), and more complex when the stakeholders involved have different technological, social and economic backgrounds or interests (Yoo et al., 2005). Knowledge complexity is likely to be exacerbated when sustainable development issues are driving innovation (Matos and Hall, 2007; Zollo and Winter, 2002) as is the case in the construction industry (discussed below).

Narayanana and Chen (2012) reveal, implicitly, that knowledge complexity in standardization has the potential to influence architectural innovation at the community level (i.e., competing firms and their technological platforms) and modular innovation within the product offerings. These types of innovation come from a classification (modular, radical, incremental and architectural) based on the extent to which the innovation involves new interfaces between components and or involves new components alone (Henderson and Clark, 1990). These types of innovation are relevant to the issue of knowledge complexity in standardization which usually determines the interfaces that links components in a product. For example, Kleinsmann et al. (2010) identified different collaborative mechanisms within four types of interface from company, project and actor levels in the context of knowledge complexity. Standards provide opportunities for changes in the way in which the component knowledge are linked together, while leaving the core component knowledge untouched (Henderson and Clark, 1990).

2.2. Standardization efforts from a search perspective

As discussed above, the standardization studies listed in Table 1 have placed little emphasis on search processes. This is somewhat surprising given that a key aspect of innovation is that it involves the search for and transfer of new knowledge (Rogers, 2003), or recombining existing ideas or technologies (Schumpeter, 1934). Understanding the search for knowledge and how it is conducted has been recognized as crucial for understanding the innovation process (Miller et al., 2007; Rogers, 2003; Tsai, 2001), as knowledge provides the foundation for learning (Cohen and Lenvinth, 1990; Shenkar and Li, 1999). Search is central to innovation and standardization efforts. Drawing on the work of Nelson and Winter (1982), we define search in these contexts as an organization's problem-solving activities that involve the creation and recombination of technological knowledge.

We propose that a search perspective linked to the dimensions of technological knowledge can help reconcile the inconsistencies in the literature focused on standardization and innovation. Different types of search activity have been found to influence whether a firm innovates incrementally or radically. For example, Chiang and Hung (2010) argue that search depth could facilitate incremental innovation performance while search scope enhances radical innovation. The reason is that the knowledge features, for example the age of knowledge (Katila and Ahuja, 2002) and learning mechanisms associated with diverse search activities, tend to differ (March, 1991; Rosenkopf and Nerkar, 2001; Chiang and Hung, 2010), leading to varying innovation performances.

3. Methods

A case study of a firm that was highly successfully in using standards to innovate effort can advance our understanding of standardization efforts and the role of search processes. Consequently, we now describe our methodology and explain why and how we conducted the case study of Vanke. We also explain our approach to data collection and we identified, synthesized and illustrates the different knowledge dimensions, search processes and innovation outcomes in Vanke's standardization effort.

3.1. Case context and selection

We selected the Chinese building sector because it has undergone a substantial transition, with new approaches to improving energy efficiency and the adoption of information and communication technologies. Although traditionally the building sector has not been considered innovation-intensive, there have been recent measures adopted to improve innovative practices through standards (Saltzman et al., 2008).

The Chinese building sector is an interesting and important industry in terms of the need to innovate, as it accounts for almost a third of China's total energy consumption. Such demands are exacerbated by the sheer scale of China's economy and its rapid urbanization. The percentage of the population living in urban areas is expected to increase from 36% in 2000 to an estimated 50% by 2020 (Chen and Shu, 2012). Indeed, an additional 2 billion square meters of newly constructed buildings have been added yearly in China over the last 10 years. Existing buildings currently account for around 40 billion square meters in area, around 95% of them failing to meet the existing requirements for energy-efficient buildings (Kleinsmann et al., 2010).

The Chinese government has developed and announced sets of standards to help increase innovative construction. For example, it has encouraged the implementation of Building Information Model (BIM) technology in the life cycle of buildings, which includes design, construction and operations standards. Local governments have also prepared their own standards for implementing BIM. The Chinese government also announced the standard for energy efficient building assessment (GB/T 50668-2011) in 2011, for building an energy-efficient community. Companies that meet the standard can gain tax reductions and exemptions from the government. The standard outlines basic assessment requirements and different classification levels for building systems including architectural planning, building envelope, HVAC (Heating, Ventilating and Air Condition), water supply and drainage, power supply and lighting, indoor environment and operation and the management of buildings both residential and public. To keep pace with and satisfy the changing requirements in these areas of building design and construction, firms in the Chinese building sector have had to deliver innovative responses of the right type and at the appropriate speed. However, while most innovation in this sector has been driven by standardization efforts, little is known about the efficacy of such innovations.

Following Siggelkow (2007), we chose Vanke, one of China's largest property developers, as our case for three reasons. First, Vanke is the leading Chinese company for 'housing industrialization', their long-term strategy since 1999. Housing industrialization promotes mass off-site prefabrication instead of conventional on-site construction methods. Standardization is a basic premise of housing industrialization. For example, building components have to be standardized to facilitate design, mass off-site prefabrication and assembly on the construction site. Housing industrialization thus not only changes the way to build, it also requires a standardization effort that changes the relationship between the stakeholders involved in the building sector supply chain. These changes may have a substantial impact on other sectors because the building industry has close relationships with for example, the steel industry, forestry, electrical appliance industry, water treatment and even the medical industry.

Second, to foster housing industrialization, Vanke has had to initially overcome many disadvantages. These included the high costs of housing industrialization building methods compared with those of conventional building methods, outdated construction technologies and lack of capital, supportive government policies and skilled labor in the building sector. Currently, housing industrialization has been accepted by the Chinese government and welcomed by industry. Over the past 16 years, Vanke has thus been at the forefront of developing standards for housing industrialization, providing us with a useful opportunity to explore this phenomenon in the Chinese building sector.

Third, the large scale and established industry presence of Vanke is important as it represents a large part of the sector's standardization effort. Vanke is one of the largest real estate developers in China. In 2012, it had approximately 22 billion US dollars of sales revenue (gross) and 31,019 employees, and had developed 14.33 million square meters of building work. The large scale of Vanke helps buffer the company from external contingent factors such as fiscal policies and economic changes to firms, which can disrupt smaller developers. In addition, Vanke has a relatively long history in the Chinese building sector, having launched its business in 1984. Its 30 years of constant operation thus allows us to investigate the formation and dynamics of the capabilities developed by the company.

3.2. Data categories and collection

To develop a framework to understand a firm's standardization effort, we sought data regarding the relationship between knowledge dimensions, search processes and innovation outcomes. Following guidelines for collecting case data by Eisenhardt (1989) and Yin (2003), we categorised these elements. For example, in terms of knowledge dimensions the degree of codification and complexity (low versus high in each case), while relative, can be substantiated. We followed a similar approach for collecting data on different search processes and types of innovation. The final four categories and twelve sub-categories of data are presented in Table 2.

We collected data for this study from both archival sources and interviews. The archives included annual company reports, corporate social responsibility reports, scholarly journals, internal company documents (reports and presentations), national standards, news papers and the autobiographies and other writings of Shi Wang, the founder and current chairman of Vanke. Scholarly journal articles focused on Vanke were obtained from sources such

Table 2
Categories and sub-categories of data coding.

Categories (4)	Subcategories (12)			
Knowledge Dimensions (KD)	Low complexity high codification (LH)	High complexity high codification (HH)	Low complexity low codification (LL)	High complexity low codification (HL)
Search Process (SS)	Search process of LH	Search process of HH	Search process of LL	Search process of HL
Innovation Type (IT)	Incremental	Architectural	Modular	Radical

as the China National Knowledge Index (CNKI). Autobiographies of the current chairman of Vanke included Wang (2012a, 2012b, 2013, 2014a, 2014b).

We conducted 28 interviews (telephone and face-to-face) with project and procurement managers, customer service and R&D staff, accounting department representatives and administrators working nationwide at Vanke. We also interviewed government officials and researchers. The interviews lasted between twenty minutes and one and a half hours. We also used additional open-ended questionnaires after the first round of interviews. All interviews were conducted between April 2014 and March 2015.

3.3. Data coding and analysis

The collected data were coded following guidelines for qualitative content analysis (Eisenhardt, 1989; Kohlbacher, 2006). Detailed write-ups of the archival and interview data were produced to ensure intimate familiarity with the case. The data were then sorted into the 4 categories and 12 sub-categories of the dimensions of knowledge, search process and innovation outcome, in effect making them variables in our study. This allowed us to make inferences, verifications and a theory guided analysis of the data. Table 3 provides examples of the data coding.

Further tables were used to help analyse cross-sectional data and to sequence and organize longitudinal data. The longitudinal data were collected to increase the internal validity of the case study. The data were also divided by source and the patterns that emerged were analysed and compared with those from the interviews. When both were consistent, the findings were considered to be stronger and better grounded. When evidence from the two sources conflicted, the evidence was reconciled by either probing the difference or by collecting additional data. For example, archival data indicated that Vanke planned to apply housing industrialization to all of its projects by 2014. However, interview data from Chongqing indicated that only one project used the technologies of housing industrialization. Further data verified that Vanke had applied different levels of standardization and innovation in different districts, depending on the availability of supporting resources.

4. Findings and typology

The findings in this study suggest that a standardization effort is a complex phenomenon shaped by multiple search processes for different dimensions of knowledge and innovation outcomes. This is depicted in a theoretical framework (see Fig. 2) that shows how the two proposed dimensions of knowledge (codification and complexity) combine to produce a typology of four types of search (active, integrative, decentralized and passive) and four types of innovation outcome (modular, radical, incremental and architectural). We now validate and illustrate the typology using the case findings and drawing upon previous research on innovation and standardization.

4.1. Decentralized search and incremental innovations

The first type of search and related innovation outcome we discuss occurs when the knowledge in a standardization effort is of low complexity and is highly codified. This creates what we refer to as *decentralized* search and results in *incremental* innovation outcomes. Decentralized search means that the search is not centrally coordinated by a unit in the organization. The search is autonomously led by different individuals and units, each of which may be tracking a specific aspect of the environment, such as market demand, competitor actions, product and technological innovation, and regulatory updates (McCarthy et al., 2010; Daft and Weick, 1984). Decentralized search is suitable for low complexity knowledge especially as the search is typically conducted and controlled by individuals, especially at the executive level (Daft et al., 1988). These individuals serve as the strategic scanning interface between the organization and the external environment.

The trip to Brazil's Amazon River Basin in 2008 made by Vanke's CEO (Shi Wang) is an example decentralized search. The search was not undertaken by a team of analysts. Only Shi Wang was involved as the knowledge complexity was low. The knowledge that was acquired was also highly codified in that it could be seen, documented and presented by an individual – it is not routinized and does not involve many interactions within a firm. The resulting innovations are typically incremental and are supposed to provide developmental plasticity or flexibility to the internal and external environments, improving the ability to value external

Table 3
Examples of data coding.

Coding category	Example
Low complexity high codification (LH)	Knowledge embedded in Shi Wang's trip to Brazil's Amazon River Basin in July, 2008
Search process of LH	Information seeking by Shi Wang that a large number of timbers in this area were transported to China and some of them were used on construction sites
Incremental innovation	Vanke formed a new procurement policy and joined the Global Forest & Trade Network (GFTN) in 2011
High complexity high codification (HH)	Knowledge embedded in the application for the platinum certification of LEED
Search process of HH	Vanke invited LEED consultants to participate in the whole process of LEED application and work with partners to conduct and prepare relevant documents
Architectural innovation	The combination of green technology with design, construction, material supply and building operation
Low complexity low codification (LL)	Knowledge embedded in the R&D center of housing industrialization
Search process of LL	In addition to investing millions of $US encouraging trial and error to develop standards of housing industrialization, Vanke sent teams overseas to learn, gain experience and become familiar with technologies. More importantly, Vanke had to face suspicious opinions arising from peers on doing so. This is because some people including governors, academics and practitioners were not optimistic about the future of housing industrialization in China due to cheap labor, outdated technologies in this sector and lacking of support resources for housing industrialization
Modular innovation	Vanke applied the standards of housing industrialization in some projects where supporting resources are sufficient
High complexity low codification (HL)	Knowledge embedded in processes that consistently seek to be innovative, sustainable and aligned with Corporate Social Responsibility (CSR)
Search process of HL	An integrative search involves search processes interchanging or simultaneously developing a decentralized search, a passive search and an active search. Vanke took a decentralized, passive search to strategically transition by collaborating with high-tech companies such as Baidu, Xiaomi and Tecent, to develop customized products. Vanke also adopted a passive search to enlarge housing industrialization standards to products concerned with social welfare, by exploiting current knowledge
Radical innovation	The dynamic capabilities developed from an integrative search have helped Vanke maintain a competitive advantage in the building sector for years

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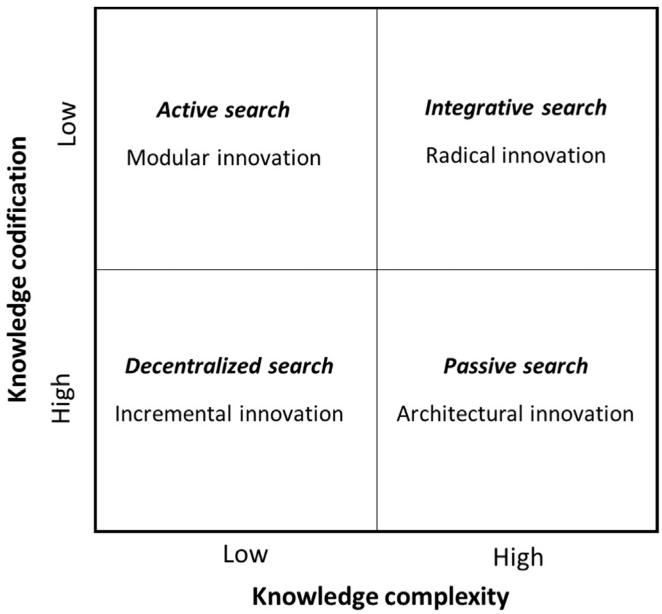

Fig. 2. Standardization efforts and embedded knowledge dimensions: a typology of search processes and innovation outcomes.

knowledge. These incremental innovations are minor improvements that build on incumbent knowledge (Dewar and Dutton, 1986).

In the case of Shi Wang's trip to the Amazon River Basin, the search and knowledge resulted in Vanke becoming a member of the Global Forest & Trade Network (GFTN) whose aims are to eliminate illegal logging and improve forest management. This helped Vanke identify societal concerns about its practices and pioneer its culture of Corporate Social Responsibility (CSR). For example, a new procurement policy was adopted to restrict use of non-renewable forest resources for Vanke's operations. The adoption of the procurement policy was relatively straightforward (i.e., an incremental innovation) as it did not require major changes to operational units. The process of forming and applying the procurement policy and joining GFTN diversified Vanke's goal of improving CSR and the sustainability of their operations, while also building the company's flexibility to adapt to the external environment.

4.2. Passive search and architectural innovations

The second type of search and innovation outcome we discuss occurs when the knowledge in a standardization effort is highly complex and highly codified. This creates what we refer to as *passive* search and results in *architectural* innovation outcomes. By passive we mean a situation where a firm takes whatever information comes its way, which can result in knowledge discovery and transfer efficiencies. However, the potential to receive novel ideas that underlie major solutions tends to be reduced by simply waiting for knowledge to arrive. This is because passive search has inertia and is satisficing in nature i.e., once an organization has received information to meet its requirements, waiting for further and better alternatives is considered time-consuming (March, 1991).

Highly complex knowledge in a standardization effort will likely require other complementary knowledge and additional processing to be understood. Therefore, the standardization effort also has to acquire and assimilate this additional knowledge often drawing upon different organizational subunits and external partners. To help mitigate the risk and costs of this complexity, codifying that knowledge is a common approach. Together these factors support a standardization effort suited to producing architectural innovations. This is because an architectural innovation changes the way in which the components of knowledge are linked together, while leaving the core knowledge untouched (Henderson and Clark, 1990). The capabilities for an architectural innovation include the ability to reconfigure the current structure of a system or to enlarge the current system by taking in new subsystems (Yoo et al., 2005).

An example of a passive search and architectural innovation outcome by Vanke is their adoption of Leadership in Energy and Environmental Design (LEED), a third-party certification scheme for assessing green building. LEED measures the environmental performance of various aspects of construction, such as the development of sustainable architectural designs, water efficiency, energy, materials and resource use, emissions and indoor environmental quality. Adopting LEED certification is an architectural innovation as it requires the use of complex interrelated knowledge and coordination of capabilities with suppliers to attain. According to the U.S. Green Building Council (USGBC), this typically involves a specified application procedure, and can be communicated through documentation (high codification). Vanke invited LEED consultants to participate during the application procedure and cooperated with partners such as designers and construction firms, preparing relevant documents on certification of qualification, construction methods, energy saving, recyclable material, etc.

4.3. Active search and modular innovations

The third type of search and innovation outcome in our typology is when the knowledge dimensions have low complexity and low codification. This results in an *active* search and *modular* innovation. In contrast to passive search, active search involves allocating resources to vigorously explore, test and shape the environment (Daft et al., 1988). An active search includes sending agents to places and events in the environment (Smith et al., 2010) and engaging in trial and error learning (Daft and Weick, 1984). This type of search suits low complexity knowledge as it is exists independently outside a firm's boundary and requires little integration the firm's existing knowledge (Beckert, 1999). Also, low codified knowledge is suited to experiential learning methods that involve interacting with the environment (Kamp et al., 2004). This is essential for acquiring, forming and applying such knowledge.

An example of active search by Vanke is when it established an R&D center in 1999 to develop standards for building components in China. To accumulate knowledge and technologies for housing industrialization, Vanke sent teams of researchers overseas (especially to Japan) to find and internalize the acquired knowledge by working with researchers at partner organizations. Vanke has invested millions of U.S. dollars annually in these learning secondments and the R&D center.

Active search was an important mechanism for Vanke in overcoming skepticism to its housing industrialization strategy. There was skepticism from the Chinese government and from Vanke's peers in the building sector that this approach might not be suitable for China due to availability of inexpensive, low skilled labor suitable for its outdated construction technologies. Vanke's active search sought innovations and standards that would demonstrate the viability of the strategy and overcome the skepticism. In this respect, an active search tends to be an action oriented and self-regulating process that helps ensure the firm's standardization effort suits external conditions.

The learning from active search typically remains in the teams or sub-units of the firm that undertake the search. Consequently, at the product level this learning promotes modular innovations by changing component knowledge while leaving the product's structural knowledge unchallenged (Henderson and Clark, 1990). At the organizational level, active search and modular innovation has limited impact on routines and systems.

Vanke has residential projects nationwide, but the rollout of housing industrialization was initially limited to just Shenzhen and Beijing. It was several years later that this strategy and standardization effort was applied elsewhere, for example in the southwestern city of Chongqing. This restricted rollout of housing industrialization was partly because of the delays in routinizing, institutionalized and standardizing the implementation of the innovations. Also, Vanke applied different levels of housing industrialization in different districts, depending on the availability of supporting resources in the districts. In addition, the Chinese government had not until recently enacted any legislation requiring the use of housing industrialization methods in the construction industry. The legitimacy of housing industrialization was cemented as Vanke used active search to aggressively develop nine major standards and innovations, which were eventually approved by the Chinese government in March, 2015. Since then all construction projects in China are required to meet the national standards on housing industrialization pioneered by Vanke.

4.4. *Integrative search and radical innovations*

The final search type and innovation outcome in our typology is *integrative* search and *radical* innovations, involves embedded knowledge with high complexity and low codification. The search is integrative because it employs and builds on the decentralized, passive and active search types. Integrative search toggles between these different search processes to produce both explorative and exploitative learning (McCarthy and Gordon, 2011). It is suited to environments where the regulations, demand, innovation and competitive actions in the industry are all changing at different rates and in different directions. This is considered to be a 'conflicted' industry dynamic that is unlikely to suit just one type of search process (McCarthy et al., 2010).

The embedded knowledge in this case is linked to learning by repetitive operation, as suggested by Nelson and Winter (1982). Hierarchical learning may also be assimilated and gradually accumulated within an organization's memory, becoming a specific part of routines that support dynamic capabilities and the production of radical innovations (Tushman and O'Reilly, 1996). Dynamic capabilities are cultivated through the recombination of previous knowledge, and the amalgamation of new and different knowledge vectors. These conditions promote radical innovations that are clear departures from existing knowledge and practices (Dewar and Dutton, 1986).

Central to the success of Vanke standardization effort was the company's use of an integrative search. It initially adopted passive search to apply for LEED and develop and standardize green technologies for housing industrialization. Vanke gradually enlarged the implementation of its housing industrialization innovations to its commercial products, as well as to its social welfare projects such as indemnificatory apartments including low-rent, affordable, price-fixed and public rental housing. A plan of quality management, the Panshi Plan, was developed by refining and documenting Vanke's best practice experience from these projects into a set of standards for the whole company.

Vanke also conducted decentralized and active searches. It recognized the possibility of being overthrown by emerging companies in other sectors, such as manufacturing, information and communication technology, and this resulted in the proposed strategic transition of the company from developer to city service provider. In 2014 Vanke organized in-company teams to learn from companies such as Haier (household appliances manufacturer), Alibaba (e-commerce), Tencent (internet service provider), Xiaomi (smartphone manufacturer) and Baidu (internet search engine). The decentralized and active searches opened the potential for Vanke to collaborate with these firms to provide novel products in the Chinese market. For example, Vanke now provides value-added services to customers using the data services of Baidu. Vanke also collaborated with partners to develop standards and innovations for universal serial bus (USB) plugs, sanitary appliances, air filters and door opening technology using cell phones. The integrative search, dynamic capabilities and radical innovations also led Vanke to restructure the relationships between firms in its supply chain. Vanke initiated a supply chain alliance that included manufacturers, designers, developers, construction and home decoration companies as well as research institutions such as Tsinghua University, Tongji University and Tianjin University.

5. Discussion

While standardization efforts have been recognized as playing a crucial role in how firms create and profit from innovation, we found that existing empirical research offers inconsistent findings on the relationship between standardization and innovation. To help resolve these inconsistencies and further our understanding of standardization, we examined how degrees of knowledge complexity and codification impact the type of search required and the resulting innovation outcome. We explained how these two dimensions of knowledge combine to produce a typology of four types of search process and four types of associated innovation outcome. Using a detailed case study, we illustrated and verified each dimension of our typology. Together the typology and the case study help us to better understand how search impacts the inter-play and relationship between standardization and innovation outcomes.

5.1. *Implications for the theory and practice*

We now discuss four major implications of this, which we believe are of relevance to both management practice and future empirical research.

First, this study demonstrates that search processes are important to major standardization efforts. In our case study it is clear that multiple types of search were employed to acquire and assimilate different dimensions of knowledge. The processes for gaining this knowledge are at the heart of a standardization effort and the associated innovation outcomes. Our typology and case study show that there is a contingency relationship between standardization, search and innovation outcomes, where one size does *not* fit all. The quest for different types of knowledge, involves different search approaches that in turn underlie the type of innovation outcome produced.

A second implication of our research is that the case study provides provisional evidence for understanding how standardization efforts can be suited to different types of search process. For example, we find that standardization efforts that employ decentralized and passive search processes are positively linked to incremental and architectural innovation outcomes. This is due to the knowledge embedded in the standardization effort, which is highly codified and complex. It promotes consensus and recombination among stakeholders, explaining why a standardization effort strongly diffuses within the industry (Hashem and Tann, 2007) and in turn shapes the industry structure (Lecocq and Demil, 2006) and its value chain (Yoo et al., 2005).

Passive search that involves highly codified knowledge can lead suppliers to lock-in with one another around the resulting standards and innovations (Unruh, 2000), resulting in strong technological trajectories (Dosi, 1982; Smith et al., 2010). In contrast, when the knowledge in a standardization effort is characterized as having low complexity and low codification it suits an active search for modular innovations that involve designing 'open' component systems (Tassey, 2000), using trial and error search activities (Daft and Weick, 1984) and conducting field studies (Smith et al., 2010). When the knowledge is characterized as high complexity and low codification it suits integrative search and radical innovation outcomes. As shown in our case study, integrative search involves recombining current relationships between stakeholders and encouraging novel solutions resulting in component systems that disrupt existing product standards and offerings.

A third implication is that a single standardization effort can shift between different search processes over time. This is because standardization efforts are complex activities that can take many years to complete; the type of knowledge required during the course of a standardization effort can vary and change. Consequently, as found in our case study, there will likely be a pathway of different search processes involved in a major standardization effort.

In Fig. 3 we show the search pathway observed in our case study. It begins with decentralized search, followed by active search, passive and then integrative search. The knowledge characteristics for decentralized search provide the starting point in this pathway. The standardization effort begins with the search for simple codifiable knowledge that often focuses on identifying obvious gaps and needs to be addressed by the standardization effort. An active search follows, as any lack of knowledge codification requires a more skilled and costly search process to identify, understand, assimilate and exploit the knowledge. Next is passive search, as the efficiency of the investments in search become more important and firms seek more explicit standards and complex solutions to suit market needs. The final search in the pathway is integrative. It is the most sophisticated, impactful, but difficult form of search. The pathway of search types reflects the learning and capabilities that prepare firms to undertake integrative search and pursue radical innovation outcomes. This concept of a learning pathway is what McCarthy et al. (2006: 440) refer to as "a ladder of abstraction" for interpreting and managing different and higher order types of search for different types of innovation outcome. We thus suggest that a more strategic orientation towards standards can prevent inhibiting creativity and unnecessary delays as identified by Hamel (2006) and Hill and Rothaermel (2003).

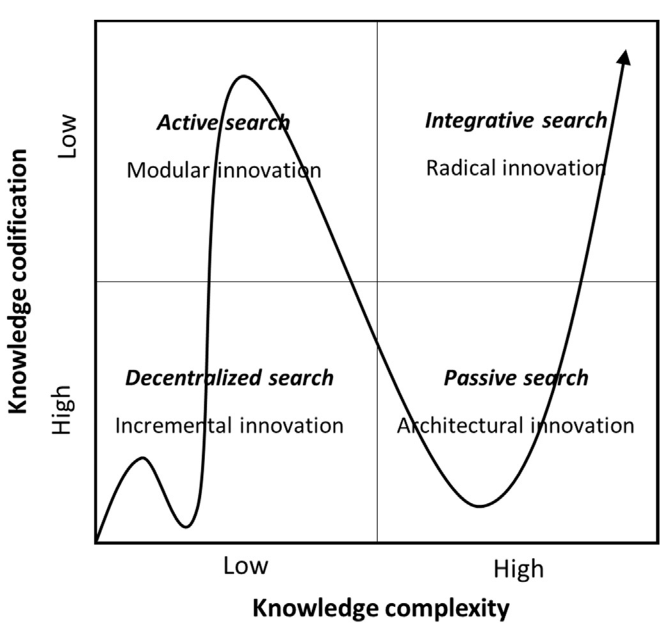

Fig. 3. Pathway of search processes involved in a standardization effort.

A fourth implication concerns managerial efforts in practice. If management's goal is primarily incremental and/or architectural innovation, it should be expected that the knowledge will be standardized, and that decentralized and passive search processes can be used. If the managerial objective is concerned with modular and/or radical innovations, the knowledge will not likely be standardized, and as a result active and integrative search processes are appropriate. For company and government policies, if decentralized and passive searches in the standardization efforts are performed, incremental and architectural innovation are expected. To foster radical and modular innovations, it is necessary to enable active and integrative search processes.

5.2. Imitations of this study

Some limitations of this study and related opportunities for future research are worth noting.

While our case study allowed us to explore deeply the activities, events and interactions of a major standardization effort, like all case studies, the generalizability of our finding maybe restricted. For example, as the search pathway in Fig. 3 is based on the standardization effort of just one case (Vanke), it is likely there could be alternative viable pathways. These would involve some or all of the search processes but in different orders, and thus the different pathways will suit different standardization efforts. The matching of a standardization effort with a given pathway will likely be determined by the knowledge complexity and codification as well as the innovation context in terms of factors such as time scales, complexity, regulations and costs. For example, the rapid development of code division multiple access (CDMA) standards for radio communication technologies in Korea would have a known innovation outcome that could involve a different search pathway. The importance of the pace of innovation to a search pathway is supported by Hill and Rothaermel (2003) who claim that standardization efforts postpone the gestation period between invention and successful commercialization.

While it can be argued that our findings may be less applicable to firms in other industries, the value of the typology and findings are grounded in prior theories and research. Furthermore, as this particular industry setting has traditionally not been considered innovation-intensive, we speculate that our typology is likely to have even greater relevance for settings where innovation is fast changing and core to sustained competitive advantage. This should help motivate and make it easier for scholars to apply the typology and ideas to other industry contexts.

Another limitation of this research is that our case was focused on a successful case of a standardization effort that resulted in industry leadership. We recognize that not all standardization efforts will result in similar competitive advantages. Indeed, it would be fruitful to explore cases where such efforts resulted in a downward competitive trajectory, for example by creating bureaucratic inefficiencies or commoditizing of the industry, as was the case for nuts, bolts and screws.

6. Conclusion

The benefits and challenges of standardization have captured the attention of managers and scholars, yet the empirical findings on the impact of standardization on innovation are inconsistent. Focusing on a standardization effort (i.e., when a firm pursues standards to further innovation), our work draws upon on research on the importance of search processes for innovation and adopts a contingency approach to standardization effort, search process and innovation outcome relationships. To examine these relationships we developed a typology that provides a descriptive, explanatory and predictive framework for researchers to examine the diversity and impact of different standardization efforts. An important implication is that standardization efforts need to be seen as a long-term strategic initiatives that drive the creation and adoption of standards and innovations. If the search processes and resulting standards are not coordinated in pursuit of an innovation goal, then the risk is the effort will be a collection of disconnected standardization exercises that result in bureaucratic inefficiencies, commoditization or the stifling of creativity.

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