Research Policy 39 (2010) 1174–1184

Contents lists available at ScienceDirect

Research Policy

journal homepage: www.elsevier.com/locate/respol

Relational mechanisms governing multifaceted collaborative behavior of academic scientists in six fields of science and engineering

Yamini Jha*, Eric W. Welch[1]

Science, Technology, and Environment Policy Lab, Department of Public Administration, University of Illinois at Chicago, 412 S. Peoria Street, Chicago, IL 60607-7064, USA

ARTICLE INFO

Article history:
Received 5 January 2010
Received in revised form 1 June 2010
Accepted 3 June 2010
Available online 8 July 2010

Keywords:
Multifaceted collaboration
Relational
Homophily
Heterophily
Scientists

ABSTRACT

Norms of academic science and engineering are moving in the direction of broader applicability and transferability of knowledge beyond the borders of the university. In response, scientists are expected to engage in collaboration that includes both basic and applied collaborative activities. More specifically, the norms of science are beginning to change to allow for novel forms of collaboration that involve sharing of research ideas on multiple facets of collaborative work. This paper examines the extent to which multifaceted collaboration is attributable to relational aspects of individuals' networks. Specifically, we ask the question: what relational aspects of social capital determine multifaceted collaboration among scientists in six fields of science and engineering? Borrowing literature from social capital and science and technology (S&T) human capital, this paper develops a multi-level model of multifaceted collaboration and presents a set of testable hypotheses. Then using data from a national survey of men and women faculty in six fields, we analyze the multi-level data: relationship or dyad level (level 1) and ego level (level 2) with hierarchical linear modeling (HLM) to predict multifaceted collaboration of academic scientists. Findings show that some relational characteristics explain multifaceted collaborative behavior as predicted, while others behave in unexpected ways. Conclusions place the findings in context for theory and policy.

1. Introduction

As collaborative research among scientists has grown dramatically over the past several decades (Fox and Faver, 1984; Katz and Martin, 1997), policy, financial and political demands have increasingly challenged universities to better capture value from research and demonstrate effective transfer of knowledge to society (Etzkowitz, 1998). These pressures have encouraged a gradual transformation, redefinition and expansion of the practice of academic science and engineering toward broader applicability and transferability of knowledge. Collaboration has transformed along several dimensions including: *intensity*, which represents the frequency or significance of interaction among scientists; *substance*, which refers to the range of aims and content of collaborative work (e.g. producing fundamental knowledge, developing technologies, training, bonding, and so on); and *heterogeneity*, which concerns the variety of participants and purposes involved in research (Hackett, 2005, see Table 1). As norms of research collaboration continue to move towards greater heterogeneity and intensity and as universities continue to encourage this type of broadening, scientists are increasingly willing to engage in a wider range of collaborative activities. When scientists collaborate on traditional publication-oriented collaboration as well as more applied patent and product development activities, they are simultaneously enacting new norms and exchanging research ideas across multiple different types of collaborative work (Hackett, 2005; Etzkowitz, 1998, 2003; Etzkowitz et al., 2000a,b).

Prior research has primarily examined collaboration among academic scientists in terms of co-authorships on journal articles, even though the range of simultaneous collaborative activities extends well beyond journal articles. This paper is concerned with a particular form of collaboration, which we term as *multifaceted collaboration*. Multifaceted collaboration is defined as a particular kind of collaborative interaction in which two scientists collaborate on multiple activities (or facets) such as grant proposals, conference papers and journal articles, product development, and patent application at the same time. Not all scientists engage in "multifaceted" collaboration; some collaboration leads exclusively to journal articles, while other collaboration undertakes patents, grant proposals and applied projects. Multifaceted collaboration is one way to operationalize the expression of new norms of science because it captures the extent to which a scientist pair collaborates on a broad range of activities that include both the "extension of knowledge" and "capitalization of knowledge" developed in the more theoretical "Triple Helix model"(Etzkowitz, 1998).

* Corresponding author. Tel.: +1 603 892 1904.
E-mail addresses: yjha2@uic.edu (Y. Jha), ewwelch@uic.edu (E.W. Welch).
[1] Tel.: +1 312 413 2416.

0048-7333/$ – see front matter
doi:10.1016/j.respol.2010.06.003

Table 1
Transformation of research collaboration.

Dimension of research collaboration	Measures
Extent	Distribution over social, geographic space, or time
Intensity	Frequency of interaction Significance of interaction
Substance/content	Basic research collaboration Developing technology Training
Heterogeneity	Variety of participants Variety of purposes
Modality	Face to face Electronically mediated Episodic
Velocity	Rate at which results are produces, analyzed, interpreted, published
Formality	Contractual agreements Handshake agreements Unstated understanding among friends

Multifaceted collaboration may result in several important outcomes: (1) increased quantity and quality of knowledge exchange among scientists because research ideas or knowledge exchanged on one facet of collaborative work may complement or inform another facet (Van Looy et al., 2004); (2) generation of career related social capital through access to a greater number and diversity of networks (Ahuja, 2000); and (3) facilitation of shared learning that occurs during knowledge exchange (Bozeman and Corley, 2004; Dietz and Bozeman, 2005). If there are knowledge-sharing implications, then it is worth asking: What determines multifaceted collaboration among scientists? Why do some scientists engage in more multifaceted collaboration with some collaborators but not with others?

The aim of this paper is to better understand how relational attributes of social capital within scientist's professional networks predict multifaceted collaboration. While there is literature on the factors that enhance collaboration among academic scientists, there is little work on the importance of micro-level relational factors that influence collaboration among scientists (Rigby and Edler, 2005). Relational attributes comprise a set of different tie characteristics – status homophily, knowledge homophily, gender homophily – that exist between collaborators. We base our investigation within the developing social network literature on academic science, where relational and structural characteristics of network ties are recognized to be important for the development and exchange of knowledge (Newman, 2001). In particular, we focus on the association between relational characteristics of dyads of research partners and multifaceted collaboration, where a dyad is defined as an ego-alter pair in which an ego is a focal node, that is connected to (collaborates with) other nodes known as alters.

The paper first presents prior literature, a model and hypotheses that guide our study. Then, using survey data collected from a national network survey of men and women faculty in science and engineering, we present estimation results from a hierarchical linear model (HLM) in which attributes of the relationship at the first level of analysis and characteristics of the ego at the second level explain multifaceted collaboration. Findings indicate that relational factors of social capital such as knowledge homophily, close friendships and duration of ties are positively associated with multifaceted collaboration. Because gender homophily results did not behave as predicted, the paper further explores gender homophily and its interaction with status homophily as predictors of multifaceted collaboration. Conclusions place the findings in context for theory and policy.

1.1. Literature and hypotheses

Prior research has discussed social capital as the sum of resources embedded within, available through, and derived from the network of relationships possessed by an individual. Social capital thus comprises both the network and the assets that may be accessed and actuated through that network (Nahapiet and Ghoshal, 1998). There has been a gradual adoption of the concepts of social capital in the study of science. Price and Beaver (1966) and Crane (1969) worked on the concept of the invisible college and recognized the importance of social capital to scientists and science. Invisible colleges are built on interpersonal relationships that facilitate various forms of collaboration. More recently, Bozeman et al. (2001) conceptualized social capital as the cooperative glue that binds collaborators together in knowledge exchange.

Nahapiet and Ghoshal (1998) discuss three dimensions of social capital—structural, relational, and cognitive. Structural social capital refers to the presence or absence of network ties between actors and patterns of network ties in terms of density or connectivity. Relational social capital refers to particular relationships people have and focuses on concepts such as trust, respect, friendship, and so on. Cognitive social capital refers to shared interpretations, and systems of meaning between actors. In this paper we pay particular attention to the relational mechanisms that may affect the access to and actuation of assets embedded within the social network that link academic researchers (Burt, 1992).

Relational characteristics of social capital consist of interpersonal relationships and the assets rooted in the structure of these relationships (McFadyen and Cannella, 2004; Nahapiet and Ghoshal, 1998). Assets exist within a structure of relationships and the relational characteristics provide access to and encourage usage of the assets. Within the context of this study, relational social capital provides beneficial structural opportunities for a broader range of collaborative interaction.

Hite further shows that two separate components of relational social capital facilitate different types of trust (Hite, 2005). *Personal goodwill trust* results from personal relationships, and *competence based trust* that results from dyadic interaction. Close friendships and gender-positively influence the willingness to exchange knowledge by developing personal goodwill trust. Development of personal good will trust and shared norms may provide a platform to both collaborators (egos and alters) for exploration of new types of collaborative activities (Uzzi, 1996, 1997). Characteristics affected or understood through interaction, such as duration of a relationship, knowledge homophily, or status homophily, helps build competence based trust between collaborators. Through competence based trust, both collaborators develop confidence in each other's competence, realize the value of each other's knowledge and abilities, and are less willing to switch to new partners. Dyadic interaction through the development of competence-based trust exposes both actors to activities beyond their current collaborative activity causing the collaborative relationship to be multifaceted (Lewicki et al., 1998; McEvily et al., 2003). In the academic world, this may mean that what initially begins as interaction between two scientists on a conference paper may lead to the joint development of a grant proposal.

In sum, relational social capital develops personal goodwill trust and competence based trust, which provide the opportunity for both ego and alter to share knowledge on multiple facets of collaboration. Trust developed through homophily, friendship, and longer interaction provide the motivation to maintain the relationship,

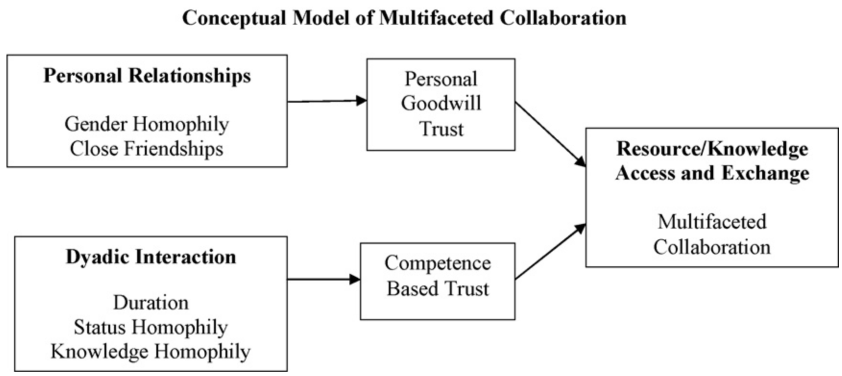

Fig. 1. Conceptual model of multifaceted collaboration.

inhibits opportunism and encourages value-seeking behavior (Hite, 2005). Based on Hite's categorization, we select two personal relational characteristics – close friendships and gender homophily – and three dyadic interaction characteristics – duration of relationship, knowledge homophily, and status homophily – for this study (Fig. 1).

1.2. Homophily

Homophily refers to the degree to which an ego-alter pair shares similar characteristics, such as age, sex, prestige, education, and occupation, race among others (McPherson et al., 2001; Monge and Contractor, 2003). Rogers and Bhowmik (1970) discuss that homophily and effective communication reinforce each other; when a homophilous pair interacts, communication is more effective, which in turn rewards consensus and leads to higher rate of interaction. Within the context of research collaboration, wherein scientists exchange research ideas with each other, the role of effective communication is especially important. Brass et al. (1998) shows that homophily increases the predictability of behavior, and fosters trust and reciprocity. In this section, we develop hypotheses to predict the effect of three types of homophily (status, gender and knowledge) on multifaceted collaboration among academic scientists.

1.2.1. Status homophily

Status homophily is one kind of homophilous relationship in which both ego and alter occupy a similar hierarchical position. This type of homophily may refer to formal status in a professional context; Brass et al. (1998) found that individuals are more likely to interact with others who are similar with respect to their formal position. Status homophily may also refer to less formal "peer" relationships. Kram and Isabella (1985) discuss that lack of hierarchical dimension in a peer relationship makes it easier for two individuals to achieve communication, mutual support, and collaboration. Peer relationships offer a degree of mutuality that enables both ego and alter to experience being the giver and receiver of information. In an academic context, status homophily may refer to a colleague of the same rank or formal status in the hierarchy, or to a peer of the same level of knowledge and experience.

Peer relationships provide instrumental as well as psychosocial functions. Instrumental functions involve exchange of job related resources such as work-relevant information, expertise, professional advice, political access, and material resources. Psychosocial functions involve exchange of social support, personal feedback, counseling, confirmation, and friendship (Kram and Isabella, 1985). By providing both of these functions, peer relationships may promote greater reciprocity and mutuality, which has been found to facilitate a higher level of knowledge sharing (Raabe and Beehr, 2003; Kram and Isabella, 1985). Etzkowitz et al. (2000a,b) have shown that relationships among academic scientists that are high on power imbalance tend to reduce academic productivity, as measured by number of publications.

Through systematic analysis of 25 relationship pairs, Kram and Isabella (1985) identified a range of instrumental and psychosocial benefits that peer relationships can offer. For example, information sharing among peers may result in new research ideas, new opportunities to apply for grants, or technical and policy oriented information about patents and product development. Peer relationships may also facilitate access to structurally available assets and persuade or encourage their application in new types of collaborative activities. In sum, the literature indicates that peer relationships are more likely to enable reciprocity, exchange, support and mutuality leading to greater access to knowledge and opportunity to collaborate on a broader range of activities. Therefore, we hypothesize that:

Hypothesis 1. Homophily of status in a collaborative relationship will be positively associated with multifaceted collaboration.

1.2.2. Gender homophily

Etzkowitz et al. (2000a,b) found from interviews of academic scientists that there exist two scientific worlds—one male, and the other female. Men scientists form close social ties with other men scientists within and beyond the department that facilitate access to collegial resources and information, which in turn help them to identify promising studies, manage labs, or learn about publishing and tenure process. In contrast, women scientists report that their relationships with male scientists tend to lack the closeness and reciprocity compared to male–male relationships. In a prior study of the interaction pattern of men and women in an organizational context, it was found that women tend to interact more with women and men tend to interact more with men resulting in two segregated networks operating in the organization (Brass, 1985).

Ruef et al. (2003) found gender homophily to be a strong mechanism that influences team formation. In previous research on the differences of women and men's interpersonal networks in academia by Rothstein and Davey (1995) found that female faculty tend to interact more with other female faculty. That study also found that female faculty had more females in their networks and perceived more career support from their networks than did male faculty. Gender homophily is expected to apply to both men and women. Hence, we expect women faculty will be more likely to seek out and build collaborative ties with other women, and men faculty will be more likely to form collaborative relationships with other men. Same sex collaborative relationships, as compared to male–female collaborative relationships, develop a greater level of personal trust and share more knowledge, leading to multifaceted collaboration. Therefore, we posit:

Hypothesis 2. Gender homophily in a collaborative relationship will be positively associated with multifaceted collaboration.

1.2.3. Knowledge homophily: objective and subjective

Monge and Contractor (2003) discuss two main lines of reasoning that support the conception of homophily: similarity attraction (Byrne, 1971) and self-categorization (Turner, 1987). Similarity attraction predicts that people are more likely to interact with others who share similar objective characteristics such as educational history, race, language, culture and so on. For instance, being PhD students together indicates similarity based on shared experiences and norms of education, which may enable more effective communication and higher potential for knowledge sharing.

Self-categorization recognizes that people self-identify as being similar or dissimilar to others in terms of objective as well as subjective bases. Objective refers to observable similarity between the ego-alter pair. Identical doctoral training may indicate that two individuals will be able to more effectively communicate and that interaction will hold a higher potential for knowledge sharing (Rogers and Bhowmik, 1970). Subjective categorization refers to the perception by individuals about their similarity to others (Rogers and Bhowmik, 1970). People sometimes categorize themselves and others based on subjective perceptions and use these subjective perceptions to further differentiate among similar and dissimilar others. The subjective perceptions on which people differentiate between similar and dissimilar others could be perceived expertise, perceived values and attitudes, and so on. For example, Borgatti and Cross (2003) found that individuals are more likely to seek information from those people whose area of expertise is perceived to be known to them. Based on this logic, one can posit that individuals would be more likely to engage in higher knowledge sharing with individuals whose areas of expertise are similar to their own. Knowledge homophilous relationships may help to access assets and encourage their use and uptake in new collaborative activities.

Hypothesis 3. Knowledge homophily in a collaborative relationship will be positively associated with multifaceted collaboration.

1.3. Relational closeness and duration

Close personal relationships build personal goodwill trust, and contribute to greater exchange of information or research ideas, which in turn may expose both actors to opportunities to explore new activities beyond the current one (Uzzi, 1996, 1997). Similarly, the duration of a relationship may also result in greater range of activity. As the duration of interaction between the ego-alter pair increases, the pair is exposed to a wider range of activities, possibly resulting in the collaborative relationship becoming multifaceted (Lewicki et al., 1998). Moreover, a longer period of interaction may lead to more fine-grained information transfer between actors, creating a platform for exploration of new types of interaction (Uzzi, 1996, 1997).

In the academic world, this may mean that collaboration between two scientists on a conference paper may lead to closer personal relationships, greater exposure to and exchange of new ideas, or greater depth of understanding of scientific material. As a result of any one of these, a scientist pair may decide to collaborate further on the joint development of a grant proposal, thereby creating multifaceted collaboration. In this paper, we consider two additional possible relational determinants of multifaceted collaboration: whether the relationship is characterized as a close friendship and the duration of the dyadic interaction. We hypothesize that both of these will predict the potential for exchange of information and an increase in either personal goodwill or competence based trust, both of which are expected to result in a higher

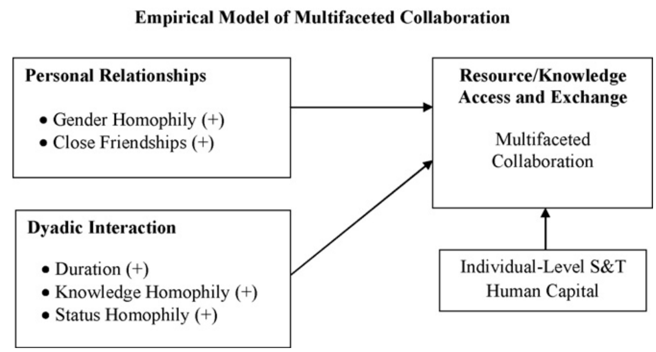

Fig. 2. Empirical model of multifaceted collaboration.

likelihood that the ego-alter-pair engage in multifaceted activities. Because multifaceted collaboration between ego and alter may depend on characteristics of the relationship such as length of interaction, and close friendship we hypothesize:

Hypothesis 4. Relational closeness in a collaborative relationship will be positively associated with multifaceted collaboration.

Hypothesis 5. Relational duration in a collaborative relationship will be positively associated with multifaceted collaboration.

1.4. S&T human capital determinants of multifaceted collaboration

Scientific and technical human capital can be defined as background and experiential endowments of academic scientists (Bozeman et al., 2001). Numerous human capital variables may contribute to multifaceted collaborative relationships. For example, Lin and Bozeman (2006) found that scientists who had prior experience in the private sector submitted six more research grant and contract proposals and in turn were awarded nearly four more grants and contracts than those who did not have any industry experience. Dietz and Bozeman (2005) found that the proportion of time spent in private sector has a positive relationship with patent productivity. It is plausible that scientists with prior experience in the private sector would engage in more applied collaborative activities with their collaborators. Therefore, one may expect that scientists with a prior experience in the private sector engage in collaborative relationships that are multifaceted.

Scientists who have a higher number of grants on average may have more projects that are active, may be more productive and may have a large number of collaborators. Bozeman and Corley (2004) found that scientists with large grants have a higher number of collaborators. One may expect that scientists who submit higher number of grant proposals on average would be exposed to different kinds of collaborative opportunities and therefore would become involved in multiple collaborative activities with their collaborators.

Finally, Hart and Mars (2009) found that faculty members holding joint appointments have a broader perspective towards academic work and are more successful in obtaining external grant funding. It is plausible that faculty holding joint appointments and working on grants are more likely to collaborate on a wider range of activities (Fig. 2).

2. Data

The data for this study come from a 2007 national survey of academic scientists and engineers in Research I universities in the United States. The survey collected data on individual background, career timeframe and experiences, research and teaching responsibilities, productivity, satisfaction and collaborative networks. The study is unique in that it gathers data on network content and knowledge exchange at a national scale. The survey uses an ego-centric network design to explore the respondents' relationships with the individuals in the respondents collaborative and advice networks, not the global network of which individuals are members (Wasserman and Faust, 1994). Through the use of detailed survey questions, respondents describe their networks for select activities and their relations with network members (Burt and Minor, 1983; Straits, 2000; Marin, 2004). As a result, the survey captures multiple dimensions of the collaborative and advice networks that are not accessible through existing data such as bibliometrics.

The survey instrument collected network data using a series of *name generator* and *name interpreter* questions. Respondents were first asked to write in the names of key collaborators or advisors in research collaboration as well as advice and support networks into five name generator questions. These included closest collaborators within their own university, closest collaborators outside their university, individuals with whom "they talk about their research but have never collaborated" and individuals in two types of advice scenarios – those with whom they talk about career advice and with whom they discuss departmental matters. Although, the first three (research) networks are mutually exclusive, there is some overlap between the research and advice networks. Once the survey respondent provided names in each of the five name generator questions, the names were piped forward into a series of *name interpreter* questions, for which the respondent was asked to respond. Name interpreter questions addressed the type of the collaboration undertaken with the collaborator, details about the level of relationship and origin of acquaintance, closeness of research expertise, communication frequency, grant activity, and general demographics. Alter-level data were converted to respondent attribute data through the aggregation of mean or sum values within an individual's network, depending on desired variable structure. In addition to the name generator and interpreter questions, respondents were asked about their research activities, including grant submission and success rate, teaching and committee responsibilities, attitudes about and involvement in interdisciplinary research, work environment, and detailed demographic and academic background questions.

The survey was implemented online using Sawtooth Software®, posted as a webpage and completed by participants online. Individuals were invited to the survey via traditional mail with a series of personalized email follow-ups. Each of the invitations provided individually assigned user-id and password and directed the individual to the survey website. The complex nature of the name generator and interpreter questions required a specialized electronic platform where duplicate name entries were automatically removed and piped forward where they were embedded within the appropriate name interpreter questions. Overall, the survey took between 30 and 45 min to complete.

A random sample of 3667 participants stratified by sex, rank, and discipline was developed from the population of academic scientists and engineers in six disciplines in Carnegie-designated Research I universities (150 universities). The population was constructed by manually retrieving information from the web sites of the relevant departments or university directories, and copying the faculty information for assistant, associate, and full professors (all of which indicate rank). The disciplines (biological sciences, chemistry, computer science, earth and atmospheric sciences, electrical engineering, and physics) were selected based on the level of female representation (low, transitioning, and high fields). Sample weights were calculated using the inverse of the probability of selection and employed in calculating all results presented below.

Of the 1774 completed surveys, 176 were removed because of ineligible rank, or discipline. Also, 21 partially completed surveys were deemed to have sufficient information (over 95% of questions answered) and included. The final analysis sample size was therefore 1598 surveys. The overall response rate of the survey, calculated using the RR2 method of the American Association for Public Opinion Research (AAPOR) was 45.8%. The weighted response rate was 43.0%. The final regression subset, after observations with missing values were deleted consists of 1303 academic scientists. For the estimation reported later in the paper, missing values reduced the size of the ego file to 1069 while the accompanying alters number 5141.

2.1. Measures

2.1.1. Dependent variables

We are primarily interested in understanding the effect that relational factors of social capital have on multifaceted collaboration. To measure multifaceted collaboration, we asked the respondent egos to first name a set of close collaborators with whom they had collaborated over the previous two years. Collaboration was defined as including proposal generation, working on a research project, writing/presenting an academic paper/book or book chapter, or developing industrial products or patents. This question generated up to five names of collaborators within the university and five names of collaborators outside of the university, for a total possible ten collaborators. Then, in follow-on name interpreter questions, we asked the respondent to indicate for each of the named collaborators, whether they collaborated on one or more of five types of activities: grant proposals, conference papers, journal articles, product development, or patents (see Appendix A for specifics of the survey question).

We compute two measures of multifaceted collaboration: a count variable of the number of different types of collaborative activities identified by the respondent per alter and a discrete variable indicating the presence of multifaceted collaboration in the collaborative relationship. The first variable has a range of one to five, where one indicates that the ego-alter pair engage research collaboration has only one type of product, while the five would indicate that the ego-alter pair engage in a broad range of collaborative activities ranging from journal articles to patenting. The discrete variable is coded "1" when counts of collaborative activities is greater than 1, and "0" when counts of collaborative activities is equal and less than 1. Theoretically, count of multifaceted collaboration represents the extent to which a scientist pair collaborates on a broad range of collaborative activities, and the discrete construct represents whether the collaborative interaction is broad or not. Descriptive statistics (Table 2) show that 54% of collaborative relationships are multifaceted and that on average, respondents report 1.80 activities per alter.

2.1.2. Independent variables

There are five different types of variables that capture the characteristics of relationships discussed in the hypothesis sections above: status homophily, gender homophily, knowledge homophily, closeness, and duration. Status homophily is based on responses to a name interpreter question asking the ego to indicate if the alter is "senior to you," "junior to you," or "neither senior nor junior to you." The survey did not ask whether the individual was a "peer" because that term was expected to have different interpretations. If the respondent ego indicated that the named alter was "neither senior nor junior," we coded the variable *Peer* '1' and '0' otherwise. Approximately, 33% of relationships in the sample are peer relationships.

For the variable *Gender Homophily*, the relationship was coded '1' if the ego-alter pair was either all female or all male. The survey requested respondents to indicate whether the named alter was male or female. However, the research team also verified the

Table 2
Descriptive statistics.

Variable name	N	Mean	Standard deviation
Relationship/tie level			
Status homophily: peer	5309	0.33	0.47
Gender homophily	5141	0.54	0.5
Knowledge homophily: understanding of expertise	5283	0.52	0.5
Knowledge homophily: PhD students together	5309	0.04	0.19
Duration	5296	2.38	0.73
Closeness	5309	0.26	0.44
Multifaceted collaboration (count)	5309	1.8	0.88
Multifaceted collaboration (discrete)	5309	0.54	0.5
Ego level			
Full professor	1069	0.44	0.5
Associate professor	1069	0.28	0.45
Assistant professor	1069	0.28	0.45
Ego female	1069	0.47	0.5
Grant average	1069	2.55	2.37
Lab affiliation	1069	0.22	0.42
Joint appointment	1069	0.19	0.44
Private sector	1069	0.09	0.28
Physics	1069	0.18	0.38
Biology	1069	0.19	0.39
Chemistry	1069	0.2	0.4
Computer science	1069	0.14	0.35
Earth and environmental science	1069	0.19	0.39
Electrical engineering	1069	0.1	0.31

correctness of the response by checking the websites of named collaborating scientists. Approximately 54% of all relationships are gender homophilous.

Knowledge Homophily is measured using two different types of variables. *PhD Students* was coded '1' (0 otherwise) if the respondent and the named alter had studied together as PhD students ("We were PhD student together"). Four percent of the collaborative relationships in the sample were with former fellow PhD students. Additionally, Knowledge of Expertise (subjective knowledge homophily) is a discrete variable indicating that the respondent has a "detailed understanding" of the alter's area of expertise. Of all relationships, 52% were coded '1'.

Closeness was measured as whether the respondent indicated that the alter was "a close friend," while *Duration* was measured as whether the respondent knew the named alter from "less than three years" (1), "three to six years" (2), or "more than six years" (3). The average duration of a collaborative relationship is approximately 2.4, indicating that most relationships between egos and alters in the dataset are longer than three years in length. Finally, respondents indicated that about 26% of their named collaborators were close friends.

Several variables capture some of the S&T human capital variables that might affect multifaceted collaboration. *Lab Affiliation* is a discrete variable indicating whether the scientist is formally affiliated with a permanent science and engineering lab (22%). *Joint Appointment* and *Private Sector* indicate whether the respondent holds a joint appointment in another department (19%) and worked full time in the private sector in the last ten years (9%), respectively. Several productivity variables are present in the dataset. However, because they are highly correlated with each other, we have selected only one – "average grant proposals submitted over the last five years" – as the measure of ego level productivity in the model.

We include discrete variables for the six fields (physics, chemistry, biology, earth and environmental science, computer science, and electrical engineering), rank (assistant, associate, and full), and ego female as additional control variables. In the sample, approximately, 18% of faculty members are from physics, 19% from biology, 20% from chemistry, 19% from earth and environmental science, 14% from computer science, and 10% are from electrical engineering. Assistant, Associate and Full professors make up 28%, 28% and 44% of the sample, respectively. All descriptive statistics are presented in Table 2.

3. Methods

Multi-level analysis or hierarchical linear modeling (HLM) can be viewed as a modified version of multiple linear regression designed to deal with data with a hierarchical nested structure (Van Duijn et al., 1999). This nested structure of the data is common to many sample designs where the data at one level cannot be assumed to be independent from data at another level. One such nested structure occurs in the study of personal networks, where relationships are nested within the egos. Relationships are "level one" units and egos (survey respondents) are the "level two" units.

Previous studies by Van Duijn et al. (1999) and Snijders et al. (1995) have applied HLM to analyze social network data in which ties are nested within egos. In this paper we expand on this previous work and to illustrate the usefulness of hierarchical modeling for ego centered networks. We use the HLM6 statistical package (Raudenbush and Bryk, 2002) to first estimate "level one" parameters describing the relationship between predictor and outcome variable. At this first level, we are using characteristics of relationships (e.g. duration and closeness) to predict multifaceted collaboration. Once fitted, the intercept and slopes estimates in the "level one" model become the outcome variables for the "level two" analysis. The following equations specify the modeled relationships.

"relationship/dyadic" level model:

$$\begin{aligned} Yjk = {} & \beta 0k + \beta 1k(\text{Status Homophily/Peer}) \\ & + \beta 2k(\text{Gender Homophily}) \\ & + \beta 3k(\text{Understanding of Expertise}) \\ & + \beta 4k(\text{PhD Students together}) \\ & + \beta 5k(\text{Duration of Collaborative Interaction}) \\ & + \beta 6k(\text{Close Friendship}) + R_{jk} \end{aligned} \quad (1)$$

"Ego" model:

$$\begin{aligned} \big(\beta 0k = {} & \gamma_{00} + \gamma_{01}(\text{Lab Affiliation})k + \gamma_{02}(\text{Joint Appointment})k \\ & + \gamma_{03}(\text{Worked in Private Sector})k + \gamma_{04}(\text{Grant Average})k \\ & + \gamma_{05}(\text{Full Professor})k + \gamma_{06}(\text{Associate Professor})k \\ & + \gamma_{07}(\text{Ego Female})k + \gamma_{08}(\text{Biology})k + \gamma_{09}(\text{Chemistry})k \\ & + \gamma_{010}(\text{Electrical Engineering})k + \gamma_{011}(\text{Computer Science})k \\ & + \gamma_{012}(\text{Physics})k + U_{0k}\big) \end{aligned} \quad (2)$$

In the level 1 model, β_{0k} is the ego specific intercept where the six named variables are the relationship level covariates and β_{1k} is the associated coefficient signifying the partial effect of each variable associated with each ego k. R_{jk} is the random error (independently distributed with a constant variance) associated with the relationship level.

In the level 2 model, γ_{00} is the adjusted mean multifaceted collaboration relationship, and the other 12 γ coefficients indicate the effect that variation in the ego level variables have on relationship level coefficients in Eq. (1). U_{0k} is the random error (independently distributed with a constant variance) associated with the ego level.

Hierarchical linear modeling also requires that the distinction be made between fixed and random effects. Fixed effects are defined as those coefficients that do not vary across groups, while random effects are allowed to vary across groups. In this case, the level 2 (ego level) intercept, β_{0k}, is designated to vary around its overall mean, while the other variables in the equations are fixed. Finally, HLM provides estimates of the variance component associated with level 1 (relationship) and level 2 (ego) residuals. The variance component enables the comparison of total variance explained across different estimates of the model. For example, it is useful to compare the unconditional variance (the HLM model without fixed effects included) with the full model specification to understand the proportion of within- and between-level variation explained.

4. Results

In general, regression estimations produced several expected results and two primary unexpected results. We first discuss the expected results from duration, closeness and knowledge homophily (H3, H4, and H5) before discussing the unexpected findings related to status and gender homophily (H1 and H2).

In terms of expected findings, both *Duration* and *Closeness* were found to be positively related to multifaceted collaboration. The longer ego had known the alter, the higher the likelihood that the collaboration between them is multifaceted. Also, a relationship with a close friend was more likely to be associated with multifaceted collaboration. These findings clearly support hypotheses H4 and H5 and reinforce how these dimensions of relational social capital may work to provide access and opportunity for broader interaction among collaborators. Close friendships and longer-term interactions may promote higher levels of personal goodwill and competence based trust that provides that basis for further collaboration.

Similarly, evidence tends to favor hypothesis H3: Knowledge homophily will be positively associated with multifaceted collaboration. *Understanding of Expertise* is strongly positively related with multifaceted collaboration, indicating that when the partners of a dyad have greater understanding of each other's areas of expertise they are more likely to collaborate in multifaceted ways. Additionally, when an ego-alter pair were *PhD students together* they are more likely to engage in multifaceted collaboration as measured by the count of collaborative activities. However, being *PhD students together* is not significantly related to the discrete measure of multifaceted collaboration. As a result, there is partial evidence that knowledge homophily is predictive of multifaceted collaboration. Returning to the theoretical model, and recognizing that we are not testing this longitudinally, it is possible to explain these results in terms of relational social capital in which higher levels of knowledge-based dyadic interaction would lead to greater competence based trust, which in turn enables access to resources and opportunities to collaborate in multiple contexts or on multiple collaborative activities (Table 3).

Additionally, we find several of the ego-level variables to be significant. As expected, individuals who produce more grant submissions on average per year are more likely to be involved in multifaceted collaboration. Perhaps this indicates that grant writing exposes faculty to large collaborative networks that provide opportunities to engage in multifaceted collaboration, although we do not have the longitudinal data to support this supposition. In addition, scientists who are affiliated with a lab are more likely to engage in multifaceted collaboration (count model) and senior faculty are more likely to engage in multifaceted collaboration than junior faculty. Biologists appear to have fewer multifaceted relationships than faculty in the earth and atmospheric sciences reference field, while computer scientists and engineer are likely to have more. Overall, level 1 variance calculations show that the model explains only five percent of the explainable within ego variation for the count estimation and only two percent for the discrete estimation. While it is likely that other factors such as the funding source, departmental, university and disciplinary incentives and other individual background characteristics would explain more of the level 1 variance, data limitations precluded our ability to include these variables. Level 2 variance explained is 0.33 for the count variable and 0.13 for the discrete model.

Unexpected findings relate to the first two hypotheses (H1 and H2): peer relationships (status homophily) and same gender relationships (gender homophily) were hypothesized to lead to higher

Table 3
HLM findings.

	Multifaceted collaboration (count)	Multifaceted collaboration (discrete)
Relationship level		
Intercept	−0.29 (0.02)***	0.10 (0.04)**
Status homophily: peer	−0.10 (0.04)***	−0.14 (0.07)**
Gender homophily	−0.19 (0.04)***	−0.30 (0.08)***
Knowledge homophily: understanding of expertise	0.26 (0.03)***	0.39 (0.07)***
Knowledge homophily: PhD students together	0.16 (0.08)**	0.14 (0.20)
Duration	0.13 (0.03)***	0.13 (0.06)**
Closeness	0.26 (0.05)***	0.55 (0.09)***
Ego level		
Grant average	0.05 (0.01)***	0.08 (0.02)***
Lab affiliation	0.19 (0.06)***	0.28 (0.12)**
Joint appointment	0.06 (0.06)	0.06 (0.13)
Private sector	0.03 (0.09)	−0.12 (0.18)
Full Professor	0.13 (0.06)**	0.07 (0.11)
Associate Professor	0.11 (0.05)**	0.11 (0.12)
Ego female	−0.03 (0.04)	−0.09 (0.08)
Physics	0.02 (0.09)	0.03 (0.14)
Biology	−0.21 (0.07)***	−0.40 (0.14)***
Chemistry	−0.02 (0.08)	−0.13 (0.14)
Computer science	0.17 (0.08)**	0.21 (0.15)
Electrical engineering	0.22 (0.08)**	0.12 (0.18)
Level 1 variance	0.05	0.02
Level 2 variance	0.33	0.13

* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

levels of multifaceted interaction. Results show that both status homophily (when ego perceives the alter to be neither junior nor senior) and gender homophily are negatively associated with multifaceted collaboration. These findings are important as they tend to run counter to the literature and may potentially represent conventional wisdom about how gender and status matter for the production of science. As a result, the next section of the paper presents further exploration of the gender and status homophily through the use of interactive variables.

4.1. Further exploratory analysis of gender homophily effects on multifaceted collaboration

To further explore homophily, we conduct two new estimations: The first specifically examines the association of male homophily and female homophily on multifaceted collaboration. This analysis assesses whether the negative coefficient on gender homophily in the above estimation is due to male pair or female pair effects. The second estimation addresses the potential interactive effects of gender and status homophily on multifaceted collaboration: Do women peer dyads, male peer dyads and heterophilous (male–female) dyads predict multifaceted collaboration differently? Prior research by Johnson (1994) has found that at positions of similar formal status, there are few differences in the way men and women interact with individuals of either the same or opposite gender. Therefore, we expect that male–male peers, female–female peers and male–female peers will contribute similarly to multifaceted collaboration. More specifically, we were interested in exploring how "being peers" and "being of the same gender" contribute simultaneously to multifaceted collaboration.

Table 4
Additional descriptive statistics.

Variable name	N	Mean	Standard deviation
Relationship/tie level			
Female homophily	5141	0.11	0.31
Male homophily	5141	0.44	0.5
Peer*female homophily	5249	0.04	0.19
Peer*male homophily	5249	0.14	0.35
Gender heterophily	5141	0.46	0.5
Peer*gender heterophily	5249	0.14	0.34

4.1.1. Additional explanatory variables

Two additional measures of gender homophily were developed: *Male Homophily* and *Female Homophily*. Male and Female Homophily variables were coded '1' (0 otherwise) if the ego alter pair were all male or all female, respectively. Approximately 11% of all relationships were female homophilous and about 44% of all relationships were male homophilous. Four other interactive variables were also developed: peer male homophily, peer female homophily, gender heterophily, and peer gender heterophily. Descriptive statistics for these additional variables are presented in Table 4. Heterophily is the reference in the first pair of estimations presented in Table 5, while peer male homophily is the reference variable in the second pair of models.

4.2. Exploratory results

Results for both estimations of the Exploratory Model I in Table 5 show gender homophily to be significantly negatively related to multifaceted collaboration, regardless of whether the dyad is composed of men or women. In Exploratory Model I, *Male Homophily*

Table 5
Exploratory HLM findings.

	Exploratory model I Multifaceted collaboration (count)	Exploratory model I Multifaceted collaboration (discrete)	Exploratory model II Multifaceted collaboration (count)	Exploratory model II Multifaceted collaboration (discrete)
Relationship level				
Intercept	−0.29 (0.02)***	0.10 (0.04)***	−0.29 (0.02)***	0.10 (0.04)***
Status homophily: peer	0.03 (0.05)	0.17 (0.13)	−0.16 (0.04)***	−0.27 (0.09)***
Gender homophily				
Knowledge homophily: understanding of expertise	0.26 (0.04)***	0.39 (0.07)***	0.26 (0.04)***	0.39 (0.07)***
Knowledge homophily: PhD students together	0.14 (0.09)	0.09 (0.20)	0.14 (0.09)	0.09 (0.20)
Duration	0.13 (0.03)***	0.13 (0.06)**	0.13 (0.03)***	0.13 (0.06)**
Closeness	0.26 (0.05)***	0.54 (0.09)***	0.26 (0.05)***	0.54 (0.09)***
Female homophily	−0.11 (0.07)	−0.24 (0.15)*	0.02 (0.08)	−0.05 (0.19)
Male homophily	−0.14 (0.05)**	−0.19 (0.13)		
Gender heterophily			0.14 (0.05)**	0.19 (0.13)
Peer*female homophily	0.02 (0.11)	0.20 (0.24)	0.22 (0.10)**	0.64 (0.23)***
Peer*male homophily	−0.20 (0.07)***	−0.44 (0.15)***		
Peer*gender heterophily			0.20 (0.07)***	0.44 (0.15)***
Ego level				
Grant average	0.04 (0.00)***	0.07(0.03)**	0.05 (0.01)***	0.07(0.03)**
Lab affiliation	0.19 (0.06)***	0.28 (0.13)**	0.19 (0.06)***	0.28 (0.13)**
Joint appointment	0.05 (0.06)	0.07 (0.13)	0.05 (0.06)	0.07 (0.13)
Private sector	0.02 (0.09)	−0.12 (0.19)	0.02 (0.09)	−0.12 (0.19)
Full professor	0.12 (0.06)**	0.07 (0.11)	0.12 (0.06)**	0.07 (0.11)
Associate professor	0.10 (0.06)	0.11 (0.12)	0.10 (0.06)	0.11 (0.12)
Ego female	−0.04 (0.04)	−0.09 (0.08)	−0.04 (0.04)	−0.00 (0.09)
Physics	0.02 (0.09)	−0.08 (0.18)	0.02 (0.09)	0.03 (0.14)
Biology	−0.22 (0.08)***	−0.37 (0.15)***	−0.22 (0.08)***	−0.37 (0.15)***
Chemistry	−0.03 (0.08)	−0.13 (0.16)	−0.03 (0.08)	−0.13 (0.16)
Computer science	0.15 (0.08)**	0.22 (0.16)	0.15 (0.08)**	0.22 (0.16)
Electrical engineering	0.22 (0.09)**	0.15 (0.19)	0.22 (0.09)**	0.15 (0.19)
Level 1 variance	0.04	0.02	0.05	0.02
Level 2 variance	0.33	0.13	0.33	0.13

* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

is significantly negatively related to the count of multifaceted collaboration, while *Female Homophily* is significantly negatively associated with discrete multifaceted collaboration (even though the signs are consistently negative for both estimations). This is further evidence that compared to gender heterophilous relationships, gender homophilous relationships are less likely to access assets within the social network.

Results for Exploratory Model II also indicate that compared to their non-peer dyads, peer dyads of women (peer female homophily) and peer men–women dyads (peer gender heterophily) are more likely to result in multifaceted collaboration. Also, mixed men–women dyads (gender heterophily) are more likely to engage in multifaceted collaborations, although gender heterophily is significant only in the count model. Finally, the variable *Status Homophily: Peer* is negatively related to multifaceted collaboration indicating that similar to the results in Table 3, peer homophilous dyads are much less likely to collaborate on multiple types of activities than non-peer dyads. Perhaps this is due to the need for complementary skills, abilities, interests and resources that exist between dyads of different status levels.[2]

5. Conclusion

This study provides empirical evidence on the role of micro level relational characteristics such as homophilous relationships, close friendships, and duration in facilitating multifaceted collaboration. As a result this paper seeks to fill a key gap in the literature on collaboration among academic scientists in the field of science and engineering. Components of relational social capital such as duration of interaction, close friendships, and knowledge homophily provide access to assets found in the structure of relationships and encourage application of those assets in multifaceted ways. The longer ego-alter pair work with each other, the more they trust each other's competence, the more likely they will discover new opportunities for collaboration. Similarly, close friendship facilitates greater access to assets rooted within the social structure and provides the motivation to apply those assets in diverse collaborative activities. Knowledge based dyadic interaction also leads to greater competence based trust, which in turn enables access to resources and opportunities to collaborate in multiple contexts or on multiple collaborative activities.

Contrary to our expectation, gender homophilous dyads are less likely to be multifaceted than gender heterophilous dyads, and therefore less likely to access assets and apply them through multifaceted collaboration. This finding may be due to the heterogeneous nature of multifaceted collaboration. Rhoten and Pfirman (2007) discuss that the learning styles of women are centered on the notions of interconnectedness, which may allow easier dyadic linkage across multiple research ideas and activities. Differences in learning styles between men and women may translate into differences in forming collaborative relationships. Additionally, the authors cite prior work suggesting that on average, women may be more interested in activities that have a problem solving orientation and societal relevance whereas men may be more interested in fundamental theory and computation. Because multifaceted collaboration, as we measured it, involves collaboration on applied collaborative activities, our findings may provide further support of Rhoten and Pfirman's work.

Also contrary to expectations, peers compared to non-peers are less likely to conduct multifaceted collaborations. Possibly this is the result of complementary skills, abilities, interests and resources that exist between status heterophilous pairs. By contrast, peer dyads of women and peer men-women dyads are more likely to result in multifaceted collaborations. Kram and Isabella (1985) discuss that peer relationships make it easier to achieve collaboration, communication, and mutual support compared to hierarchical relationships. Additionally, as Ely (1994) points out that junior women might not perceive senior women as source of validation and support in work environments where men predominate in positions of authority. Rather junior women may seek resources and opportunity through either ties with men or through connections with more trusted peers. These preferences may reduce the likelihood of multifaceted collaboration for non-peer women dyads. Previous research by Fritz (1997) has also found that women's peer relationships are stronger than men's peer relationship.

Ultimately, these findings tend to show that homogeneity does not consistently predict collaborative interaction. New norms of science that demand greater complexity of interaction and activity may also encourage complementary heterogeneous pairings among scientists in ways that provide access to and application of network-embedded resources. Some heterogeneous dyads may be more able to create complementary science products that have a broader range of characteristics and objectives. Gender heterophily and status heterophily are two possible expressions of complementary heterogeneous pairing. On the other hand, the findings do not show the dominance of heterophily; peer homophilous female pairs are likely multifaceted collaborators and knowledge homophily, close ties and duration all explain multifaceted collaboration. Perhaps heterogeneity has its limits, or that it inhabits key niches that advantage dyads, groups and teams in some ways but not others. Future research should more fully explore the interactions among status and gender heterophily as they affect science outcomes. It should also more carefully explore the range of homophilous and heterophilous contributors to collaborative interaction.

[2] In order to make sure that the homophily and heterophily variables are not excessively collinear, we conducted VIF and tolerance tests. We found the VIF's of all the homophily and heterophily variables to be between 1 and 2.62.

Appendix A. Variable and question wording

Factors	Variables	Questions/Item wording
Dependent variable: multifaceted collaboration	Multifaceted collaboration (count)	What types of collaboration have you had with your collaborators over the past two academic years? (Range 1–5; 1 = one type of collaboration, 5 = five types of collaborations; where the types of collaborations are research grant proposal, unpublished working or conference paper, academic journal article/book chapter, product development, patent application)
	Multifaceted collaboration (discrete)	What types of collaboration have you had with your collaborators over the past two academic years? ("1" when counts of collaborative activities is greater than 1, and "0" when counts of collaborative activities is equal and less than 1).
Homophily	Status/peer homophily	Please indicate if the person you have named is neither senior nor junior to you? (1/0)
	Gender homophily	Please indicate whether the individual you named is female? (1/0)
	Knowledge homophily (objective and subjective)	Please indicate about the individuals you have named, whether you were PhD students together? (1/0)
		Recognizing that you interact with people who have different areas of expertise, please indicate the extent to which you understand their area of expertise? (1 = Detailed understanding, 0 = Little or no understanding)
Relational closeness and duration	Close friend	Please indicate whether the individual you named is a close friend? (1/0)
	Duration of interaction	How long have you known the individuals you named? (1 = less than 3 years; 2 = 3–6 years; 3 = more than 6 years)
S&T Human capital	Lab affiliation	Are you a member or have a formal affiliation with a permanent science or engineering Laboratory or center? (1 = yes; 0 = no)
	Joint appointment	Do you hold a formal joint appointment with another academic department? (1 = yes, 0 = no)
	Grant average	Over the past five years, on average how many proposals have you submitted per year?
	Worked in private sector in the past ten years	During the last ten years, have you worked full time for private industry? (1 = yes, 0 = no)
	Rank (Assistant Professor, Associate Professor, Full Professor)	Are you currently an assistant professor? (1 = yes, 0 = no)
		Are you currently an associate professor? (1 = yes, 0 = no)
		Are you currently a Full professor? (1 = yes, 0 = no)

References

Ahuja, G., 2000. Collaboration networks, structural holes, and innovation: a longitudinal study. Administrative Science Quarterly 45 (3), 425–455.

Borgatti, S.P., Cross, R., 2003. A relational view of information seeking and learning in social networks. Management Science 49 (4), 432–445.

Bozeman, B., Corley, E., 2004. Scientists' collaboration strategies: implications for scientific and technical human capital. Research Policy 33 (4), 599–616.

Bozeman, B., Dietz, J., Gaughan, M., 2001. Scientific and technical human capital: an alternative model for research evaluation. International Journal of Technology Management 22 (7), 716–740.

Brass, D., 1985. Men's and women's networks: a study of interaction patterns and influence in an organization. The Academy of Management Journal 28 (2), 327–343.

Brass, D., Butterfield, K., Skaggs, B.C., 1998. Relationships and unethical behavior: a social network perspective. The Academy of Management Review 23 (1), 14–31.

Burt, R.S., 1992. Structural Holes: The Social Structure of Competition. Harvard University Press, Cambridge, MA.

Burt, R., Minor, M., 1983. Applied Network Analysis: A Methodological Introduction. Sage Publications, Beverly Hills, CA.

Byrne, D.E., 1971. The attraction paradigm. Academic Press, New York.

Crane, D., 1969. Social structure in a group of scientists: a test of the invisible college hypothesis. American Sociological Review 34 (3), 335–352.

Dietz, J.S., Bozeman, B., 2005. Academic careers, patents, and productivity: industry experience as scientific and technical human capital. Research Policy 34 (3), 349–367.

Ely, R., 1994. The effects of organizational demographics and social identity on relationships among professional women. Administrative Science Quarterly 39 (2), 203–238.

Etzkowitz, H., 1998. The norms of entrepreneurial science: cognitive effects of the new university–industry linkages. Research Policy 27 (8), 823–833.

Etzkowitz, H., 2003. Research groups as 'quasi-firms': the invention of the entrepreneurial university. Research Policy 32 (1), 109–121.

Etzkowitz, H., Kemelgor, C., Uzzi, B., 2000a. Athena Unbound: The Advancement of Women in Science and Technology. Cambridge University Press, Cambridge, UK.

Etzkowitz, H., Webster, A., Gebhardt, C., Terra, B.R., 2000b. The future of the university and the University of the Future: evolution of ivory tower to entrepreneurial paradigm. Research Policy 29 (2), 313–330.

Fox, M., Faver, C., 1984. Independence and cooperation in research: the motivations and costs of collaboration. The Journal of Higher Education 55 (3), 347–359.

Fritz, H., 1997. Men's and women's organizational peer relationships: a comparison. Journal of Business Communication 34 (1), 27–44.

Hackett, E., 2005. Introduction: special guest-edited issue on scientific collaboration. Social Studies of Science 35 (5), 667–671.

Hart, J., Mars, M., 2009. Joint appointments and the professoriate: two houses but no home? Innovative Higher Education 34 (1), 19–32.

Hite, J., 2005. Evolutionary processes and paths of relationally embedded network ties in emerging entrepreneurial firms. Entrepreneurship: Theory and Practice 29 (1), 113–145.

Johnson, C., 1994. Gender, legitimate authority, and leader–subordinate conversations. American Sociological Review 59 (1), 122–135.

Katz, J., Martin, B., 1997. What is research collaboration? Research Policy 26 (1), 1–18.

Kram, K., Isabella, L., 1985. Mentoring alternatives: the role of peer relationships in career development. The Academy of Management Journal 28 (1), 110–132.

Lewicki, R., McAllister, D., Bies, R.J., 1998. Trust and distrust: new relationships and realities. The Academy of Management Review 23 (3), 438–458.

Lin, M., Bozeman, B., 2006. Researchers' industry experience and productivity in university–industry research centers: a "scientific and technical human capital" explanation. The Journal of Technology Transfer 31 (2), 269–290.

Marin, A., 2004. Are respondents more likely to list alters with certain characteristics? Implications for name generator data. Social Networks 26 (4), 289–307.

McEvily, B., Perrone, V., Zaheer, A., 2003. Trust as an organizing principle. Organization Science 14 (1), 91–103.

McFadyen, M.A., Cannella, A.A., 2004. Social Capital and Knowledge Creation: Diminishing Returns of the Number and Strength of Exchange. The Academy of Management Journal 47 (5), 735–746.

McPherson, M., Smith-Lovin, L., Cook, J.M., 2001. Birds of a feather: homophily in social networks. Annual Review of Sociology 27 (1), 415–444.

Monge, P., Contractor, N., 2003. Theories of Communication Networks. Oxford University Press, Oxford, NY.

Nahapiet, J., Ghoshal, S., 1998. Social capital, intellectual capital, and the organizational advantage. Academy of Management Review 23 (2), 242–266.

Newman, M., 2001. Scientific collaboration networks. I. Network construction and fundamental results. Physical Review E 64 (1), 16131.

Price, D., Beaver, D., 1966. Collaboration in an invisible college. American Psychologist 21 (11), 1011–1018.

Raabe, B., Beehr, T., 2003. Formal mentoring versus supervisor and coworker relationships: differences in perceptions and impact. Journal of Organizational Behavior 24 (3), 271–293.
Raudenbush, S.W., Bryk, A.S., 2002. Hierarchical linear models: Applications and data analysis methods, 2nd ed. Sage, Newbury Park, CA.
Rhoten, D., Pfirman, S., 2007. Women in interdisciplinary science: exploring preferences and consequences. Research Policy 36 (1), 56–75.
Rigby, J., Edler, J., 2005. Peering inside research networks: some observations on the effect of the intensity of collaboration on the variability of research quality. Research Policy 34 (6), 784–794.
Rogers, E., Bhowmik, D., 1970. Homophily–heterophily: relational concepts for communication research. The Public Opinion Quarterly 34 (4), 523–538.
Rothstein, M, Davey, L., 1995. Gender differences in network relationships in academia. Women in Management Review 10 (6), 20–25.
Ruef, M., Aldrich, H., Carter, N.M., 2003. The structure of founding teams: homophily, strong ties, and isolation among US entrepreneurs. American Sociological Review 68 (2), 195–222.
Snijders, T., Spreen, M., Zwaagstra, R., 1995. The use of multilevel modeling for analyzing personal networks: networks of cocaine users in an urban area. Journal of Quantitative Anthropology 5 (2), 85–105.
Straits, B.C., 2000. Ego's important discussants or significant people: an experiment in varying the wording of personal network name generators. Social Networks 22 (2), 123–140.
Turner, J.C., 1987. Rediscovering the social group: A self categorization theory. Blackwell, Oxford.
Uzzi, B., 1996. The sources and consequences of embeddedness for the economic performance of organizations: the network effect. American Sociological Review 61 (4), 674–698.
Uzzi, B., 1997. Social structure and competition in interfirm networks: the paradox of embeddedness. Administrative Science Quarterly 42 (1), 35–67.
Van Duijn, M., Van Busschbach, J., Snijders, T.A.B., 1999. Multilevel analysis of personal networks as dependent variables. Social Networks 21 (2), 187–210.
Van Looy, B., Ranga, M., Callaert, J., Debackere, K., Zimmerman, E., 2004. Combining entrepreneurial and scientific performance in academia: towards a compounded and reciprocal Matthew-effect? Research Policy 33 (3), 425–441.
Wasserman, S., Faust, K., 1994. Social Network Analysis: Methods and Applications. Cambridge University Press.