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SOCIAL CAPITAL AND KNOWLEDGE CREATION: DIMINISHING RETURNS OF THE NUMBER AND STRENGTH OF EXCHANGE RELATIONSHIPS

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This study analyzed the relationship between social capital and knowledge creation at the individual level. Our limited theory of knowledge creation encompasses the number and strength of the relationships that a person maintains. Hypothesis tests in a sample of biomedical research scientists strongly supported predictions. As relationships increased in number, returns to knowledge creation diminished. Increased interactions with a single other showed a similar effect. The strength of interpersonal relations had a higher marginal effect on knowledge creation than the number of relations.

Knowledge is recognized as one of the most important resources of the 21st century and has received considerable attention in the management literature. Much of the research on knowledge examines the organization as the unit of analysis and provides insight into the importance of knowledge transfer and acquisition between and within organizations (Ahuja, 2000; Hansen, 1999). The creation of new knowledge, however, has not received as much attention. We define *new* knowledge as discoveries about phenomena that were not known previously. Knowledge researchers have begun to explore a knowledge creation theory (Grant, 1996; Nahapiet & Ghoshal, 1998; Nonaka, 1994), and while this research has provided significant evidence as to the importance of new knowledge, little is known about how new knowledge is created, and empirical work is particularly lacking.

Researchers have recently positioned social capital as a key factor in understanding knowledge creation (Nahapiet & Ghoshal, 1998). Drawing upon previous research, we define *social capital* as the interpersonal relationships of a person, as well as the resources embedded in those relationships (Bourdieu, 1986; Coleman, 1988; Lin, 2001; Nahapiet & Ghoshal, 1998). According to theory, social capital and knowledge creation will have a positive relationship because social capital directly affects the combine-and-exchange process and provides relatively easy access to network resources (Nahapiet & Ghoshal, 1998). Social capital, however, comes at a cost. As Nahapiet and Ghoshal (1998) pointed out, interpersonal networks can, over time, produce strong norms and mutual identification among network members, thus limiting openness to new information and diverse views. More important to our study, interpersonal relationships take time and effort to create and maintain.

The purpose of our study was to explore how direct relationships impact new knowledge creation. Direct relationships are critical to knowledge creation as direct ties stimulate the exchange of resources embedded within the relationships (Nahapiet & Ghoshal, 1998). We examined the creation of new knowledge. Publications in biomedical research present documented new knowledge and indicate the extent to which it advances a field of research (Stephan & Levin, 1991).

Our study explored how individuals must manage the tension between the need for access to particular types of resources and the need to develop and maintain jointly held resources (Lin, 2001). Having a number of direct exchange partners provides an individual with the opportunity to obtain resources, while the strength of the relationships provides the opportunity to develop the jointly held resources. Yet does the effort required to establish, develop, and maintain direct ties interfere with knowledge creation? Similarly, do exchange partners exhaust commonly held resources and thus diminish the odds of co-creating new knowledge?

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We used the biomedical research context to address these questions. With the goal of extending understanding of the link between resources available through social capital and knowledge creation, we studied the number and strength of direct exchange relationships to examine historical interactions between exchange partners. In addition, we examined interactions between individuals who had the freedom to interact with anyone. These observations enabled us to observe patterns of "committed interaction" (Blau, 1964), which is likely to be a critical component in knowledge creation (Nonaka, 1994). Finally, we examined both the positive and negative aspects of social capital as we looked for evidence of diminishing returns to knowledge creation.

In summary, our research extends previous work by examining how interpersonal exchange relationships are linked to new knowledge creation. Our study of over 7,000 scientific discoveries by 173 biomedical research scientists over 11 years provides important evidence that the relationship between social capital and the amount of knowledge created is not a simple linear function. On the contrary, social capital is costly to create and maintain, and at some level it may create diminishing returns to the number and strength of exchange relations.

THEORY AND HYPOTHESES

Knowledge Creation

Critical to understanding knowledge creation is the notion that knowledge resides within and is created by individuals (Nonaka, 1994). The know-how and information that individuals gain over time forms their knowledge stocks. Current knowledge stocks shape the scope and direction of the search for new knowledge, so knowledge creation is a path-dependent process (Dosi, 1982). Newly acquired inputs are integrated with existing knowledge stocks.

Interpersonal exchange networks are important to scientific discovery both because knowledge is combined and shared with network members and because it is through networks that research findings become "certified knowledge" (Mulkay, 1976). Scientific discovery is a process that involves reading, writing, and experimentation (tasks largely pursued alone) in addition to joint "sensemaking" and discussions with others (social interactions) (Latour & Woolgar, 1979). Reading, attending conferences, and other methods of transferring codified knowledge are very important to knowledge creation, but in and of themselves, they are not sufficient for new knowledge creation (Cockburn & Henderson, 1998). Further, a balance is needed between solo activities and interpersonal exchanges, as time and effort are required for both. Note that our approach contrasts somewhat with that of Burt (2003), who examined new ideas proposed by a sample of supply chain managers. While (like us) he took the individual as the unit of analysis (in contrast to what he did in his earlier work), his notion of idea generation more closely resembles what we would define as knowledge transfer than what we define as knowledge creation. In his study, an idea that is new and potentially useful *to an individual's company* counts as new knowledge, regardless of its true origin. In our study, new knowledge is something that does not exist anywhere before it is discovered and published by research scientists.

Much of the knowledge used in the scientific discovery process is complex and is embedded in particular fields and associated methodologies. Information exchanged is frequently tacit, in that it can only be combined and exchanged with others who have some level of shared knowledge and experience (Polanyi, 1966). Knowledge creation requires that network members jointly experience problem-solving processes and spend time together discussing, reflecting, observing, and interacting (Seufert, vonKrogh, & Bach, 1999) in addition to doing the solo work of reading, writing, and running experiments. After scientists have made sense of their findings, they attempt to codify what they have learned in publications designed to further the knowledge and understanding of their field (Latour & Woolgar, 1979; Polanyi, 1966).

Social Capital

Social capital includes both interpersonal relationships and the resources embedded in the relationships (Burt, 1992). Our study examined the *relational* dimension of social capital, which consists of the strength of a person's interpersonal exchange relationships (Nahapiet & Ghoshal, 1998). Through interactions, individuals are able to access and leverage resources embedded in relationships. The strength of relations indicates how well an individual knows his or her exchange partners. Key facets of the relational dimension of social capital are shared language and experiences, norms and sanctions, obligations and expectations. The *structural* dimension of social capital is also important, and indicates the degree of "closure," or interconnectedness, among the members of a network (Nahapiet & Ghoshal, 1998). The structural dimension includes both the direct and indirect ties individuals maintain with others (Granovetter, 1973). The number of direct ties a researcher maintains provides insight into the redundancy of knowledge resources he or she is exposed to in the research process (Burt, 1992; Coleman, 1988). We only considered *direct* ties for two reasons. First, including indirect ties would have greatly increased the complexity of our study. Second, as we discuss in more detail below, we believe direct ties are absolutely central to knowledge creation, much more central than they are for knowledge transfer.

Because explicit knowledge is codifiable, it can be easily transferred from one person to another, frequently without interpersonal interaction. Previous research has provided insight into how indirect interpersonal exchange ties facilitate explicit knowledge transfer (Hansen, 1999; Tsai, 2001). Direct ties have not been as widely studied in knowledge transfer, because theory suggests that individuals who are directly tied to one another know what each other knows. Therefore, unique transfer opportunities through direct ties are somewhat limited.

Knowledge creation, in contrast, is more dependent on the combination and sharing of tacit knowledge. For example, in knowledge transfer, people often seek answers to specific questions, or seek out specifiable information that they are aware that they need. In knowledge creation, information exchange is frequently emergent, in that partners to the exchange are often unable to articulate, a priori, the specific knowledge that they need. This kind of exchange requires very direct interaction, as the parties grapple with research puzzles. In effect, new knowledge emerges through the direct interactions of research partners.

As the same research partners spend time with one another, their relationship evolves, typically strengthening. Part of the evolution is good, in that partners develop shared understandings, habits, trust, and a base of language and experience that facilitates smooth interaction. Over time, this relationship may "converge" (Coleman, 1988), in that the understandings, habits, language, and experiences of the partners become very similar. Although convergence enhances the efficiency of exchange, the consistent mind-set implied by convergence lessens the diverse opinions and perspectives essential to new knowledge creation.

Hypotheses

Relationships between individuals are developed through interpersonal exchanges and shared experiences. Increasing the number of direct exchange partners in a network increases the amount of information, ideas, and resources in it. Increasing one's access to resources is important to knowledge creation as it increases the probability of obtaining specific resources needed. However, relationships require time, energy, and attention to establish and maintain, and because these are limited, relationships involve costs. There are also start-up costs associated with interpersonal relations (Boissevain, 1974). Therefore, there will be a limit to the number of productive relationships that any given person can maintain, and no guarantee that any particular set of network partners will be optimal for knowledge creation (Zucker, Darby, Brewer, & Peng, 1995).

Although the number of an individual's relations positively affects knowledge creation, the association is not strictly linear. Identifying, developing, and maintaining relationships are, as noted above, costly activities, and the number of others with whom any particular person can maintain close relations is limited. At the margin, establishing and maintaining more direct ties begins to cut into the time available for the solo activities that are also critical to knowledge creation—such as reading, writing, and running experiments (Latour & Woolgar, 1979).

Effort is required to develop new relationships, shared language, and shared experiences and then integrate information gained from the relationships. Individuals must therefore manage the tension of having an optimal number of direct relations in order to optimize knowledge creation. The effort associated with establishing and maintaining relationships may result in diminishing or negative returns to knowledge creation. The greater the number of different relationships that an individual must maintain, the less the effort the individual can put into creation activities. Yet too few ties may limit knowledge creation because of insufficient new information, ideas, and resources. Although the number of different relations increases an individual's potential for creating new knowledge, an increasing number of relations will eventually lead to less new knowledge creation.

Hypothesis 1. The number of relations that an individual maintains has a quadratic (inverted U-shaped) relationship with knowledge creation.

Interpersonal relationships take time to develop, as does the amount of information and know-how that individuals exchange with one another. Bouty (2000) reported that the initial number of exchanges with a new partner is often limited. This is especially true during the scientific discovery process, when information and know-how are considered sensitive and individuals may share cautiously so as to protect their ability to claim first discovery rights (Thackray, 1998). In scientific research there is a broad norm of sharing discoveries widely, once new knowledge has been created and evidence gathered in support of it (Merton, 1949). However, in the discovery process and prior to the actual creation of new knowledge, shared experiences are important to those who seek complementary knowledge (Polanyi, 1966).

The frequency of interactions during a relationship is an important index of the time and effort that the partners have invested in one another (Boissevain, 1974). Relationships deepen as the partners spend time together. Krackhardt (1992) proposed the term "philos" to describe a relationship in which two people have a history of interactions with each other and feel affection for one another. Time spent together also leads to norms of behavior between the partners, and affection motivates them to treat one another well. In an enduring relationship, parties are more willing and more able to exchange information and know-how and thus have more efficient exchanges than those who have not developed long-term relationships (Bouty, 2000). As a researcher maintains the same exchange partners over time, exchanges become more efficient and the number of shared experiences increases.

A potential drawback to the strength of relations, however, is that through repeated interactions, researchers and their exchange partners become more alike and develop similar knowledge stocks (Coleman, 1988). Knowledge creation may become inhibited as the length of time that individuals spend with the same partners increases. While we expect to see an initial positive relationship between the number of interactions that researchers have had with their exchange partners and the amount of knowledge created, we also anticipate that increasing relationship strength will eventually lead to less knowledge creation.

Hypothesis 2. The strength of relations that an individual maintains is quadratically (in an inverted U-shape) related to knowledge creation.

METHODOLOGY

Sample

Our sample consisted of research scientists involved in university-related biomedical research. The biomedical research industry is a good setting for studies of knowledge creation, because the primary function of research scientists is to create and disseminate new knowledge in the form of scientific discoveries (Latour & Woolgar, 1979). Scientists have strong incentives to publish because they are rewarded for being the first to document discoveries (Merton, 1949).

Our sample was drawn from two of the top U.S. biomedical research universities identified by the National Institutes of Health (NIH). Researchers within each university were organized into 14 different departments (roughly corresponding to research areas). Hagstrom and Sharon (1972) proposed that individual research departments within universities, rather than entire universities, be studied when examining research productivity, because departments are organized differently across universities, and the amount of research in different research areas often differs importantly (Cockburn & Henderson, 1998). The departments represented in our study from university 1 were molecular virology and microbiology; pharmacology; cell biology; urology; and immunology; and from university 2, they were oncology; neuroscience; biological chemistry; gynecology and obstetrics; urology; gastroentology; cell biology; cardiology; and pharmacology.

Our sample tracked 173 scientists from 1989 through 1999 in a panel data methodology whereby data were gathered for each scientist, each year. To predict the amount of knowledge created in each focal year, we used information gathered from the previous year for our measures of the amount of knowledge created and the control variables and used information from the previous five years combined for our measures of the social capital measures. Therefore, the first five years of the data were used only for measurement of independent and control variables, and our first prediction of the amount of knowledge created was for 1994.[1] Our final sample consists of 1,038 observations (scientist-years).

Our methodology relied heavily on scientific publications, both as measures of knowledge creation and as measures of social capital (coauthors). Publications document discoveries and are an important indicator of knowledge creation (Stephan & Levin, 1991). Publications also reflect collaborations between individuals in the generation and exchange of knowledge. Coauthorship indicates that those involved have engaged in extensive discussion and exchange of ideas during problem solving. Therefore, publication data provide a

[1] We also used three-year windows to examine the hypotheses, and the results were unchanged. These analyses are available from the first author upon request.

venue for not only observing knowledge creation, but also for gathering objective information about the number and strength of relations among scientists.

Data were obtained through several archival sources. Our primary source was the vitae of the scientists obtained from the Community of Science (COS) expertise database. Four other archival sources—Science Citation Index, PubMed, the National Library of Medicine search service, and the Institute for Scientific Information's (ISI) search services—were used for verification and additional information about publications listed in the COS profiles.

Measures

Dependent variable: Knowledge created. Following Stephan and Levin (1991), we used the Institute of Scientific Information's "impact factor" to assess knowledge creation represented by a given scientist's publications in a given year. The assumption underlying this approach is that the more frequently cited a journal is, the more valuable publications in the journal are to the scientific community, ceteris paribus. The ISI adjusts the measure to remove the advantage of larger journals over smaller, of frequently issued journals over less frequently issued, and of older journals over newer. To gauge knowledge created, we summed the impact-factor-weighted articles published by each scientist each year. For example, if a scientist has four publications in two journals, with three in journal A, which has an impact factor of 1, and one in journal B, which has an impact factor of 5, the value for the scientist on our variable for knowledge creation would be 8 ($[3 \times 1] + [1 \times 5]$).

Citation count measures can also be used to estimate the impact of knowledge created. However, for our study, these measures raised several concerns. First, citations reflect the size, nature, and growth rate of a field. These factors give different research fields varying propensities to be cited. Second, the lag between date of publication and date of citation is uncertain, and this uncertainty limits the use of citation counts only to those publications that have been in print long enough to have had an important impact (Stephan & Levin, 1991). This second concern is quite problematic for panel data analyses, as publications achieved earlier in time naturally tend to have higher citation counts.

Independent variables. We measured number of relations on the basis of definitions posed by Granovetter (1973) and others (Hansen, 1999; Uzzi, 1996). The *number of relations* for a given scientist-year was the sum of that scientist's coauthors during the previous five years. For example, the number of relations for a given scientist in 1994 was the count of that scientist's coauthors from 1989 through 1994, inclusive. To test for the hypothesized curvilinear association, we also included *number of relations squared.*

The *strength of relations* reflected the number of interactions and, therefore, how well a given scientist knew his or her research partners. We measured strength of relations for each scientist in each year by counting the average number of times that the scientist published with the same coauthor during the previous five years. Put differently, we counted the total number of times that a scientist published with each coauthor during the five-year window. We then summed these numbers for each researcher and divided by the total number of coauthors to create an average number of times published per coauthor during the five-year window. We tested the curvilinear association by including *strength of relations squared.*

Control variables. All models included a *lagged dependent variable* to control for unobserved variables and for other potentially important, but omitted, predictors of knowledge creation (see Greene, 2000: 720). We included several additional variables to control for the scientists' human capital and knowledge stocks. *Tenure as a researcher* in the biomedical research industry, coded in years, was used to capture a scientist's career experiences. *Administrative position* (coded 0, "no," or 1, "yes") was included because those holding administrative positions have less time to devote to research. All of the scientists included in our sample had Ph.D.'s, but we included a dummy variable, *dual degrees* (0, "no," or 1, "yes") to indicate those scientists also holding M.D.'s.

To control for a scientist's knowledge stock, we included the number of papers, published during the past five years, on which the scientist was the first author (*first-authored papers*) and the number of papers on which the scientist was the sole author (*sole-authored papers*). Further, we summed the number of times in which the focal scientist was the principal investigator of a research project reported in a paper.[2] The position of first author, sole author, and principal investigator all show the extent to which a scientist has been a critical contrib-

[2] Each paper published has a principal investigator. Interestingly, the principal investigator in medical research is virtually always the last author on the paper (Shapiro, Wenger, & Shapiro, 1994).

utor to scientific discovery and thus reflects the individual's knowledge stock.

We created 13 dummy variables to control for the heterogeneity of the dependent variable across the 14 research areas. Further, a variable for the number of scientists within a research unit controlled for the *size of research unit.* We included this measure because we anticipated that scientists would have a greater propensity to publish in environments in which they had a high level of exposure to other scientists.

We also included several coauthor control variables. First, we measured the location of principal investigators with whom a scientist published in a given year, reflecting some of the costs associated with that relationship. We used five separate count measures for this purpose, each deriving from the principal investigators with whom each scientist had coauthored during the previous five years: (1) within the scientist's research unit, (2) within the university but outside the primary research unit, (3) outside the primary research unit, but geographically close (within 50 miles), (4) further than 50 miles from the scientist's location, and (5) outside the United States. We summed the number of principal investigators by location during the previous five years.

Statistical Methods

Three characteristics of our data made the use of ordinary least squares (OLS) methods inappropriate. First, there were repeated observations for the same scientist across time, so the residual error terms were likely to be correlated. This characteristic violates the OLS assumption of independent observations. Second, the data were likely to be heterogeneous in the variance of the disturbance terms across different cross-sectional units (researchers), presenting the heteroscedasticity issue that causes problems for OLS methods. Finally, our dependent variable was a nonnegative count measure, thus violating the OLS assumption of a normally distributed dependent variable. Therefore, we used a panel data methodology to account for serial correlation and heteroscedasticity. Additionally, because we had a nonnegative count-dependent variable, we elected to use a negative binomial model to address the suspected overdispersion of the dependent variable distribution (Greene, 2000: 886).

RESULTS

Table 1 provides the means, standard deviations, and correlations for the variables used in the models. The data were examined for violations of assumptions of normality and multicollinearity. The dependent variable followed a negative binomial distribution, and all other variables approximated normal distributions. Examining pairwise correlations showed that, with the exception of the squared terms, the correlations were fairly low. We centered the measures for number of relations and strength of relations in order to minimize potential multicollinearity in the squared terms. Because our methodology was a maximum likelihood one, no statistics such as variance inflation factors (VIFs) were available. However, our results remained quite stable across a number of analyses, and this fact, coupled with the low correlations among the independent variables, led us to conclude that multicollinearity was not a problem.

The results of the negative binomial regression models are reported in Table 2. Model 1 shows the results of the full model. Hypothesis 1 predicts a quadratic (inverted U-shaped) relationship between the number of relations and the amount of knowledge created. The coefficient for the number of relations is positive and significant ($\beta = .41$, $p < .001$), and the coefficient for the number of relations squared is negative and significant ($\beta = -.21$, $p < .01$). These findings provide strong support for Hypothesis 1. Hypothesis 2 predicts a quadratic (inverted U-shaped) relationship between the strength of relations and amount of knowledge created. The coefficient for strength of relations is positive and significant ($\beta = .39$, $p < .001$), and the coefficient for strength of relations squared is negative and significant ($\beta = -.34$, $p < .01$). These results provide support for Hypothesis 2.

Figures 1 and 2 provide graphs of the quadratic associations. Some comments about the graphs are in order. First, our negative binomial methodology involved a nonlinear transformation of both independent and dependent variables. Therefore, the coefficients reported in Table 2 could not simply be plotted directly, because the association changed for different values of the independent variables, and not in a linear manner (see Petersen [1985] for a full explanation). Further, because our dependent variable (knowledge creation) was weighted by the journal in which the knowledge was published, we could not directly associate a number of relations or a strength of relations to a raw number of publications. However, we can note that peak creation, for our sample, occurs with about 93 unique coauthors (1.0 standard deviation from the mean), and on average 1.56 interactions (0.60 standard deviations from the mean) occur with the same coauthor over a five-year period.

To determine whether number of relationships or strength of relationships had the larger marginal

TABLE 1
Descriptive Statistics[a]

Variable	Mean	s.d.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
1. Amount of new knowledge	21.79	28.01																	
2. Amount of new knowledge$_{t-1}$	21.54	27.59	.59																
3. Tenure as a researcher	16.55	8.38	.09	.10															
4. Administrator	0.21	0.41	−.02	−.03	.30														
5. First-authored papers	2.04	3.19	.17	.23	.02	−.02													
6. Sole-authored papers	0.83	1.46	.10	.13	.13	.14	.32												
7. Principal investigator papers	3.83	6.49	.45	.46	.14	−.16	.36	.22											
8. Dual degree[b]	0.31	0.46	.02	.01	.06	.20	.11	.15	.02										
9. Principal investigator located within research unit	0.30	0.90	.29	.13	.08	.02	−.06	−.07	−.09	−.07									
11. Principal investigator located within university	0.43	1.01	.29	.15	.19	.26	−.06	.04	−.10	.08	.13								
11. Principal investigator located within 50 miles	0.09	0.64	.12	.10	.05	.16	−.03	−.02	−.04	.11	.01	.16							
12. Principal investigator located outside 50 miles	0.30	0.73	.26	.17	.06	.14	−.03	.06	−.11	.09	.07	.27	.18						
13. Principal investigator located outside U.S.	0.08	0.41	.16	.10	.08	.12	.04	.06	−.02	−.02	.04	.15	.15	.24					
14. Research-unit size	26.23	9.71	.07	.02	.02	−.13	−.13	−.09	−.16	−.23	.09	.02	−.03	.09	.03				
14. Number of relations	46.50	45.15	.48	.55	.28	.21	.25	.14	.25	.20	.24	.36	.33	.29	.22	−.04			
15. Number of relations squared	4,198.89	10,189.19	.37	.43	.21	.19	.14	.10	.13	.16	.19	.33	.41	.30	.21	.00	.90		
16. Strength of relations	1.33	0.38	.24	.28	.04	−.05	.35	.07	.47	.09	.03	−.01	−.02	−.06	−.03	−.14	.24	.11	
17. Strength of relations squared	1.92	1.11	.24	.27	.03	−.08	.37	.06	.52	.09	.01	−.04	−.03	−.08	−.05	−.11	.19	.08	.95

[a] Correlations > .06 are significant at $p < .05$.
[b] Coded 0, "no," and 1, "yes."

TABLE 2
Results of Negative Binomial Panel Data Regression Analyses for Amount of New Knowledge

Independent Variables[a]	Base Model	Model 1
Constant	.71*	−.68*
Amount of new knowledge$_{t-1}$	.01***	.01*
Human and knowledge capital control variables		
Tenure as a researcher	.00	.00
Administrator	−.06	−.11
First-authored papers	.03*	.02
Sole-authored papers	.00	.01
Principal investigator papers	.05***	.05***
Dual degree	.13	.10
Coauthor control variables		
Location of principal investigators		
Within research unit	.25***	.22***
Within university	.22***	.19***
Within 50 miles	.12***	.09***
Outside 50 miles	.22***	.19***
Outside United States	.12***	.12***
Research-unit control variables		
Research-unit size	.00	.01
Research units		
U1—Molecular virology and microbiology	.31	.31
U1—Pharmacology	−.01	−.11
U1—Cell biology	.28	.24
U1—Immunology	.40	.28
U1—Urology	.33	.42
U2—Oncology	.31	.24
U2—Neuroscience	−.19	−.13
U2—Biological chemistry	−.05	.14
U2—Gynecology and obstetrics	−.45	−.40
U2—Urology	.31	.26
U2—Gastroentology	−.35	−.35
U2—Cell biology	−.11	.02
U2—Pharmacology	.08	−.11
Predictor variables		
Number of relations		.41***
Number of relations squared		−.21**
Strength of relations		.39***
Strength of relations squared		−.34**
Observations	1,038	1,038
Number of scientists	173	173
χ^2	825.29***	924.24***
$\Delta\chi^2$		45.14***
−2 log-likelihood	−3,771.13	−3,748.34
Pseudo R^2	.25	.27

[a] Research-unit dummies and "dual degree" were coded 0, "no," and 1, "yes."
* $p < .05$
** $p < .01$
*** $p < .001$

impact on knowledge created, we took the derivatives of the mean knowledge created with respect to the number and strength of relationships. We then computed a point estimate (z) for the linear combination of the coefficients to test whether or not the coefficients for the number and strength of relation-

FIGURE 1
Amount of New Knowledge and Number of Relations

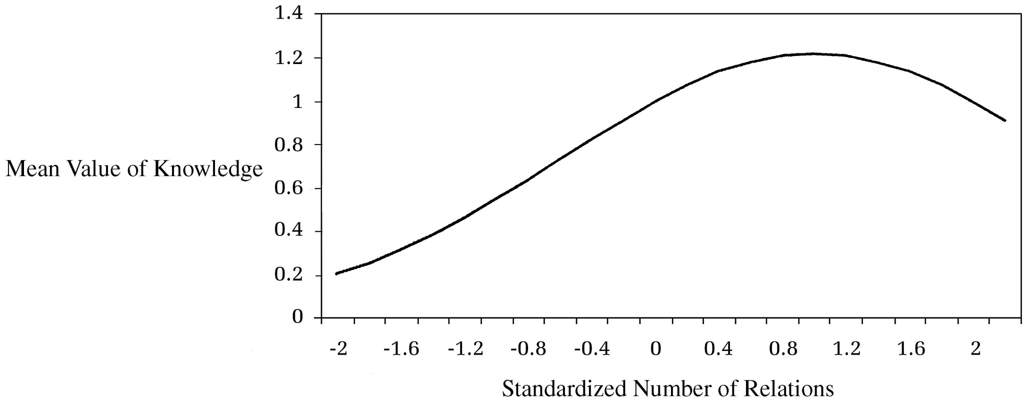
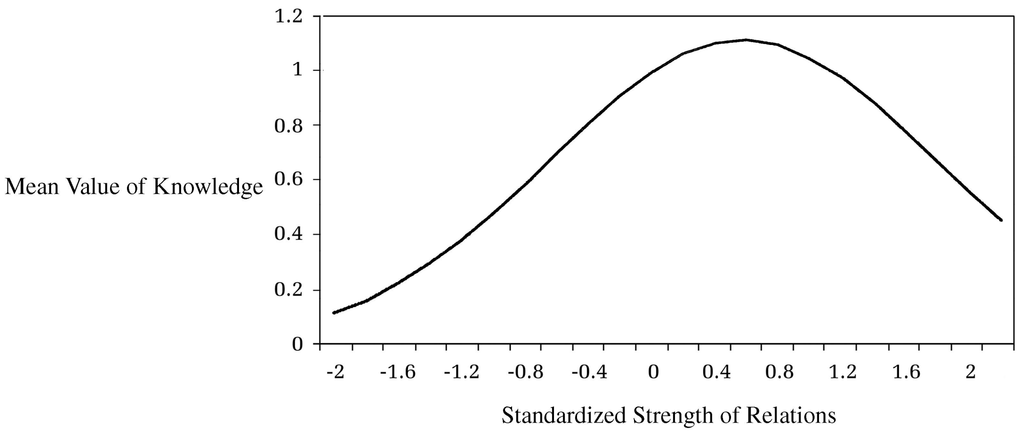


FIGURE 2
Amount of New Knowledge and Strength of Relations



ships differed significantly from each other, thus testing the null hypothesis ($\beta_{number} - \beta_{strength} = 0$). If z was greater than zero, the marginal effect of number of relations was greater than that for strength of relations, and vice versa. If z was not significantly different from zero, then the two had approximately the same marginal effect. The test yielded a z of -2.91 ($p < .005$), indicating that the strength of relations had a higher marginal effect on knowledge creation than did the number of relations.

DISCUSSION

The purpose of our study was to theoretically and empirically examine the direct interpersonal exchange relationships of research scientists to extend understanding of the link between social capital and knowledge creation. Our study provides evidence that new knowledge creation is dependent upon the number and strength of direct relationships that individual scientists have with other research scientists and that the association between the direct relations and the amount of knowledge created is nonlinear. Our study contributes to previous research in several ways. First, it is one of the few studies that examines the history of direct interpersonal exchange relationships at the level of individual research scientists, rather than at the organization level. Second, we applied the notion of diminishing benefits to the both the number of direct ties and the strength of the direct ties. Third, we found evidence that the strength of direct ties has a higher marginal effect on knowledge creation than the number of direct ties.

We proposed that individuals develop relations with others to exchange information and know-how in order to create new knowledge. Our findings indicate that number of exchange partners has a positive, and then a negative, effect on the amount of knowledge that a person creates. This pattern of results implies that relationships include an opportunity cost that may directly affect the amount of time that an individual allocates between developing access to needed resources and developing and nurturing contacts. Our evidence supports the notion that when individuals seek others with whom to exchange and combine information and know-how, they have the opportunity to add new information and know-how to their knowledge stocks. Yet, as additional relationships are added, the cost of developing the relationships eventually begins to outweigh the benefits. We believe these findings provide evidence of the critical role that number of exchange partners plays in explaining new knowledge creation.

We also found evidence that the strength of relationships produces a positive, and then a negative, impact on knowledge creation. Long-term partnerships are thought to increase shared experiences, trust, common language, silent communication systems, and bonds of friendship. Although the strength of relationships is also critical to knowledge creation, extended time with the same exchange partners can negatively impact knowledge creation because the exchange partners eventually develop homogeneous knowledge stocks and may become subject to group norms, obligations, and expectations. Finally, we found that the strength of relationships had a higher marginal effect on knowledge creation than did the number of relationships.

We interpret this difference to mean the following: although initially an increase in the number of times that individuals share experiences with one another has a higher marginal positive impact on knowledge creation than does an increase in the number of direct exchange partners, a continued increase in shared experiences with the same others leads to a higher negative marginal impact on knowledge creation than does a continued increase in the number of direct contacts. In other words, the positive resources gained from increasing shared experiences (that is, trust, common language, and bonds of friendship) have a higher positive marginal effect on knowledge creation than increasing the opportunity to access resources. However, the negative implications of continuing to increase shared experiences (that is, group norms, obligations and expectations) have a higher negative marginal effect on knowledge creation than do the negative implications of continuing to increase the number of direct ties (that is, increased costs related to identifying, establishing, and maintaining new direct ties). These findings emphasize that shared experiences produce both a positive and a negative impact on knowledge creation. It is through shared experiences that individuals develop and exchange tacit knowledge, a resource that is key to the creation process; however, interacting with the same others increases the probability of developing similar resources, thus constraining the creation process. In other words, collaborative efforts with the same others, although they are the most vital element in the creation process, are also the most limiting to the creation process.

Limitations and Extensions

Ours is one of the few empirical efforts to have examined the relationships between social capital and knowledge creation. The insights gained from our study are important, but the study has several limitations. First, our sample of biomedical research scientists may not be representative of most organizations. However, we do believe that our sample of research scientists is representative of knowledge workers engaged in R&D activities across a range of industrial settings. We gathered evidence from two universities, albeit from 13 independent research units within them. In future work, researchers should strive for a broader sample of organizations and individuals.

Second, we were unable to gather primary data on all of the interactions that our scientists had with others, and our study captured only those interactions evident in the trail left by publications. Undoubtedly, other interactions took place between researchers in our sample that were not captured by the lists of coauthors on publications. Some research has examined interactions through the collection of primary data via surveys (Hansen, 1999; Tsai, 2001; Uzzi, 1996). Surveys, however, depend on recall, and the responses are subjective. Future research that combines both primary and secondary data to generate new measures may provide additional insights. Third, assessing knowledge creation by weighting the quality of the journals in which the knowledge is published also poses a limitation. Although previous research supports the use of journal impact factors, we also note that some articles published in top journals may never be influential and some articles not published in top journals may be quite influential. Finally, our study was limited to direct ties and the strength of the direct ties. Additional research is needed to develop a deeper understanding of additional structural aspects of social capital and of the interaction between structural and relational dimensions. Possibly most insightful would be a study that combined both dimensions in a dynamic study of changes in network configuration and of the implications of these dynamic changes for knowledge creation. Future research is needed to further understanding of the coevolution of knowledge creation and interpersonal exchange relations.

Managerial Implications

Our findings should be of interest to those who manage knowledge workers, because our results provide important insights into management of interpersonal exchange networks. Managing the number of relationships that individuals develop and maintain during the knowledge creation process is important. Managers and knowledge workers should be aware that an increasing number of partners eventually leads to diminishing returns. While individuals should be encouraged to seek new exchange partners, eventually the effort used in establishing and developing relationships diminishes the amount of knowledge created. Additionally, while the number of times that a scientist interacts with the same interpersonal exchange relationships may provide benefits up to a point, increasing interactions with the same exchange partners leads to diminishing, then negative, returns. Finally, while both the number of relationships and the strength of relationships influences the knowledge created, managers should also be aware that the strength of relationships has a higher marginal impact on knowledge created than the number of relationships. This finding is critical as it emphasizes the role of collaboration in knowledge creation. Sharing experiences with others is crucial to the creation of new knowledge; however, sharing should not be done at the expense of recognizing and seeking new resources.

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