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BEYOND BOUNDARY SPANNERS: THE 'COLLECTIVE BRIDGE' AS AN EFFICIENT INTERUNIT STRUCTURE FOR TRANSFERRING COLLECTIVE KNOWLEDGE

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This research introduces a framework for selecting efficient interunit structures in facilitating the transfer of knowledge with different levels of complexity. We argue that while the boundary spanner structure is efficient for transferring discrete knowledge, it is inadequate for transferring collectively held complex knowledge. We propose that the transfer of such knowledge requires a more decentralized interunit structure—collective bridge, which is a set of direct interunit ties connecting the members of the source and the recipient units, with the configuration of the interunit ties matching the complexity of knowledge to be transferred. We suggest that while a collective bridge is inefficient in transferring discrete knowledge relative to a boundary spanner structure, it is more efficient for transferring collective knowledge.

INTRODUCTION

Collective knowledge, which is the knowledge embedded among individuals regarding how to coordinate, share, distribute, and recombine individual knowledge, is a key element of firms' competitive advantage because its complexity deters imitation by competitors (Grant, 1996; Spender, 1996). However, for the same reason, it is also challenging to replicate or transfer such knowledge within the firm and efficiently exploit it in newly expanded markets or business units as the complexity of collective knowledge also forges strong barriers to internal transfer and replication (Argote *et al.*, 2000; Pil and Cohen, 2006; Simonin, 1999; Szulanski, 1996). Given the importance and challenge of transferring collective knowledge, the existing knowledge transfer literature has not sufficiently studied the intra-organizational structure that can facilitate this type of task. In this paper, we conceptualize an interunit organizational structure that is appropriate for transferring collective knowledge; as we define below, we refer to this structure as a *collective bridge*. In developing the argument, we explore the trade-offs between effectiveness and cost in using collective bridge and boundary spanner structures, a widely discussed knowledge transfer structure and study how these trade-offs vary with the level of knowledge complexity.

We begin with an examination of the widely discussed knowledge transfer structure, boundary spanner structure, which is a centralized interunit structure characterized by indirect knowledge transfer channels through limited number of boundary spanners (Aldrich and Herker, 1977; Conway, 1997; Leifer and Delbecq, 1978).

Keywords: knowledge transfer; collective knowledge; complexity; boundary spanners; collective bridge; organizational structures
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Boundary spanner structure has long been established as an effective device for cross-boundary information and knowledge transfer by management scholars (Allen, Tushman, and Lee, 1979; Dollinger, 1984; Leifer and Delbecq, 1978; Tushman and Scanlan, 1981a, b). Expanding on this stream of research, we examine the effectiveness and cost of this structure in the context of interunit transfer of knowledge with varying degrees of complexity. We argue that the effectiveness of boundary spanner structure is not absolute but contingent on the complexity of knowledge that it is used to transfer.

Given the cognitive and motivational limitations of boundary spanners in transferring highly complex knowledge, we propose an alternative interunit knowledge transfer structure, a *collective bridge*, which is a set of direct interunit ties connecting the members of the source and the recipient units, with the configuration of the ties matching the complexity of collective knowledge intended for transfer. A collective bridge is distinct from the boundary spanner structure in that, while the boundary spanner links two units with mostly indirect ties through the centralized intermediary of boundary spanners, a collective bridge is a decentralized interunit structure with a broad range of *direct* interunit ties between members of the two units. A collective bridge exists when the members of the recipient unit develop multiple within- and cross-expertise relationships with members of the source unit based on the complexity of knowledge to be transferred. Figure 3(a) illustrates a collective bridge for transferring collective knowledge. This type of interunit structure exists widely in real organizational settings, especially in firms involving complex products. For example, a collective bridge was developed between a group of Chinese engineers of the R&D unit at Volkswagen's joint venture in Shanghai and the German engineers of Volkswagen's home R&D unit when these Chinese engineers underwent an extensive on-site training in Germany (Zhao, 2005). This collective bridge, which consists of a vast array of direct ties between Chinese and German engineers, allowed the Chinese engineers to communicate with German engineers effectively and promptly whenever they needed technical support as they developed their own R&D capabilities in the joint venture after the training was over.

By integrating knowledge-based arguments and motivation literature, we argue that compared with a boundary spanner structure, a collective bridge is more effective for enabling and motivating the transfer of knowledge with a high level of complexity. The effectiveness advantage of a collective bridge over a boundary spanner structure escalates as the level of knowledge complexity increases. However, an effective structure may not be efficient due to the excessive costs it incurs. Accordingly, we investigate the cost of boundary spanner structures and collective bridges as a function of knowledge complexity. The core contribution of this paper lies in the development of a contingency framework that compares the overall *efficiency*, i.e., effectiveness less cost, of these structures at different levels of the knowledge complexity.

While much research has been done regarding intra-firm knowledge transfer, this paper helps fill several gaps. First, there is a lack of attention on the fine-grained interunit structure between the source and recipient units. Among research aimed to understand the facilitating factors for knowledge transfer, the focus is mostly on the attributes and strategies of either the source or the recipient unit (e.g., Simonin, 1991; Szulanski, 1996; Zhao and Anand, 2009; Zhao, Anand, and Mitchell, 2005). Most of the knowledge network studies that examine interunit structures treat interunit structure as a single tie rather than a broad nexus of relationships among members of the units involved in knowledge transfer (Phelps, Heidl, and Wadhwa, 2012). The second gap is the lack of simultaneous study of effectiveness and cost of interunit structure. The utility of an interunit knowledge transfer structure depends not simply on its effectiveness but rather on its efficiency, which is effectiveness less the cost of development and maintenance. The third gap is the ignorance of a key characteristic of knowledge—complexity—as a contingent factor that affects the effectiveness and cost of interunit knowledge transfer structures. The role of knowledge characteristics as a contingent factor is scarcely studied in knowledge transfer literature (Phelps *et al.*, 2012). Social network research has also remained agnostic regarding what flows through instrumental relations between actors—whether it is simple information or a complex technology that flows through the ties has not been sufficiently studied (Hansen, 1999). An implicit assumption in knowledge transfer research is that the effectiveness and cost of an organizational structure are invariant to the complexity of knowledge to be transferred. In this paper, we seek to fill these gaps by addressing this question: What kinds of interunit structures between the source and the recipient units can efficiently facilitate the transfer of knowledge with different levels of complexity? Specifically, we study how the efficiency of two different interunit structures, i.e., boundary spanners and collective bridge, are contingent on knowledge complexity. Such analyses provide implications for the use of different organizational structures as conduits of knowledge and for exploiting firm competitive advantage.

COLLECTIVE KNOWLEDGE AND ITS TRANSFER

Collective knowledge and knowledge complexity

Collective knowledge—the knowledge embedded among individuals regarding how to coordinate, share, distribute, and recombine individual knowledge (Grant, 1996; Spender, 1996) —is qualitatively distinct from individual knowledge, as it is not carried through isolated individuals but is mutually shared among multiple individuals within a unit or organization.

Collective knowledge is a crucial part of the knowledge set characterized by a high level of *complexity*—a key knowledge characteristic, which can be gauged by the extent of interdependencies among different subareas of the totality of the knowledge set (Simon, 1962; Simonin, 1999; Sorenson, Rivkin, and Fleming, 2006; Winter, 1987; Zander and Kogut, 1995). The interdependencies among areas of expertise arise when one area of expertise significantly affects the contribution of one or more other areas of expertise to the overall outcome (Sorenson *et al.*, 2006). For example, in the Pratt and Whitney jet engine development project, an engine involves 569 interdependencies among 54 components. These interdependencies take the form of structural connection or the transfer of material, energy, forces, or control signals. The extent of knowledge complexity in engine design is reflected by the number of interdependencies among expertise areas of various components (Sosa, Eppinger, and Rowles, 2007). When a set of knowledge is highly complex, i.e., it involves a large amount of interdependence among expertise areas, 'a specialist familiar with a particular technology cannot predictably enhance the value of the product design based solely on the knowledge he or she possesses, in this case, the value of any particular design change will interact with a host of other potential design changes determined by specialists possessing distinctly different knowledge sets' (Nickerson and Zenger, 2004: 620). As illustrated in Figure 1, a knowledge set with high complexity involves many interdependencies among different areas of individual knowledge. At a dyadic level, each pair of interdependence between individual knowledge areas requires a specific collective knowledge shared between the experts carrying these areas of individual knowledge, as collective knowledge is essential to help these experts to coordinate and integrate their interdependent areas of individual knowledge. As such, the more complex the knowledge set, i.e., the more interdependencies exist among different areas of individual knowledge, the greater the extent of collective knowledge will be needed to coordinate and integrate them. For instance, although the two sets of knowledge in Figure 1 have the same amount of individual knowledge (i.e., E_i, $i = 1-4$), the knowledge set with more complexity has a greater level of interdependence among expertise areas and thus involves a greater extent of collective knowledge (i.e., E_{ij}, i, $j = 1$ to 4, $i \neq j$).

To substantiate the concept of collective knowledge, we identify two key elements of collective knowledge based on prior literature: (1) common knowledge shared by individuals regarding the pattern of interaction or interpersonal coordination routines (Nelson and Winter, 1982) and common language or syntax (Carlile, 2002; Grant, 1996; Reagans and McEvily, 2003) and (2) cross-expertise understandings, which is the knowledge held by an individual regarding how his or her decisions may impact the effectiveness of another specialist with different expertise or vice versa when working jointly in an interdependent task. These two elements of collective knowledge allow certain knowledge overlaps among individuals with different and interdependent expertise and are necessary and essential in order for these individuals to achieve effective communication, coordination, and mutual adjustment in conducting complex tasks. A concrete and simple illustration of collective knowledge can be found in Carlile's (2002) description of the design capability of the onboard vapor recovery valve. The design of the valve requires a high level of interdependent

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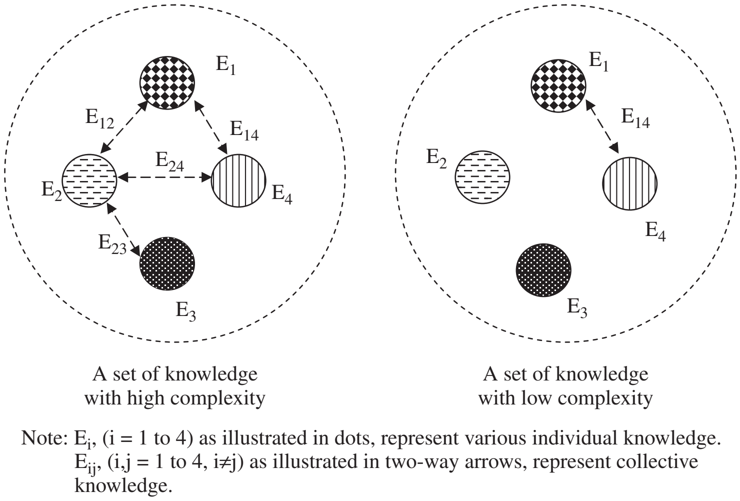

Figure 1. An illustration of knowledge complexity, individual knowledge, and collective knowledge

decision making between a design engineer with expertise in product design (denoted as E_1) and a manufacturing engineer with expertise in designing production process (denoted as E_2). Successfully carrying out the design process relies on not only their relevant individual knowledge (i.e., E_1 and E_2) but also on the collective knowledge between them (denoted as E_{12}), which includes the common knowledge in the forms of patterns of interactions or coordinative routines, such as how to use CAD models to lay out all of the design and manufacturing specifications of a new product, as well as common syntax, code, or heuristics they used to discuss the interface issue between design and manufacturing; and cross-expertise understanding such as (1) their mutual understanding of each other's scope of expertise, priorities, constraints; (2) decision tradeoff regarding design features, cost, and manufacturability; and (3) their ability to make adjustments in order to communicate and accommodate each other's decisions. A design engineer with a good grasp of cross-expertise understanding is able to design a product that is easy for a manufacturing engineer to work with and develop the relevant production equipment and process for it.

Transferring collective knowledge

Transferring organizational capabilities across units involves transferring both individual and collective knowledge. Transferring collective knowledge is in essence helping the recipient unit to replicate the coordination routines, common syntax and cross-expertise understanding of the source unit. Transferring collective knowledge is much more challenging than transferring individual knowledge because the interdependence among various knowledge elements renders the knowledge difficult to be fully articulated (Hansen, 1999). In car design, for example, the most difficult areas to identify and measure were the interdependencies across various expertise areas. It is hard to grasp and explicate how putting in a larger engine will impact the styling, weight, cooling requirements, gas mileage, and crash-test outcomes (Carlile, 2004). Moreover, transferring knowledge with a high level of complexity (i.e., interdependence among different knowledge elements) is prone to failure because a small error in replication of one element of the knowledge may cause a large distortion in the overall knowledge transfer (Rivkin, 2000).

The success of transferring collective knowledge, according to findings from prior research, depends critically on the access to the original 'template' or the broad understanding of how different knowledge elements are interdependent (Rivkin, 2000, Winter and Szulanski, 2001). Thus, to transfer collective knowledge, the members of the recipient unit not only need to communicate with their counterparts (i.e., individuals who specialized in the same area of expertise) in the source unit, they also need to establish ties with members with different areas of expertise in the source unit, which we call *interunit cross-expertise ties*. An interunit cross-expertise tie, which is a communication link between a member of the source unit with a certain expertise area (E_i) and a member of the recipient unit with a different expertise area (E_j, $j \neq i$), is imperative in transferring collective knowledge (E_{ij}) because it helps the members of the recipient unit to understand fully the implication of the interdependence between E_i and E_j through gaining the perspectives from other individuals involved in this interdependent relationship at the source unit. These cross-expertise perspectives will help individuals at the recipient unit to see the broad 'template' of interaction among different expertise areas, which is critical to the successful transfer of collective knowledge (Rivkin, 2000; Winter and Szulanski, 2001). Reagans and McEvily (2003) also point out that cross-expertise ties with external individuals can help an individual of an organization to gain a broader perspective and thus help him or her to acquire complex knowledge.

Consider again the simple case of dyadic coordination between a design engineer and a manufacturing engineer in designing a valve. Suppose a project team (i.e., source unit) that holds the design capability of the valve is to transfer or deploy this capability to a newly formed project team (i.e., recipient unit). The design engineer in the recipient unit not only needs to acquire the expertise of product design (E_1) from the design engineer in the source unit, he or she also needs to communicate with the manufacturing engineer (E_2) in the source unit in order to gain the collective knowledge that resolves the interdependence between E_1 and E_2 (i.e., E_{12}). An interunit cross-expertise tie does not transfer an entirely new individual expertise to members of the recipient unit (e.g., a design engineer in the recipient unit does not have to gain full scope of expertise in the manufacturing process through his or her interunit cross-expertise tie to the manufacturing engineer in the source unit). However, this type of tie may help to transfer cross-expertise understanding or perspective in the forms of (1) how an individual in the other knowledge area reacts and adjusts to the decisions made by his or her own expertise area, (2) what technical language an expert in another knowledge area understands in dealing with the cross-expertise boundary issues, and (3) what constraints and concerns an expert in another knowledge area has that may affect the decision regarding his or her own knowledge area.

INTERUNIT KNOWLEDGE TRANSFER STRUCTURES

The main goal of this paper is to understand the trade-offs between effectiveness and costs in the use of two different interunit structures, i.e., boundary spanners and collective bridge, at different levels of knowledge complexity. Effective knowledge transfer with a particular structure implies quality and timeliness of their facilitation of knowledge transfer. Specifically, we assess *effectiveness* as the lack of productivity loss due to the distortion of knowledge (e.g., loss of content or reduction of accuracy) or time delay in the process of knowledge transfer. A structure is considered highly effective when it incurs a low level of productivity loss.

However, the *efficiency* of an interunit structure depends not just on its effectiveness but also the costs of time, effort, and tangible resources for developing and maintaining its functions (Ahuja, 2000; March and Simon, 1958; Tushman and Scanlan, 1981b). An excessive magnitude of such costs may render an effective structure infeasible or undesirable. In the following section we discuss the effectiveness and costs of boundary spanners and collective bridges respectively, at different levels of knowledge complexity.

The boundary spanner structure

Boundary spanners are individuals who operate at the periphery or boundary of an organization, performing organizationally relevant tasks and relating the internal organization to external elements (Leifer and Delbecq, 1978). These individuals are both internal and external communication stars (Tushman and Scanlan, 1981b). The function of a boundary spanner is twofold: first, to maintain a high level of contact with the external environment and gather information from it; and, second, to maintain high levels of contact with the internal organization and thus filter, translate, and diffuse external information to it in terms that can be understood by his or her colleagues (Allen *et al.*, 1979). In the context of interunit knowledge transfer, boundary spanning structure is a centralized

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interunit structure characterized by indirect knowledge transfer channels through a limited number of boundary spanners (Conway, 1997). Boundary spanners enjoy the benefit of preferential access to information and, in some situations, may skew the flow of information to their advantage (Burt, 1992). Authority and technical expertise are two key credentials for internal communication stars. Tushman and Scanlan's (1981b) study shows that about half of the internal communication stars are supervisors; they are seen by their colleagues as being technically competent, and as such, they are consulted more frequently. Interunit knowledge transfer structures based on boundary spanners can take different forms. As described by Conway (1997), interunit boundary spanners can be at either the source or recipient unit or both (see Figure 2). Boundary spanners can be representatives from the source unit or well-trained members of the recipient unit who have broad relations with various experts in the source unit or supervisors (Katz and Tushman, 1983). They act as information and knowledge hubs, receiving information, questions, answers, and suggestions from the members of one unit, as well as processing, filtering, translating, and feeding them to the members of the other unit. An important characteristic of a boundary spanner structure is that the nonboundary spanners are dependent on boundary spanners for new knowledge input. The nonboundary spanning members of either the source or recipient units usually do not have direct access to the members of the other units. They either do not know the appropriate individual at the other organizational unit that they should contact or lack the authorization or credibility and trust to address their issues directly with members of the other side. As such, they have a high level of dependence on the boundary spanners.

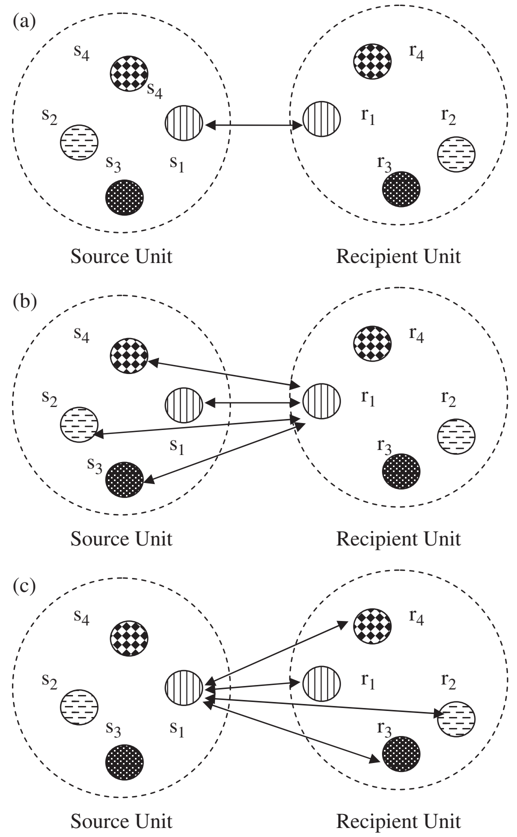

Figure 2. (a) One-to-one interunit boundary spanning. (b) Many-to-one interunit boundary spanning. (c) One-to-many interunit boundary spanning

The effectiveness of a boundary spanner structure

Boundary spanner structure has long been deemed as an effective strategy for knowledge transfer. For example, prior empirical studies have shown that this structure leads to improved performance in small businesses and R&D organizations (e.g., Allen *et al.*, 1979; Ancona and Caldwell, 1992; Dollinger, 1984). However, a closer examination of these studies reveals a common thread among them—boundary spanner structure is effective for transferring a specific type of knowledge—individually held or discrete knowledge. For example, these studies include information regarding problem definition, evaluation, location of resources, and administrative matters needed for decision making (Allen *et al.*, 1979; Leifer and Delbecq, 1978; Tushman and Scanlan, 1981a). Note that such knowledge does not involve significant interdependencies and is easily transmitted by individuals. Boundary spanners with their access to the source unit's supply of discrete knowledge are in a good position to facilitate such a transfer.

Departing from most of the prior studies regarding boundary spanner as a universally effective knowledge transfer structure, we argue that its effectiveness is contingent on the type of knowledge it attempts to transfer. We suggest that, as the level of knowledge complexity increases, the effectiveness of the boundary spanner structure in transferring knowledge diminishes due to the following reasons. First, when transferring highly complex knowledge, the long and indirect knowledge transmission paths of a boundary spanner structure may cause incompletion, distortion, and time delay. When a source and a recipient unit are connected by a boundary spanner structure, the majority of their members, who are not boundary spanners, have to rely on indirect and long knowledge transfer paths through the intermediary of boundary spanners. As discussed before, transferring collective knowledge requires gaining cross-functional understanding through interunit cross-expertise ties. When the knowledge is highly complex, boundary spanners have to act as intermediaries connecting members of different expertise across the two units. For example, in Figure 2(a), a member of the recipient unit (i.e., r_1) and a member of the source unit (i.e., s_1) serve as boundary spanners at the recipient and source units respectively. If a nonboundary spanner member in the recipient unit (e.g., r_2) needs to establish an interunit cross-expertise communication with a nonboundary spanner member in the source unit (e.g., s_3), r_2 has to contact the boundary spanner at the recipient unit (r_1), who in turn will contact the boundary spanner at the source unit (s_1), who then contacts s_3. After s_3 receives the request from s_1, he or she will provide feedback to s_1, who then will convey this feedback to r_1, who in turn will finally bring the feedback to r_2. Overall, this knowledge path involves five interpersonal contacts.[1] Such long and indirect interunit cross-expertise paths may lead to information distortion and communication interruption in the knowledge network especially when knowledge to be transferred is highly complex (Hansen, 2002), since individuals along the knowledge transmission paths are not likely to be capable of fully and accurately conveying the nature and implication of interdependence among expertise areas from one unit to the other. The longer the path, the more likely knowledge distortion may occur. Long and indirect knowledge transfer paths may also cause time delays and fruitless searches, as Hansen (2002: 234) finds in his empirical study:

> [A] project manager in my study told me that he had been told by a third party in the company about a group of engineers in another unit who were supposed to have some useful technical know-how, but when he was able to reach them after trying for a while, it turned out that the know-how was not relevant for the project. Such fruitless searches not only take time, but also cause delays in the project to the extent that the needed knowledge input holds up the completion of other parts of the project.

Second, when the knowledge to be transferred is highly complex, the volume and scope of the collective knowledge involved may exceed the cognitive capacity of boundary spanners to transfer it across units due to bounded rationality. Even for highly capable boundary spanners, it is difficult to comprehend and convey fully the richness of interpersonal or interfunctional coordination patterns as well as the meanings and perspectives underpinning the interdependence among expertise areas. Therefore, giving boundary spanners the responsibility to transfer collective knowledge can lead to role overload, knowledge loss or distortion, and time delay. Such an overload of boundary spanners negatively affects team viability and performance (Aldrich and Herker, 1977; Marrone, Tesluk, and Carson, 2007). These detrimental effects will intensify as the complexity of knowledge to be transferred increases. When the complexity of knowledge is high enough, the workload and time required for boundary spanners to transfer collective knowledge may rise to prohibitive levels.

Finally, using boundary spanners as an interunit structure for transferring collective knowledge not only leads to severe *cognitive* challenges, it may also cause *motivational* problems. First, the potential of role overload will likely reduce the boundary spanners' motivation to take on the responsibility of facilitating the transfer of knowledge, especially when the knowledge is highly complex. Second, the lack of direct ties between nonboundary spanning members of both source and recipient units hinders the development of trust and social relationships between the members of the two units; and as a result, it may reduce the incentive for members of the source unit to transfer complex knowledge, since trust and social relations established through direct ties is a key condition to motivate individuals to transfer deep perspectives of complex knowledge (Coleman, 1988; Sorenson

[1] We count the communication from Person 's_1' to Person 's_3' and from Person 's_3' to Person 's_1' as one contact since they are adjacent and reciprocal, thus this communication can happen in one conversation.

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et al., 2006). Lastly, adopting a boundary spanner structure may hamper the sense of empowerment and autonomy for nonboundary spanning members of both source and recipient units. Compared to transferring individual or discrete knowledge, transferring collective knowledge is harder to specify and measure and consequently harder to motivate by monetary incentives. Therefore, it has to rely more on the commitment or intrinsic motivation of the members of both the source and the recipient unit to collaborate with each other during the transfer process. The boundary spanner structure, however, represents a centralized structure. Unlike boundary spanners who enjoy brokerage authority in knowledge transfer and distribution, nonboundary spanners in both the source and recipient unit have to go through boundary spanners when seeking or sharing knowledge. As such, the nonboundary spanners are likely to experience a lack of autonomy, power, and control, which in turn may reduce their commitment to organizational goals and their willingness to seek or share knowledge (Rousseau, 1998). In summary, as knowledge complexity increases, the motivation of both boundary spanners and other members of the two units becomes lower due to an excessive workload as well as lack of trust and autonomy. This loss of motivation may negatively impact the quality and timeliness of knowledge transfer efforts.

Overall, a boundary spanner structure is effective for transferring knowledge with low complexity, yet due to its cognitive and motivational limitations, its effectiveness declines as knowledge complexity increases. When knowledge complexity reaches a threshold, under the pressure of transferring knowledge within a time limit, overloaded boundary spanners and demotivated unit members may find it impossible to complete the knowledge transfer task. The pressure and frustration may ultimately lead to the dysfunction of the units involved. At this point, the productivity loss due to knowledge distortion, communication interruption, and time delay may sharply rise to a point where the viability of the units is jeopardized (Marrone *et al.*, 2007).

> *Proposition 1: The effectiveness of the boundary spanner structure as a means to transfer knowledge decreases as the complexity of knowledge increases. Beyond a certain threshold of knowledge complexity, the effectiveness of boundary spanner structure may diminish sharply as this structure fails as a viable means to transfer knowledge.*

The costs of developing and maintaining a boundary spanner structure

Although one of the key advantages of a boundary spanner structure over a broad range of communication ties across organizational boundaries is cost saving (Arrow, 1974), developing and maintaining this structure still incurs substantial costs for hiring, retaining, developing, and supporting boundary spanners. A study shows that boundary spanners have more scope and length of work experiences and assume higher positions in hierarchy than nonboundary spanning individuals (Tushman and Scanlan, 1981b). Accordingly, hiring and retaining them may require significant financial investment. Developing the skills of boundary spanners usually requires training and job rotation, which could cost time and effort. Moreover, to maintain the effective function of boundary spanners, firms need to support them with liberal budgets of information technology and related services as well as a travel allowance (Tushman and Scanlan, 1981b). For each boundary spanner, these costs may increase with knowledge complexity, because the greater knowledge complexity, the greater incentives, training, and support are needed per boundary spanner. But since the number of boundary spanners remains relatively few and invariant with knowledge complexity, the total cost (i.e., the product of cost per boundary spanner and the number of boundary spanners) does not rise significantly with knowledge complexity.

> *Proposition 2: The costs of developing and maintaining a boundary spanner structure increase slightly with the level of knowledge complexity.*

Collective bridge

In sight of the limitations of the boundary spanner structure in transferring highly complex knowledge, we propose an alternative knowledge transfer structure, *collective bridge*, which is a set of direct interunit ties connecting the members of the source and the recipient unit with the configuration of the ties matching the complexity of knowledge to be transferred. Specifically, a

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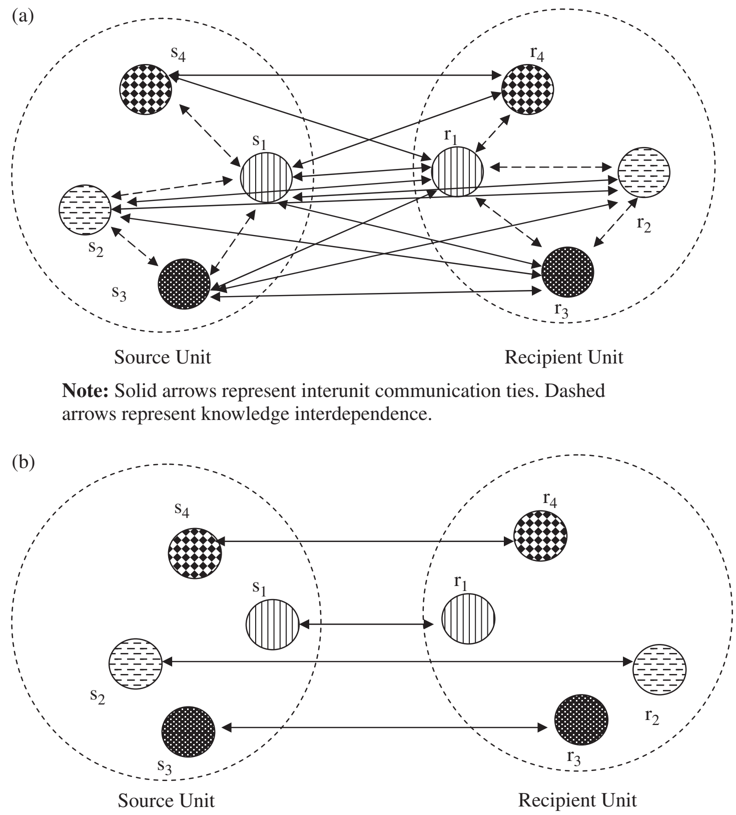

Figure 3. (a) An interunit collective bridge for transferring collective knowledge. (b) An interunit collective bridge for transferring individual knowledge

collective bridge as shown in Figure 3(a) entails that a member in the recipient unit (r_j) specialized in expertise area E_j has both direct interunit within-expertise ties with his or her counterpart in the source unit (s_j) and interunit cross-expertise ties with all other source unit members (s_i, $i \neq j$) whose expertise areas are interdependent with his or her knowledge area. We use a binary variable Z_{si_rj} to denote the presence of an interunit direct tie between s_i and r_j, with 1 indicating its presence and 0 indicating its absence. We use another binary variable E_{ij}[2] to describe the interdependence between expertise area *i* and *j*, with 1 meaning E_i and E_j are interdependent and 0 meaning otherwise. The following formulae explain the scope of a collective bridge for transferring collective knowledge that involves N expertise areas, with i and $j = 1, \ldots, N$, $(i \neq j)$:

$$Z_{si\_rj} = \begin{cases} 1, & \text{if } E_{ij} = 1 \\ 0, & \text{if } E_{ij} = 0 \end{cases} \tag{1}$$

$$Z_{si\_ri} = 1 \tag{2}$$

Equation 2 indicates that interunit within-expertise direct ties should always be present in a collective bridge regardless of the overall complexity of the knowledge to be transferred. Equations 1 describe the condition for interunit cross-expertise ties to exist. When expertise areas E_i and E_j are interdependent (i.e., collective knowledge $E_{ij} = 1$), interunit cross-expertise ties should be present (i.e., $Z_{si\_rj} = 1$) in a collective bridge. On the other hand, if such interdependence does not exist, it is unnecessary to establish and maintain an interunit cross-expertise tie between s_i and r_j. Our definition of collective bridge as defined in Equations 1 and 2

[2] Note, E_{ij} and E_{ji} are equivalent, since the interdependence between two expertise areas is nondirectional. However, Z_{si_rj} is not the same as $Z_{sj\_ri,}$, since these represent two different interunit cross-expertise ties.

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takes the most efficient form.[3] In Figure 3(a), for example, since E_1, E_2, and E_3 are interdependent (i.e., E_{12}, E_{13}, and E_{23} are present), each one of r_1, r_2, and r_3 should have direct ties with all three members of s_1, s_2, and s_3. In other words, direct ties Z_{si_rj}, (i, j = 1, 2, and 3) should all be present in this collective bridge. However, since E_4 is only interdependent with E_1, r_4 should have direct ties with only s_1 and s_4, meaning only Z_{s1_r4} and Z_{s4_r4} should exist in this collective bridge, while other interunit cross-expertise direct ties involving r_4 are unnecessary.

A collective bridge is distinct from a boundary spanner structure in two aspects. First, while the centralized interunit structure of boundary spanner links the two units with indirect ties through the intermediary of boundary spanners, a collective bridge is a decentralized interunit structure that provides a broader range of *direct* interunit ties between members of the two units. Even the simplest form of collective bridge offers broader interunit within-expertise ties than any form of boundary spanner structure as depicted in Figure 3(b). When the knowledge to be transferred across units is mainly individual knowledge [i.e., $E_{ij} = 0$ $(i \neq j)$], a collective bridge, taking its simplest form, involves only interunit within-expertise ties (Z_{si_ri}, $i = 1, \ldots, N$) between counterparts of the source and recipient units as illustrated in Figure 3(b). Second, the configuration of interunit ties involved in a collective bridge is contingent on the complexity of the knowledge to be transferred, whereas the amount and scope of ties in the boundary spanner structure is invariant to the complexity of knowledge.

A collective bridge between units is not just a theoretical construct but exists widely within and between organizations. For example, as described in a field study of international joint ventures in the Chinese automobile industry by Zhao (2005), in order to transfer R&D capabilities to its joint venture in Shanghai, Volkswagen arranged for a group of 41 Chinese R&D engineers from its Shanghai joint venture to receive on-the-job training at its R&D center in Germany. By working alongside German engineers across a wide range of expertise, the Chinese engineers not only gained knowledge from these German engineers but, more importantly, developed personal relationships with them. Some of these relationships are within-expertise and some are cross-expertise. The vast array of relationships between the 41 Chinese engineers and the German engineers they worked with formed a collective bridge. As the training came to an end and the Chinese engineers returned to the Shanghai joint venture, the advantage of this collective bridge between the Chinese and German R&D units became more pronounced. With this interunit collective bridge, the Chinese engineers continued to communicate with various German engineers via E-mail and phone whenever they needed technical support as they developed their own R&D capabilities in the joint venture. This collective bridge, although deemed as a 'windfall' rather than a result of intentional design, was regarded by the Chinese engineers and managers as highly beneficial for their subsequent capability transfer efforts between the German source unit and the Chinese recipient unit when the two units were geographically apart.

A collective bridge can organically form through various ways that facilitate direct and broad interactions among members of source unit and recipient unit such as on-the-job training of members of recipient unit in the source unit. A collective bridge may also form from job rotation training, since such training allows individuals from a recipient unit to develop relationship with a broad range of experts in other units. Hansen and Nohria's study (2004) shows that even after job rotation training is over, the bonds among individuals who worked together survive.

The effectiveness of a collective bridge

A key to the effective transfer of collective knowledge is to establish a broad range of direct interunit cross-expertise communications between members of the source and the recipient unit that match the nature of interdependence among different expertise areas. Compared to the boundary spanner structure, a collective bridge provides several advantages in transferring collective knowledge. First, a collective bridge links the members of the source and recipient units with the shortest (i.e., direct) interunit within-expertise and cross-expertise communication path. For example, as we discussed before using Figure 2(a), in the context of boundary spanners, the length of interunit cross-expertise communication path

[3] Other less efficient types of collective bridges may allow some or all Z_{si_rj} to be nonzero when $E_{ij} = 0$.

between r_2 and s_3 involves five contacts with one-to-one boundary spanner and three contacts with one-to-many or many-to-one boundary spanner structure. However, with a collective bridge, every interunit cross-expertise communication involves only one contact, the shortest length possible. Thus, collective bridges reduce the risk of knowledge distortion and loss, as well as time delay during the transfer of collective knowledge. This advantage of a collective bridge is illustrated in a comment made by a Chinese manager whom the first author interviewed at a Chinese–U.S. automotive joint venture:

> The broad network of connections we [i.e., Chinese trainees from the joint venture] developed with American colleagues [i.e., engineers and managers who work at the American parent company] through our overseas training is very valuable, because it allowed us to connect with the right person when we needed help after we returned from the overseas training. Our American colleagues have a very finely defined division of labor. If I did not find the right person to answer my question at the first time, chances are the question would be passed on to the second or even the third person. The more persons the question must pass through, the less likely it will be answered correctly or answered at all. So, having a broad connection with American experts can ensure us to always get needed information and consultation in a timely manner.

Second, a collective bridge is able to reduce overload on individual boundary spanners when transferring complex knowledge. As we discussed before, when the knowledge to be transferred is highly complex, the volume and scope of collective knowledge that have to transfer between the source and recipient units is likely to exceed the capacity of individual boundary spanners. A study by Marrone and her colleagues (2007) suggests that when all members of a team engage in boundary spanning activities instead of relying on limited number of boundary spanners, not only can more information be acquired in a timely fashion, but the stress and role overload of team members will also be significantly reduced. In effect, a collective bridge offers a sufficient range of direct ties for transferring collective knowledge without overloading the interunit knowledge conduits.

Third, a collective bridge also better facilitates the transfer of complex knowledge by offering a synchronized pace of learning for the members of the recipient unit. With a boundary spanner structure, there is usually a time lag between boundary spanners and nonboundary spanners in getting external information. By contrast, a collective bridge allows *all* relevant members of the recipient unit involved in interdependent tasks to communicate with and learn from relevant members of the source unit simultaneously. This synchronized pace of learning allows for stronger consensus among members of the recipient unit on how and why the routines should be carried out in certain ways. When the simultaneous access to the broad expert base of source unit is not available to all members of recipient unit, the first learners within the recipient unit will be overloaded and even frustrated as they try to diffuse their learning to others in the recipient unit who do not learn at the same pace. Moreover, these first learners have to overcome inertia for adopting new routines, as most of the members at the recipient unit have not fully understood the meaning and perspectives behind the source unit's collective knowledge. Collective bridges, by synchronizing the learning pace among members in the recipient unit, expedite the process of transferring new collective knowledge.

Fourth, the broad range of direct interunit ties in a collective bridge also facilitates the transfer of collective knowledge by establishing common heuristics, mutual knowledge, and a shared communication framework among members of the two units. These common cognitive frameworks can help individuals involved in knowledge transfer to understand and cooperate with each other better and reduce the time it takes to explain the knowledge and understand one another (Cramton, 2001; Uzzi, 1997). Common knowledge is developed when members of the source unit and the recipient unit have engaged in direct interactions and formed direct ties. In a study of time-to-market performance of new product development projects in a global high-tech company, Hansen and Nohria (2004: 27) found that 'project engineers who worked with counterparts from other divisions or subsidiaries took 20–30% longer to complete their projects when close personal relationships between them did not exist beforehand. The

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engineers found it hard to articulate, understand and absorb complex technologies that were transferred between organizational units.'

In addition to providing the above cognitive benefits, a collective bridge also offers several motivational advantages over a boundary spanner structure in the transfer of collective knowledge. First, the direct ties among members of the source and recipient units within the collective bridge can help them to establish social relationships and trust, which promote frequent and in-depth communication and thus help to transfer deep perspectives or the 'know-why' underlying complex knowledge (Coleman, 1988; Sorenson *et al.*, 2006). Hansen's empirical study (2002: 235) finds evidence of the benefit of direct relationships in sharing an in-depth perspective of technical knowledge:

> In a number of projects in my sample, team members were frequently able to obtain software code from engineers in other business units, but sometimes the engineers who wrote the code needed to explain it and help the team to incorporate the code into the new project. Receiving such help was often much easier when the team and the engineers providing the code knew each other beforehand. This likely positive aspect of direct relations needs to be compared with their maintenance costs.

A second motivational benefit of a collective bridge lies in its ability to instill a strong sense of empowerment and autonomy in employees involved in the knowledge transfer at both the source and recipient units. As we discussed previously, compared to transferring individual or discrete knowledge, transferring collective knowledge is harder to specify and measure and consequently harder to motivate by monetary incentives. As a result, transferring collective knowledge has to rely more on the intrinsic motivation of the members of both the source and the recipient units to collaborate with each other. Compared with a boundary spanner structure, a collective bridge offers a more decentralized interunit communication structure, which allows members of both the source and recipient unit to enjoy a greater level of autonomy in knowledge transfer, in that they can freely seek or give knowledge without going through any intermediary. According to self-determination theory (Deci, 1975; Deci and Ryan, 1985), autonomy is an important source of intrinsic motivation. Moreover, the decentralized interunit structure of a collective bridge also makes it easier for the members of both units to communicate, which in turn removes a motivational barrier for individuals of both units to engage in sharing and receiving knowledge. In summary, compared to a boundary spanner structure, a collective bridge can better motivate members of both the source and the recipient units to transfer collective knowledge by instilling a higher level of empowerment and autonomy among members of these units.

Based on the above discussions, a collective bridge is more effective than a boundary spanner structure in coordinating and motivating the interunit transfer of collective knowledge. The superiority of a collective bridge over a boundary spanner structure in the effectiveness of knowledge transfer becomes more pronounced as the knowledge complexity increases, because while the loss of productivity may rise sharply when using a boundary spanner structure to transfer highly complex knowledge, the loss of productivity remains low with a collective bridge.

A collective bridge is also more effective than a boundary spanner structure in transferring knowledge with low complexity. When the knowledge to be transferred across units is mainly individual knowledge [i.e., $E_{ij} = 0$ $(i \neq j)$], a collective bridge, taking its simplest form, would involve only interunit within-expertise ties (Z_{si_ri}, $i = 1, \ldots, N$) between counterparts of the source and recipient units (see Figure 3b). Compared to a boundary spanner structure, a collective bridge allows for direct ties and a shorter transfer path between counterparts of the two units. These features of the collective bridge help to reduce the information distortion or loss and time delay associated with transferring individual knowledge via a boundary spanner structure. The direct interunit within-expertise ties will also motivate knowledge transfer more effectively by enhancing trust, social relationships, and empowerment among members of the two units. As such, setting aside the cost of network development and maintenance, a collective bridge should be more effective than a boundary spanner structure in transferring individual knowledge.

Proposition 3: A collective bridge is more effective than a boundary spanner structure in the interunit transfer of knowledge at all levels of complexity. The superiority of a collective bridge over a boundary spanner in the effectiveness of knowledge transfer becomes more pronounced as the knowledge complexity increases.

The costs of developing and maintaining collective bridge

Organization scholars have long argued that establishing and maintaining a boundary spanner structure is less costly or more efficient than developing and maintaining a broad set of ties across organizational boundaries (Arrow, 1974; March and Simon, 1958; Tushman and Scanlan, 1981a). With a collective bridge, the cost to develop and maintain each tie in the form of training, travel, and IT support may not increase significantly with the complexity of knowledge to be transferred. The total cost of developing and maintaining a collective bridge, however, increases with the level of knowledge complexity. Based on the definition of collective bridge given in Equations 1 and 2, the total number of ties (denoted as Y) in a collective bridge that is used to transfer a set of knowledge with N expertise areas and K interdependencies can be calculated as $Y = N + 2K$. Thus, the total cost of building and maintaining a collective bridge, the product of Y and the cost per tie, increases with K, which is an indicator of knowledge complexity.

There are other forms of cost associated with maintaining a collective bridge. First, when many members engage in cross-unit knowledge transfer, development and maintenance of contacts with members of other units can take a lot of time and may divert attention from performing productive activities and may also undermine group cohesion within the unit (Ancona, 1990). Second, without a centralized authority in the interunit structure, a collective bridge may lack direction and control and consequently engender more confusion and conflict than a centralized boundary spanner structure (Arrow, 1974). Third, a broad network of knowledge transfer may result in critical breaches of confidentiality (Bouty, 2000). Accordingly, additional effort and investment for preventing undesirable knowledge spillover may be necessary when using a collective bridge. Given these costs, a collective bridge is likely to be more expensive than a boundary spanner structure even when knowledge complexity is low.

Proposition 4: The costs of developing and maintaining a collective bridge are greater than the corresponding costs of a boundary spanner structure at all levels of knowledge complexity. The costs of developing and maintaining a collective bridge increase with the level of knowledge complexity at a rate that is greater than the corresponding rate of a boundary spanner structure.

A CONTINGENCY FRAMEWORK OF INTERUNIT STRUCTURES

The above discussions explain how the effectiveness and the costs of development and maintenance of two interunit structures may vary with the level of knowledge complexity. What determines the utility or desirability of a structure at a given level of knowledge complexity is its efficiency, which is its effectiveness less its cost of development and maintenance. We regard effectiveness of an interunit structuring as the lack of productivity loss due to its incapability of transferring knowledge. Since knowledge is invested within a given business practice, flaws or failures in knowledge transfer cause substantial loss of productivity (Carlile, 2004). By combining the cost due to productivity loss (denoted as C_{pl})—the inverse of effectiveness—and the cost of development and maintenance (denoted as C_{dm}), we obtain the total cost associated with using a certain knowledge transfer structure (C_{total}), which in essence is the inverse of the overall efficiency (i.e., effectiveness less cost of development and maintenance or C_{dm}) of a knowledge transfer structure. Specifically, a low level of C_{total} implies a high level of efficiency.

As discussed above, both effectiveness (i.e., the inverse of C_{pl}) and costs of development and maintenance (i.e., C_{dm}) of the two interunit structures may change with the level of knowledge complexity. The magnitude of C_{total} of these structures, therefore, also varies with the level of knowledge complexity. Figure 4 illustrates C_{total}, C_{pl}, and C_{dm} of these two structures. The thin lines represent C_{dm} as a function of knowledge complexity (denoted as x), the thick

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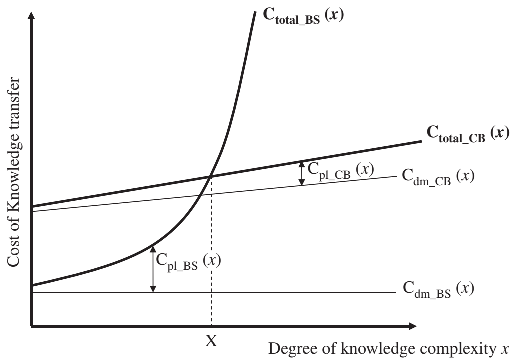

Figure 4. Cost of boundary spanner and collective bridge as functions of knowledge complexity

lines represent C_{total} as a function of x, and the gap between the thick and the thin lines represents the magnitude of C_{pl} as a function of x. The main goal of this paper is to develop a contingency framework that compares the total cost (i.e., the inverse of efficiency) of boundary spanner structures (denoted as C_{total_BS}) and that of collective bridges (denoted as C_{total_CB}) at different levels of knowledge complexity. We derive this framework by taking the following steps.

First, we compare the development and maintenance cost of the collective bridge and boundary spanner structure (denoted as C_{dm_CB} and $C_{dm\_BS,}$ respectively). Proposition 4 suggests that at any given level of knowledge complexity, a collective bridge is more costly than a boundary spanner structure to develop and maintain. As the level of knowledge complexity increases, C_{dm_CB} increases faster with x than C_{dm_BS}, according our discussions leading to Proposition 4. As such, the difference between C_{dm_CB} and $_{C\ dm\_BS}$ increases with the knowledge complexity.

Second, we compare the cost of productivity loss of the two knowledge transfer structures (i.e., C_{pl_CB} and C_{pl_BS}), as functions of knowledge complexity. As discussed in the section leading to Proposition 1, with boundary spanner structures, the cost of productivity loss (C_{pl_BS}) can become prohibitively high when the extent of knowledge complexity reaches a certain threshold. In other words, when x reaches a certain level, the function of C_{pl_BS} (x) will exhibit a steep increase (see Figure 4). On the other hand, when using a collective bridge, the cost of productivity loss will rise mildly with the increase of knowledge complexity, because as discussed in the section leading to Proposition 3, by including a broader range of interunit ties, the collective bridge can effectively overcome the cognitive and motivational challenges related to the transfer of collective knowledge.

Finally, since both C_{dm_BS} and C_{pl_CB} increase mildly with x, the comparison of the total cost between the two knowledge transfer structures boils down to the comparison between C_{pl_BS} (x) and C_{dm_CB} (x), which rise significantly with x. Based on prior discussions, C_{dm_CB} (x) increases linearly with x, whereas C_{pl_BS} (x) rises steeply after x reaches a threshold as the complexity of knowledge reaches beyond the cognitive limit of boundary spanners. As a result of this difference between C_{pl_BS} (x) and C_{dm_CB} (x), $C_{total\_BS}(x)$ will exceed C_{total_CB} (x) when x reaches a critical point X as shown in Figure 4. When x is below the X, C_{total_BS} (x) is lower than C_{total_CB} (x). As x increases, the gap between the two functions diminishes quickly. Eventually, when knowledge is sufficiently complex, i.e., when x reaches the critical point X, C_{total_BS} (x) intersects and surpasses C_{total_CB} (x). In summary, when knowledge complexity is sufficient large, the cost of productivity loss due to a boundary spanner structure's inability to coordinate and motivate the transfer of collective knowledge offsets its advantage of lower development and maintenance cost, and as a result, a collective bridge surpasses the boundary spanner structure as the more efficient transfer structure. In other words, when knowledge complexity is high, the higher cost of productivity loss of the boundary spanner structure will justify the use of a collective bridge, even though a collective bridge incurs higher development and maintenance costs at all levels of knowledge complexity.

Proposition 5: For interunit knowledge transfer, a boundary spanner structure is more efficient than a collective bridge when the level of knowledge complexity is relatively low; however, when knowledge complexity increases above a certain threshold, a collective bridge becomes more efficient than a boundary spanner structure.

DISCUSSION

Efficient transfer of knowledge, especially collective knowledge, is imperative for a firm's

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competitive advantage. While factors that facilitate knowledge transfer have been studied extensively in the strategy literature, most attention has been given to the attributes and strategies of a source or a recipient unit rather than the linkage between the two units. This paper seeks to spur thinking on a long neglected but critical issue: the *interunit structures* that efficiently facilitate the transfer of knowledge with different degrees of complexity. According to a review of empirical knowledge network research in the past four decades (Phelps *et al.*, 2012), most studies treat interunit structures as unitary ties rather than a complex nexus of relationships. In this paper, we go beyond this simplistic treatment of interunit structure by studying this structure as a set of relationships rather than as a single tie. Our goal is to develop a fine-grained understanding of how the configuration of the interunit structure facilitates the transfer of knowledge with different levels of complexity.

By introducing an alternative knowledge transfer structure to the boundary spanner structure—collective bridge—we made several contributions to the understanding of knowledge transfer and organizational structure. First, we uncover the importance of interunit cross-expertise ties for the transfer of collective knowledge. A key to the success of transferring collective knowledge is the understanding of the broad scheme of interdependencies among knowledge elements (Rivkin, 2000). Interunit cross-expertise ties that match the complexity of the knowledge to be transferred can effectively help the members of the recipient unit to understand the nature and implication of interdependence among different expertise areas, and thus help them to achieve better communication and understanding with each other in order develop desirable capabilities.

Second, by introducing the concept of the collective bridge, we bring needed attention to the interunit knowledge transfer structure, which is understudied in both network and knowledge transfer literature. With a comparison to the centralized interunit structure of boundary spanners, we point out several unique advantages of the decentralized collective bridge in transferring collective knowledge, such as shortest (i.e., direct) interunit cross-expertise ties which allows for less knowledge loss, distortion, and time delays, as well as motivational benefits due to lighter workload, greater trust, and more autonomy or empowerment.

The third and the most important contribution of this paper is the development of a contingency framework of the interunit knowledge transfer structures by examining of the efficiency of boundary spanner structures and collective bridges as a function of knowledge complexity. This framework shows that neither a boundary spanner structure nor a collective bridge is universally efficient. When the knowledge to be transferred across units is relatively simple, i.e., contains less collective knowledge, a boundary spanner structure is more efficient than a collective bridge. However, when the knowledge transferred across units becomes sufficiently complex, a collective bridge will surpass a boundary spanner structure in efficiency. This framework extends the well-received research on boundary spanners by including an alternative interunit knowledge transfer structure (i.e., collective bridge), integrating the concept of knowledge complexity with knowledge transfer structure and combining effectiveness considerations with cost concerns.

This paper also bears practical significance. The key insight here is to select an interunit knowledge transfer structure that *matches* the nature of knowledge. Managers facing the task of interunit capability transfer should first consider whether the knowledge they intend to transfer has a high level of collective knowledge content. Capabilities in the areas such as production, R&D, logistics, and general management usually involve a high level of knowledge complexity among different expertise areas, and thus have a significant amount of collective knowledge. To transfer these types of capabilities from one unit to the other, decision makers should consider using a collective bridge rather than solely relying on boundary spanners. However, if the knowledge to be transferred across units is discrete or individually held, a collective bridge would be an inefficient overshoot. When the knowledge to be transferred is complex to a point where it would be more efficient to use a collective bridge, decision makers need to decide on the configuration of a collective bridge based on the interdependencies among expertise areas involved in the capability to be transferred. For example, if the capability to be transferred is the R&D capability of a certain product, which involves in interdependence among K areas of expertise, then the collective bridge between a source and a recipient unit should include direct interunit cross-expertise ties among these areas. In other words,

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an individual with one of the K areas of expertise in the recipient unit should develop direct ties with individuals in all of the K areas in the source unit.[4] This diverse set of interunit ties will help members of the recipient unit to understand the overall 'template' of the source unit's R&D capability and, as result, will develop in an efficient way their own R&D capability based on this template. One of the ways to develop a collective bridge in a timely manner is by exposing relevant members of a recipient unit to the working environment of the source unit over a sufficient period of time through joint work projects. As we mentioned before, an empirical study found that sending a R&D team from a multinational firm's foreign affiliate to the multinational firm's home R&D unit for on-the-job training helped to develop a collective bridge between the two R&D units (Zhao, 2005).

We hope this paper encourages more research in the areas of interunit knowledge transfer structures and collective knowledge. Here we suggest a few potential areas for future study. First, for succinctness, we discuss collective bridge and boundary spanner structures as two alternatives in this paper. However, these two knowledge transfer structures may not be mutually exclusive in practice. In fact, boundary spanners may play a valuable complementary role in capability transfer. It would be interesting to study the relationship between these two structures in order to understand whether they are complementary or substitutive at different levels of knowledge complexity.

Second, an organizational ability to recognize, develop, and utilize different interunit structures under different conditions could be an important component of the knowledge transfer capability. Since this capability affects a firm's spread and exploitation its competencies, the causes and effects of such capability could be a useful topic for future research.

Third, it would be interesting to study further the effect of interunit ties on the formation of intraunit ties in a recipient unit. In this paper, we suggest that interunit cross-expertise ties will help the formation of intraunit cross-expertise ties during the knowledge transfer process. Future studies may examine fine grained network features (such as tenure heterogeneity) of a collective bridge and their effect on the formation of cross-expertise ties within the recipient unit.

Lastly, it is important to study the impact of the increasingly efficient adoption of information technologies on the differential cost between maintaining a collective bridge and a boundary spanner structure. Since a collective bridge involves more ties than a boundary spanner structure, lower cost of information technology implies greater cost savings for the collective bridge than for the boundary spanner structure. As a result, the point of intersection between the total cost of a boundary spanner structure and a collective bridge (i.e., X) as shown in Figure 4 may move toward the left side on the axis of knowledge complexity, indicating that with a more efficient adoption of information technology, the efficiency of a collective bridge may exceed that of a boundary spanner structure even when transferring less complex knowledge.

In summary, this paper advances knowledge transfer and knowledge network literature by proposing an interunit knowledge transfer structure—a collective bridge—as an alternative to a boundary spanner structure. By examining how the effectiveness and costs of collective bridge and boundary spanner structures vary with the extent of knowledge complexity, we develop a contingency framework of knowledge transfer efficiency that helps to guide the choice of efficient interunit knowledge transfer structure based on the level of knowledge complexity.

[4] It should be noted that the strength (measured by the frequency of communication) and duration among these K ties may differ. Interunit and within-expertise ties may likely be stronger and more lasting than interunit cross-expertise ties, because the former type of ties transfers both individual and collective knowledge, whereas the latter type only serves to transfer collective knowledge.

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APPENDIX

Concept	Definition
Boundary spanner	Boundary spanners are individuals who operate at the periphery or boundary of an organization, performing relevant organizational tasks and relating the internal organization to external elements (Leifer and Delbecq, 1978).
Interunit boundary spanner structure	In the context of interunit knowledge transfer, boundary spanner structure is a centralized interunit structure characterized by indirect knowledge transfer channels through limited number of boundary spanners (Conway, 1997).
Collective bridge	Collective bridge is a set of diverse and direct interunit ties connecting the members of the source and the recipient unit, with the configuration of the ties matching the complexity of collective knowledge intended for transfer.
Complexity of knowledge	A key dimension of knowledge is complexity, which refers to the extent of interdependencies or interactions among different subareas of the totality of the knowledge (Simonin, 1999; Winter, 1987).
Interdependence among expertise areas	The interdependence among areas of expertise arises when one area of expertise significantly affects the contribution of one or more other areas of expertise to the overall outcome (Sorenson *et al.*, 2006).
Collective knowledge	Collective knowledge is the knowledge embedded among individuals regarding how to coordinate, share, distribute, and recombine individual knowledge (Grant, 1996; Spender, 1996).
Cross-expertise understandings	Cross-expertise understandings are the knowledge held by one specialist regarding how the decisions of another specialist with different expertise may impact the effectiveness of his or her own decisions when working jointly in an interdependent task.
Tie	A tie refers to a relationship connecting two entities or actors for transmitting knowledge or information.
Interunit cross-expertise tie	An interunit cross-expertise tie is a communication link between a member of the source unit with a certain expertise area (E_i) and a member of the recipient unit with a different expertise area (E_j, $j \neq i$).

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