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Where Do Creative Interactions Come From? The Role of Tie Content and Social Networks

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Understanding the determinants of creativity at the individual and organizational level has been the focus of a long history of research in various disciplines from the social sciences, but little attention has been devoted to studying creativity at the dyadic level. *Why are some dyadic interactions more likely than others to trigger the generation of novel and useful ideas in organizations*? As dyads conduit both knowledge and social forces, they offer an ideal setting to disentangle the effects of knowledge diversity, tie strength, and network structure on the generation of creative thoughts. This paper not only challenges the current belief that sporadic and distant dyadic relationships (weak ties) foster individual creativity but also argues that diverse and strong ties facilitate the generation of creative ideas. From a knowledge viewpoint, our results suggest that ties that transmit a wide (rather than narrow) set of knowledge domains (within the same tie) favor creative idea generation if exchanges occur with sufficient frequency. From a social perspective, we find that strong ties serve as effective catalysts for the generation of creative ideas when they link actors who are intrinsically motivated to work closely together. Finally, this paper also shows that dyadic network cohesion (i.e., the connections from the focal dyad to common contacts) does not always hinder the generation of creative ideas. Our empirical evidence suggests that when cohesion exceeds its average levels, it becomes detrimental to creative idea generation. Hypotheses are tested in a sociometric study conducted within the development department of a software firm.

Key words: creativity; knowledge diversity; tie strength; social networks; dyadic analysis
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1. Introduction

Previous research has highlighted the importance of understanding creativity in order to manage effectively the innovation process in organizations (e.g., Amabile 1996). Creativity has been studied at organizational and individual levels from different perspectives (e.g., Sternberg 1999). However, little attention has been devoted to studying creativity at the dyadic level. *Why are some dyadic interactions more likely than others to trigger the generation of novel and useful ideas*? This question has been largely ignored in previous research despite the general recognition that creativity is, in part, a social activity (Perry-Smith and Shalley 2003, Hargadon and Bechky 2006).

The creativity phenomenon typically involves individuals, pairs, or groups generating potentially creative ideas, which after internal evaluation are then presented to the community for further scrutiny and selection (Simonton 1988; Csikszentmihalyi 1988, 1996; Fleming et al. 2007; Girotra et al. 2010). This paper focuses on the generative aspect of creativity (Amabile et al. 2005).[1] We investigate how content and social properties of dyadic relationships at work trigger (or hinder) the generation of potentially creative ideas. This provides a more granular examination of the creativity phenomenon from a social perspective. Instead of studying how the aggregated set of interactions of an individual relates to her ability to produce creative outcomes, we study the microprocesses by which *each* dyadic relationship contributes to the generation of creative thoughts.

Past research on creativity has studied the factors that make some individuals more creative than others (e.g., Gardner 1993, Amabile 1996, Simonton 1999, Sternberg 1999). By considering the individual and her social networks, we have come to recognize that the structure of the individual's network influences her ability to develop creative outcomes (e.g., Perry-Smith and Shalley 2003, Burt 2004, Rodan and Galunic 2004, Obstfeld 2005, Uzzi and Spiro 2005, Perry-Smith 2006, Fleming et al. 2007, Parachuri 2010). Several studies have examined how the structure of the social network of the creator relates to the creation and implementation of potentially creative outcomes. On the one hand, creators with a large set of contacts that tend to be disconnected from each other (forming a sparse network structure around the creator) are more likely to produce ideas that are considered novel and useful by the community because they are presumably more likely to access diverse knowledge that can be combined into novel and valuable outcomes (Burt 2004, Rodan and Galunic 2004, Fleming et al. 2007). On the other hand, individuals surrounded by a tight-knit network of contacts that tend to be closely connected are more likely to have the social traction needed to get their creative ideas implemented or adopted by

others (Obstfeld 2005, Uzzi and Spiro 2005, Fleming et al. 2007). Other studies have examined the relationship between tie strength and creativity. These studies suggest that weak ties favor individual creativity because they have structural properties that facilitate access to diverse information and encourage autonomous thinking (Perry-Smith and Shalley 2003, Perry-Smith 2006). Common to all these studies is the notion that accessing diverse knowledge is not likely to be associated with access to social support. Hence, the extent to which socially supportive forces can be valuable in the "risky" endeavor of generating creative ideas remains unclear. Moreover, we have come to believe that sporadic ties to organizationally (or cognitively) distant people are better catalysts of generative creativity. This paper challenges this belief by examining the generation of creative ideas from a dyadic viewpoint.

Dyadic exchanges not only conduit knowledge but also transmit various levels of social support as reflected by the time, energy, and engagement associated with them. As a result, dyads constitute an ideal unit of analysis to disentangle more precisely the effects of knowledge diversity, tie strength, and network cohesion on the generation of creative ideas. Disentangling these effects has helped us to uncover how diversity and supportive forces of dyadic relationships may act as complementary catalytic ingredients on the generation of creative ideas. From a knowledge viewpoint, and realizing that dyadic relationships can differ significantly (even for the same individual) on the diversity of the knowledge they conduit, this paper argues that ties with greater knowledge breadth are more likely to act as cognitive catalysts that more easily ignite the generation of creative ideas. Such a consideration is important because we have typically equated access to diverse knowledge with (weak) ties to diverse groups of people, although this equation overlooks the possibility that ties with sufficient bandwidth to conduit diverse knowledge themselves may play an important role in the generation of creative ideas. From a social viewpoint, and building on the role that intrinsic and extrinsic (to the dyad) motivational factors may have on the generation of creative ideas (Amabile 1996), we argue that because strong ties are typically charged with high levels of intrinsic motivation and positive affect, they are more likely to be conducive to the generation of creative ideas. Such a dyadic social support may be fostered extrinsically when the interacting actors share common contacts that strengthen a collaborative environment around the focal relationship. However, when the influence of common contacts on the focal dyad is too strong, they can be a liability not only because they may lead to information redundancy but also because they may impose social constraints that could inhibit divergent thinking of the focal dyad.

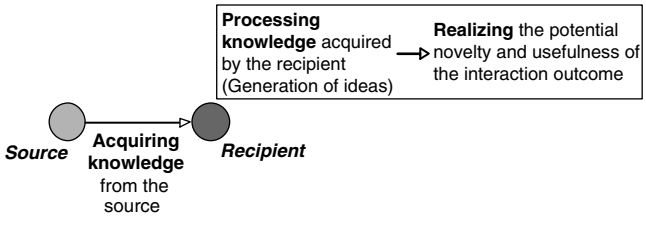
We tested the ideas outlined above in a sociometric study we conducted involving more than 600 dyadic relationships in the development department of a software firm. Toward this end, this study captures explicitly the breadth of knowledge exchanged on each dyadic relationship—an approach hindered in previous empirical studies by the difficulty of measuring the technical content of dyadic interactions. Doing so allows us to examine precisely how content and social attributes of dyadic exchanges relate to the generation of creative thoughts.

2. Theoretical Framework and Hypotheses

This paper studies the dyadic determinants of generating potentially creative ideas from product-related interactions. Product-related interactions are defined as the transfer of technical information between the source, or upstream actor sending information, and the recipient, or downstream actor receiving information relevant to the development of new products or technologies (Reagans and McEvily 2003). The recipient is the actor who "goes to the source to discuss product-related matters" during the product development effort. We focus on the outcome of a dyad from the recipient's point of view. Hence *creative interactions* are those in which the recipient is likely to generate potentially novel and useful ideas after receiving technical information from the source.

As in other studies of innovation and knowledge management, this paper takes an information processing view to examine organizational relationships between source and recipient (e.g., Thompson 1967, Galbraith 1973, Szulanski 2000, Reagans and McEvily 2003, Borgatti and Cross 2003).[2] An organizational interaction between two individual actors includes the following basic stages: the recipient's *acquiring* knowledge from the source, *processing* that knowledge, and *realizing* the potential value of the interaction outcome (see Figure 1). Processing knowledge that yields creative ideas has been the subject of studies that take a cognitive psychology perspective to study creativity (Campbell 1960, Simonton 1988, Finke et al. 1992). Within this context, creative ideas are associated with the occurrence of two distinct sets of cognitive processes: *generation* of new ideas and *evaluation* of the ideas generated to select which ones to pursue further. This model is consistent with the "blind-variation and selection-retention" model

Figure 1 An Information Processing View of an Organizational Dyadic Interaction



of creative thought proposed by Campbell (1960) and refined by Simonton (1988) and Finke et al. (1992). As the recipient evaluates the ideas that she generates after interacting with the source, she is able to realize the novelty and usefulness of the insight(s) generated from such interactions.

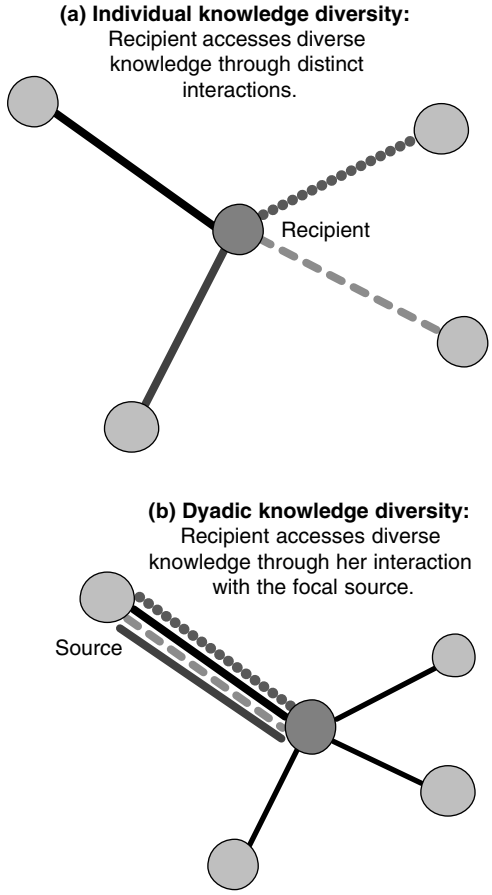
We rely on the recipient to assess the novelty and usefulness of her ideas because we study the generation of creative ideas before they get exposed to the community for further evaluation. Our approach is consistent with Simonton (1988, 1999), who suggests that the creator evaluates her creations before presenting them to the community for further scrutiny. We are also in line with Csikszentmihalyi (1996), who acknowledges that "a person who wants to make a creative contribution must not only work within a creative system but must also reproduce that system in his or her mind. In other words, the person must learn the rules and the content of the domain [area of contribution], as well as the criteria of selection [and] the preferences of the field" (p. 47), which ultimately decide how novel and useful the contribution is. This structure is especially pertinent to product development organizations, where individuals have a common understanding of the knowledge domain in which ideas are potentially valuable and a sound awareness of the criteria that would categorize an idea as novel and useful. Nonetheless, it is important to recognize that what the creator considers potentially creative may not necessarily be considered creative by the community. Therefore, the theoretical arguments and results presented in this paper must be considered in light of the generative aspect of creativity.

2.1. The Effects of Tie Content: Knowledge Diversity

Previous research on creativity has suggested that accessing diverse pools of knowledge and developing skills to establish novel linkages among them are important conditions to generate creative outcomes (Simonton 1999, Amabile 1996). Consistent with this argument, organizational studies have shown that individuals who access diverse knowledge are more adept at generating creative ideas. If diverse knowledge is accessed by connecting to distinct organizational groups that are not interconnected, an individual (or group) positioned in the middle of such distinct pools of knowledge has access to diverse ideas and is thus more likely to generate creative outcomes (Hargadon and Sutton 1997, Burt 2004, Rodan and Galunic 2004, Fleming et al. 2007). Hence individuals with a portfolio of dyadic interactions that conduits distinct knowledge domains are expected to be highly proficient at generating creative ideas. This individual-level view of knowledge diversity is illustrated in Figure 2(a).

This paper examines the role of knowledge diversity at the dyadic level (see Figure 2(b)). Dyadic knowledge diversity is the extent to which the content acquired by the recipient through her interactions with the source includes knowledge across distinct (technological) domains. This situation is certainly possible in organizations that develop several distinct products that require specific technologies. In such settings, some development actors are able to interact with regard to a wide range of distinct products and technologies, whereas the interactions of others are limited to a narrow set of products or technologies.[3] Would dyadic exchanges conducting various types of knowledge have a greater chance of triggering creative ideas? This is not a trivial question because individual-level analyses have emphasized the value of accessing diverse knowledge through ties to diverse groups of people, which overlooks the possibility that ties that conduit diverse knowledge may also themselves facilitate creative idea generation.

Figure 2 Knowledge Diversity at Individual and Relational Levels



The effect of dyadic knowledge diversity is grounded in the role of cognitive variation in the generation of creative ideas (Campbell 1960, Simonton 1988). The greater the variation in idea options generated by the creator, the greater the population of potentially novel and useful ideas from which to choose. As cognitive

variation depends on the existence of (relevant to the problem at hand) knowledge elements that can be combined into new feasible variations in the mind of the creator, the number and breadth of cognitive elements acquired by the creator from the source are essential ingredients to generate creative ideas (Finke et al. 1992, Sternberg 1988, Simonton 1999). Hence a dyadic relationship that contributes with its diverse knowledge to increasing the cognitive variation of the creator should be more likely to facilitate the generation of creative ideas associated with such a dyadic relationship (above and beyond the knowledge diversity possessed by the creator). This insight leads to our first hypothesis.

HYPOTHESIS 1 (H1). *The breadth of distinct knowledge domains acquired through a dyadic relationship is positively associated with the generation of creative ideas.*

2.2. The Effects of Social Networks: Tie Strength and Network Cohesion

Although the diversity of the knowledge acquired through dyadic interactions may be an important determinant of generating creative ideas, dyadic interactions can also act as a catalyst (or inhibitor) of generative creativity because of their motivational and supportive attributes (or lack thereof). Building upon the model of creativity put forward by Amabile (1996, p. 84), which suggests that creative outcomes are not only determined by the knowledge and creative skills possessed (or acquired) by the creator but also by her motivation to engage in the task at hand, we argue that tie strength and network cohesion are likely to influence the generation of creative ideas because they concern both the intrinsic motivation of the interacting actors to work closely together and the extrinsic (to the dyad) social constraints imposed by strong connections with common contacts between the source and the recipient.

Tie Strength. Granovetter (1973, p. 1371) introduced the concept of the "strength" of an interpersonal tie as the "the (probably linear) combination of the amount of time, the emotional intensity, the intimacy (mutual confiding), and the reciprocal services which characterize the tie." Since then, the concept of tie strength has been the focus of a great deal of attention in the network and knowledge transfer literature (e.g., Marsden and Campbell 1984, Reagans 2005, Hansen 1999, Reagans and McEvily 2003). With respect to individual creativity, previous studies have suggested that weak ties favor individual creativity because they have structural properties that reinforce creativity-related skills by easing the access to diverse knowledge and stimulating autonomous thinking (Perry-Smith and Shalley 2003). Moreover, Perry-Smith (2006, p. 96) found that the *number* of weak ties positively relates to individual creativity outcomes. Interestingly, she also found that the effect of weak ties has a more positive impact on creativity than the number of strong ties only when tie strength is measured by duration of the tie (and marginally by communication frequency) but *not* when measured by the emotional intensity (also called closeness) of the relationship. Her finding suggests that actors linked through long-lasting relationships that involve frequent interactions are less likely to produce creative outcomes, presumably because such strong relationships are at higher risk of exchanging redundant knowledge. Empirical evidence suggests that high dyadic communication frequency is indeed positively associated with the amount of knowledge overlap between the source and the recipient (Reagans 2005). Hence two actors who communicate very frequently over a very long time have a higher risk of eventually sharing the same knowledge base, which would make them mutually redundant and therefore unlikely to trigger creative ideas in each other. However, because tie strength and knowledge overlap are not perfectly correlated and because the emotional intensity associated with a dyadic relationship is an important dimension of tie strength that can vary partially independently of communication frequency and tie duration (Marsden and Campbell 1984), we argue that strong ties may still play a positive role in the generation of creative ideas.

Previous research has highlighted the critical role of intrinsic motivation to work on the task at hand in order to achieve creative outcomes (Amabile 1996, p. 115):

> Intrinsic motivation arises from the individual's positive reaction to qualities of the task itself; this reaction can be experienced as interest, involvement, curiosity, satisfaction, or positive challenge.

Because a tie's strength is determined not just by the duration and frequency of interactions but also (and more importantly) by a party's willingness to work closely with the other party, tie strength is associated with the actors' intrinsic motivation to engage in a working relationship (Marsden and Campbell 1984). In product development organizations, individuals engage in technical interactions to resolve their task interdependences, yet individuals are intrinsically more engaged in certain work-related interactions than in others (Thompson 1967, Galbraith 1973, Allen 1977, Levin and Cross 2004). Individuals at work exhibit various levels of involvement, interest, satisfaction, and positive challenge associated with their work-related relationships. Such intrinsic motivation to engage in certain dyadic relationships may depend on the nature of the task interdependences that have triggered these relationships as well as the perception of the personal attributes of the actors involved. All this contributes to the emotional intensity associated with each dyadic relationship at work, which can in turn foster the generation of creative ideas. The motivation of the recipient to work with the source not

only influences whether the recipient will engage in such a working relationship but also determines the novelty of the interaction outcome in much the same way as creative skills (Amabile 1996, p. 103). The recipient's proactive and motivated attitude toward her working relationship with the source provides the energy needed to acquire and process knowledge from the source and to realize creative ideas from the exchange. Moreover, the closer the relationship with the source, the more likely it is that such a relationship is charged with positive affect, which in turn is more conducive to creative thoughts (Amabile 1996, p. 93; Isen 1999; Amabile et al. 2005).

The motivation of the source to engage in a work-related relationship with the recipient can also have a positive influence on creativity by supporting and encouraging the generation of novel and useful ideas (Hargadon and Bechky 2006). As reported by Madjar et al. (2002), individuals who receive more support and encouragement to pursue their initiatives, either from their contacts at work (supervisor and coworkers), their contacts at home (family and friends), or both, are more likely to be perceived as creative individuals. Such evidence is in line with the notion that close relationships are likely to develop intrinsic (to the dyad) norms that provide support for the production of creative ideas (Torrance 1970, 1971). Because strong ties at work link people who intrinsically enjoy working together, they are more likely to be conducive to the motivation, support, and positive affect that can foster the generation of creative ideas (Amabile 1996, Amabile et al. 2005).[4] To the extent that work-related closeness varies partially independently of communication frequency and tie duration, we posit our second hypothesis.

HYPOTHESIS 2 (H2). *The strength of a dyadic relationship* (*to the extent that it captures the work-related closeness of the interacting actors*) *is positively associated with the generation of creative ideas.*

Network Cohesion. At the relationship level, network cohesion is defined as the extent to which the focal dyad is surrounded by strong connections with common third parties. As a result, the presence of common third parties can exert extrinsic (to the dyad) social influences on the recipient's pursuit to generate creative ideas from her relationship with the source. On the one hand, common third parties can extrinsically encourage both the source and the recipient to positively engage in their dyadic working relationship, which can reinforce the dyadic motivation toward generating creative ideas. On the other hand, excessive presence of common third parties can extrinsically steer the focal dyad to converge toward group thinking—to the detriment of creative idea generation—not only by making the information exchanged more redundant but also by putting social pressure on the ideas generated by the focal dyad.

The benefits of network cohesion have been associated with the fostering of a collaborative environment favorable to innovation involvement (Obstfeld 2005). Such an environment eases the transfer of knowledge from the source to the recipient (Reagans and McEvily 2003) and fosters risk sharing around the focal dyad (Granovetter 1985). Dyads surrounded by moderated connections to common third parties are more likely to risk being creative because they can spread such risks among common contacts with the source (Uzzi 1997, Uzzi and Spiro 2005). This conclusion is in line with research on brainstorming and collective creativity, which suggests that momentary group cohesion can lead to creative outcomes in the presence of special supportive environmental conditions (Osborn 1953, Sutton and Hargadon 1996, Hargadon and Bechky 2006). The presence of common third parties can foster the motivation of the interacting actors to engage more closely in the work-related relationship, which could foster the collaborative conditions needed to generate creative ideas (Coleman 1990, Obstfeld 2005).

Although common third parties can promote the establishment of a supportive environment around the focal dyad that facilitates the generation of creative ideas, they can also have a controlling influence that can be detrimental to creative idea generation. When the focal dyad depends heavily on common third parties to obtain the knowledge, opinions, and beliefs that will be used to generate ideas, the focal dyad may suffer the effects of information redundancy and social pressure (Janis 1972, Amabile 1996). The risk of receiving redundant information from the source increases to the extent that what the source knows is a function of her connections to common third parties. In the extreme, excessive network cohesion can make the information exchanged in the focal dyad fully redundant because everyone around the focal dyad is "talking about similar things" (Burt 2004, Fleming et al. 2007). Yet even if we control explicitly for the knowledge diversity and knowledge redundancy associated with the focal dyadic relationship, strong connections with common third parties can still exert a negative influence on the generation of creative ideas. Network cohesion can put social pressure on the recipient to accede quickly to a solution that is acceptable to the group instead of exploring novel linkages across existing pieces of knowledge (Woodman et al. 1993, Perry-Smith and Shalley 2003). In terms of cognitive psychology, network cohesion could favor "convergent thinking" to exploit the fastest and most efficient path to reach a solution and hinder "divergent thinking" to explore alternative paths that might lead to more novel and useful outcomes (Guildford 1950). Because relationships strongly linked to many common third parties may "force" the recipient to reciprocate to others with similar ideas that favor group consensus rather than diverge from it, the recipient may feel additional pressure to

stay within the status quo rather than search for creative solutions. Such a controlling influence, which hinders divergent thinking, may be further compounded by the sensation of extrinsic surveillance or evaluation expectation that strong connections with common third parties may also create on the focal dyad (Amabile et al. 1990).

These conflicting arguments reflect the tension that exists between network cohesion and creativity. They also reflect the dual role of extrinsic motivation on creativity (Amabile 1996, p. 119): "Enabling" (or supportive) extrinsic motivators (typically associated with collaborative and cooperative environments) can be conducive to creativity, whereas "controlling" extrinsic motivators (such as redundancy, surveillance, and emphasis on the status quo) are likely to be detrimental. Similar to previous research that has identified a curvilinear effect between network structure and creativity (Uzzi and Spiro 2005, Parachuri 2010), we predict a concave relationship between dyadic network cohesion and the generation of creative ideas. On the one hand, the moderated presence of common third parties helps build an environment that fosters acquisition of knowledge and supports the interacting actors' motivation to engage in a collaborative working relationship, leading to easier generation of creative ideas. On the other hand, when connections to common third parties exceed certain levels, they become a liability to the focal relationship not only because they are likely to increase the redundancy of the information exchanged but also because they increase the social pressure to conform with group thinking. Hence we propose our final hypothesis.

HYPOTHESIS 3 (H3). *The relationship between the generation of creative ideas and network cohesion is characterized by a concave function*; *that is, increasing network cohesion favors the generation of creative ideas for low levels of network cohesion, whereas increasing network cohesion hinders the generation of creative ideas for high levels of network cohesion.*

3. The Sociometric Study

To test the hypotheses described in §2, we studied both the portfolio of products and the formal and informal organizational structure of the entire development department of a European software development company. The firm, founded in the 1980s, is a public company traded on the German stock exchange. It is one of the world leaders in a particular type of application in the software industry, and its principal market consists of business customers. The firm's development organization is distributed across three different locations in two neighboring European countries.

In 2005, the development department worked on seven distinct products. Six of these products were already available in the marketplace (hereafter, the "legacy" products) and consumed development resources because of customers' special requests or incremental product upgrades. The seventh product was a radically new one (hereafter, the "radical" product) for which the development effort was initiated in the second half of 2004. Because each of the seven products under development was technologically distinct, we were able to characterize uniquely the technical nature of a dyadic interaction by asking respondents about their communication patterns associated with each of the seven products. The resulting distinction among product-related interactions provided an ideal setting to study the impact of dyadic knowledge diversity on creative idea generation. The study focused on the firm's development department, which was organized into eleven groups: eight development groups (doing both radical and legacy development), one quality control group for testing all the products, one architecture and managerial group (which made software architecture decisions and managed the department's resources), and one support group responsible for documentation and information systems support.

3.1. Methods and Data

Two methods were used to collect the data: semistructured interviews and a Web-based survey. First, semistructured interviews with the executive team of the firm, including the CEO and VP of development, were conducted to gain insights into its portfolio of products and general organizational structure. In addition, semistructured interviews at all three sites were carried out with group leaders and developers regarding their development process and the nature of the workload associated with the products under development. We then created and distributed a survey throughout the development organization to capture individual data on product development activities and organizational interactions with other members of the development department. The survey went through several revisions (with input from both the VP of development and one of the architect and technical product managers) to ensure that the questions were valid and that the terminology and scales used matched the context of the organization. The Web-based survey was administered to the entire development department at the end of 2005 and focused mainly on the activities and interactions taking place that year. The survey took an average of 49 minutes to complete and was filled out by 58 of the 66 people in the development department (88% response rate). Although 50% of the nonrespondents were from the support group, these individuals did not significantly differ from members of the respondent groups in terms of gender or location. More importantly, using the ratings received from everyone else in the organization, we found that respondent and nonrespondent groups did not differ significantly in their average received ratings on the key

variables of this study. Hence there is no reason to suspect that nonrespondent bias significantly influenced the results.

Network data were collected using a combination of classic sociometric techniques (Wasserman and Faust 1994, pp. 43–54). First, each respondent was provided with a fixed roster of contacts formed by the 66 people in the development department. The full name and location of each person was clearly specified in the Web-based survey, and respondents were asked to select those they had "gone to" for interactions that significantly affected their work during 2005. The name generator used an "information seeking" perspective to ensure consistency throughout the survey because all the relational questions would be formulated from the recipient's viewpoint. In addition, the focus was on the interactions that affected work in order to concentrate the hypothesis testing on those ties that were more likely to be associated with the development of any of the organization's products. Even though we did not restrict the number of contacts a respondent could select, we did not particularly encourage including casual ties—people with whom the respondent "interacted casually or for trivial matters only." This approach did not appear to lead respondents to omit a significant number of less important ties. An examination of the frequency distribution of our variables for communication frequency and work-related closeness yielded similar counts for both low and high values of these variables, suggesting that the respondents were likely to identify contacts with whom their interactions were "weak" yet relevant.[5]

After the respondents identified their contacts, they were asked 16 questions about the relationship with each of their selected contacts. Using a dynamic update of the Web-based survey, we were able to include the full name of the contact person on each relational question asked. This helped the respondents focus their answers on the relationship with the contact in question. Consistent with social network research, and to ensure a high and reliable response rate, each variable was measured by a single network question (Marsden 1990, Burt 1992, Wasserman and Faust 1994). It was necessary to balance our desire for a complete survey—one that would capture all the network variables of interest—with the firm's need to maintain a reasonable survey length that respondents could fill out reliably.

The unit of analysis is the relationship as measured from the recipient's viewpoint. Respondents reported 671 relationships, of which 641 involved the development of at least one of the products in the firm's portfolio for which our measures of knowledge diversity are defined. After removing interactions for which source data were missing or incomplete, we were left with a sample of 609 observations.

3.2. Variables

Dependent Variable: Ease of Generating Creative Ideas. The dependent variable captures the extent to which the recipient generates creative ideas associated with her interactions with the source. Because we study the microprocesses by which creative ideas are generated before they get exposed to the community for further evaluation, we could not use external evaluations of the ideas generated by the creator (Amabile et al. 2005). Instead of evaluating the level of creativity of the ideas generated by the creator, we focus on the "ease" of the creator to generate creative ideas associated with each of her work-related dyadic relationships. Given the dyadic nature of this study, we focus on the generative cognitive process triggered by each dyadic relationship. Because the source and recipient are the *only* actors equipped to assess accurately the outcome of a dyadic relationship, we relied on the recipient to evaluate the process of generating creative ideas triggered by her relationship with the source during the past year. This decision is consistent with previous work in knowledge transfer at the dyadic level, which relies on the source side of the dyad to assess, instead, the ease of transferring knowledge to the recipient (Reagans and McEvily 2003).[6] As already mentioned, evaluating creativity on the recipient side of the relationship is also consistent with Simonton's (1988, 1999) and Csikszentmihalyi's (1996) individual cognitive view of creativity, which recognizes that the creator assesses the creative level of her ideas before communicating them to others. A quote from an interview with the famous inventor Jacob Rabinow illustrates vividly the point that people with training in a certain knowledge domain (like our respondents who were members of the development department of a software firm) are able to discern the creative potential of the ideas they generate, which is important to consider when assessing the ease of generating creative ideas (Csikszentmihalyi 1996, p. 49):

> And then you must have the ability to get rid of the trash which you think of. You cannot think only of good ideas, or write only beautiful music. You must think of a lot of music, a lot of ideas, a lot of poetry, a lot of whatever. And if you're good, you must be able to throw out the junk immediately without even saying it. In other words, you get many ideas appearing and you discard them because you're well trained and you say, "that's junk." And when you see the good one, you say: "Oops, this sounds interesting. Let me pursue that a little further." And you start developing it.

This view is also consistent with studies showing that individuals can make reliable self-assessment of their level of involvement in innovation activities (Ibarra 1993, Obstfeld 2005).

The ease of generating creative ideas associated with each relationship was captured by asking each

respondent to rate, on a seven-point Likert scale (from "strongly disagree" to "strongly agree"), his or her level of agreement with the following statement (Tortoriello 2005):

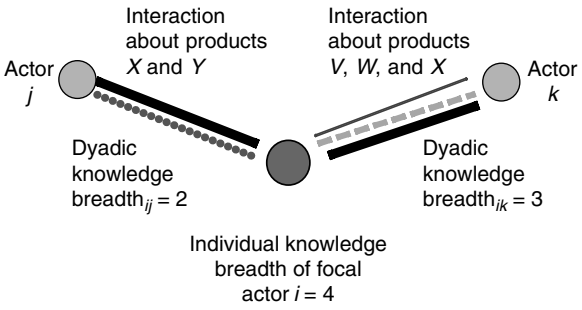
> When I interact with [name of source contact], it is easy for me to generate NOVEL creative solutions and/or ideas. These NOVEL ideas can be either related to our products or the way we do things.

Observe that the survey question captures both the novelty and usefulness dimensions of creativity so that the respondent can make an accurate assessment of the ease of generating potentially creative ideas after interacting with the source in the past year (Amabile 1996). Moreover, Marsden (1990) finds that answers to relational questions are generally reliable when used with roster methods that facilitate respondents' recall (as used in our survey), and Freeman et al. (1987) find network questions to be highly reliable when inquiring about typical interaction patterns. Hence, considering the risk of respondents dropping out of the Web-based survey if there were an excessive number of relational questions, we chose to use a single item to assess the ease of generating creative ideas associated with each dyad.

Independent Variables. Knowledge diversity is the extent to which the content acquired by the recipient through her interactions with the source includes knowledge across distinct domains (knowledge breadth) and/or various states of flux. We measured this in alternative ways. First, *dyadic knowledge breadth* was measured by counting the number of distinct product-related interactions associated with each relationship. Each respondent was asked to indicate, for each contact identified, how often (never, rarely, sometimes, very often, always) he or she went to the source "to discuss product-related matters during this year" associated with product X, with product Y, with product Z, and so on for each of the seven products under development. Hence, the dyadic knowledge breadth ranges from "1" (interactions concerning one product only) to "7" (interactions concerning all seven products under development).

In order to disentangle the effect of dyadic knowledge breadth measured at the relationship level from that measured at the individual level, we measured the *individual knowledge breadth* of the recipient (and of the source) by counting the total number of distinct product-related interactions that each recipient was involved in during the past year. This measure also varies from "1" to "7" but remains constant for all the relationships of a given recipient; the same occurs for knowledge breadth at the source. Figure 3 illustrates how both dyadic and individual knowledge breadth is determined for a focal individual with two organizational relationships with two other actors: One relationship has a dyadic knowledge breadth of 2 because the focal actor goes to actor j to acquire technical information regarding products X and Y, whereas the dyadic knowledge breadth of her relationship with actor k is equal to 3 because the focal actor goes to actor k to acquire technical information not only regarding product X but also regarding products V and W. Finally, because the focal individual acquires knowledge concerning four different products (V, W, X, and Y) across all relationships, her individual knowledge breadth is 4.

Figure 3 Example of Dyadic and Individual Knowledge Breadth



These measures of knowledge breadth (both at the dyadic and the individual level) capture the diversity of the knowledge acquired by the recipient. However, they assume that all product-related interactions are equal in terms of communication frequency and state of flux. In order to account for the unequal frequency of product-related interactions, we used two alternative measures of dyadic knowledge breadth. Thus for each relationship, *infrequent dyadic knowledge breadth* counts the number of product-related interactions that occurred "rarely" and *frequent dyadic knowledge breadth* counts the number of such interactions that occurred more frequently.[7] Finally, not all the technologies were in the same state of flux: One "radical" product involved the most recent technologies whereas the other six used distinct "legacy" technologies. We devised a dyadic measure of the *fraction of knowledge newness*, which is a function of the mix of radical and legacy product-related interactions for a given relationship. The fraction of knowledge newness of a dyad is the communication frequency associated with the radical product divided by the sum of all the communication frequencies for all product-related interactions for that dyad. For example, if actor i requests "very frequent" interactions with actor j about the radical product and also requests "very frequent" interactions with actor j about two legacy products, then the fraction of knowledge newness for such a relationship is 1/3 because a third of the total product-related communication was dedicated to the radical product.

Tie strength is a complex construct formed by a combination of tie-related factors that include duration, communication frequency, and emotional closeness (Granovetter 1973, Marsden and Campbell 1984). As in most of the network literature, tie strength was measured based on the latter two indicators (e.g., Hansen 1999,

Reagans and McEvily 2003). First, respondents were asked to indicate their average communication frequency with the identified source contact during the past year (daily, weekly, several times per month, monthly, less often). Then they were asked "How close is your working relationship with [name of source contact] (Very close—this person is among my strongest contacts; Close—we like discussing and solving issues together; Less than close; Distant—we interact only when strictly necessary)". Because the responses to the survey questions were qualitative, we transformed them into scale variables in order to calculate our network variables. We did so by using the joint distribution of these two ordinal variables, which exhibits a strong positive association between them (the independence model yields $\chi^2 = 408.01$ with 19 *df*, $p < 0.001$). Respondents at our research site indeed communicated more frequently with those they felt closer to professionally and emotionally. Because there is a strong association between communication frequency and closeness, we can infer the distance between the intervals of these variables by estimating a log-multiplicative association model developed by Goodman (1979, 1984). Fitting this model to our data yields the "distances" between the ordered categories used to measure communication frequency and work-related closeness. With such distances, our qualitative variables were fitted into a scale from 1 to 4 for both communication frequency (less often = 1.00; monthly = 1.31; several times per month = 1.89; weekly = 2.56; daily = 4.00) and for work-related closeness (distant = 1.00; less than close = 2.29; close = 3.13; very close = 4.00). To calculate tie strength, we first measured interaction intensity as the average of closeness and frequency (z_{ij}). (We also computed interaction intensity as the product of these two variables, obtaining substantively similar results.) Then we measured tie strength (p_{ij}) as the proportion of the recipient's total interactions invested in the relationship with source j, both as a result of i's seeking out j and of being sought out by j. This approach is consistent with previous network studies that transform tie intensity into a proportional measure of tie strength (Burt 1992, Gargiulo and Benassi 2000, Reagans and McEvily 2003). Hence

$$p_{ij} = \left(\frac{z_{ij} + z_{ji}}{\sum_q (z_{iq} + z_{qi})} \right); \quad i \neq j.$$

This proportional measure of tie strength allows us to capture how the focal actor i allocated her time and attention to the different people with whom she interacted on work-related matters during the last year. It is worth noting that the tie strength measure is based on all the communications in which the actors were involved as either seeker or provider of information. In this way, tie strength takes into account the proportional amount of energy and attention that actor i spends with actor j relative to all the interactions in which actor i is involved (Burt 1992, Gargiulo and Benassi 2000).

We also captured an indicator of *tie duration* by asking respondents to indicate whether they went to the source "for any type of (important) interactions BEFORE the development of the radical product kicked off." Note that for bidirectional dyads, tie duration indicates whether the source or recipient reported having interacted before this time. However, this indicator was not significantly correlated with either communication frequency or tie closeness. Therefore, tie duration was treated as an indicator of common knowledge background to be controlled for, not as an important dimension of tie strength.[8]

Dyadic network cohesion is a function that depends on the number and strength of third-party connections surrounding the focal relationship (ij). Following Burt (1992, pp. 54–56) and Reagans and McEvily (2003, p. 255), the involvement of recipient i on common third parties (q) with source j was assessed using a measure of indirect constraint (c_{ij}):

$$c_{ij} = \sum_q p_{iq} p_{qj}; \quad i \neq j.$$

This measure captures the strength of the relations surrounding the focal interaction between i and j. A relation with a common third party (q) is strong to the extent that the recipient has a strong relationship with the third party (p_{iq}) and the common third party also has a strong relation with the source (p_{qj}). Then in order to assess the overall strength of these indirect connections surrounding the focal connection between recipient and source, we need only sum over all their common contacts. (This is essentially a measure of triadic closure between actors i, j, and third parties q.) Observe that because p_{ij} measures the proportion of the recipient's total interactions invested in the relationship with source j (as a result of i's seeking out j and of being sought out by j), our measure of dyadic network cohesion properly captures the presence of common third parties even if actor i did not seek out actor q but was sought out by actor q ($z_{iq} = 0$ and $z_{qi} > 0$). It is also important to emphasize that because our measures of both tie strength and network cohesion are based on the overall communication patterns of the respondents, they capture the social dimensions of the relationship rather than the properties of the content they conduit, which we measure separately.

Control Variables. Common knowledge background. Proximity between the stock of knowledge of the source and the recipient can influence the generation of creative ideas through various mechanisms. On the one hand, common knowledge background between the source and the recipient not only eases knowledge transfer from the source's perspective (Reagans and McEvily 2003) but also facilitates the assimilation of new knowledge

on the recipient's side (Cohen and Levinthal 1990). On the other hand, excessive common knowledge can lead to knowledge redundancy, which could limit the generation of creative ideas. In the absence of a clear prediction, we control for the various sources of common knowledge background relevant to a relationship. First, we define four indicators that capture demographic and organizational proximities based on *gender*, *seniority*, *collocation*, and *group membership*. Second, we capture common knowledge background based on *expertise overlap*. To do this, we asked each respondent to indicate "the areas in which they considered themselves experts (or with significant professional experience)." Respondents could choose from a list of 13 categories (with some categories containing more than one item). Seven of the 13 categories corresponded to the seven distinct technologies associated with each product under development; the other six categories corresponded to various phases of the development process. We then measure the fraction of the recipient's number of expertise categories that coincided with those of the source. The resulting expertise overlap variable ranges from 0 to 1, with higher values signaling higher levels of common knowledge background (from the recipient's viewpoint). Third, we measure *structural equivalence* of the recipient and the source in order to capture the similarity of the actors' social networks. For this, we determined the Euclidean distance between their two network patterns and reversed its sign to capture the similarity of the social networks of the interacting individuals (Wasserman and Faust 1994, p. 367; Reagans and McEvily 2003, p. 257). Finally, because relationships with a longer history of interactions are more likely to have more common knowledge background, we include *tie duration* as an important indicator to control for.

Interaction types. People in organizations communicate not only to coordinate their technical efforts related to the components of the products they develop (Sosa et al. 2004) but also for managerial, social, and (technical) consultation reasons (Allen 1977). Dummy variables were defined to indicate whether these additional interaction types were associated with the source. For *managerial interactions*, respondents were asked if they would go to the source "for advice or help if [the respondent] had a managerial question or ran into an organizational issue at work." Managerial interactions can, in fact, have a significant influence on the creation of novel and useful procedures or routines. For *social interactions*, respondents were asked if the source was one of those people "with whom [the respondent] likes to spend his or her free time. That is, people with whom [the respondent] gets together for informal social activities such as going for lunch, coffee breaks, dinner, drinks, movies, visiting one another's homes, and so on." Controlling for the social component of dyadic relationships is important because they are likely to be charged with positive affect, which is an important determinant of creativity (Amabile et al. 2005). Finally, *consultation-type interactions* were measured by asking respondents if they would go to the source "for (technical) advice to learn about a novel (for the respondent) technical topic, or when [the respondent] encounters a particularly hairy technical problem." Because the objective of consultation-type interactions is to acquire new knowledge for generating solutions to a given technical situation, we should expect more creative ideas from relationships that include this type of interaction.[9]

Knowledge codifiability is "the degree to which knowledge can be encoded" (Zander and Kogut 1995, p. 79). Because knowledge codification affects knowledge transfer processes (Hansen 1999, Reagans and McEvily 2003), it is an important content property to control for when studying the generation of creative ideas. To measure this construct, respondents were asked to rate (on a seven-point Likert scale) their level of agreement with the following statement: "The information received from [the source] is typically well documented in writing (i.e., memos, reports, manuals, e-mails, faxes, etc.)."

Indirect product-related knowledge flows. Because dyads are not isolated from other organizational dyads, it is crucial to control explicitly for the (product-related) knowledge acquired by the recipient from her common contacts with the source. Such indirect knowledge flows can either increase dyadic knowledge breadth or make some (or all) dyadic knowledge breadth redundant. Toward that end, we measure *indirect knowledge breadth* as the number of product-related knowledge flows acquired through common third parties that are not acquired through the focal dyadic relationship. Similarly, we measure *indirect knowledge redundancy* as the number of product-related knowledge flows acquired through common third parties that are also acquired within the focal dyad.

$$IndirectBreadth_{ij} = \sum_{r=1}^{7} (ctp_{r,ij})(1 - y_{r,ij});$$

$$IndirectRedundancy_{ij} = \sum_{r=1}^{7} (ctp_{r,ij} \cdot y_{r,ij}),$$

where $y_{r,ij}$ is a binary variable that indicates whether recipient i went to source j for technical information related to the development of product r and $ctp_{r,ij}$ is a binary variable that indicates whether recipient i received technical information about product r through at least one common third party between actors i and j. Because there are seven products under development at our research site, these measures can range from 0 to 7. Finally, because the measures of indirect knowledge flows do not capture the number or the intensity

of product-related interactions through common third parties, we define additional controls that measure the overall intensity of these indirect flows as follows:

$$IndirBreadth\_intensity_{ij} = \sum_{r=1}^{7}\left[\left(\sum_{q} z_{r,iq}\cdot z_{r,qj}\right)(1-y_{r,ij})\right];$$

$$IndirRedundancy\_intensity_{ij} = \sum_{r=1}^{7}\left[\left(\sum_{q} z_{r,iq}\cdot z_{r,qj}\right)\cdot y_{r,ij}\right],$$

where $z_{r,iq}$ measures (on a scale from 0 = never to 4 = always) the frequency by which actor i went to actor q for technical information about product r. Conversely, $z_{r,qj}$ measures the frequency by which actor q and actor j exchange technical information about product r.

4. Analysis and Results

The dependent variable is the ease of generating creative ideas. To test the hypotheses, we have a sample of 609 dyads with complete information. Yet there are particular attributes of the data that make the statistical analysis a nontrivial task. First, because the dependent variable is ordered and discrete, an ordered probit regression model was used as the main statistical approach; these results are reported in Table 2.[10] Second, and more importantly, our unit of analysis is at the dyadic level and so the sample observations are not independent, which violates an important assumption underlying most regression models. Because groups of observations share either the same recipient or the same source, their error terms are likely to be correlated (i.e., network autocorrelation can artificially reduce the standard errors). Several approaches to addressing this issue have been proposed (Lincoln 1984, Krackhardt 1988). One approach used in several dyadic analyses (e.g., Stuart 1998, Reagans and McEvily 2003, Reagans 2005) is to include fixed effects for each recipient and source within the data by including a dummy variable for every actor in the sample. These dummies will be zero for all actors *except* for the dummies corresponding to the recipient and source of the focal relationship. Including individual fixed effects in this manner effectively models how the hypothesized effects explain variation in the dyadic dependent variable while controlling for any unobserved heterogeneity (regarding, e.g., age or tenure) among actors. These effects also control for any *individual* tendencies of recipients to rate interactions with others as novel and useful (either to inflate their own creative status or to be sympathetic with others) and of sources to be rated as "catalysts" of creativity. To control further for the lack of independence among groups of observations, we estimate robust standard errors clustered by a criterion that considers together observations that are likely to be nonindependent (Wooldridge 2002, p. 134; Baum 2006, p. 138). Hence, standard errors were clustered by the recipient. Clustering standard errors by the source yields substantially similar results. Calculating a Huber-White estimator of clustered standard errors allows for nonindependent observations within the cluster while assuming that observations are independent across clusters (Williams 2000, Baum 2006). Finally, to test further the robustness of our regressions to potential network autocorrelation, additional models (not reported here) using multiple regression quadratic assignment procedures were estimated (MRQAP; Krackhardt 1988, Borgatti et al. 2002, Dekker et al. 2007). The MRQAP results were consistent with the more conservative results reported here.

Table 1 shows the descriptive statistics and pairwise correlations of the main variables included in the regression models. Table 2 shows the coefficients of the ordered probit regression models predicting the ease of generating creative ideas. Model 1 includes two groups of control variables. First, the model includes demographics and organizational control variables as indicators of common knowledge background between the source and the recipient. The results show that collocated and structurally equivalent dyads are likely to facilitate the generation of creative ideas. In contrast, group membership appears to have a hindering effect, as indicated by the positive (not significant, for now) coefficient associated with interactions that occur across group boundaries ($p < 0.147$). Model 1 also includes controls for interaction types. The results show that managerial and consultation interactions increase the chances of generating creative ideas. (Note that the coefficient of social interactions is positive and significant ($p < 0.051$) before including the control for codified knowledge.) Finally, Model 1 shows that knowledge codifiability is positively associated with creative idea generation. This provides strong and novel empirical evidence suggesting that acquiring codified knowledge may contribute to the recipient's generation of creative thoughts. After considering codified knowledge as a form of visualization in problem solving, it is theoretically possible to argue for a positive link between knowledge codifiability and creative idea generation (Finke et al. 1992). However, as we will discuss in the next section, there is an important caveat concerning this latter empirical result.

Hypothesis 1, which argues that the breadth of knowledge acquired in a dyadic interaction contributes positively to the generation of creative ideas, is tested in Models 2–4. Model 2 includes measures of relational knowledge diversity in terms of both fraction of knowledge newness and overall dyadic knowledge breadth (giving equal weight to all product-related interactions, regardless of their frequency). In such a model, these two effects are not significant. Models 3 and 4 tell a different story. Model 3 includes two measures of relational knowledge breadth to capture the fact that some

Table 1 Descriptive Statistics and Correlations ($N = 609$)

Variables	Mean	S.D.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1. Ease of generating creative ideas	4.91	1.17	1.00																		
2. Same gender	0.79	0.41	−0.02	1.00																	
3. Same seniority	0.62	0.49	0.03	−0.12	1.00																
4. Collocation	0.56	0.50	0.18	−0.01	0.02	1.00															
5. Across group boundaries	0.71	0.46	−0.13	0.04	−0.10	−0.12	1.00														
6. Expertise overlap	0.54	0.29	0.10	0.09	−0.02	0.10	−0.15	1.00													
7. Structural equivalence	−24.48	5.28	0.09	−0.10	0.19	0.33	−0.47	0.11	1.00												
8. Tie duration	0.73	0.44	0.03	0.08	−0.04	−0.02	−0.02	−0.03	0.09	1.00											
9. Managerial type	0.46	0.50	0.18	0.00	−0.18	0.07	−0.16	0.15	0.02	−0.06	1.00										
10. Social type	0.56	0.50	0.28	−0.02	0.03	0.31	−0.18	0.05	0.19	0.12	0.22	1.00									
11. Consultation type	0.87	0.34	0.12	0.06	−0.03	0.04	−0.11	0.12	0.06	0.04	−0.14	0.04	1.00								
12. Knowledge codifiability	5.15	1.30	0.53	0.07	0.12	0.08	−0.10	0.06	0.06	0.00	0.10	0.16	−0.05	1.00							
13. Fraction of knowledge newness	0.53	0.37	0.02	−0.05	0.05	0.03	−0.05	0.16	−0.17	−0.33	0.04	−0.09	−0.03	0.03	1.00						
14. Dyadic knowledge breadth	1.96	1.31	0.07	0.11	−0.16	−0.09	−0.15	−0.11	0.03	0.25	0.14	0.17	0.09	−0.04	−0.36	1.00					
15. Indir. knowledge breadth	0.77	1.16	0.01	0.17	−0.06	−0.13	−0.06	−0.10	−0.18	−0.03	0.05	0.04	−0.05	0.02	−0.07	−0.03	1.00				
16. Indir. knowledge redundancy	1.75	1.18	0.05	0.13	−0.14	−0.10	−0.17	−0.06	0.05	0.22	0.17	0.17	0.05	−0.04	−0.31	0.90	0.03	1.00			
17. Indir. knowledge breadth intensity	3.38	6.49	−0.07	0.14	−0.05	−0.08	0.03	−0.13	−0.12	0.01	0.03	−0.08	−0.12	0.09	−0.20	−0.08	0.68	−0.03	1.00		
18. Indir. knowledge redundancy intensity	42.53	35.70	0.07	0.03	−0.17	−0.13	−0.09	0.14	−0.15	0.01	0.29	0.12	0.03	−0.05	0.10	0.40	0.09	0.50	0.01	1.00	
19. Tie strength	0.06	0.05	0.24	0.01	0.07	0.37	−0.37	0.29	0.43	−0.05	0.13	0.15	0.08	0.20	0.02	−0.10	−0.14	−0.11	−0.10	−0.17	1.00
20. Network cohesion	0.03	0.01	0.05	−0.01	0.12	0.38	−0.44	0.18	0.69	0.02	0.01	0.12	0.06	0.04	0.03	−0.01	−0.07	0.06	−0.03	0.01	0.37

Note. Correlations $> |0.11|$ are significant at $p < 0.01$.

Table 2 Ordered Probit Models of Ease of Generating Creative Ideas ($N = 609$)

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6[a]	Model 7	Model 8	Model 9[a]
Same gender	0.168	0.165	0.145	0.153	0.153	0.217	0.170	0.146	0.212
	(0.149)	(0.151)	(0.149)	(0.154)	(0.155)	(0.154)	(0.155)	(0.157)	(0.156)
Same seniority	−0.056	−0.060	−0.061	−0.043	−0.047	−0.103	−0.047	−0.030	−0.088
	(0.099)	(0.099)	(0.096)	(0.100)	(0.103)	(0.092)	(0.100)	(0.101)	(0.092)
Collocation	0.482***	0.465***	0.471***	0.492***	0.490***	0.393**	0.510***	0.455**	0.378**
	(0.176)	(0.177)	(0.178)	(0.175)	(0.177)	(0.177)	(0.183)	(0.185)	(0.186)
Across group boundaries	0.181	0.181	0.174	0.212	0.285**	0.337**	0.267*	0.289**	0.333**
	(0.125)	(0.130)	(0.139)	(0.141)	(0.134)	(0.133)	(0.137)	(0.134)	(0.134)
Expertise overlap	0.020	−0.027	−0.143	−0.196	−0.222	−0.302	−0.228	−0.306	−0.367
	(0.262)	(0.247)	(0.277)	(0.284)	(0.282)	(0.274)	(0.287)	(0.288)	(0.281)
Structural equivalence	0.045**	0.043**	0.036*	0.038	0.016	0.010	0.044	0.035	0.032
	(0.018)	(0.018)	(0.019)	(0.025)	(0.026)	(0.025)	(0.035)	(0.036)	(0.033)
Tie duration	0.120	0.109	0.092	0.073	0.002	−0.040	0.034	−0.009	−0.038
	(0.155)	(0.156)	(0.160)	(0.160)	(0.161)	(0.176)	(0.155)	(0.155)	(0.172)
Managerial type	0.313***	0.314***	0.302**	0.318***	0.261**	0.261**	0.252**	0.253**	0.253**
	(0.117)	(0.118)	(0.119)	(0.119)	(0.121)	(0.117)	(0.122)	(0.123)	(0.121)
Social type	0.122	0.114	0.078	0.062	0.002	−0.043	−0.001	−0.002	−0.046
	(0.152)	(0.152)	(0.151)	(0.142)	(0.146)	(0.156)	(0.148)	(0.146)	(0.156)
Consultation type	0.762***	0.747***	0.735***	0.730***	0.719***	0.582***	0.710***	0.745***	0.607***
	(0.170)	(0.174)	(0.176)	(0.186)	(0.185)	(0.187)	(0.187)	(0.186)	(0.187)
Knowledge codifiability	0.642***	0.643***	0.640***	0.659***	0.648***	0.608***	0.644***	0.651***	0.612***
	(0.083)	(0.082)	(0.083)	(0.086)	(0.086)	(0.087)	(0.086)	(0.087)	(0.087)
Dyadic knowledge breadth		0.049							
		(.073)							
Fraction of knowledge *newness*		−0.052	−0.044	−0.213	−0.205	−0.218	−0.212	−0.239	−0.246
		(0.252)	(0.253)	(0.299)	(0.306)	(0.307)	(0.303)	(0.303)	(0.303)
Infrequent dyadic knowledge breadth			−0.017	0.073	0.095	0.064	0.079	0.087	0.056
			(0.063)	(0.104)	(0.107)	(0.105)	(0.110)	(0.112)	(0.109)
Frequent dyadic knowledge breadth			0.163*	0.267**	0.260**	0.216*	0.243*	0.247*	0.204*
			(0.098)	(0.125)	(0.127)	(0.122)	(0.128)	(0.130)	(0.124)
Indir. knowledge breadth				0.199*	0.218**	0.212**	0.214**	0.218**	0.212**
				(0.109)	(0.104)	(0.101)	(0.105)	(0.106)	(0.103)
Indir. knowledge redundancy				−0.097	−0.092	−0.106	−0.080	−0.090	−0.102
				(0.104)	(0.104)	(0.102)	(0.107)	(0.108)	(0.106)
Indir. knowledge breadth intensity				−0.029*	−0.028*	−0.031**	−0.027*	−0.029*	−0.031**
				(0.016)	(0.016)	(0.015)	(0.016)	(0.016)	(0.016)
Indir. knowledge redund. intensity				0.000	0.002	0.000	0.002	0.001	−0.001
				(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Tie strength					6.535***		5.639**	6.219***	
					(2.265)		(2.297)	(2.373)	
Communication frequency[†]						0.121			0.110
						(0.097)			(0.097)
Work-related closeness[†]						0.410***			0.394***
						(0.121)			(0.123)
Network cohesion							−13.626	17.514	10.336
							(10.980)	(17.322)	(14.873)
Network cohesion SQ								−369.933**	−289.946**
								(148.821)	(130.168)
Pseudo R^2	0.3242	0.3246	0.3273	0.3315	0.3354	0.3425	0.3363	0.3381	0.3445

Notes. Robust standard errors (in parentheses) are clustered by the recipient. Models include fixed effects for each source and recipient interacting in any dyad.

[a]Alternative Models 6 and 9 are estimated with indicator variables to consider the discrete nature of both "communication frequency" and "work-related closeness." Results are consistent: Communication frequency is not significantly associated with generation of creative ideas, whereas being "close" or "very close" is positively associated with creative idea generation.

*<0.10, **<0.05, ***<0.01, (two-tailed).

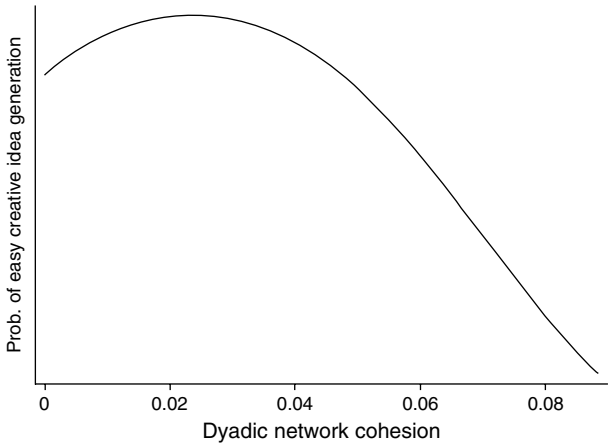
[†]Communication frequency and closeness for reciprocal ties are the average of scores reported by both source and recipient.

product-related interactions occurred more frequently (and thus probably contributed more to the knowledge breadth of the relationship), whereas other interactions occurred rarely. In this model, the coefficient of frequent knowledge breadth is positive but barely significant ($p < 0.094$). Model 4 controls for the indirect product-related knowledge flows between the source and the recipient. Model 4 shows a positive and significant coefficient of indirect knowledge breadth and a negative (yet not significant) coefficient of indirect knowledge redundancy. Model 4 also controls for the intensity rather than the breadth of indirect product-related knowledge flows. More interestingly, Model 4 exhibits a positive and significant coefficient of frequent dyadic knowledge breadth, which suggests that, controlling for indirect knowledge flows between the source and the recipient, frequent interactions that concerned various types of technologies (regardless of their state of flux) were more likely to generate creative ideas (in line with H1).[11] Model 4 also indicates that what matters is the breadth of the knowledge exchanged rather than its newness.[12] Exchanges concerned with the radical product (which involved more recent technologies) were not more likely to generate creative ideas.[13] Finally, Model 4 also includes two additional parameters (not shown) in order to test the effect of *individual* knowledge diversity of both the source and the recipient; the results show a positive and significant coefficient for the knowledge diversity of the recipient (0.215; $p < 0.028$) and a coefficient not significant for the source (0.060; $p < 0.536$). This suggests that recipients with larger knowledge diversity (measured by the number of distinct product-related interactions) reported higher levels of creative idea generation. This latter result remains significant across all subsequent models.

Models 5 and 6 test H2, which predicts a positive association of tie strength and the generation of creative ideas. Consistent with H2, Model 5 includes a positive and significant coefficient of *tie strength*. In order to examine more precisely the mechanisms behind the positive association between tie strength and creative idea generation, Model 6 includes the effects of communication frequency and work-related closeness separately, using raw scores as well as discrete categories (see Table 2, footnote a). This model shows a positive and significant coefficient of work-related closeness, whereas the coefficient of communication frequency is not significant. In short, recipients who enjoy working closely with the source (above and beyond their requirement to address their task interdependence) are more likely to generate creative ideas from their interactions with those sources, regardless of their overall frequency of interaction (in line with our argument leading to H2).

The effects of *dyadic network cohesion* are tested in Models 7 and 8. Model 7 shows a negative (but not significant) effect of network cohesion on creative idea generation. Model 8 tests H3, which predicts a concave relationship between network cohesion and the generation of creative ideas. Model 8 shows that the effect of network cohesion exhibits a significant decay for high values of network cohesion, which is partially in line with H3. In other words, network cohesion appears not to have a significant effect for small values of cohesion, but its negative impact accelerates for relationships that are surrounded by strong connections to common third parties. Incidentally, estimating an alternative model without the linear effect of cohesion also yields a significant quadratic decay for the effect of network cohesion, $p < 0.020$. Figure 4 illustrates the concave nature of the function that captures the tension between network cohesion and the generation of creative ideas (all else being equal). The plot shows how the probability that the recipient strongly agrees on how easy it is to generate creative ideas after interacting with the source varies as a function of network cohesion. The plot shows a marginally positive effect for smaller-than-average values of network cohesion, but such an effect becomes negative and significant when network cohesion exceeds its average value of 0.03. Finally, Model 9 includes the effects of communication frequency and work-related closeness instead of tie strength to confirm the results obtained in Model 6 in the presence of network cohesion.

Figure 4 Effect of Network Cohesion on the Generation of Creative Ideas



We use Model 8 to estimate the magnitude of the effects of interest. Following Wooldridge (2002, pp. 506–507), the magnitude of the effects is estimated by calculating the probability that the recipient would agree that it is easy to generate creative ideas after interacting with the source, $P(y^+ \mid \mathbf{x})$, for two values of the variable of interest and obtaining the difference, setting all other regressors at their mean values.[14] For example, to estimate the effect of collocation on creative idea generation, we estimate $P(y^+ \mid \mathbf{x}) = 0.59$ for noncollocated dyads (collocation = 0, all else at mean values) and

$P(y^+ \mid \mathbf{x}) = 0.76$ for collocated dyads (collocation = 1, all else at mean values), resulting in a 27% increase in the probability of reporting easier creative idea generation when dyads are collocated. Similarly, dyads across organizational groups have a 17% greater probability of easier creative idea generation than dyads that belong to the same organizational groups. To put the magnitude of the hypothesized effects in perspective, observe that the biggest effect in our study is associated with knowledge codifiability whose one-standard-deviation increase above its mean correlates with 33% increase in the probability of easy generation of creative ideas. Consistent with H1, a one-standard-deviation increase above the mean in frequent knowledge breadth correlates with an 11.4% increase in the probability of easier creative idea generation. In line with H2, a one-standard-deviation increase above the mean in tie strength correlates with a 13.9% increase in creative idea generation, which is likely to be driven by the effect of work-related closeness. Indeed, the effect of a one-standard-deviation above the mean increase in work-related closeness (in Model 9) correlates with a 14.1% increase in the probability of easier generation of creative ideas. The effect of network cohesion decreases after reaching its peak around average levels of cohesion (see Figure 4). Relative to its average levels, the effect of network cohesion is 3.9% lower at one standard deviation above its mean, 13.5% lower at two standard deviations above its mean, and 29.5% lower at three standard deviations above its mean.

In addition to the results presented in Table 2, we carried out several further analyses to address two issues in our study: the potential for reverse causality and for common-method bias.

An important theoretical and empirical issue in our setting concerns causality. Do the attributes of the relationship lead to creative outcomes, or do creative outcomes sharpen the nature of the relationship? This is important because previous work has recognized the interdependent nature of constructs associated with creativity (Amabile et al. 2005, Fleming et al. 2007). Hence our study is susceptible to arguments that could favor reverse causality. In the absence of longitudinal data and unavailability of appropriate instrumental variables at the dyadic level, we checked (albeit approximately) for whether reverse causality is significant by estimating the interaction effects of tie duration with the key predictor variables, such as tie strength, that might be suspected of reverse causality (Burt 1992, p. 173). The argument behind this test is that if reverse causality is significant, the relationships between predictor variables and dyadic creativity would be greater for older ties owing to the reinforcing loop between the predictor variable and creative outcomes (Repenning 2002). We estimated alternative regression models similar to those shown in Table 2 but including interaction effects between tie duration and the key predictor variables, and such interaction effects were found not to be significant. This finding, however, does not remove entirely the possibility that reverse causality is present in our study.

As mentioned previously, an important limitation of organizational studies investigating relationship outcomes is the lack of independent sources to measure the dependent relational variable. This is an important issue because results could be artificially inflated due to common-method variance (Podsakoff and Organ 1986). Although social desirability bias was discouraged during the administration of the survey by explicitly emphasizing that "individual responses will be aggregated in the analysis so that conclusions are drawn at the group level," the issue could still be salient when measuring variables—such as ease of generating creative ideas, knowledge codifiability, work-related closeness, and (to a lesser extent) knowledge breadth. This is less of an issue with the network variables because they are constructed with data that involve all the actors in the sample. Clearly, network cohesion depends on responses from all other actors because it is a function of having common contacts between the source and the recipient. Also, the proportional measure of tie strength depends on the recipient's interactions with all her contacts. Nonetheless, to assess the possibility of having significant common variance among the key variables of interest, we conducted Harman's one-factor tests (Podsakoff and Organ 1986). We ran Harman's one-factor tests including the dependent variable and three potentially troublesome independent variables (knowledge codifiability, work-related closeness, and knowledge breadth), and they loaded onto two factors. More conservative results were obtained when including tie strength and network cohesion instead of work-related closeness. This mitigates concerns that common-method variance may be driving some of the results. Yet to test further the robustness of the main effects associated with potential troublesome variables, we estimated a linear model that uses the individual *source* as the unit of analysis and whose dependent variable was the average level of creative idea generation triggered by the source, as rated by the respondents who went to the source for technical interactions. Although an individual-level analysis reduces the number of observations to 63 individuals (which limits the number of covariates to include in the analysis for appropriate statistical inference), testing the hypothesized effects suspected of common-method bias (H1 and H2) yielded results consistent with those presented in this paper. Controlling for the number of various interaction types (managerial, social, and consultation); knowledge codifiability; and individual knowledge diversity, we found that sources involved in frequent dyadic exchanges concerning, on average, several product technologies were more likely to be considered as catalysts of creative ideas

(in line with H1). Most importantly, and consistent with our dyadic analysis testing H2, the effects of average work-related closeness (assessed by both the source and her contacts) was positive and significant ($p < 0.033$), whereas the effect of average communication frequency was not significant ($p < 0.539$).[15]

5. Discussion

This paper aims to enhance our understanding of the generative phase of creativity by examining it at the dyadic level. The insights generated by this work complement what we have learned from previous studies on creativity as a social phenomenon (e.g., Burt 2004, Rodan and Galunic 2004, Amabile et al. 2005, Obstfeld 2005, Uzzi and Spiro 2005, Hargadon and Bechky 2006, Perry-Smith 2006, Fleming et al. 2007). However, instead of focusing on how the aggregated communication patterns of an individual contribute to her ability to produce creative outcomes such as new artifacts (or new proposals or patents), this paper acknowledges that not all dyadic relationships (even for the same individual) are equally good catalysts in the generation of creative ideas and thus examines precisely how both knowledge *and* social characteristics of a specific dyadic exchange affect the genesis of creative ideas emanating from it. By adopting this approach, we have learned that diversity and support are complementary ingredients that favor the generation of creative ideas. Specifically, we found that strong ties that conduit a broad set of knowledge domains and link actors who enjoy working closely together are more likely to trigger creative ideas than ties that conduit a narrow set of knowledge domains and link socially distant actors. Such strong ties are even better catalysts of creative ideas when they are free from excessive social cohesion imposed by strong connections to common third parties. Given the predominant role of creativity that individual-level analyses have ascribed to sporadic, distant, and sparse ties, our results provide an important shift to highlight the role that diverse and strong ties can play in the generation of creative ideas.

This paper studies the microprocess by which creative ideas are generated by focusing on idea generation (from the creator's viewpoint) rather than on idea evaluation (from the audience's perspective). This approach has important implications in our empirical study. What the recipient considers creative need not necessarily be considered creative by others in the organization, especially when ideas can lose their novelty because of easy diffusion to other actors in the field (Csikszentmihalyi 1988, Sternberg 1999). This suggests that caution is the watchword when considering the effects of content attributes (such as knowledge codifiability) that facilitate standardization of knowledge (Fleming and Sorenson 2001). Because codified knowledge is easier to transfer beyond the focal dyad (Hansen 1999, Reagans and McEvily 2003), ideas triggered by codified knowledge are likely to carry a higher risk of being considered less creative by others in the organization because their codified elements have already been diffused within the organization. On the other hand, knowledge dyadic attributes, such as diversity, are less susceptible to the risk of standardization and easy diffusion (Hansen 1999). This allows us to conjecture that an increase in the ease of generating potentially creative ideas, due to a given increase in dyadic knowledge breadth, has a significant chance of translating into new ideas that would be considered creative by the community. However, we cannot make a similar conjecture when considering an equivalent increase in creative idea generation as a result of an increase in knowledge codifiability.

Consistent with previous research on creativity and innovation, our results show that knowledge diversity helps to generate creative ideas at the dyadic level. However, it is important to emphasize that what positively influences creative idea generation is the knowledge breadth of the relationship itself. Having a broad knowledge base acquired by engaging in distinct technical interactions with several actors does increase the generation of creative ideas (Burt 2004, Rodan and Galunic 2004, Fleming et al. 2007). However, when considering an individual's portfolio of interactions, we see that those dyadic interactions that conduit various knowledge domains within the same relationship are more likely to facilitate the generation of potentially creative ideas. We have also learned that what matters, at the dyadic level, is the breadth of frequent knowledge exchanges rather than their newness. Interestingly, in our sample, ties that conduit frequent diverse knowledge are less likely to be weak ties, which provides a novel insight into how knowledge diversity can also contribute to creativity in collaborative relationships.[16] Without denying that possessing diverse knowledge increases the creative potential of the creator, our results show that (strong) ties that conduit diverse knowledge themselves can also play a contributory role in the generation of creative ideas. This result is consistent with recent evidence presented by McFayden et al. (2009) showing that strong ties can contribute further to knowledge creation when the focal actor is surrounded by a sparse collaboration network.

An important advantage of examining explicitly the effect of accessing (directly and indirectly) diverse knowledge, is that it allowed us to examine the marginal effects that (intrinsic and extrinsic to the dyad) social factors have on the generation of creative ideas (keeping knowledge diversity constant). First, this study provides further insights into the role of tie strength in creativity. Previous research has suggested—based on the potential positive correlation between strong ties, network cohesion, and information redundancy—that weak ties can be conducive to fostering individual creativity (Perry-Smith and Shalley 2003). Moreover, there is empirical evidence

showing that the number of weak ties can be a significant predictor of individual creativity (Perry-Smith 2006). We complement this line of research by considering the role of two important intrinsic dimensions of tie strength: communication frequency and work-related closeness. Although communication frequency on its own does not appear to directly impact the generation of creative ideas, it does moderate the effect of dyadic knowledge breadth. The effect of work-related closeness is different: Producing creative ideas based on knowledge acquired from the source requires extra energy, motivation, and support, which comes (in part) from the intrinsic willingness (and the positive affect that goes with it) to engage in working closely with the source above and beyond the need to address a given task interdependence (Amabile 1996). Our results concerning tie strength together with the evidence reported by Perry-Smith (2006) suggest that when considering the portfolio of relationships in which the focal individual is involved, a greater collection of weak ties has a significant influence on individual creativity because each tie is experienced in the context of other ties. One weak tie may not be helpful, but multiple weak ties may be because they may contribute all together to increase the knowledge diversity of the creator. On the other hand, when considering the usefulness of each individual tie, our results suggest that a strong tie can be helpful, particularly if it is charged with positive work-related emotional intensity and serves as conduit of diverse knowledge. Yet because our unit of analysis is the dyad, this study does not test whether or not multiple weak ties may also facilitate the generation of creative ideas.

Finally, this study examines the social effects of network cohesion on creative idea generation (above and beyond the access to redundant information). While doing so, it was imperative to control for the heterogeneity of the technical knowledge exchanged within (and around) each dyad (Rodan and Galunic 2004). In our study, individual knowledge diversity is negatively correlated with individual network cohesion; this is consistent with the widely accepted assumption that sparse networks provide access to nonredundant information. Moreover, such an assumption also holds (albeit marginally) at the dyadic level.[17] Hence, to examine the social effects of network cohesion above and beyond access to redundant (product-related) knowledge, it was crucial to have independent measures of knowledge diversity at the dyadic level. Based on previous research, we have learned that people in dense networks are likely to be involved in the development or deployment of innovations (Obstfeld 2005). However, the generation of creative ideas—some of which may (or may not) be adopted or deployed by others—is more likely to come from individuals surrounded by sparse networks (Burt 2004, Fleming et al. 2007). At the dyadic level, we observe stronger empirical support for the negative effect of network cohesion than for its positive effect, which is consistent with our focusing on studying the genesis of creative ideas rather than their adoption or deployment. Our empirical evidence suggests that, keeping knowledge diversity constant, network cohesion surrounding a dyad provides only marginal extrinsic (to the dyad) support for the generation of creative ideas. However, when dyadic network cohesion exceeds average levels, it becomes a liability by socially constraining the recipient from generating creative ideas based on her interactions with the source. Why does excessive dyadic network cohesion hinder the generation of creative ideas? Because our analysis explicitly controls for knowledge diversity both within the relationship and surrounding the relationship through common third parties, the results suggest that in an intra-organizational social network like the one we studied, the dominant hindering mechanism of excessive network cohesion is not the access to redundant (product-related) knowledge but rather the social pressure it imposes on the recipient to conform with the group thinking of common third parties. This conclusion is consistent with the results of Uzzi and Spiro (2005, p. 464), who suggest that excessively cohesive networks promote "reproducing rather than advancing existing ways of thinking."

Although this sociometric study provides important empirical evidence supporting the hypothesized effects outlined in the theoretical framework, the nature of the data and the limitations imposed by the dyadic unit of analysis recommend caution when generalizing the findings. In addition, our reliance upon survey results and the self assessment of generative creativity may confound effects of success and creative idea generation. On the one hand, people who generate radically novel ideas may have experienced little success implementing them, which eventually may lead the respondent to discount the level of creativity associated with her dyadic interactions with others. On the other hand, the success of past interactions with certain colleagues may overvalue the contribution of these dyadic relationships on the generation of creative ideas. Clearly, external validation of the results presented in this paper is needed, which provides opportunities for future research in this area.

By studying creativity at the dyadic level, this paper highlights the importance of understanding the knowledge networks of R&D organizations (i.e., "Who needs information from whom?" or "Who talks to whom about what?"). By considering the properties of the knowledge flows in such networks, this work has shed some light on the factors that may help (or hinder) the generation of creative ideas. Additional important insights concerning the complex topic of organizational creativity remain to be discovered.

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Endnotes

[1]In general, this paper uses the most widely accepted notion of creativity: the ability to produce something that is both novel and useful (Amabile 1996, Sternberg 1999). However, the focus of this paper is on the creator's act of generating potentially creative ideas or thoughts. This phenomenon was also studied by Amabile et al. (2005) from an affective viewpoint.

[2]Similar to Thibaut and Kelley (1986, p. 10), we view *relationships* as the set of interactions that take place between the source and the recipient within a finite period of time. More specifically, we study the set of product-related interactions in a software development organization during one year.

[3]As observed by one of the reviewers, the point here is more substantial and goes beyond the level of analysis. It involves the realization that ties can be differentiated based on the knowledge for which they serve as conduits. This holds even more so in product/software development organizations (such as the one studied here) where knowledge heterogeneity is observed within the same tie. By examining the actual variation that exists among organizational ties, it has been possible to realize that such ties (even for the same individual) can differ greatly in regard to the diversity of knowledge they channel.

[4]Although this theorizing implies a causal link from tie strength to the generation of creative ideas, one must be open to the possibility that a plausible reason for a tie's strength is that it has previously served as a catalyst of creative ideas for the recipient (Amabile et al. 2005). Such a positive outcome as perceived by the recipient could, in turn, reinforce the strength of the tie with the source. As a result, it is important to highlight here the associative nature of the relationship between tie strength and the generation of creative ideas.

[5]We also compared the distribution of our tie-strength variables against similar data from other network studies conducted in technical organizations (Reagans and McEvily 2003, Perry-Smith 2006). We did so to check (albeit approximately) whether our data collection effort has yielded significantly lower proportions of weak ties than the ones reported in those studies. In short, our data set does not exhibit significantly lower proportions of weak ties. This provides further evidence that our data collection efforts did not omit ties that were "weak" yet relevant.

[6]In organizational studies that use the dyad as the unit of analysis, an important empirical challenge is that interacting actors are typically the ones who can best evaluate the dependent variable of interest. For example, Reagans (2005) assesses tie strength by using data on communication frequency and emotional closeness that were provided by the interacting actors; Labianca et al. (1998) relies on self-report data to study the link between interpersonal relationships and perceptions of conflict; and Levin and Cross (2004) use self-reported data on perceived receipt of useful knowledge to study the mediating role of trust on effective knowledge transfer among employees in three distinct organizations.

[7]We also considered a measure of *knowledge concentration* to integrate within a single measure both knowledge breadth and communication frequency. This alternative measure captures the degree to which a relationship concentrates its interactions on one of seven possible technological domains in our study. This resembles the measure of "focus" used by Roberts and Amit (2003) to capture the degree to which an entity would concentrate on one of several active innovation categories. Here, knowledge concentration is measured as

$$knowledge\_concentration_{ij} = \left(\frac{comm\_freq\_prod_1}{\sum_{i=1}^{7} comm\_freq\_prod_i}\right)^2 + \cdots + \left(\frac{comm\_freq\_prod_7}{\sum_{i=1}^{7} comm\_freq\_prod_i}\right)^2.$$

The use of this aggregated measure is less preferred than the two main measures of knowledge breadth (for "rarely" and "more often" communication frequencies) because it does not allow us to disentangle the effects of knowledge breadth and communication frequency.

[8]Cronbach's *alpha* reliability coefficient for a composite scale formed by frequency, closeness, and duration is 0.55, whereas this coefficient for a scale formed by frequency and closeness is 0.76.

[9]Interaction types are measured from the recipient's viewpoint, even for bidirectional ties. We do this because it is the recipient's acquisition of managerial and technical knowledge that is more likely to be associated with creative idea generation. For consistency, we also use a recipient-only viewpoint to measure social interactions for bidirectional ties. Nonetheless, we also use indicators that capture the views of both source and recipient, obtaining results for the key predictor variables of interest that are consistent and even more significant than those reported here.

[10]Although both ordered probit and ordered logit regressions typically yield similar results when one wants to acknowledge the discrete, ordered nature of the response, ordered probit regressions are more appropriate when the categories in the response variable (as in this case) are not equally distributed and better represented by a normal distribution (Wooldridge 2002). In an ordered probit regression, an underlying probability score is estimated as a linear function of a set of independent variables and a set of cutoff points k_1 to k_6. Thus the probability of observing outcome i corresponds to the probability that the estimated linear function, plus random error, is within the range of the cutoff points estimated for the outcome. For instance, if the outcome of the regression function (for a given set of values of the independent variables) is smaller than or equal to k_1 then the predicted value of such a regression corresponds to the recipient "strongly disagreeing" on how easy it is to generate creative ideas after interacting with the source, whereas if the regression outcome is greater than k_6 then our model predicts that the recipient "strongly agrees" on how easy it is to generate creative ideas after interacting with

the source. As for the coefficients shown in Table 2, a positive coefficient, β_j, indicates that an increment in predictor, x_j, shifts the underlying probability distribution of the dependent variable to a higher level. Hence the sign and statistical significance of the coefficients of our ordered probit regressions can be interpreted in a similar manner to those in OLS (ordinary least square) regressions. Ordered logit and OLS regressions yielded similar results.

[11]We also estimated an alternative regression model that includes an aggregated measure of knowledge diversity called *knowledge concentration*. As expected, the coefficient for this variable is negative (-0.261) but not significant ($p < 0.337$). This further corroborates our initial conjecture (see endnote 7) that it is worthwhile disentangling—rather than aggregating—the effects of knowledge breadth and communication frequency in order to understand the association between relational knowledge diversity and dyadic creativity. Model 4 suggests that communication frequency indeed moderates the effect of knowledge breadth at the dyadic level.

[12]The measures of knowledge breadth used here assume that all product-related interactions would be provided by sources with similar levels of expertise and would have an impact on the recipient independently of her level of expertise. To test this assumption, we devised two additional measures of *frequent knowledge breadth*. First, (dyadic) *source frequent knowledge breadth* was measured as the number of product-related interactions for the focal relationship that would coincide with the level of expertise of the source. Similarly, (dyadic) *recipient frequent knowledge breadth* was assessed by counting the product-related interactions (for the focal relationship) that would coincide with the level of expertise of the recipient. We estimated a model (similar to Model 4) that included these two additional variables and found that their coefficients were not significant ($p < 0.602$ for *source* frequent knowledge breadth; $p < 0.245$ for *recipient* frequent knowledge breadth). Hence there is no evidence in our data to suggest that the level of expertise moderates the impact of (dyadic) frequent knowledge breadth.

[13]We also tested for the interaction effect between frequent knowledge breadth and knowledge newness, finding that the interaction effect was positive but not significant ($p < 0.657$).

[14]Observe that we define $\mathrm{P}(y^+ \mid \mathbf{x}) = \mathrm{P}(y = \text{“marginally agree”} \mid \mathbf{x}) + \mathrm{P}(y = \text{“agree”} \mid \mathbf{x}) + \mathrm{P}(y = \text{“strongly agree”} \mid \mathbf{x})$, where the estimated response probabilities are determined by transforming the probability score obtained from the ordered probit regression model into a probability for each category (Wooldridge 2002, p. 505). Such transformation depends on the values of the cutoff points estimated along with the regression coefficients. The cutoff points for Model 8 are $k_1 = -3.42$; $k_2 = -2.64$; $k_3 = -2.12$; $k_4 = 0.03$; $k_5 = 1.07$; $k_6 = 3.36$.

[15]The effect of dyadic network cohesion (H3) was difficult to test reliably with an individual-level analysis of this sort because it would require aggregating dyadic data twice; first, our measure of dyadic network cohesion aggregates data by summing over all the common third parties associated with each dyad, and then such a dyadic measure would need to be averaged over all the contacts of the source. As a result, it is not surprising that testing for a linear and quadratic effect of dyadic network cohesion using an individual-level analysis yielded nonsignificant estimates. We also tested for the effect of the individual constraint (Burt 1992, p. 55) of the source as well as the average of constraint of the source's recipients and found effects that were not significant. This further illustrates the value of using a dyadic statistical analysis to examine precisely how factors that are intrinsic and extrinsic to the dyad itself relate to its outcome.

[16]Frequent knowledge breadth was positively correlated with tie strength (0.076, $p < 0.061$). Furthermore, after controlling for other dyadic features relevant in this study, frequent knowledge breadth was positively associated with tie strength (3.849, $p < 0.014$). As expected, there was also a positive association with both communication frequency (0.143, $p < 0.066$) and work-related closeness (0.122, $p < 0.041$).

[17]In our data set, individuals occupying brokerage network positions indeed access more diverse knowledge (Burt 2004, Fleming et al. 2007). The correlation between individual knowledge breadth (measured as the total number of distinct product-related interactions) and individual constraint (Burt 1992, p. 55) is -0.5805 ($p < 0.001$). Moreover, we found a negative and significant association between individual constraint and individual knowledge breadth (-14.321; $p < 0.005$) while controlling for the average codifiability of the knowledge exchanged; the number of managerial, social, and consultation-type of interactions in which the focal individual is involved; and the average tie strength of the focal individual's communication with others. At the dyadic level, knowledge breadth and network cohesion were not significantly correlated (-0.007, $p < 0.868$). However, after controlling for other dyadic features relevant to this study, there was a significantly negative association between them ($p < 0.032$).

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