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Corey Phelps, Ralph Heidl and Anu Wadhwa

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Knowledge, Networks, and Knowledge Networks: A Review and Research Agenda

Corey Phelps
HEC Paris
Ralph Heidl
Michigan State University
Anu Wadhwa
Ecole Polytechnique Fédérale de Lausanne

A large and growing body of empirical research shows that social relationships and the networks these relationships constitute are influential in explaining the processes of knowledge creation, diffusion, absorption, and use. The authors refer to such networks as "knowledge networks." They advance an understanding of knowledge networks at multiple levels by conducting a systematic review and analysis of empirical research published on this topic in leading management, psychology, sociology, and economics journals. The authors develop a comprehensive framework that organizes the knowledge networks literature, which they use to review extant empirical research within and across multiple disciplines and levels of analysis. They identify points of coherence and conflict in theoretical arguments and empirical results within and across levels and identify emerging themes and promising areas for future research.

Keywords: *knowledge networks; social networks; knowledge; learning; creativity; innovation*

Ever since Drucker (1969) coined the term *knowledge economy*, analysts have argued the world economy is driven increasingly by the intensive production, diffusion, and use of knowledge (Powell & Snellman, 2004). Evidence suggests the economic performance of individuals, organizations, and countries is growing more dependent on knowledge

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Corresponding author: Corey Phelps, HEC Paris, 1 rue de la Libération, 78351 Jouy-en-Josas, France

E-mail: phelps@hec.fr

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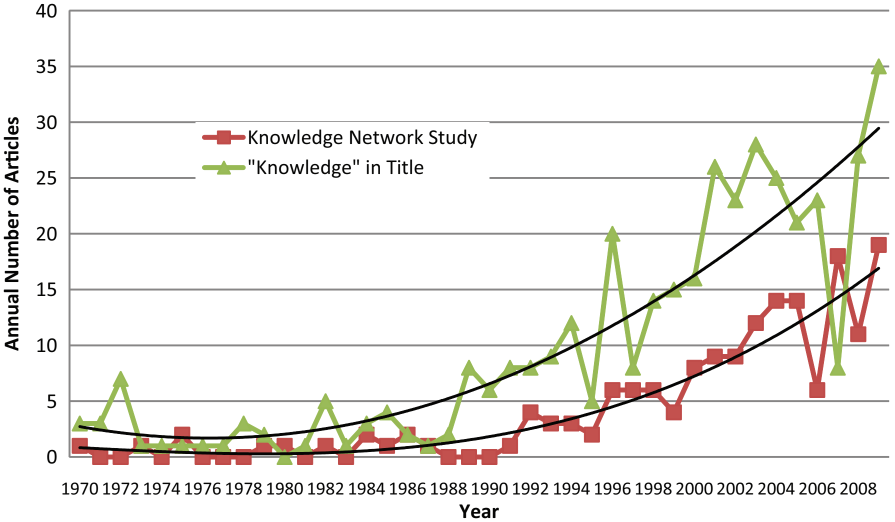
Figure 1
Growth in Studies on Knowledge and Knowledge Networks, 1970–2009 (12 journals)



production (Blundell, Dearden, Meghir, & Sianesi, 1999; Furman, Porter, & Stern, 2002; Roberts, 1999). A knowledge revolution is also occurring in academic research. In macroeconomics, the development of endogenous growth theory, where knowledge production and diffusion are central elements (Romer, 1990), led to a wave of research on the role of knowledge in economic growth (Aghion, Howitt, Brant-Collett, & García-Peñalosa, 1998) and radically altered thinking about the sources of economic expansion (Warsh, 2006). Strategy scholars are developing a "knowledge-based view" of the firm, theorizing firms exist because they provide efficiency advantages in the use, creation, and commercialization of knowledge relative to markets (Kogut & Zander, 1996) and that aspects of the knowledge-creation process influence a firm's scale and scope (Nickerson & Zenger, 2004). There is also a growing recognition that the development and deployment of knowledge is a principal source of firm competitive advantage (Eisenhardt & Martin, 2000; Grant, 1996). Finally, the appreciation of the economic importance of knowledge helped spawn the fields of "knowledge management" and its IT counterpart "knowledge management systems" (Maier, 2004), both of which address the management of organizational processes related to the creation, storage, retrieval, transfer, and application of knowledge (Alavi & Leidner, 2001). In sum, many fields are increasingly exploring how knowledge affects economic organization and performance and what individuals and collectives can do to manage knowledge. Consequently, the word *knowledge* has increasingly appeared in the titles of articles published in leading management, economics, psychology, and sociology journals in the past 20 years (see Figure 1).

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Interest in the relationship between knowledge and economic performance raises a fundamental question: What explains variation in the production, diffusion, and absorption of knowledge across individuals and collectives? Research suggests new knowledge is created from the novel combination of existing knowledge (Fleming, 2001; Nelson & Winter, 1982). The extent to which actors can effectively and efficiently search for, access, transfer, absorb, and apply knowledge influences their ability to create knowledge (Galunic & Rodan, 1998; Nahapiet & Ghoshal, 1998). A fast-growing body of research shows that characteristics of social relationships and the networks they constitute influence the efficacy and efficiency by which individuals and collectives create knowledge by affecting their ability to access, transfer, absorb, and apply knowledge (Figure 1). Collectively, we refer to such studies as "knowledge networks" research. We define a knowledge network as a set of nodes—individuals or higher level collectives that serve as heterogeneously distributed repositories of knowledge and agents that search for, transmit, and create knowledge—interconnected by social relationships that enable and constrain nodes' efforts to acquire, transfer, and create knowledge.[1] An understanding of knowledge networks is vital to understanding knowledge creation and economic growth: Knowledge production and diffusion, which are central to explaining economic growth (Romer, 1990), are increasingly the result of collaborative relationships among individuals, groups, and organizations (Powell & Grodal, 2005; Wuchty, Jones, & Uzzi, 2007), and collaboration can improve the quality and economic value of newly created knowledge (Singh & Fleming, 2010).

Knowledge networks research spans multiple fields and levels of analysis. For example, at the interpersonal level, sociologists, psychologists, and organizational behavior scholars have studied the influence of social networks on individual creativity (Burt, 2004; Perry-Smith, 2006) and the influence of relational quality on knowledge sharing between individuals (Bouty, 2000). In sociology, there is a tradition of research on the influence of social network structure on the diffusion of information and the adoption of innovations (Becker, 1970; Bothner, 2003). Recently, economics has begun to explore how networks influence knowledge production and diffusion (Azoulay, Zivin, & Wang, 2010; Jackson, 2008). At the group level, management scholars have examined how the social network structure within and beyond teams influences how they exchange, combine, and create knowledge (Reagans & McEvily, 2003; Reagans & Zuckerman, 2001). Psychologists have explored how groups develop "transactive memory systems" and how this affects group performance (Austin, 2003). Within organizations, scholars have investigated how the strength of interdivisional ties influences knowledge transfer (Hansen, 1999) and how a division's position within its intraorganizational network affects its innovativeness (Tsai, 2001). Finally, at the interorganizational level, strategy researchers have examined how characteristics of strategic alliances affect interfirm knowledge transfer (Lane & Lubatkin, 1998) and how alliance network structure affects firm innovation (Ahuja, 2000; Schilling & Phelps, 2007).

The diversity of this knowledge networks research raises several important, yet largely unexplored questions. Are there points of convergence in this research? To what extent are theoretical arguments about the influence of social networks on knowledge-related processes isomorphic across levels of analysis? Moreover, to what extent have empirical results accumulated and been replicated across fields and levels? Are researchers who focus on different levels of analysis and who come from different fields investigating unrelated or

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similar aspects of knowledge networks? What are the current themes emerging from this research and the unanswered questions? As research continues to progress within fields and levels, it becomes increasingly important to evaluate the degree of coherence and integration across these separate areas of inquiry. Without systematically addressing this issue, we risk the balkanization of research on knowledge networks, reducing the ability of researchers to learn from one another.

Although knowledge networks research is inherently multilevel and has grown rapidly in the past decades by attracting much attention from multiple disciplines, it has not been the subject of previous review, making it an ideal topic for systematic examination (Short, 2009). We advance an understanding of the influence of social networks on knowledge creation, diffusion, and use at multiple levels by conducting the first systematic review and analysis of *empirical* research published on this topic in top management, psychology, sociology, and economics journals during the past 40 years. In doing so, we make several contributions. First, while recent work has reviewed various aspects of the social networks literature (Borgatti & Cross, 2003; Brass, Galaskiewicz, Greve, & Tsai, 2004; Hoang & Antoncic, 2003; Provan, Fish, & Sydow, 2007) and related research on social capital (Payne, Moore, Griffis, & Autry, 2011), no systematic review of empirical research on knowledge networks exists. This is surprising given the importance of the topic and the growing attention it has received. Second, we develop a comprehensive framework that organizes this literature, which we use to review empirical research within and across multiple disciplines and levels of analysis. Third, we identify points of coherence and conflict in theoretical arguments and empirical results within and across levels and across knowledge-related outcomes. Fourth, we identify network-related constructs, relationships among them that are isomorphic across levels, and cross-level relationships, thereby contributing to the development of a multilevel theory of knowledge networks (Moliterno & Mahony, 2011). Finally, we highlight promising areas for future research by identifying emerging themes, important unexplored questions, and critical limitations of extant research. By synthesizing and critically evaluating four decades of research about knowledge networks across multiple fields and levels, we hope to foster a greater understanding of, and increased knowledge creation about, knowledge networks.

Method of Review and Organizing Framework

We followed a five-step approach to manage the scope of our review and ensure representative coverage of relevant studies. First, because our focus is on taking stock of what we know about knowledge networks through accumulated empirical evidence, we followed previous reviews with a similar objective and limited our review to empirical studies (Haleblian, Devers, McNamara, Carpenter, & Davison, 2009; Provan et al., 2007). Including untested theoretical arguments would make it difficult to compare and contrast studies since some would contain empirical findings regarding particular theoretical arguments while others would not. Moreover, mixing insights from untested theoretical ideas with empirical results could prove misleading as unsubstantiated and possibly incorrect ideas are given equal credence as rigorously tested and replicated empirical results. Finally,

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because insights from theoretical/conceptual work typically find their way into empirical research, excluding such research should not substantively diminish our conclusions. We limited our review to empirical studies in economics, management, psychology, and sociology from 1970 to 2009. Second, we limited our search to research published in six leading management journals and six leading social science disciplinary journals.[2] We developed this list by identifying top-ranked journals in the relevant fields in published journal rankings. We oversampled management journals because they publish much of the research on the topic. Third, we searched the titles and abstracts of these journals using combinations of keywords drawn from lists indicative of the term *knowledge* and of the concept of *network*. This search yielded 3,261 articles. Fourth, we independently reviewed the abstracts of these articles for relevance. We deemed an article as potentially relevant if it satisfied three conditions: (1) it was empirical (rather than theoretical or conceptual), (2) at least one explanatory variable or construct represented a characteristic of a social relationship or a collection of social relationships, and (3) the (or at least one) dependent variable was indicative of knowledge creation, knowledge transfer/flow, knowledge storage, knowledge retrieval, knowledge adoption, knowledge use, or learning by an individual or social collective. We resolved differences in opinions about inclusion/exclusion through discussion. Using these criteria, we removed 3,028 articles. Finally, we performed a detailed content analysis of each study to confirm relevance, resulting in a final set of 167 articles.

We then coded and categorized these articles. We coded the primary variables and key findings and induced a framework for organizing research on knowledge networks, which facilitates its presentation. Our induction process was informed by: (1) conceptualizing social networks as consisting of nodes and relationships among nodes (Wasserman & Faust, 1994), (2) schemas used in reviews of social network research that categorize studies by the features of social networks (Borgatti & Cross, 2003), and (3) reviews of knowledge management research that emphasize knowledge processes (such as transfer, use, and creation) and characteristics of knowledge (Argote, McEvily, & Reagans, 2003). Our typology organizes knowledge network research based on three important dimensions: *knowledge outcomes* (knowledge creation, knowledge transfer and learning, and knowledge adoption), *knowledge network properties* (properties of network structure, relations, nodes, and knowledge flows), and *level of analysis* (interpersonal, intraorganizational, and interorganizational). Figure 2 displays this framework.

We identified three types of knowledge-related outcomes. *Knowledge creation* refers to the generation of new knowledge, typically in the form of ideas, practices, research papers, technical inventions, or products. *Knowledge transfer* refers to the efforts of a source to share information and knowledge with a receiver and the receiver's efforts to acquire and absorb (i.e., learn) it. *Knowledge adoption* refers to the decision and ability to use or implement a discrete element of knowledge, often in the form of a product, practice, or paper. Studies of the adoption and diffusion of novel artifacts, such as innovative products or practices, are useful to understanding knowledge networks because this research explains artifact adoption by identifying how and why networks influence to whom information about such artifacts flows. Although conceptually distinct, these outcomes are related. Once knowledge is created, cognitive and other resources are needed to transform and translate it to facilitate its transfer, which is often necessary for discrete, embodied knowledge to be adopted and used

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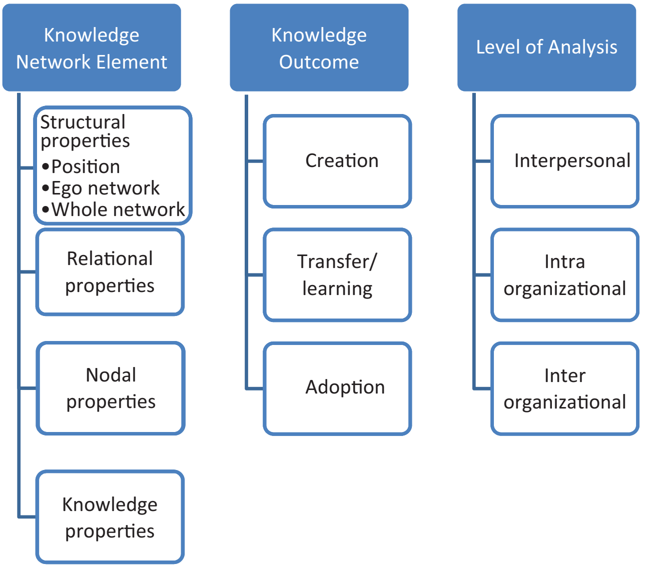
Figure 2
Organizing Framework for Knowledge Networks Research



in subsequent recombination efforts (Carlile, 2004). Most studies examined knowledge transfer (44%), followed by creation (38%) and adoption (17%).

We also organized knowledge networks research based on the network element(s) a study examined. We conceptualize knowledge networks as consisting of *nodes* that serve as repositories of knowledge and agents that search for, adopt, transmit, and create knowledge. Nodes are simultaneously sources and recipients of information and knowledge. Nodes may be individuals or collectives such as teams, organizational subunits, organizations, or even nation-states. The inherent characteristics, traits, and resource endowments of network nodes are generally referred to as *network composition*. Knowledge networks also consist of social *relationships* between nodes. These relationships constitute a means by which nodes search for information and knowledge, a medium through which information and knowledge diffuse and flow, and a lens through which nodes evaluate each other (Podolny, 2001). Knowledge networks research has explored a variety of characteristics of formal and informal relationships that influence knowledge outcomes. Next, research has examined how the pattern of relationships that exist among a set of nodes (i.e., knowledge network *structure*) affects knowledge outcomes. Broadly, research has explored three structural features of knowledge networks: the location of a node relative to others (i.e., network position), the pattern of ties within a focal node's immediate set of contacts (i.e., ego network structure), and the pattern of ties among all nodes in a bounded population (i.e., whole network structure). Finally, this research has examined how various *properties of knowledge*, such as tacitness and complexity, influence its creation, transfer, and adoption. Structural properties of knowledge networks

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were the focus of the largest proportion of studies (33%), followed closely by relational (27%) and nodal properties (26%). Knowledge attributes were much less studied (12%).

The final dimension concerns the level of analysis employed in knowledge network studies. We categorized studies based on whether they focused on interpersonal, intraorganizational, or interorganizational relationships. Interpersonal studies focus on individuals and the relationships among them, while interorganizational studies focus on organizations and the ties that connect them. Intraorganizational research differs from interpersonal and interorganizational studies because of its dual focus on the relationships among members of a collective within an organization, such as a team or division, and the relationships these collectives have with each other in the same organization. The largest portion of studies in our sample focused on the interorganizational level (42%), followed by interpersonal (31%) and intraorganizational (27%).

We organize our review first by level of analysis and secondarily by network element and knowledge outcome. The nodes at each level of analysis (e.g., individuals, groups, and organizations) represent the principal agents of action that are involved in and pursue the knowledge outcomes of creation, transfer, and adoption. These agents affect and are affected by the other knowledge network elements (i.e., network structure, relational, and knowledge characteristics). These nodes represent nested systems because organizations are multilevel systems of relationships (Hitt, Beamish, Jackson, & Mathieu, 2007). Nodes at lower levels of analysis are nested in higher level collectives and these collectives are themselves networks of nodes at lower levels of analysis (Harary & Batell, 1981). Because knowledge outcomes exist at multiple levels of analysis and each lower level unit is nested in a higher level unit, knowledge networks are fundamentally a multilevel phenomenon and require a multilevel theory. However, nearly all knowledge network research has focused on a single level of analysis and within-level network elements. Discriminating knowledge networks research by level allows us to compare and contrast concepts, theoretical mechanisms, and results across levels and contribute to the development of a multilevel theory of knowledge networks (see Moliterno & Mahony, 2011).

The remainder of the article is organized as follows. In the next section, we review the results of knowledge networks research within the interpersonal, intraorganizational, and then interorganizational levels of analysis. Within each level, we examine how each knowledge network element (in the order of structural, relational, nodal, and knowledge properties) affects each knowledge outcome. Finally, we identify points of coherence and conflict in theoretical arguments and empirical results across levels and provide recommendations on how future research should proceed to address unexplored topics, ambiguous results, and other limitations of extant research.

Within-Level Analysis

Interpersonal Knowledge Network Research

Structure

Interpersonal knowledge network research has examined three structural features of networks: network position, ego network structure, and whole network structure.

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Network position. An individual's network position captures her or his social proximity to other individuals in a network. Studies define proximity in terms of the number, length, and strength of the paths that connect individuals (i.e., social cohesion) or in terms of the similarity of their profiles of network relations (i.e., structural equivalence). The cohesion perspective views ties as pipes through which information and knowledge flow and characterizes network position in terms of centrality—the extent to which an individual is well connected, both directly and indirectly, to others in the network. Direct ties enable greater communication frequency and the sharing of more relevant and higher fidelity information than indirect ties (Singh, 2005). The typical cohesion explanation for the effect of network position on knowledge outcomes is that centrality provides individuals with timelier access to more, richer, and more diverse information, increasing the extent to which they learn from their network and their potential to synthesize and recombine this information into novel ideas (e.g., Burt, 2004; Ebadi & Utterback, 1984; Morrison, 2002).

Consistent with this perspective, persons with more ties to prior adopters of an innovation are more likely to adopt it (Strang & Tuma, 1993), and individuals with larger networks in their organization learn more about it (Morrison, 2002). Innovations are more likely to be adopted when the innovators occupy more central positions because centrality increases the availability of information about the innovator and provides a positive signal of her or his quality, both of which reduce potential adopters' uncertainty (Nerkar & Paruchuri, 2005). The extent to which an innovator's contacts are disconnected can amplify the quality signal associated with centrality (Nerkar & Paruchuri, 2005). Finally, because central individuals tend to have greater access to and control over valuable information flows, they have more power to influence others (Burt, 1982), which can increase their motivation and ability to adopt and implement innovations (Ibarra, 1993).

Research on network position and knowledge creation, however, has yielded conflicting results. While some studies suggest more direct ties improve an individual's innovativeness (Audia & Goncalo, 2007; Ebadi & Utterback, 1984; Laband & Tollison, 2000), others have found an inverted U-shaped effect (McFadyen & Cannella, 2004), suggesting the costs of more ties can ultimately exceed their benefits. Alternatively, the influence of network position may depend on whether an individual's ties span organizational boundaries. Individuals are more creative when their networks combine many ties to persons in other organizations, since boundary-spanning ties provide access to diverse information, with few intraorganizational ties, because peripheral players can act on diverse information free from the constraining influence of others (Perry-Smith, 2006).

In contrast to cohesion, structural equivalence defines social proximity as the similarity of two actors' profiles of network relations (Burt, 1987). Equivalent actors occupy substitutable social roles and compete for resources provided by others to which they are jointly connected, increasing their incentives to imitate each other to ensure no one has an advantage (Burt, 1987). Increasing equivalence between prior and potential adopters increases the odds of adoption (Burt, 1987; Strang & Tuma, 1993), while increasing equivalence among persons in an organization increases the similarity of what they learn and know about their organization (Walker, 1985).

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Ego network structure. This research has focused on triadic closure—whether or not a focal individual's direct contacts have ties to each other. When two of the ego's contacts do not share a tie, a structural hole exists between them (Burt, 1992). When all three maintain ties with one another, the triad is closed. Ego network density captures the extent to which triads in an ego network are closed, while measures of structural holes capture the extent to which triads are open. Research provides conflicting results and explanations about the influence of ego network structure on innovation adoption and implementation. One study suggests that because structural holes provide timely access to diverse information (Burt, 1992), innovators who span such holes are perceived as being rich and efficient sources of useful information, increasing the attractiveness of their ideas (Nerkar & Paruchuri, 2005). Other research suggests network closure promotes the adoption of an innovator's novel idea by increasing the rate and extent to which information about the idea spreads, increasing others' familiarity and affinity with it and the odds they will adopt it (Fleming, Mingo, & Chen, 2007). Network closure can also increase a person's involvement in implementing an innovation because ego can use the social capital generated by network closure to gain the cooperation of network members in implementing the innovation (Obstfeld, 2005).

Results of research examining the main effect of ego network structure on knowledge transfer are consistent yet conflict with the consistent findings on knowledge creation. While studies show network density increases knowledge transfer among network contacts and enhances learning (Morgan & Soerensen, 1999; Morrison, 2002; Reagans & McEvily, 2003), other research has consistently found a positive effect of structural holes on individual knowledge creation (Burt, 2004; Fleming, Mingo, et al., 2007; McFadyen, Semadeni, & Cannella, 2009). The positive effect of structural holes for knowledge creation increases with the strength of the ego's ties because strong ties promote intense knowledge sharing (McFadyen et al., 2009). However, because tie strength and network density tend to be mutually reinforcing and strongly correlated (Granovetter, 1983; Louch, 2000), a trade-off exists between social cohesion in an ego network and its structural diversity: While social cohesion from tie strength and network closure promotes greater knowledge flows, structurally diverse ego networks characterized by structural holes reduce such flows.

A contingency perspective may help reconcile these conflicting results since it is unlikely a particular network structure is universally beneficial (Adler & Kwon, 2002). The effect of ego network density may depend on the knowledge-related task being pursued, where structural holes are beneficial for some tasks and density is beneficial for others (Morrison, 2002), or on the network boundary—while density among the ego's contacts can enhance learning and knowledge transfer, contacts who span structural holes beyond the network can facilitate learning and knowledge creation by ensuring novel information flows into it (Morgan & Soerensen, 1999).

Finally, scholars have investigated the interaction effect of ego network structure and network composition on knowledge creation and have produced conflicting results. In finding a positive interaction between the diversity of knowledge possessed by an individual's direct contacts and the structural holes among them, Rodan and Galunic (2004) argued that measuring both the knowledge diversity in an individual's network and its structure enabled them to empirically separate the information and social control benefits associated with

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structural holes (Burt, 1992). In contrast, greater ego network density combined with contacts having more diverse expertise or more collaborative ties themselves can increase an individual's knowledge production because network density facilitates trust and reciprocity among network members, which increases their willingness to share their diverse knowledge and information with ego (Fleming, Mingo, et al., 2007).

Whole network structure. The few extant whole network studies show network connectivity (density) increases the rate, extent, and fidelity of information diffusion in a network (Singh, 2005), which can increase an innovation's diffusion by increasing the information available about it (Abrahamson & Rosenkopf, 1997) and can increase network member innovativeness (Ebadi & Utterback, 1984). Similarly, a decrease in a network's average path length increases network connectivity and improves network members' average innovation performance (Fleming, King, & Juda, 2007). Likewise, the probability of knowledge transfer between individuals declines as the path length between them increases (Singh, 2005). Finally, an innovation diffuses more rapidly and widely when otherwise disconnected segments of a network are linked by a concentration of ties (Abrahamson & Rosenkopf, 1997) and the transfer of complex knowledge between segments is enhanced when numerous ties, or "wide bridges," connect them (Centola & Macy, 2007).

Relational Properties

Research examining relational properties—the most studied aspect of interpersonal knowledge networks—has investigated the influence of the strength of interpersonal ties and the similarity or proximity of the actors involved on knowledge outcomes.

Tie strength. Relational research consistently shows strong interpersonal ties—characterized by high communication frequency, long duration, and affective attachment (Marsden & Campbell, 1984)—are more effective than weak ties in enhancing knowledge transfer and learning (e.g., Bouty, 2000; Levin & Cross, 2004; Uzzi & Lancaster, 2003). Strong ties help establish trust and reciprocity norms between individuals, which reduce concerns about opportunistic behavior and increase expectations of cooperation (Bouty, 2000; Levin & Cross, 2004; Uzzi & Lancaster, 2003), thereby increasing individuals' awareness of and access to each other's knowledge and their willingness to incur costs to transfer, receive, and absorb knowledge (e.g., Appleyard, 1996; Kachra & White, 2008; Quigley, Tesluk, Locke, & Bartol, 2007). In contrast, the degree to which an individual *distrusts* her or his contacts can increase her or his awareness of their competencies, increasing her or his efficiency in searching her or his network for useful knowledge (Jarvenpaa & Majchrzak, 2008).

Research also shows tie strength improves particular types of knowledge transfer, learning, and an individual's ability to benefit from collaborating with diverse partners. Tie strength increases the ease and efficacy of transferring complex, tacit knowledge (Centola & Macy, 2007; Reagans & McEvily, 2003) and private knowledge (Uzzi & Lancaster, 2003) and improves exploratory learning (Uzzi & Lancaster, 2003). Individuals who have strong ties to others with dissimilar competencies (Ebadi & Utterback, 1984) or to others separated by structural holes (McFadyen et al., 2009) are more innovative, suggesting the social cohesion

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provided by strong ties enhances an individual's ability to create knowledge from collaborating with partners possessing diverse knowledge.

Finally, studies have examined how tie strength affects knowledge creation. Although the putative utility of weak ties for creativity is that they provide access to disconnected partners and thus diverse information (Burt, 1992; Granovetter, 1973), Perry-Smith (2006) found a person's weak ties had a positive effect on creativity beyond that provided by structural holes. This result suggests weak ties may have heretofore unacknowledged benefits for knowledge creation. In contrast, Zhou, Shin, Brass, Choi, and Zhang (2009) showed the number of weak ties had an inverted U-shaped effect on creativity. Research that averages the strength of a person's ties provides conflicting results. Some studies suggest average tie strength improves knowledge creation (Ebadi & Utterback, 1984; Moran, 2005; Scott & Bruce, 1994). Others have found an inverted U-shaped effect, arguing that increasing tie strength beyond a moderate level reduces the diversity of knowledge to which ego has access and thus knowledge creation (McFadyen & Cannella, 2004; McFadyen et al., 2009), which suggests a mixture of weak and strong ties is best for ego's knowledge creation.

Nodal proximity/similarity. While two individuals are *socially* proximate when they maintain a direct tie, the effects of other dimensions of dyadic proximity on knowledge outcomes have also been explored, including competitiveness, geography, expertise, status, and personality.

Although ties within an organization reduce competitive concerns and increase individuals' willingness to transfer and absorb knowledge (Kachra & White, 2008), persons involved in ties that cut across competitive groups within an organization or across competing organizations have diminished motives to share knowledge (Bouty, 2000; Kachra & White, 2008). The rate of technological change in an industry reduces the willingness of persons from rival firms to share knowledge because doing so can facilitate rivals' imitation of each other's innovations, which are more frequent and strategically important in rapidly changing industries (Appleyard, 1996).

The geographic distance between members of a tie also influences their knowledge outcomes. Although geographic proximity can increase the efficiency and efficacy of communication and knowledge transfer, the knowledge transferred will be less novel, and thus less useful, than knowledge transferred between geographically distant persons because knowledge tends to be more homogenous within a geographic region than across regions (Bell & Zaheer, 2007). The institutional domain of knowledge creation—either in the open scientific community or in the commercial domain—moderates the influence of geographic proximity on its subsequent adoption (Gittelman, 2007). Although knowledge produced by geographically close collaborators is more likely to be used as the foundation for a new technology and less likely to be used by other scientists, research produced by long-distance collaborations is less likely to serve as the basis for a new technology but more likely to be used by other scientists (Gittelman, 2007).

Finally, the similarity of dyad members' expertise, status, and personality affects knowledge transfer. Dyad members with similar expertise can communicate more efficiently, increasing their expectations that knowledge transfer costs will not exceed the benefits, thus increasing their motivations to share and absorb knowledge (Black, Carlile, & Repenning,

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2004; Reagans & McEvily, 2003). While social status differences can increase the motivations of lower-status persons to share knowledge with those of higher status (Thomas-Hunt, Ogden, & Neale, 2003), higher-status persons tend to reject such efforts (Black et al., 2004; Thomas-Hunt et al., 2003). In contrast, status similarity increases a person's willingness to receive knowledge, facilitating its transfer (Black et al., 2004). Personality similarity can increase trust, mutual identification, and respect, increasing collaborators' motivation to share and receive knowledge (Allen & Eby, 2003).

Nodal Properties

The few studies that consider individuals apart from other knowledge network elements have examined a person's power, absorptive capacity, transfer capacity, and diversity of network contacts. Individuals with power derived from their organizational role are able to challenge the status quo and effect change, which can increase their willingness to adopt and implement innovations (Ibarra, 1993). Individuals with more diverse expertise can communicate with and learn from others better, and ego network density enhances this effect because density increases collaborators' knowledge-sharing efforts (Fleming, Mingo, et al., 2007). Experience collaborating with others with diverse expertise increases a person's ability to convey complex ideas to diverse audiences, increasing the ease to which she or he can transfer knowledge to others (Reagans & McEvily, 2003). Likewise, a person's ability to adapt her or his communication to a recipient can increase the knowledge flow between them (Wang, Tong, Chen, & Kim, 2009).

Nodal research also shows the diversity of knowledge possessed by network contacts affects learning and knowledge creation. Consistent with structural holes theory (Burt, 1992), individuals learn more about their organizations when their direct contacts work in different organizational units because such contacts are disconnected from one another and provide diverse information about the organization (Morrison, 2002). Similarly, ego network knowledge diversity increases individual knowledge creation because such networks provide ego access to diverse knowledge, increasing opportunities for novel recombinations (Perry-Smith, 2006; Rodan & Galunic, 2004).

Other research examines the moderated and mediating influences of network composition. The positive effect of ego network knowledge diversity on individual knowledge creation is enhanced by the increased knowledge flow generated by social cohesion, through either network density (Fleming, Mingo, et al., 2007) or tie strength (Ebadi & Utterback, 1984). In contrast, an individual's network knowledge diversity can also mediate the relationship between the number of weak ties and creativity: Weak ties increase the presence of structural holes and access to diverse knowledge, which improves creativity by increasing the potential for novel recombinations of this knowledge (Perry-Smith, 2006). These results also imply a bandwidth-structural diversity trade-off: While social cohesion increases information and knowledge flow, it reduces structural holes.

Knowledge Properties

Interpersonal studies that have examined knowledge attributes are rare and have explored how properties of knowledge influence its transfer. These studies show that simple, codified

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knowledge is easier and more efficient to transfer than complex, tacit knowledge and that interpersonal tie strength increases the ease and efficacy of transferring complex, tacit, and private knowledge (Centola & Macy, 2007; Reagans & McEvily, 2003; Uzzi & Lancaster, 2003).

Intraorganizational Knowledge Network Research

Intraorganizational research differs from interpersonal and interorganizational research because of its dual focus on the relationships among individual members of a collective within an organization, such as a team or division, and the relationships these collectives have with each other. None of the intraorganizational studies we reviewed examined knowledge adoption.

Structure

Structural studies of intraorganizational networks have investigated the network position of collectives within organizations and network structure within and beyond a focal unit.

Network position. The results of research on the main effect of an organizational unit's network position on its knowledge outcomes are consistent. Because more central units have more and shorter paths to other knowledge sources in their intraorganizational networks, they are able to access and obtain more knowledge of greater fidelity (Gupta & Govindarajan, 2000; Hansen, 2002; Monteiro, Arvidsson, & Birkinshaw, 2008). As a result, a unit's intraorganizational network centrality enhances its knowledge creation (Tsai, 2001; Tsai & Ghoshal, 1998). Finally, the degree to which an organizational unit maintains ties with other organizations can increase the extent to which other units in its organization consider it an important source of knowledge, thereby increasing their motivation to learn from it (Andersson, Forsgren, & Holm, 2002).

Other studies have examined the contingent effects of a unit's network position. The influence of a unit's network centrality depends on its absorptive capacity: For units with little absorptive capacity, the costs of maintaining numerous relationships can exceed their knowledge benefits (Tsai, 2001). The effect of a unit's interunit ties on its performance depends on the properties of the transferred knowledge: The costs of maintaining direct ties to transfer codified knowledge typically exceed their benefits since such knowledge can be effectively transmitted and absorbed without such ties, whereas direct ties increase the efficiency of transferring tacit knowledge (Hansen, 2002).

Network structure within and beyond an organizational unit. Results regarding the influence of a collective's internal network structure on its knowledge outcomes are mixed. While studies show teams with internally dense networks are less likely to seek knowledge in the broader intraorganizational network (Hansen, Mors, & Lovas, 2005; Katz, 1982), others suggests dense internal structures promote knowledge sharing within collectives (Keller, 1986; Reagans & Zuckerman, 2001; Tushman & Katz, 1980), particularly when members possess specialized knowledge (Rulke & Galaskiewicz, 2000). Moving beyond a unit's internal network structure, Hansen (1999) found the density of a unit's ego network of interunit ties increases the knowledge it receives from them.

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Research that explores both the internal network structure of collectives and their composition may help reconcile these mixed results. Groups combining high internal density with more compositionally diverse members exhibit greater knowledge creation (Reagans & Zuckerman, 2001) and greater knowledge flows (Rulke & Galaskiewicz, 2000). These results suggest the compositional diversity of group members, in terms of their demographic characteristics or expertise, proxies for the structural holes they span beyond the group because diverse group members have different sets of extramural contacts and information sources (Cummings, 2004; Reagans & Zuckerman, 2001). Greater internal density increases internal knowledge flows and a shared understanding of who knows what in a group, which allows it to utilize the diverse external knowledge inflows more effectively in creating knowledge (Hulsheger, Anderson, & Salgado, 2009). These results indicate the internal network structure of an organizational unit and its ties to others beyond the unit are important to understanding its knowledge outcomes.

Whole network structure. Some research suggests the structure of an entire intraorganizational network affects knowledge flows within it. Tsai's (2002) results suggest high network centralization—the extent to which organizational units are connected only to a central unit, such as corporate headquarters—impedes intraorganizational knowledge transfer by reducing the discretion and willingness of organizational units to share their knowledge with one another.

Relational Properties

Intraorganizational knowledge networks research has examined tie strength between intraorganizational collectives and their geographic and competitive proximity.

Tie strength. Interunit tie strength provides both benefits and costs for a unit's knowledge outcomes. Regarding benefits, research consistently shows that strong ties—indicated by high levels of social interaction or frequent communication and affective closeness—within and between units lead to more effective knowledge sharing (e.g., Hansen, 1999; Schulz, 2003; Szulanski, 1996) and promote knowledge creation (Tsai & Ghoshal, 1998). Increasing tie strength among team members increases their knowledge sharing (Smith, Collins, & Clark, 2005) and helps them develop accurate mental models about which members know what, increasing their efficiency in searching for useful knowledge and improving group problem solving and innovation (Austin, 2003). Tie strength also provides beneficial moderating effects. Increasing tie strength promotes knowledge transfer by mitigating the negative influence of geographic distance, technological differences, and competition between units (Hansen & Løvås, 2004; Tsai, 2002) and improves the transfer of tacit and complex knowledge (Hansen, 1999; Hansen et al., 2005).

In contrast to these benefits, some studies suggest the costs of strong ties can diminish their knowledge-related benefits. Increases in the strength of a unit's interunit ties increase its search costs by reducing its autonomy and access to diverse information (Hansen, 1999; Hansen et al., 2005). At high levels of interunit tie strength, the cost of maintaining such ties

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can outweigh their knowledge-sharing benefits, reducing unit performance (Hoegl & Wagner, 2005). Increasing average tie strength among members of a collective encourages them to search for knowledge within the group and reduces their motivation to search beyond it (Hansen et al., 2005).

Nodal proximity/similarity. Research shows the closeness of organizational units in competitive and geographic space affects knowledge transfer between them. The extent to which organizational units compete for organizational resources reduces the motivation of a knowledge source to share knowledge, thus increasing the transfer costs for the knowledge-seeking unit (Hansen et al., 2005). The colocation of team members increases communication frequency and information sharing within teams (Bulte & Moenaert, 1998), while geographic proximity between units increases the efficacy of knowledge transfer between them (Hansen & Løvås, 2004; Salomon & Martin, 2008). The negative effect of geographic distance on knowledge transfer is mitigated when organizational units are members of the same formal organizational entity, such as a division or business group, and when they have collaborated in the past (Hansen & Løvås, 2004).

Nodal Properties

Nodal studies have treated the individuals who constitute organizational units and the units themselves as nodes and have examined characteristics of nodes associated with their absorptive capacity, transmission capacity, and power, the depth of knowledge possessed by a node's contacts, and the compositional diversity of intraorganizational collectives.

Research has examined characteristics of nodes as both recipients and sources of knowledge. The absorptive capacity (Cohen & Levinthal, 1990) of a receiving unit improves knowledge transfer (Szulanski, 1996) and its ability to utilize knowledge inflows to create knowledge (Smith et al., 2005; Tsai, 2001). Similarly, the depth of a recipient's knowledge increases its motivation and ability to receive knowledge, increasing the efficacy of transfer (e.g., Gupta & Govindarajan, 2000; Salomon & Martin, 2008). The depth of knowledge available to a recipient in its network provides it more opportunities to recombine this knowledge in novel ways, thereby increasing its innovativeness (Almeida & Phene, 2004). A recipient can also benefit from sources with deep expertise because they are more effective at transferring their knowledge (Salomon & Martin, 2008). A recipient unit with organizationally critical and unique knowledge has greater expertise power, which it can use to induce other units to transfer knowledge to it (Wong, Ho, & Lee, 2008). Conversely, units possessing organizationally unique knowledge (Schulz, 2001) that is of greater relevance to other units (Yang, Mudambi, & Meyer, 2008) are called on more to transfer their knowledge. Large units with substantial knowledge are more attractive knowledge sources and experience greater demand for their knowledge from less endowed units (Gupta & Govindarajan, 2000). Finally, compensating unit managers based on organizational performance increases their motivation to transfer and receive knowledge (Fey & Furu, 2008; Gupta & Govindarajan, 2000).

Results of research on the effect of compositional diversity within a collective on knowledge transfer and creation are mixed. Some research shows diversity in organizational

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tenure, function, and other demographic characteristics reduces a collective's innovativeness (Ancona & Caldwell, 1992; Lovelace, Shapiro, & Weingart, 2001). A meta-analysis found team members with more diverse information resources were less likely to share information with each other (Mesmer-Magnus & DeChurch, 2009). In contrast, West and Anderson (1996) found team cognitive diversity had no effect on team innovativeness. Another meta-analysis suggests the job-related (e.g., function, tenure) diversity of group members has a positive impact on group innovativeness, while differences in age, gender, or ethnicity have a negative influence (Hulsheger et al., 2009). Similarly, diversity in terms of members' location, functional role, and supervisor increases a team's access to diverse sources of knowledge beyond the team because diverse members have nonoverlapping sets of external contacts, which increase the positive effect of external knowledge sharing on team problem solving (Cummings, 2004). Finally, the utility of group knowledge diversity depends on the type of problem a group is solving: Relative to homogenous groups, those with diverse competences can find better solutions to cross-functional problems, but this advantage disappears as problem complexity increases (Kavadias & Sommer, 2009).

Research adopting a network perspective suggests these conflicting findings may be reconciled by disentangling the effects of diversity (Reagans & Zuckerman, 2001). While compositionally diverse groups have greater access to diverse information beyond the team (Cummings, 2004), they can suffer from ineffective communication and coordination, reducing their ability to use the diverse knowledge to which they have access (Reagans & Zuckerman, 2001). Teams with internally dense networks can overcome these problems: Groups that have both internally dense ties and bridges to diverse external knowledge are more innovative (Reagans & Zuckerman, 2001).

Knowledge Properties

Intraorganizational research on the relationship between knowledge properties and knowledge outcomes is scarce. A consistent finding is that codification facilitates knowledge transfer while tacitness impedes it (e.g., Cheng, 1984; Haas & Hansen, 2007; Zander & Kogut, 1995). The tacitness of knowledge inflows decreases a unit's ability to recombine this knowledge into novel knowledge (Cheng, 1984). Other studies suggest the complexity (Salomon & Martin, 2008) and causal ambiguity (Szulanski, 1996) of knowledge impede its transfer. The presence of a direct tie (Hansen & Løvås, 2004), the strength of this tie (Hansen, 1999; Hansen et al., 2005), and the number of such ties (Hansen, 2002) improve the transfer of tacit knowledge. Similarly, intraunit communication facilitates the development of shared mental models, which increases the internal sharing of tacit knowledge and unit knowledge creation (Cheng, 1984).

Interorganizational Knowledge Network Research

Structure

Similar to research at lower levels of analysis, interorganizational knowledge networks research has examined how organizational knowledge outcomes are influenced by interorganizational network position, ego network structure, and whole network structure.

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Network position. Many interorganizational studies have found that social proximity based on the number and intensity of direct ties to prior adopters increases the likelihood of adoption (e.g., Davis & Greve, 1997; Kraatz, 1998; Still & Strang, 2009). Studies examining the influence of interfirm partnerships on firm innovation, however, provide conflicting results. While many studies have found the more interfirm partners a firm has, the greater its innovation performance (e.g., Ahuja, 2000; Owen-Smith & Powell, 2004; Shan, Walker, & Kogut, 1994), other research suggests an increasing reliance on partners for knowledge can have a diminishing and ultimately negative effect on knowledge creation (Rothaermel & Alexandre, 2009; Wadhwa & Kotha, 2006), suggesting the costs of maintaining an increasing number of interorganizational relationships can exceed their knowledge-creating benefits. Still other research suggests it is the depth (Stuart, 2000) and diversity of knowledge (Baum, Calabrese, & Silverman, 2000) to which an organization has access via its partnerships that affects its innovation performance rather than the number of ties per se. Thus, an organization's number of partners may be a poor proxy for the volume, quality, and diversity of knowledge to which it has access. Finally, a rare multilevel study found that formal, contract-based interorganizational ties were largely ineffective in aiding organizations' source external knowledge relative to informal, interpersonal research collaborations that span organizational boundaries (Liebeskind, Oliver, Zucker, & Brewer, 1996). This result demonstrates the importance of examining both formal and informal relationships at multiple levels of analysis to understand better how knowledge networks influence organizational knowledge outcomes.

Research also has examined centrality measures that incorporate indirect ties. While indirect ties can benefit a recipient organization's knowledge production by providing it access to more diverse information, direct contacts collect and process this indirect information and can share it with greater richness and fidelity, thereby diminishing the influence of indirect ties on innovation (Ahuja, 2000). Similarly, recipient organizations whose direct ties connect them to a larger number of indirect ties have timelier access to more diverse information, which increases organizational learning (Beckman & Haunschild, 2002). Finally, an organization's centrality can increase an innovation's diffusion in a network, regardless of whether it adopted the innovation, because central nodes increase network connectivity and thereby increase the speed and extent to which information about an innovation reaches other network members (Gibbons, 2004).

A few studies have explored how an organization's network position and geographic location interact to influence its knowledge creation. While a firm's centrality within an alliance network of geographically dispersed firms improves its knowledge creation (Owen-Smith & Powell, 2004; Whittington, Owen-Smith, & Powell, 2009), centrality in a network of geographically close firms has either no effect (Owen-Smith & Powell, 2004) or a small positive influence (Whittington et al., 2009). Although knowledge diffuses more readily among colocated organizations (because employee mobility and informal social networks facilitate diffusion), these channels become less viable and influential as organizations become geographically dispersed, making an organization's centrality in the broader network of formal knowledge-sharing ties more influential (Owen-Smith & Powell, 2004). Finally, because an organization's centrality in a network of geographically dispersed organizations and its centrality in a network of colocated organizations provide similar benefits for knowledge creation, the two are partial substitutes (Whittington et al., 2009).

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Studies defining social proximity in terms of structural equivalence suggest a direct tie is unnecessary for information to diffuse between organizations (Burt, 1987). Computer makers are more likely to adopt the same technology previously adopted by structurally equivalent producers (Bothner, 2003), and a country is more likely to adopt a particular quality standard when structurally equivalent countries adopted the standard (Guler, Guillen, & Macpherson, 2002). The influence of equivalence is moderated by status: Low-status firms are more likely to imitate the adoption behavior of their structurally equivalent counterparts (Bothner, 2003). However, as the status similarity of a potential adopter and its structurally equivalent rivals increases, it is less likely to imitate their behavior because its managers may perceive there is little to learn from such rivals and imitation would undermine their own organization's status (Still & Strang, 2009).

Finally, a source organization's network position also affects how strongly it influences the decisions of potential adopters (Davis & Greve, 1997). Because greater centrality is associated with higher social status (Podolny, 1993) and higher status organizations are perceived as being of higher quality and more informed and diligent in their decisions (DiMaggio & Powell, 1983), the adoption decisions of more central organizations are more influential on potential adopters (Davis & Greve, 1997). Similarly, because central firms have many partners to assist them and have timely access to diverse information of high integrity, there is less uncertainty about their research quality and ability to commercialize new products, increasing the odds their products are adopted by customers (Soh, Mahmood, & Mitchell, 2004). This induces central firms to invest in innovation because it reduces their uncertainty about the returns to such investments (Soh et al., 2004).

Ego network structure. Two competing perspectives exist about the influence of ego network structure on actor knowledge outcomes, each with different causal mechanisms linking network structure to knowledge outcomes. Research has found support for both views, yielding conflicting results. While studies suggest structural holes in a firm's network enhance its knowledge creation (Baum et al., 2000; McEvily & Zaheer, 1999), other research suggests network closure improves firm innovation (Ahuja, 2000; Schilling & Phelps, 2007). Consistent with the latter results, research shows network closure enhances the diffusion of novel practices (Lawrence, Hardy, & Phillips, 2002) and the transfer of tacit knowledge (Dyer & Nobeoka, 2000). Like research on interpersonal networks, some interorganizational scholars have argued a contingency perspective of ego network structure may help reconcile these conflicting results. Ahuja (2000) argued that the type of tie is an important contingency variable: Because alliances among competitors are subject to substantial risks of partner opportunism, partners in horizontal alliances will benefit more from network density because it deters opportunism and encourages knowledge sharing.

Whole network structure. Little research has examined how the structure of a whole interorganizational network affects knowledge outcomes. Simulation research shows structures that increase the rate and extent of information diffusion, such as dense structures, also reduce information diversity (Lazer & Friedman, 2007). While rapid information diffusion enhances firm innovation and network performance, declining information diversity reduces them. Other studies suggest a "small-world" structure can balance these

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opposing forces. This research finds whole networks in which groups of organizations are densely interconnected yet maintain some ties across clusters, thereby reducing the network's average path length, can improve organizational innovation (Schilling & Phelps, 2007; Uzzi & Spiro, 2005). Both studies argued that local clustering promotes social cohesion and knowledge sharing, while a short average path length allows diverse knowledge from different clusters to diffuse across clusters. Excessive clustering, however, can reduce organizational innovation by creating dysfunctional levels of social cohesion and reducing the availability of diverse information within clusters (Uzzi & Spiro, 2005).

Relational Properties

This research has explored aspects of interorganizational ties that influence knowledge outcomes, including relationship strength, formal governance, and the competitive, technological and geographic proximity of the organizations involved.

Tie strength. Research provides conflicting results about the influence of interorganizational tie strength on organizational knowledge outcomes. Much of this research shows strong ties—characterized by long relationship duration, frequent and intense collaboration, and repeated partnering over time—increase innovation adoption (Goes & Park, 1997; Kraatz, 1998), knowledge transfer (Simonin, 1999; Tiwana, 2008; Williams, 2007), and organizational knowledge creation (Capaldo, 2007; Lavie, Lechner, & Singh, 2007; Sampson, 2007). The explanation for these results is that social cohesion (i.e., trust, reciprocity, and social identity) provided by strong ties increases the motivation of firms to share and receive knowledge. Greater social interaction (Sobrero & Roberts, 2001), the development of relational capital (Tiwana, 2008), and longer relationship duration (Simonin, 1999) have a positive effect on interfirm learning and knowledge transfer, while an increase in the depth and scope of interorganizational interactions helps diffuse practices (Lawrence et al., 2002). Increasing relationship duration can increase a recipient firm's understanding of a source's knowledge, improving its ability to adapt the source's knowledge to its operations and local context, thereby improving knowledge transfer (Williams, 2007).

Research also shows interorganizational tie strength improves the transfer of specific types of knowledge and an organization's ability to benefit from diverse partners. Greater joint problem solving by alliance partners, which is enhanced by interfirm trust and communication, facilitates the transfer of complex and tacit knowledge between them (McEvily & Marcus, 2005). The extent to which firms maintain different types of ties with each other strengthens their connection and the positive impact of partner diversity on firm learning (Beckman & Haunschild, 2002). Tie strength also increases the flow of diverse knowledge from bridging structural holes (Tiwana, 2008).

However, research also suggests strong interorganizational ties can have a negative influence. Prior alliances with the same partner, an indicator of tie strength, can reduce current R&D alliance project performance (Hoang & Rothaermel, 2005). Increasing levels of trust between partners can reduce their innovativeness by locking them into relationships at the expense of gaining access to diverse knowledge from new partners (Molina-Morales & Martinez-Fernandez, 2009; Yli-Renko, Autio, & Sapienza, 2001). While Molina-Morales

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and Martinez-Fernandez (2009) found an inverted U-shaped effect of interorganizational trust on organizational innovation, Yli-Renko et al. (2001) found that greater trust in a firm's tie with its primary customer reduced its innovativeness.

Governance. Research on interorganizational governance has found equity joint ventures facilitate knowledge transfer better than other governance modes (Mowery, Oxley, & Silverman, 1996; Oxley & Wada, 2009) and lead to increased organizational knowledge creation (Keil, Maula, Schildt, & Zahra, 2008; Sampson, 2007). Joint ventures also can increase the rate by which partners integrate each other's knowledge and can mitigate the unintended leakage of partner knowledge that is unrelated to the partnership (Oxley & Wada, 2009). The industry relatedness of partners can enhance the influence of formal governance on firm knowledge creation (Keil et al., 2008).

Nodal proximity/similarity. Research provides mixed results regarding the effect of partner dissimilarity on knowledge transfer and creation. An organization's ability to learn from a partner increases as the knowledge bases of the partners become more similar and complementary (Hamel, 1991; Lane & Lubatkin, 1998; Simonin, 1999). Similarly, national and organizational differences between partners reduce their ability to share knowledge (Simonin, 1999). However, moderate levels of partner knowledge (dis)similarity seem to be best for interfirm knowledge transfer and firm knowledge creation because at very high levels of knowledge overlap partners have little to learn from one another, while at very low levels of overlap partners find it difficult to communicate with and learn from each other (Mowery et al., 1996; Sampson, 2007). In contrast, Rosenkopf and Almeida (2003) found knowledge differences had no effect on knowledge transfer.

In contrast to knowledge differences, research consistently shows that similarities in partners' product markets can impede interfirm knowledge transfer and organizational knowledge creation because partners tend to be highly protective of their knowledge when they are market rivals (Baum et al., 2000; Dutta & Weiss, 1997; Hamel, 1991; Simonin, 1999). An alternative explanation is that interindustry alliances provide firms access to more diverse knowledge than intraindustry alliances, which improves their innovation performance (Kotabe & Swan, 1995).

Nodal Properties

This research has examined characteristics of organizations associated with their absorptive capacity, transmission capacity, collaborative capability, prestige, and internal resource endowments and the depth and diversity of knowledge possessed by partners.

Research examining the influence of an organization's absorptive capacity on its knowledge outcomes provides consistent results. Organizations that have accumulated experience with using innovations that are similar to a focal innovation are more likely to adopt it (Pennings & Harianto, 1992). An organization's absorptive capacity increases its ability to leverage the diverse expertise of its innovation supplier to adapt the innovation to its own needs (Weigelt & Sarkar, 2009) and increases the efficacy of knowledge transfer from partners (Zhao & Anand, 2009) and the knowledge-creating benefits it derives from them (Rothaermel & Alexandre, 2009; Rothaermel & Hess, 2007). The extent to which a firm is open to new ideas

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and experimentation with different approaches to innovation improves its ability to learn from its partners (Fey & Birkinshaw, 2005).

While an organization's absorptive capacity affects its ability to receive and use knowledge, its transmission capacity affects its ability to transfer knowledge. An innovation supplier's diversity of technical experience increases its ability to develop and implement solutions, which increases a client's likelihood of adopting the innovation (Weigelt & Sarkar, 2009). In contrast, innovation suppliers have difficulty in learning from increasingly diverse clients about how to develop and implement innovations but are increasingly able to do so as client diversity increases beyond a moderate level (Weigelt & Sarkar, 2009). As the collective teaching capacity of an organization increases, it can transfer knowledge more effectively to its partners (Zhao & Anand, 2009).

Research suggests organizations can develop a collaborative capability based on their accumulated collaborative experience, which can increase the knowledge-related benefits they derive from their partnerships (e.g., Sampson, 2005; Simonin, 1997). A collaborative capability can enhance an organization's ability to benefit from partnerships by providing it with effective and efficient routines for searching within existing partnerships for new knowledge (Zollo, Reuer, & Singh, 2002). Other studies show increasing alliance experience exhibits diminishing returns to knowledge creation (Sampson, 2005) and R&D alliance performance (Hoang & Rothaermel, 2005). Finally, the effect of alliance experience on knowledge creation is enhanced when it is applied to alliance activities that are more uncertain or complex (Sampson, 2005).

Some research has examined how the prestige of source organizations influences adoption. The success an organization's partners achieve with an innovation can increase their prestige and the likelihood it will adopt the innovation (Kraatz, 1998). A prior adopter's generalized prestige (i.e., status) can increase the influence it has on the adoption decisions of potential adopters (Still & Strang, 2009). Similarly, the extent to which scientific collaborations involve individuals from prestigious research institutions and prestigious firms can increase the intensity to which their publications are cited by others (Gittelman, 2007). In contrast, publications produced by collaborators from more prestigious organizations are less likely to be the basis for patented inventions, suggesting high-status scientists tend to pursue research with benefits for the open scientific community rather than for private, commercial benefits (Gittelman, 2007).

An organization's internal resources can moderate the knowledge-creating benefits it receives from its collaborations. As a firm grows, the positive influence of alliances on its innovation may decline as it increasingly substitutes the use of internal resources for the most promising innovation projects (Rothaermel & Deeds, 2004). Similarly, a rare multilevel study found that as the number of nonstar scientists a pharmaceutical firm employed increased, the positive effect of technology alliances on its innovation performance weakened, which suggests firms substitute internal human capital for knowledge sourcing from external partners (Rothaermel & Hess, 2007).

Finally, the depth and diversity of the innovation capabilities of source organizations influence a recipient organization's learning and knowledge creation. An increase in the depth of a firm's innovative capabilities reduces potential recipients' uncertainty about the quality of its knowledge, making it a more attractive knowledge source, particularly for potential recipients located far away because they lack other means by which to evaluate a

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source's knowledge. Consequently, the depth of a source's innovative capabilities reduces the negative influence of geographic and cultural distances on the likelihood of knowledge transfer (Tallman & Phene, 2007). The depth of the innovation capabilities of a firm's partners improves its ability to create knowledge (Baum et al., 2000; Stuart, 2000), while the experiential diversity of a firm's network contacts improves its learning (Beckman & Haunschild, 2002) and knowledge creation (Baum et al., 2000).

Knowledge Properties

Research suggests simple, discrete, and codified knowledge is easier to transfer between organizations (Attewell, 1992; Simonin, 1999). The transfer of complex and tacit knowledge between partners is enhanced when their relationship is characterized by joint problem solving, trust, and frequent communication (McEvily & Marcus, 2005).

Conclusion

In the past 20 years, scholars have produced a considerable body of research on different dimensions of knowledge networks at the interpersonal, intraorganizational, and interorganizational levels of analysis. Research at each of these levels has focused disproportionately on structural and relational properties of knowledge networks and their influence on knowledge creation and transfer. Within each level, relatively few studies have examined whole networks and properties of knowledge. While intraorganizational knowledge networks research is unique in that it addresses the dual nature of collectives as bounded networks and as unitary actors embedded in larger networks, this level of analysis has received much less attention than the more micro and macro levels. Intraorganizational knowledge adoption studies are particularly rare, which is surprising since some research shows there is substantial heterogeneity within organizations in the extent to which their subunits adopt and implement particular practices, processes, and products and that one unit's adoption choice can influence others' choices (Tucker, Nembhard, & Edmondson, 2007).

Across all three levels of analysis, while some studies yield consistent results, several studies have produced inconsistent and often conflicting results. These areas of conflicting results represent valuable opportunities for future research, particularly in terms of identifying the causal mechanisms linking observed knowledge network elements and knowledge outcomes and moderators of these mechanisms. Table 1 summarizes unexplored domains of research at each level of analysis, which represent opportunities for future study. For each domain, we provide potentially useful and interesting research questions for future studies to address.

Across-Levels Analysis

In comparing and contrasting empirical results across levels of analysis and within each network property and knowledge outcome in our framework, we identified points of coherence and conflict, topical areas in which effects examined at one level have not been examined at other levels, and topics that have attracted little or no research attention

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Table 1
Unexplored Knowledge Network Topics and Questions

Level: Interpersonal

Influence of tie strength on innovation adoption
- When, why, and how does tie strength influence individuals' innovation adoption and implementation?
- How does this depend on characteristics of the innovation?

Influence of nodal proximity on knowledge creation?
- When, why, and how do knowledge similarity, interpersonal rivalry, geographic distance, personality similarity, and other nodal proximity aspects of knowledge-sharing relationships affect individual knowledge creation?

Influence of knowledge properties on knowledge creation and adoption
- When, why, and how do properties of knowledge inflows influence individual knowledge creation?
- Are the effects of properties of knowledge inflows on knowledge creation moderated by ego network structure, tie strength, or nodal characteristics?
- When, why, and how do properties of knowledge associated with understanding a particular knowledge artifact (e.g., innovation) influence its adoption and diffusion?

Level: Intraorganizational

Influence of network structure, tie strength, nodal proximity, nodal properties, and knowledge properties on knowledge adoption
- No intraorganizational studies on adoption

Influence of whole network structure on knowledge creation
- When, why, and how does the intraorganizational knowledge network structure of an organization affect an organizational unit's knowledge creation and the organization's knowledge creation?

Influence of nodal proximity on knowledge creation
- When, why, and how does knowledge similarity, competitive rivalry, and geographic distance between collaborating organizational units affect unit knowledge creation?
- How does interunit tie strength moderate these effects?

Level: Interorganizational

Influence of ego network structure on knowledge adoption
- When, why, and how does the structure of an organization's ego network influence its adoption and implementation of an innovation?
- How does this depend on characteristics of the innovation?

Influence of whole network structure on knowledge adoption
- When, why, and how does the structure of a whole interorganizational knowledge network affect an organization's adoption and implementation of an innovation and the rate and extent the innovation diffuses to others?

Influence of nodal proximity on knowledge adoption
- When, why, and how do knowledge similarity, competitive rivalry, and geographic distance between collaborating organizations influence their adoption and implementation of an innovation?
- How does tie strength moderate these effects?

Influence of relationship governance on knowledge adoption
- When, why, and how does interorganizational governance influence a partner organization's adoption and implementation of an innovation?

Influence of knowledge properties on knowledge creation
- When, why, and how do properties of knowledge inflows influence organizational knowledge creation?
- Are the effects of properties of knowledge inflows on knowledge creation moderated by ego network structure, tie strength, or nodal characteristics?

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(see Table 2). Below, we discuss each of these aspects of our across-levels analysis to identify important opportunities for future research. We organize this discussion by knowledge network element. Next, we compare and contrast constructs and theoretical explanations for observed effects across levels and identify and discuss other limitations of this research, all of which leads to the identification of additional research opportunities and recommendations. Table 3 presents a summary of the research opportunities and recommendations generated from our across-levels analysis.

Before discussing each network element, an examination of Table 2 is instructive. The table shows knowledge networks research has produced results across levels of analysis that are more consistent than conflicting. Research has generated coherent results primarily about knowledge transfer and learning, while nearly all conflicting results come from studies of knowledge creation. Below, we explain why these conflicting results represent important opportunities for future research. The empty cells in Table 2 indicate aspects of knowledge networks that are either largely unexplored or have not been examined across levels. The unexplored areas include the influence of tie strength and knowledge properties on knowledge adoption, and nodal proximity on knowledge creation. The areas in which similar effects have not been examined across levels include how knowledge adoption is influenced by ego network structure, whole network structure, nodal proximity, and nodal properties and how knowledge properties affect knowledge creation.

Network Position

Although a substantial amount of research at each level of analysis has examined the influence of an actor's network position on its knowledge outcomes, the effects of centrality are ambiguous. Many studies across all levels have found that a central network position, defined either in terms of the number of direct contacts or both direct and indirect contacts, has a positive influence on knowledge creation, transfer, and adoption (e.g., Ahuja, 2000; Nerkar & Paruchuri, 2005; Smith et al., 2005). However, the causal mechanism used to explain these results is almost always assumed rather than examined, and some research provides conflicting evidence (McFadyen & Cannella, 2004; Wadhwa & Kotha, 2006). Future research should pay greater attention to network composition, to observing the volume and content of actual information flows between actors, and to identifying the costs associated with particular network positions to contribute to an improved understanding of how and when network centrality influences knowledge outcomes.

First, research that examines the influence of network position on knowledge-related outcomes assumes central positions provide timely access to a larger volume of more diverse information. Given the challenges in observing the information flowing through social relationships, this simplifying assumption is understandable. However, it comes at the cost of internal validity since information flow is the causal mechanism linking network position to an actor's knowledge-related outcomes. While knowledge networks research often ignores inherent attributes of network nodes, consideration of network composition may help clarify the influence of network position. In particular, the diversity and/or depth of knowledge possessed by an actor's network contacts can provide a more direct measure of the extent to

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Table 2
Synthesis of Knowledge Networks Research across Levels

Knowledge Network Element	Outcome: Knowledge Creation	Outcome: Knowledge Transfer/Learning	Outcome: Knowledge Adoption/Implementation
Structure: Network position	Conflicts • An actor's degree centrality has a positive OR inverted U-shaped influence on its knowledge creation	Coherence • An actor's degree centrality increases the knowledge it receives and its learning	Coherence • Ties to prior adopters increase an actor's adoption odds • An actor's centrality increases the influence its adoption choices have on others • Structural equivalence between a prior and potential adopter increase the odds of adoption
Structure: Ego networks	Conflicts • Structural holes have a positive OR negative effect on actor knowledge creation • The combination of structural holes and network member knowledge diversity has a positive OR negative interaction effect on actor knowledge creation	Coherence • Network density increases knowledge sharing among network members • Networks combining high-density access to diverse knowledge beyond the network improve ego's learning	
Structure: Whole networks	Conflicts • Network density increases OR decreases actor knowledge creation • Networks with high clustering and short average path length improve OR do not affect knowledge creation	Coherence • Increasing network connectivity increases knowledge flows through the network	

Relational: Tie strength	Conflicts
	• Increasing tie strength has a positive OR negative OR inverted U-shaped effect on actor knowledge creation
		Coherence
		• Increasing tie strength:
		  • Increases the efficacy of knowledge transfer
		  • Improves tacit and complex knowledge transfer
		  • Increases an actor's ability to receive knowledge from increasingly dissimilar others	

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Table 2 (continued)

Knowledge Network Element	Outcome		
	Knowledge Creation	Knowledge Transfer/Learning	Knowledge Adoption/Implementation
Relational: Nodal proximity		Coherence • Interactor competition reduces knowledge sharing Conflicts • Partner knowledge dissimilarity has a negative OR inverted U-shaped effect on knowledge transfer	
Nodal properties	Coherence • The knowledge-based diversity of an actor's direct contacts increases its knowledge creation • An actor's absorptive capacity increases its ability to leverage knowledge inflows in creating knowledge Conflicts • The combination of structural holes and network knowledge diversity has a positive OR negative interaction effect on actor knowledge creation	Coherence • An actor's absorptive capacity increases its ability to receive knowledge from its network contacts • An actor's teaching capacity (also depth and diversity of knowledge) improves its ability to transfer knowledge to others	
Knowledge properties		Coherence • Simple and codified knowledge is easier to transfer than complex, tacit knowledge • Increasing tie strength improves the transfer of complex and tacit knowledge	

Note: Coherence = results replicated across at least two levels; conflicts = results from at least two levels of conflict with one another.

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Table 3
Future Research Opportunities and Recommendations

Theme	Research Opportunities and Recommendations
Network position	• Investigate and clarify the efficiency of network centrality for an actor's knowledge outcomes by considering centrality's costs and benefits. • Understand the actor characteristics that moderate the efficiency of network centrality for its knowledge outcomes. • Test the mechanisms that prior research assumes to operate. • Does network centrality provide actors with timely access to diverse information? Does timely access to diverse information increase actor knowledge creation?

Ego network structure	• Clarify the contingencies regarding the influence of ego network structure (i.e., network closure vs. structural holes) on an actor's knowledge outcomes.
	  • Understand the conditions under which ego network density benefits an actor's knowledge outcomes and when structural holes are beneficial.
	  • Understand when the social control benefits of structural holes improve actor knowledge outcomes and when the social control benefits of network closure are beneficial.
	• Test the mechanisms that prior research assumes to operate.
	  • Does ego network closure (i.e., density) increase trust? Does trust generated by triadic closure increase knowledge transfer, adoption, and creation?
	  • Do structural holes provide actors with timely access to diverse information? Does network density reduce timely access to diverse information?

Ego network composition	• Examine the interdependencies between ego network structure and knowledge composition to understand when structure and composition are complements and substitutes in their influence on actor knowledge outcomes. • Distinguish between stocks of knowledge possessed by actors and flows of knowledge within ties. • Does network structure influence the content of information and knowledge flowing within ties independent of knowledge composition of network members?
Whole networks	• Investigate the influence of whole network structure on actor- and network-level knowledge outcomes. • Under what conditions does whole network structure influence an actor's knowledge production? • Examine the potential trade-offs for network-level knowledge production between structures that promote efficient knowledge diffusion and those that promote knowledge diversity within the network.
Tie strength	• Investigate and clarify the efficiency of strong ties for an actor's knowledge outcomes by considering both the costs and benefits of tie strength.

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Table 3 (continued)

Theme	Research Opportunities and Recommendations

Nodal characteristics and agency	• Examine how differences in an actor's internal knowledge structure moderate the influence of the quality and structure of its network ties on it knowledge outcomes.
	  ◦ Are internal and external knowledge diversity complements or substitutes? When?
	• Explore how the motives of an actor's network contacts toward knowledge sharing are influenced by network structure and position and how these influence the actor's knowledge outcomes.
	  ◦ When does network structure affect an actor's forgetting, withholding, or distorting information?

Knowledge characteristics	• Conduct more research examining the characteristics of knowledge being transferred, adopted, and created. • Endogenize knowledge tacitness: examine how network structure and relational characteristics influence an actor's decision to invest in transforming tacit knowledge to codified knowledge.
Multiple networks	• Understand how the presence of multiple types of ties among the same actors influences their knowledge outcomes.
Relative influence	• Assess the relative (marginal) effects of structural, relational, nodal, and knowledge characteristics on an actor's knowledge outcomes.
Time	• Examine how the aging of relationships within knowledge networks influences actor knowledge outcomes.
Institutional context	• Explore how, when, and why informal and formal institutions enable and constrain knowledge networks.
Causality: Mechanisms and micro foundations	• Understand the micro foundations of the relationships between higher level (e.g., intraorganizational, interorganizational) knowledge networks and macro-level knowledge outcomes. • Pursue multilevel theorizing and empirical research about knowledge networks.
Causality: Endogeneity	• In nonrandomized observational studies, account for the potential endogeneity (because of self-selection, unobserved heterogeneity, and/or simultaneity) of knowledge network variables (e.g., network position, ego network structure, network composition) when assessing their influence on knowledge outcomes.
Methodological	• Use multiagent simulation methods to explore the micro foundations of higher level knowledge networks and to explore macro–micro effects. • Use experimental and quasi-experimental designs to improve the identification of causal effects of structural, relational, and compositional variables. • Conduct more longitudinal, process-oriented, multilevel qualitative research to establish the micro foundations of higher level knowledge network outcomes. • Conduct more panel data studies using unit fixed/random effects to improve causal estimation.

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which diverse knowledge and information flows to it in a timely manner than the number of direct and indirect ties it has (Phelps, 2010; Rodan & Galunic, 2004). Distinguishing between the knowledge composition of network members and network structure is analogous to the distinction between stocks and flows of knowledge. Although an actor's stock of knowledge reflects its accumulated and retrievable knowledge, a knowledge flow represents the effective transfer of knowledge from one actor to another (Gupta & Govindarajan, 2000). Most knowledge networks studies equate the amount and content of the information and knowledge flowing through network ties to the network structure of such ties and the network positions of actors, rather than to the knowledge composition of network members. However, to the extent social ties provide an actor access to others with deep and diverse knowledge, more and more diverse information may flow to the actor. Indeed, the results of a few studies are consistent with this expectation (Almeida & Phene, 2004; Hansen, 2002; Stuart, 2000). This raises an important yet largely unexplored question: To what extent does network structure influence the depth and diversity of knowledge flows within network ties independent of the depth and diversity of the stocks of knowledge possessed by network members? It seems questionable to assert, for example, that the absence of structural holes (i.e., network density) necessarily results in the flow of similar information and knowledge and thus the convergence of knowledge stocks among network members. Future research needs to untangle the influence of network position and structure on knowledge flows from the influence of the depth and diversity of network member knowledge stocks on knowledge flows and knowledge creation.

Second, rather than infer the nature of information and knowledge flows from observed compositional characteristics, a more precise approach to assessing the causal claims of prior positional research would be to observe the volume and content of actual flows among actors. Despite the historical difficulty in observing such flows, the explosion in the use of electronic communication, such as email and real-time chat/instant messaging, has created promising opportunities for knowledge networks research. These data not only allow for objective observation of dyadic ties and networks (e.g., Kossinets & Watts, 2009) but can also be used to observe the volume and content of codified communication (i.e., information flows) among actors (e.g., Aral & Van Alstyne, 2011). Using email data generated by executive recruiters in a midsize recruiting firm, Aral and Van Alstyne (2011) found an individual's degree centrality and the bandwidth of her or his direct ties, defined as the average volume of communication between ego and her or his alters in a given time period, had much stronger positive effects on the total amount of nonredundant (i.e., diverse) information she or he received than that generated by the presence of structural holes among her or his contacts. This finding supports causal claims made in prior research that degree centrality provides actors with access to greater volumes of novel information. Also, while Aral and Van Alstyne (2011) found that structural holes increased the diversity per unit of information and the total amount of diverse information received by an individual, they also showed that bandwidth was a more powerful predictor of the amount of diverse information received. Finally, they found that increasing bandwidth, which is associated with the social cohesion provided by strong ties and ego network density, and structural holes are negatively related, demonstrating a trade-off between bandwidth and network structural diversity in the extent to which each

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provides ego access to diverse information. Contrary to the causal mechanism claimed by many studies that examined the influence of network centrality on knowledge outcomes, these results suggest that, independent of the ego's network size, being central in a network in ways that provide actors with broader reach to different segments of the network may not provide them with more timely access to more diverse information relative to less globally central actors. Consequently, future research should seek to identify the causal mechanism(s) linking global network position (e.g., betweenness centrality) and actor knowledge outcomes. The use of electronic communication data may be especially useful in this regard.

Finally, most studies of network position emphasize the information and social control benefits of centrality while ignoring the associated costs. Increasing centrality is associated with at least two types of costs. First, increasing centrality implies an increase in the number of relationships an actor forms and maintains. Actors incur costs in searching for and forming relationships and the costs of monitoring and maintaining existing relationships. Moreover, to receive benefits from partners, actors must reciprocate by providing benefits (Hansen, 1999). Highly central actors may become overembedded in that they spend excessive time and resources on managing partner demands (Uzzi, 1997). Eventually, the costs of establishing and maintaining more relationships can exceed their information benefits. Indeed, research has found an inverted U-shaped effect of an actor's degree centrality on its innovation performance (McFadyen & Cannella, 2004; Wadhwa & Kotha, 2006). Second, to the extent increasing centrality provides access to more diverse information, actors may need to expend greater cognitive effort and resources to understand and utilize this information (Cohen & Levinthal, 1990). Extant knowledge networks research has not attempted to unpackage these two types of costs and their influence on an actor's knowledge-related outcomes. Attention to the knowledge diversity available to an actor in its network of contacts may help researchers distinguish the cognitive costs of increasing information diversity from the costs of forming and maintaining more relationships.

Local Network Structure and Composition

Next to research on network position, studies of the influence of an actor's ego network structure on its knowledge outcomes are the most prevalent type of structural research. Despite its popularity, this research has yielded conflicting results, both within and across levels of analysis and knowledge outcomes. This research is often framed as a debate about the information benefits of structural holes versus the social control benefits of network closure. Structural holes are assumed to provide timely access to diverse information and referrals (Burt, 1992), while network closure is assumed to promote trust and reciprocity and therefore greater cooperation and sharing of resources, particularly information and knowledge, among network members (Portes, 1998). While Burt (1992) also argued that structural holes provide social control benefits since they allow actors to behave free from the normative influence of others in their network, research into the influence of network structure on knowledge creation and adoption has stressed informational rather than control benefits (e.g., Burt, 2004; Obstfeld, 2005). Resolving this debate is challenging because structural

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holes and network closure are inversely related, implying the information benefits of structural holes must come at the expense of the cooperative benefits of closure and vice versa. Three approaches may help resolve this debate and reconcile the conflicting results.

First, like the causal argument linking an actor's network position to knowledge outcomes, the underlying causal processes linking ego network structure to knowledge outcomes are merely assumed to operate and are rarely examined or observed (a recent exception is Rodan, 2010). Studies that provide direct evidence of the relationship between structural holes and an actor's timely access to diverse information are rare, as are studies that link network closure to increased trust and reciprocity. Research suggests structural holes are neither necessary nor sufficient for providing access to diverse information (Phelps, 2010; Rodan & Galunic, 2004). Moreover, research on the influence of ego network density on trust is, at best, inconclusive (Gulati & Sytch, 2008). Given these concerns about the putative causal mechanisms linking ego network structure to knowledge-related processes and outcomes, researchers should identify the conditions under which structural holes provide actors timely access to diverse information, when network closure promotes trust and reciprocity and thus greater resource sharing, and when access to greater diversity of information and knowledge is more or less beneficial for particular knowledge outcomes relative to access to a larger volume of information and knowledge. The insights from such research would inform and improve the ability of researchers to specify when, how, and why ego network structure influences knowledge processes and outcomes.

As discussed in the previous section, an explicit consideration of the knowledge diversity of an actor's network contacts may be useful in this regard (Phelps, 2010). Separating the influence of the knowledge composition of an ego network from the influence of the network's structure on ego's knowledge outcomes is particularly important given that prior research often confounds the two by using differences in network member's attributes to proxy for unobserved structural holes (e.g., Baum et al., 2000; Tiwana, 2008). Doing so replaces the intended network structure explanatory variable (structural holes) with a compositional variable (actor diversity) that may be more proximal to capturing the putative benefit of structural holes (i.e., timely access to diverse information) but is not a measure of network structure. This approach assumes homophily determines tie formation and that actors with diverse attributes do not maintain ties with one another—a dubious assumption given extant evidence to the contrary (e.g., Kotabe & Swan, 1995; Rodan & Galunic, 2004; Rosenkopf & Almeida, 2003). Future research should investigate the interdependencies between ego network structure and knowledge composition to understand when structure and composition are complements and substitutes in their influence on actor knowledge outcomes. Doing so may also help resolve the conflicting results about the influence of the interaction of ego network structure and knowledge composition on actor knowledge creation.

A second approach to helping resolve the debate and conflicting results would be to follow another of our recommendations for network position research and observe the volume and content of actual information and knowledge flows between actors. Aral and Van Alstyne (2011) provide an initial and exemplary study in this regard. Consistent with structural holes theory, they found that structural holes in an actor's network increased the diversity per unit of information and the total amount of diverse information received by the actor. However,

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they also showed the bandwidth of an actor's ties had a much stronger effect on the amount of diverse information received. Because social cohesion from increasing tie strength and ego network closure is associated with increasing bandwidth but decreasing structural holes, Aral and Van Alstyne (2011) concluded that brokers with bridging ties to disparate parts of a social network can be *disadvantaged*, relative to actors that are densely connected to others with strong ties, in their timely access to novel information. Although these results strengthen the causal inferences made by studies showing a positive effect of ego network density on knowledge creation, transfer, and adoption, they call into question the causal mechanism assumed to operate in research that shows a positive influence of structural holes on actor knowledge outcomes. The direct observation of the nature of information and knowledge flows allows for direct tests of the causal processes merely assumed by prior research to operate. An improved understanding of how and why ego network structure affects the volume and content of information and knowledge flows is essential to understanding the relationship between ego network structure and knowledge outcomes. By understanding the mechanisms linking structure and outcomes, researchers are better prepared to resolve conflicting results regarding observed relationship between these variables. In particular, the identification of the mediating causal processes may help researchers resolve the conflicting results by considering how these mechanisms depend on the influence of other variables.

Accordingly, a third way out of the debate is to explore potential moderators. Adler and Kwon (2002) argued that a particular ego network structure is unlikely to be universally beneficial. They encouraged researchers to identify contingencies that influence the relationship between ego network structure and actor behavior and outcomes. Research suggests the value of open versus closed networks for knowledge-related processes and outcomes is contingent on the type of task being pursued (Hansen, 1999), the type of tie (Ahuja, 2000), whether the ego is acquiring information or providing it to others (Gargiulo, Ertug, & Galunic, 2009), and the institutional environment (Owen-Smith & Powell, 2004). Attention to other important contingencies may yield additional insights into understanding the influence of network structure on actor knowledge outcomes. For example, Aral and Van Alstyne (2011) found that high bandwidth ties are more important for providing actors with access to larger volumes of more diverse information when the stock of knowledge in an actor's environment is changing rapidly, when its alters possess complex knowledge spanning many domains, and when its alters possess highly similar information. In contrast, they showed ties that span structural holes provide access to larger volumes of more diverse information when the knowledge in an actor's environment is stable and its alters possess simple knowledge spanning few domains with little overlap with one another. These results suggest ego network density will be particularly beneficial for an actor's knowledge creation and adoption when its knowledge environment is changing rapidly and when its alters possess nonoverlapping, complex knowledge, while structural holes will be more beneficial in stable knowledge environments and when alters possess overlapping, simple knowledge. These untested propositions represent important opportunities for future research. In general, research focused on explaining when structural holes provide actors timely access to greater volumes of diverse information and when network closure does so would be helpful in identifying new contingencies.

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Whole Network Structure

Despite their demonstrated influence on knowledge creation, transfer, and adoption (Ebadi & Utterback, 1984; Schilling & Phelps, 2007; Uzzi & Spiro, 2005), studies of whole knowledge networks are rare. This may be the result of the challenges of observing the relationships among a large, bounded population of actors (e.g., Schilling, 2009). Additional research is necessary to better understand how the structural characteristics of whole networks influence knowledge outcomes. Although some research suggests whole network density increases information diffusion and actor innovation (Abrahamson & Rosenkopf, 1997; Ebadi & Utterback, 1984), other research suggests the information diffusion benefit provided by increasing density comes at the cost of a reduction of information diversity within the network (Lazer & Friedman, 2007). Given that information diversity is important to the knowledge-creation activities of actors within a network, a reduction in available diversity will tend to reduce long-run innovation and network performance, suggesting an inherent trade-off between information diffusion and diversity (Lazer & Friedman, 2007). This insight assumes that the diversity of information in a network is fixed. However, large-scale network research on small-world structures and ego network research challenges this assumption and therefore the finding of an efficiency–diversity trade-off.

Small-world network structures are surprisingly efficient in the rate and extent of information diffusion and increase the innovation performance of network members (Schilling & Phelps, 2007; Uzzi & Spiro, 2005). To the extent knowledge creation is a process of the novel recombination of existing knowledge (Fleming, 2001) and the recombination of diverse knowledge begets more, and more diverse, knowledge (Fleming, 2001; Kauffman, 1995), small-world networks may lead to increased network-level diversity despite their efficiency in diffusing information. Research that examines the influence of large-scale network structure on network-level performance needs to account for both diffusion and knowledge creation to understand if and when a trade-off exists between network structure's influence on the efficiency of information diffusion and its diversity. In addressing this issue, research may be able to better specify when small-world structures will (and will not) improve the knowledge-creation performance of network members.

Tie Strength

A consistent finding across levels of analysis is that strong ties improve aspects of knowledge transfer and learning (e.g., Bouty, 2000; Kale, Singh, & Perlmutter, 2000; Schulz, 2003). However, the results of research exploring the influence of tie strength on actor knowledge creation are inconsistent and contradictory. While much of this research emphasizes the benefits of strong ties for knowledge creation, the negative aspects of strong ties have been largely ignored. Strong ties entail higher maintenance costs than weak ties (Hansen, 1999) and can limit access to diverse information, reduce autonomy, and increase dependence (Hansen, 1999; Uzzi, 1997). Future research should seek to understand what drives these costs, the conditions under which they are more or less likely to occur, and when they will

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exceed the benefits of increasing tie strength for actor knowledge creation. In short, a focus on the *efficiency* of tie strength is needed to disentangle prior conflicting results. More broadly, research should identify and examine other boundary conditions and moderators of the effect of tie strength on actor knowledge outcomes to contribute to an improved understanding of when and how tie strength affects knowledge outcomes.

Nodes as Black Boxes and Nodal Agency

With some exceptions, knowledge networks research at all levels treats actors (i.e., network nodes) as black boxes. While much research has examined the diversity of knowledge possessed by the alters in an actor's network, relatively few studies have examined how differences across actors influence their knowledge outcomes and how these differences interact with other knowledge network elements to influence knowledge outcomes. Most knowledge networks research treats nodal differences as a nuisance source of heterogeneity to be controlled or even ignored. Specifically, although theoretical arguments often reference cognitive characteristics of actors such as their absorptive capacity and a few studies examine how an actor's absorptive capacity moderates the influence of structural and relational elements on knowledge outcomes, differences in the cognitive capabilities of actors are rarely considered in conjunction with other knowledge network elements such as network structure or relational properties. This is both ironic and surprising given that knowledge is a property of human cognition. Similarly, much of the research reviewed, but particularly studies of network structure, implicitly assumes that actors in networks are cognitively hollow, passive vessels through which information and knowledge flow unimpeded and unchanged. These limitations present important opportunities for future research.

First, variation in the internal knowledge structures of actors is likely to influence their knowledge outcomes and moderate the influence of network structure and tie characteristics on knowledge outcomes. Individuals and collectives are repositories of knowledge, and the structure of knowledge in these repositories greatly influences the extent to which actors can retrieve information and absorb new information (Austin, 2003; Bates & Elman, 2008; Yayavaram & Ahuja, 2008). Research in psychology and cognitive science suggests that human memory, and thus knowledge, is organized as a pattern of associations among concepts in the mind (Rogers & McClelland, 2004). The associations among concepts give them meaning. Thus, the knowledge contained in a cognitive network is defined by the structure of relationships among concepts (Bates & Elman, 2008). Analogously, Yayavaram and Ahuja (2008) conceptualized an organization's knowledge as a pattern of relationship among knowledge components and found that the structure of these relationships influenced how easy it was for organization members to access and utilize organizational knowledge. Because an actor's knowledge structure influences the extent to which it can access and absorb knowledge (Cohen & Levinthal, 1990), heterogeneity in the knowledge structures within individuals, groups, and organizations will influence their ability to absorb, create, and transfer knowledge in a network of social relationships. Greater attention to the differences in knowledge structures among actors may allow researchers to untangle some of the conflicting results related to knowledge network structure and tie strength. For example, variation in knowledge structures may help explain why some actors are able to realize

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greater knowledge creation by collaborating with more partners while others experience diminishing and even negative returns. Similarly, the influence of large-scale network density on actor knowledge creation may depend on differences across networked actors in their internal knowledge structures. Indeed, Bhattacharyya and Ohlsson's (2010) simulation study finds support for this proposition. Finally, the influence of an actor's network knowledge diversity on its knowledge outcomes may depend on the diversity of its own (internal) expertise. Examining when internal and external knowledge diversity complement or substitute for one another will contribute to an improved understanding of how actor (nodal) knowledge heterogeneity interacts with the knowledge heterogeneity available in its ego network in influencing its knowledge outcomes.

Second, research on the *structure* of knowledge networks typically portrays network nodes in their role as transmitters of information and knowledge as being empty vessels with no strategic interests, and, as such, information and knowledge flow through them unimpeded and undistorted. This imagery is odd given research that focuses on actors as recipients and producers of knowledge suggests they are active, strategic agents that vary substantially in their abilities to absorb and create knowledge. Moreover, this assumption is also inconsistent with relational research that shows actors differ regarding their motivation and ability to share information and knowledge and that such motives are often strategic. Given these results, it is likely that when actors in networks vary in terms of their internal knowledge structures and their strategic motives, they will also vary in the amount, fidelity, and integrity of knowledge they share. Recent research suggests that when individuals pursue strategic objectives in their relationships with one another, they are more likely to conceal and/or intentionally distort important information they possess (Steinel, Utz, & Koning, 2010). Similarly, when individuals distrust the intentions of a collaborator, they are more likely to actively hide their knowledge (Connelly, Zweig, Webster, & Trougakos, in press). Thus, strategic motives impede the amount of information shared and its quality and are therefore likely to diminish knowledge-creation efforts. While some relational research has examined the influence of strategic motives on the willingness to share information and knowledge, it has ignored the influence of such motives on the intentional distortion of knowledge. In addition, although structural research has largely ignored this issue, a recent study suggests that an actor's strategic motives are related to its network position, which affects the amount and quality of information it shares (Schilling & Fang, 2010). Finally, variation in internal knowledge structures influences the extent to which actors effectively absorb, store, retrieve, and transmit knowledge (Cohen & Levinthal, 1990; Rogers & McClelland, 2004; Yayavaram & Ahuja, 2008), which will also influence the amount of knowledge sharing and the integrity of the knowledge. In sum, future research should investigate when and how actor strategic motives and internal knowledge structures influence the amount and integrity of information and knowledge flows between actors and how this influences knowledge creation and adoption.

Knowledge Properties

Properties of knowledge constitute the least examined aspect of knowledge networks. The few studies that investigate how knowledge properties affect knowledge outcomes treat the

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different properties as inherent and fixed attributes of knowledge. In particular, knowledge networks studies that examine the tacit–explicit dimension of knowledge—which represents the most-studied knowledge property—assume this property is exogenous in its influence relative to the other knowledge network elements. The extent to which knowledge is tacit or explicit is largely a matter of choice and action—actors can invest time, effort, and resources to transform tacit knowledge to explicit and then codified knowledge (Cowan, David, & Foray, 2000), which raises the question of what influences actors' motivations to invest in codification, thereby affecting the ease and efficiency of knowledge transfer. In other words, to understand better how the tacit–explicit dimension of knowledge influences knowledge outcomes such as transfer, creation, and adoption, knowledge networks research needs to endogenize this aspect of knowledge as a variable to be explained by other dimensions of knowledge networks. Although studies suggest structural and relational characteristics influence actors' motivations to expend resources in transferring knowledge (e.g., Hansen et al., 2005; Reagans & McEvily, 2003), this research does not consider how these knowledge network elements affect an actor's motivation to convert tacit knowledge to codified form. For example, do strong ties and network closure facilitate the transfer of tacit knowledge by increasing the willingness of the source to first invest in codifying knowledge to affect its transfer? How does this process occur at different levels of analysis? Extant research provides little insight into these questions, making this area ripe for future research.

Multiple Networks, Relative Influence, and Time

Multiple networks. With rare exceptions (i.e., Beckman & Haunschild, 2002; Hansen et al., 2005), knowledge network research has considered only one type of relationship and thus only one type of network, thereby ignoring the fact that actors are typically involved in multiple, different types of ties and networks. This lacuna represents an important area for future research to address. Multiplexity—the extent to which two actors maintain more than one type of substantive tie with each other (Minor, 1983)—can increase trust between actors, their access to each other's knowledge, and their social influence on each other (Beckman & Haunschild, 2002), which may influence knowledge transfer, creation, and adoption. The multiplexity of the ties in an ego network may therefore influence ego's knowledge outcomes by reinforcing the effects of the structure of one type of tie or by diminishing its effects. For example, to the extent ego network density promotes trust, reciprocity, and thus knowledge sharing among network members, increasing network multiplexity among network members may reinforce these effects. Similarly, as the multiplexity of ego's ties that enable it to span structural holes increases, its alters may be more willing to share their diverse information with ego. Finally, by examining multiplexity, researchers may be able to untangle some of the conflicting results related to ego network structure and tie strength. For example, by considering multiple types of ties, structural holes that appear to exist when only one type of tie is examined may no longer exist when different types of ties connect actors. Because ego network multiplexity is rarely observed, it may have led to an omitted variable bias in prior studies that examined the influence of ego network structure on actor knowledge creation. Once network multiplexity is observed, the conflicting results may be

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reconciled. In sum, future research should seek to understand how the presence of multiple types of relationships among the same actors influences their knowledge outcomes.

Relative influence. Although ample research has focused on each knowledge network element, research examining multiple elements simultaneously is rare. Specifically, research has not examined all four elements together in the same study. This omission is important because extant research provides little insight into the relative influence of each knowledge network element on the various knowledge outcomes. Future research should seek to estimate and compare the effect sizes of variables associated with each knowledge network element to identify which variables and elements are most important in understanding variation in knowledge outcomes.

Time. While relational research suggests characteristics of ties influence knowledge transfer and knowledge creation, structural research typically ignores the relational characteristics of ties. In particular, although relational research shows the duration of a tie has a significant influence on knowledge transfer, structural studies do not consider how the heterogeneity of the age of the ties in the network may moderate the influence of network structure on knowledge outcomes. A recent study shows tie age moderates the influence of a firm's ego network on its performance (Baum, McEvily, & Rowley, in press). Although currently unexplored in the knowledge networks literature, tie age may be an important contingency variable in explaining when a particular type of structure (i.e., closed vs. open) will improve actor knowledge creation. This may help in reconciling conflicting results about the influence of ego network structure on actor knowledge creation.

Additional Recommendations for Future Research

Our cross-level analysis also revealed important yet rarely addressed research issues that are independent of particular knowledge network elements. These themes are summarized in Table 3.

Institutional Context

Knowledge networks research is concerned with how the nature of actors' social embeddedness influences their creation, transfer, and adoption of knowledge. Social embeddedness is, however, only one form or source of embeddedness (Dacin, Ventresca, & Beal, 1999). Other sources include informal cultural systems of meaning and formalized political-legal institutions (Dacin et al., 1999; Zukin & DiMaggio, 1990). These sources of embeddedness are nested in one another in that social relations and the networks they constitute are anchored in formal political-legal institutions, which, in turn, are nested in broader cultural systems (Dacin et al., 1999). The knowledge networks research we reviewed is undercontextualized in that nearly all of it overlooks the influence of the broader formal and informal institutional context on knowledge network processes and outcomes. Future research should explore how, when, and why informal institutions (such as culture) and

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formal political-legal institutions (such as the content and enforcement of particular laws, regulations, and codes) enable and constrain knowledge networks. Comparative institutional studies could help establish the boundary conditions and generalizability of knowledge network processes and outcomes identified in existing research. Similarly, research that examines the influence of institutional heterogeneity on knowledge networks could help uncover potentially important contingencies by showing how particular relationships between knowledge network elements and outcomes differ by particular institutional characteristics. Such research may help explain some of the conflicting results in extant knowledge networks research.

Causality: Mechanisms, Processes, and Micro Foundations

While a benefit and an attraction of social network analytic methods is that they can be applied to any level of analysis (Wasserman & Faust, 1994), the causal mechanisms linking elements of networks and knowledge outcomes are unlikely to be isomorphic across levels. Nearly all of the research we reviewed, however, assumes a high degree of theoretical isomorphism across levels, particularly from the interpersonal level on up. Most studies of intra- and interorganizational knowledge networks use causal explanations from interpersonal network research and implicitly assume these explanations hold for networks of social collectives. For example, drawing on Coleman's (1988) explanation linking interpersonal network structure and individual trustworthiness, alliance researchers have argued dense alliance networks, in which a firm's partners are also directly allied, will tend to produce trust among alliance partners (and their personnel) much like closure in an interpersonal network generates trust (e.g., Ahuja, 2000). Similarly, interorganizational research has appropriated explanations about tie strength from interpersonal research and applied them to interorganizational relationships. This research treats collectives, including divisions, subsidiaries, and entire organizations as simple, unitary actors rather than the large, internally complex, and geographically distributed collectives they are. Although anthropomorphizing social collectives may be theoretically and empirically appropriate for some research purposes (see King, Felin, & Whetten, 2010), the extent to which doing so is appropriate is a matter for theory and empirics to discern. Future research needs to examine the extent to which causal explanations generated from interpersonal network research are isomorphic to the intra- and interorganizational levels. In particular, we need a richer understanding of the micro foundations that underlie interorganizational relationships. For example, to what extent is it empirically valid to claim (theoretically) that two multinational firms with thousands of employees distributed around the world have a strong tie and that such a tie increases trust among the employees of these two firms involved in the tie and their willingness to share knowledge?

These questions point to related research opportunities that are best framed according to Coleman's (1990) so-called "boat" or "bathtub," which stipulate that causal relationships between macro-level phenomena should be explained and substantiated in reference to the micro properties and mechanisms that generate them—from the macro to the micro and

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then from the micro to the macro. This would entail explaining how and why macro properties, such as an organization and its interorganizational network centrality, enable and constrain individual-level cognition and action, how and why individuals choose to act in response to these opportunities and constraints, and how and why these actions generate the observed organization-level knowledge outcomes. One opportunity is to explore cross-level relationships in the direction of higher to lower levels. While studies of the influence of network structure on actor outcomes can be framed as cross-level in that a network represents a higher order collective, the type of cross-level research we propose is to examine how interorganizational ties and networks influence the knowledge outcomes of intraorganizational units and individuals and how intraorganizational networks influence individual knowledge outcomes. This type of research is rare (although recent exceptions include Paruchuri, 2010; Rothaermel & Hess, 2007), but social network scholars are beginning to develop such multilevel theories for other phenomena (Moliterno & Mahony, 2011; Payne et al., 2011). Next, given the questionable theoretical isomorphism from the micro to macro levels, the idea that organizations are nested systems that consist of lower level collectives and ultimately individuals (Hitt et al., 2007), and that network nodes at lower levels of analysis are nested in higher level nodes (Harary & Batell, 1981), future research should focus on explicating the micro foundations of higher level knowledge networks. Research should examine how individual actions, abilities, and choices generate observed relationships involving higher order collectives (see Felin & Foss, 2005). For example, research should examine how interpersonal relationships among organizational boundary spanners complement and conflict with interorganizational level outcomes, such as the efficiency and efficacy of interorganizational knowledge transfer, and how interpersonal networks within organizations affect organizational knowledge creation.

A methodological approach that is well suited to the examination of multilevel relationships is agent-based simulation modeling (Macy & Willer, 2002). Agent-based modeling (ABM) enables the analyst to specify individual micro-level motives and initial relationships and observe how the micro-level behaviors of interacting agents generate macro-level outcomes and how changes in such micro-level conditions change macro-level outcomes. ABM allows researchers to specify agent motives based on insights into human motivation and behavior and test hypotheses about how micro-level mechanisms influence macro outcomes, making it possible for analysts to integrate theoretical ideas with the results of empirical research (Hedström & Ylikoski, 2010). ABM also allows analysts to specify how macro-level outcomes feed back to influence micro behavior, thereby enabling the modeling of the macro to micro transition and the micro to macro transition. Although simulation research is rare in our set of knowledge networks studies, some research that employs ABM has begun to be applied to multilevel questions of knowledge networks (for a survey, see Garcia, 2005). A complementary approach to investigate multilevel knowledge network influences and causal mechanisms is longitudinal, process-oriented, case-based qualitative research. Such an approach is well-suited for exploring "how" questions involving multiple levels of analysis (Eisenhardt & Graebner, 2007). While only about 4% of our set of knowledge networks studies used a qualitative methodology, none focused on multiple levels of analysis. Maurer

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and Ebers (2006) employ precisely such an approach in their study of the influence of the interorganizational networks of six young biotechnology firms on their growth.

Causality: Identification

About 90% of all studies we reviewed use observational data for estimating relationships. Such data present severe challenges to causal inferences (Gangl, 2010). In particular, almost all of this research assumes network structure is exogenous in examining its effect on knowledge outcomes. That is, research typically assumes that observed network structural measures are not caused by the observed knowledge-related dependent variable and are not correlated with unobserved characteristics of individuals that can affect network structure. Essentially, actors are treated as being randomly assigned particular network positions or ego network structures. Some knowledge networks research questions this assumption by showing that individuals form ties for instrumental reasons that are correlated with knowledge outcomes (e.g., Lee, 2010).

The exogeneity of an actor's structural and relational knowledge network characteristics is questionable for a few reasons. The formation and dissolution of the types of collaborative relationships that knowledge networks research examines reflect choices made by individuals or collectives. These choices are often made for systematic, instrumental purposes that may be correlated with desired knowledge outcomes, which introduces the possibility of a sample self-selection bias. If the underlying causes for these choices are unobserved, then the observed effects of relationships on knowledge outcomes may be influenced by omitted variables, resulting in biased parameter estimates (Shaver, 1998). A similar estimation problem, endemic to research on adoption, is known as the "reflection problem" (Manski, 1993). This problem represents a challenge to the identification of the effect of an actor's direct ties to prior adopters of a knowledge artifact on the actor's adoption decision because unobserved similarities between prior and potential adopters (such as demographic characteristics) can cause them to form relationships with each other (through a process of homophily or assortative matching) and have similar preferences for adopting the same knowledge artifact, thereby creating a spurious relationship between direct ties and adoption. An endogeneity bias may also result from reverse causality. For example, highly innovative actors or actors that have created large stocks of knowledge may be more attractive as collaborators and therefore come to occupy a more central network position. Nearly all the research we examined ignored the potential influence of endogeneity on the reported results, which calls into question the internal validity of research on the structure of knowledge networks because the implicit assumption this research maintains about the exogeneity of network structure may be unfounded. Echoing recent recommendations by strategy scholars (Hamilton & Nickerson, 2003; Shaver, 1998) and social network researchers (Reagans, Zuckerman, & McEvily, 2004), we suggest that future research into knowledge networks attempt to account for the influence of endogeneity to more accurately identify (parameter) estimates of observed effects.

Although the identification of social network effects is difficult and a thorough treatment of potential remedies is beyond the scope of this article, we offer some basic recommendations.

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The first is for researchers to design studies in which tie formation and network structure are exogenous by (experimentally) randomly assigning ties and manipulating structure. Alternatively, researchers could adopt quasi- (or natural) experimental designs that exploit a naturally occurring external event or institutional/contextual condition that creates exogenous variation in the knowledge network variable of interest (Cook & Campbell, 1979), thereby enabling them to identify its causal effect on the knowledge outcome of interest using instrumental variables or difference-in-difference estimations (Angrist & Krueger, 2001). In a recent application of this approach to the domain of knowledge networks, Azoulay et al. (2010) used the quasi-experimental variation in the structure of collaborative coauthorship ties among life scientists generated by the premature and sudden death of active superstar scientists to identify the effect of such collaboration on scientists' quality-adjusted publication rates.

Because (quasi-)experimental studies of knowledge networks are often difficult to implement and studies typically use observational data, researchers should control for the propensity and ability of actors to form and maintain relationships and the temporal ordering of variables in their research design. They should also use panel data designs to control for time-invariant sources of unobserved actor heterogeneity using either fixed or random effects. Only 35% of the studies we reviewed used longitudinal data, and about half of these employed panel regression estimation. Interpersonal knowledge networks research consists almost entirely of cross-sectional data generated by surveys. Although panel designs and estimation allow for control of time-invariant sources of unobserved heterogeneity, they do not control for time-varying sources of unobserved heterogeneity that may confound observed relationships between explanatory and outcomes variables. Consequently, researchers may need to employ additional estimation techniques such as selection and treatment effects models that employ time-varying instruments (see Mouw, 2006; Stuart & Sorenson, 2007) or propensity score matched sampling techniques (e.g., Aral, Muchnik, & Sundararajan, 2009) to help improve the identification of network structural effects.

Conclusion

Two observations motivated this critical review. First, a large and growing body of empirical research shows that social relationships and the networks they constitute are influential in explaining the processes of knowledge creation, transfer, and adoption. Second, no systematic review of this empirical research on knowledge networks existed. Accordingly, we sought to contribute to an understanding of knowledge networks at multiple levels by conducting a systematic analysis of empirical research published on this topic in leading management, psychology, sociology, and economics journals. We developed a comprehensive framework that organizes the knowledge networks literature, which we used to review extant empirical research within and across multiple disciplines and levels of analysis. We identified points of coherence and conflict in theoretical arguments and empirical results within and across levels and knowledge outcomes and identified emerging themes and promising areas for future research. By synthesizing and critically evaluating four decades of research about knowledge networks across multiple fields and multiple levels, we hope to have contributed to a greater understanding of knowledge networks and to have stimulated increased knowledge creation about them.

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Notes

1. Broadly construed, a knowledge network is a set of nodes—which can represent knowledge elements, distributed repositories of knowledge, and/or agents that search for, transmit, and create knowledge—that are interconnected by relationships that enable and constrain the acquisition, transfer, and creation of knowledge (Monge & Contractor, 2003; Yayavaram & Ahuja, 2008). Nodes can consist of knowledge elements (such as those embodied in discrete artifacts like patents, papers, and products), nonhuman repositories of knowledge (such as databases and catalogs), and individuals and higher level collectives (such as teams and organizations), which serve as agents and heterogeneously distributed repositories of knowledge. The relationships among such nodes can be cognitive (such as semantic or schema-based associations among mentally held concepts), social (such as formal and informal collaborations among individuals and social collectives), technological (such as human–computer interfaces connecting human agents with nonhuman knowledge repositories), or associational (such as the combination and consequent affiliation of knowledge elements in the process of creating new knowledge). These relationships represent a means by which nodes search for information and knowledge, a medium through which information and knowledge flow, a lens through which social actors evaluate each other's knowledge stocks, and a record of past and a guide for the future combinations of knowledge elements. Given the dominant focus in social science research on the social dimensions of knowledge networks (i.e., how the social relationships among individuals and social collectives influence knowledge acquisition, transfer, and creation), we focus on this aspect of knowledge networks. While it may be more precise to refer to this type of knowledge network as a *social knowledge network*, we use the simpler and less awkward term *knowledge network*.

2. Management journals include *Academy of Management Journal*, *Administrative Science Quarterly*, *Journal of Management*, *Management Science*, *Organization Science*, and *Strategic Management Journal*. Economics journals include *Quarterly Journal of Economics* and *Journal of Political Economy.* Sociology journals include *American Journal of Sociology* and *American Sociological Review*. And psychology journals include *Journal of Applied Psychology* and *Psychological Bulletin*.

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