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Ties That Last: Tie Formation and Persistence in Research Collaborations over Time

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Abstract

Using a longitudinal dataset of research collaborations over 15 years at Stanford University, we build a theory of intraorganizational task relationships that distinguishes the different factors associated with the formation and persistence of network ties. We highlight six factors: shared organizational foci, shared traits and interests, tie advantages from popularity, tie reinforcement from third parties, tie strength and multiplexity, and the instrumental returns from the products of ties. Findings suggest that ties form when unfamiliar people identify desirable and matching traits in potential partners. By contrast, ties persist when familiar people reflect on the quality of their relationship and shared experiences. The former calls for shallow, short-term strategies for assessing a broad array of potential ties; the latter calls for long-term strategies and substantive assessments of a relationship's worth so as to draw extended rewards from the association. This suggests that organizational activities geared toward sustaining persistent intraorganizational task relationships need to be different from activities aimed at forging new ones.

Keywords: research collaborations, network ties, tie formation, tie persistence, long-term ties, task relationships

Organizations frequently require and benefit more from interpersonal ties that persist over time than they do from new ties. Repeated collaborations have fewer startup costs than new ones, they entail greater certainty and trust, and the individuals engaged in long-standing ties frequently communicate better (Marsden and Campbell, 1984; Uzzi, 1997). From this follow all manner of benefits, from easier and more effective communication to a more complete

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transfer of information and reciprocal forms of exchange (Katz, 1982). In short, organizations are often more interested in factors that nurture the continuation of extant collaborations than they are in creating an expanded portfolio of new contacts.

Unfortunately, research on social network dynamics and organizational networks seldom focuses on the processes that sustain and nurture intraorganizational collaborations. Social network research focuses almost exclusively on factors of tie formation (Coleman, 1974; Snijders, 2001; Levi Martin and Yeung, 2006; Robins et al., 2007; Baldassari and Diani, 2007). As Burt (2002: 343) said, all the focus is on formation and there is ''almost no research on the stability of interpersonal relationships.'' In addition, social network research typically concerns personal ties such as friendship, which frequently occur beyond the organizational setting and are distinct from the more instrumental forms of work collaboration central to a firm's functioning (e.g., see Lazarsfeld and Merton, 1954). The goal of this paper is to fill this gap in the literature: to direct attention towards intraorganizational task relationships and the factors leading to their formation and persistence.

One must turn to interorganizational research to find a discussion of how collaborations form *and* persist (Palmer, 1983). Some of this work focuses on the persistence of exclusive firm-client relations (Seabright, Levinthal, and Fichman, 1992; Baker, Faulkner, and Fisher, 1998; Broschak, 2004). Researchers have found that such ties dissolve when the clients' resource needs shift and they find alternatives; and they persist when pre-established relations are strong enough to focus the client's resource needs on what the firm can afford (Seabright, Levinthal, and Fichman, 1992). In other studies, researchers have found that interorganizational collaborations form when common third-party ties bring them together, or when firms enter alliances to access critical resources and information about each other (Palmer, 1983). Conversely, these alliances dissolve when such factors are uncertain or partial (Gulati and Gargiulo, 1999; Ingram and Torfason, 2010). This literature nicely highlights interorganizational factors we might draw upon, but they do not explicitly concern intraorganizational relationships.

Missing from the literature is a focus on intraorganizational task relationships and their dynamics, arguably a core feature of many organizations. There has also been little discussion of how the process of forming work collaborations may differ from the process of sustaining them. On purely intuitive grounds, it makes sense that the factors associated with the formation of task relations will differ from those that lead them to persist. After all, the tie formation process is one in which factors bring strangers into a relation, while the tie persistence process is one in which factors guide people who are familiar with each other to repeat and extend their association. As such, the factors initially bringing us together may not be the same as those that keep us together. But research on personal networks assumes that the factors guiding tie formation also guide tie persistence. For example, after a long discussion of tie formation, McPherson, Smith-Lovin, and Cook (2001: 436–438) called for future research on tie persistence and speculated that the processes driving tie persistence likely mimic those of tie formation, but with weaker effects. From extant research on personal tie formation in organizations, we know that ties form due to people having organizational foci in common, homophily, and attraction for status reasons (Ruef, Aldrich, and Carter, 2003). Hence, if we extend the

argument of McPherson, Smith-Lovin, and Cook, these same factors should extend to the persistence of task relations. That is, same-gender individuals should be more likely to begin collaborating, and such collaborators should persist because they share a greater sense of interpersonal understanding and security. In this reasoning, traits remain salient to tie formation and persistence—the persons associating do not grow accustomed to visible traits as they shift from being newly relating strangers to repeatedly collaborating individuals who are familiar with each other.

Other literature suggests that the processes of tie formation and tie persistence may differ. According to a consistent strand of research on interorganizational networks, ties persist because of path dependence and inertia (March and Simon, 1958; Cohen, March, and Olsen, 1972). The general argument is that once a relationship forms, it takes on a life of its own and sustains itself via its history or a logic of attachment (Stinchcombe, 1965; Seabright, Levinthal, and Fichman, 1992). That is, once a tie is formed, people tend to satisfice and stay in their current collaboration despite the availability of potentially better matches. This argument highlights the features of a tie itself as factors for sustaining the tie into the future, and these features are not logically relevant to tie formation.

Both arguments may be partially correct when it comes to explaining the formation and persistence of intraorganizational task relationships. The processes of tie formation and tie persistence occur in different contexts, and these processes draw on different informational cues and resources. Individuals who have already collaborated have different information than those who have never met and who lack firsthand information. Some cues are only available after a tie has formed, and other cues are available at both stages of formation and persistence. A theory of tie formation and persistence thus needs to determine when a factor is salient and whether it influences the formation and persistence of ties in distinct ways. Tie persistence occurs in the context of an existing relationship between people. When deciding whether to sustain that tie, its participants reflect on a rich assortment of information concerning the quality of shared experiences and returns from their tie. By contrast, tie formation occurs in the context of two unfamiliar individuals meeting and seeking points of similarity, mostly in appearances and credentials. As such, tie formation occurs in an uncertain and broad context of strangers applying short-term strategies to quickly assess and forge ties on the basis of shared traits. Tie persistence occurs in a more certain context of familiar others in which people apply long-term strategies to make substantive assessments of a relationship's worth so as to draw extended rewards from the association. Tie formation and tie persistence therefore represent qualitatively different stages of relational decision making and a shift in context that is quite profound for studies of social networks and organization theory. To explain how they differ, we build a systematic, empirical study of the factors promoting the formation and persistence of work collaborations in organizations.

Distinguishing tie persistence and tie formation as distinct network dynamics requires a large and rich longitudinal dataset on intraorganizational networks. Needless to say, such information is hard to come by. Given the prevalence of the current knowledge economy, and the centrality of knowledge creation activities within it, we turned to universities and academics' collaborations in written publications and grant applications (Weingart, 2000; Peterson, 2007).

Publications and grants are central to a research university's prestige and the faculty member's prospects for tenure. Collaborations that increase the quality and quantity of publications and grants are a premium resource in these organizations. In fact, the prevalence of collaboration among scientists has increased steadily over the last three decades (Wuchty, Jones, and Uzzi, 2007). Collaborations are particularly common in the natural sciences because of the need to access new instrumentation (De Solla Price, 1963) and address complex problems too difficult for any single individual to solve (Basalla, 1988). While some information on publications is readily available, it must be linked to a rich assortment of information about the faculty so as to control for alternative explanations, evaluate the relative importance of different structural factors, and explain the variation in tie formation and tie persistence. We turned to uniquely detailed information about the Stanford University faculty in 1993–2007 that allowed us to identify when new, untenured faculty arrived at the university and began to form their first ties and explain why some of these ties persisted over time to become repeat collaborations.

TIE FORMATION AND PERSISTENCE IN RESEARCH COLLABORATIONS

In analyzing the collaborations of academics, we considered six different factors of tie formation and persistence to develop a set of hypotheses: (1) shared organizational foci, (2) homophily in attributes and interest, (3) tie advantages from popularity (cumulative advantage), (4) tie reinforcement from third parties (triadic closure), (5) strength and multiplexity of ties (tie inertia), and (6) the instrumental returns of a tie's products (means-ends rationalization). Although we examined the hypotheses in the context of research collaborations, we believe they apply more broadly to instrumental relationships than to socio-emotional relationships (Morris, Podolny, and Sullivan, 2008). The instrumental ties we study concern task relationships formed with the intention to derive some kind of reward or create a joint product. Our analyses focus on the structural factors of tie formation and persistence, acknowledging that some scholars offer a more cultural perspective of networks (Emirbayer and Goodwin, 1994; Ruef, 2002).

Organizational Foci

It is common for network scholars to identify a network process without paying close attention to organizational structure, yet as Brass and colleagues (2004: 796) suggested, people's and groups' positions locate formal actions in physical space and in workflows and hierarchies, ''restricting their opportunity to interact with some others and facilitating interaction with still others.'' While most interaction is voluntary, organizational structures bring together people who might not otherwise associate. Feld (1981) characterized these shared positions and activities as ''foci,'' or social, psychological, legal, or physical entities around which joint activities are organized. When individuals share organizational foci, they are more likely to form social bonds. Festinger, Schachter, and Back (1950) even suggested that foci trump other important factors of collaborations such as homophily. Recent work has also proposed that shared foci deepen existing relationships (Reagans, 2011). It is less clear, however, how this differs in the formation and persistence of ties.

At least two organizational foci are relevant in the context of universities: departments and research centers. Departments are the most obvious foci around which collaborations form. Departmental faculty are often located near one another, share similar research training, and engage in many joint activities such as student advising, teaching the same sets of students, performing similar research, and engaging in joint decisions about hiring, promotion, and so on. As such, departments are constrained foci (Coser, 1974; Merton, 1976: 25), and they come to represent formal, jurisdictional boundaries within the modern university (Blau, 1973; Abbott, 2001). Intradepartmental ties should therefore be more likely to form and persist over time.

That said, interdepartmental collaborations also occur, though at a lesser rate (Friedkin, 1978). Cross-departmental ties are partly driven by scientists seeking to solve particular kinds of problems by using expertise from several different disciplines (Jacobs and Frickel, 2009). But ties spanning departments are hard to form and sustain because they expose scholars to dissonant ideas that are not necessarily compatible with their frames of reference. Burt (2002) argued that bridges across disconnected groups decay faster than other ties because they require more negotiations between disparate interests. Although such ties may be beneficial, they can also be time-consuming to maintain, as there are ''fewer individuals involved to carry the cost of the collaboration'' (Burt, 2002: 344).

The university's organizational structure has been augmented with a second class of organizational foci—interdisciplinary research centers—to support and sustain some of these interdepartmental collaborations. In general, research centers are secondary foci to the primary foci of departments. Departments are typically the locus of pay, career tracks, and disciplinary affiliations and therefore hold more sway over faculty members' behavior. In contrast, research centers bring faculty together on visible research projects and topics that often span departments, and they frequently sustain interaction with research funding. Some faculty members even find interdisciplinary discussion more enlivening because there are discussions of different methods, writing styles, and epistemic cultures (Lamont, 2009). In fact, once faculty members reach tenure, the constraints on interdisciplinary collaboration diminish, and they may find extracurricular associations to be more novel and interesting.

In general, we expect organizational foci like departments and research centers to be positively associated with tie formation and tie persistence but not to the same extent. The underlying mechanism is one of exposure: faculty who become aware of one another are more likely to affiliate. We thus expect the effect of foci to be salient for tie formation but not for tie persistence. Most connected persons will already be proximate to one another, and they will incrementally seek some degree of novel experience.

Hypothesis 1 (H1): Organizational foci have positive effects on tie formation but not on tie persistence.

Homophily

A salient factor for research collaboration is homophily, or the tendency of people to select collaborations with others similar to themselves. Lazarsfeld and Merton (1954: 24) drew ''a distinction between status-homophily (observed tendencies for similarities between the group-affiliation of friends or between

their positions within a group) and value-homophily (observed tendencies toward correspondence in the values of friends).'' McPherson, Smith-Lovin, and Cook (2001: 419) extended Lazarsfeld and Merton's distinction:

> Status homophily includes major sociodemographic dimensions that stratify society—ascribed characteristics like race, ethnicity, sex, or age, and acquired characteristics like religion, education, occupation, or behavior patterns. Value homophily includes the wide variety of internal states presumed to shape our orientation toward future behavior.

Collaborations frequently form in broad contexts in which many unfamiliar others are present and actors use homophily to quickly winnow the field. Hence, we expect tie formation will be most associated with status homophily because it is based on characteristics people can often glean from visual cues. By contrast, tie persistence should occur in contexts in which more firsthand information is present. Therefore, we expect tie persistence will be associated with value homophily.

Status homophily. Many scholars submit that, among a sea of possible ties, we are likely to forge collaborations with similar others. An expansive literature shows that people are more likely to associate when they share attributes of age, gender, education, and ethnicity (Lazarfeld and Merton, 1954; McPherson and Smith-Lovin, 1987; Ibarra, 1993; McPherson, Smith-Lovin, and Cook, 2001). Homophily is often seen as an explanation for initial tie formation, and some also believe it explains why some relationships persist longer than others. McPherson, Smith-Lovin, and Cook (2001) encouraged research in this area, as there is very limited empirical evidence and few theoretical arguments relating status homophily to tie persistence. The few studies available note that factors generating tie persistence appear to mimic tie formation, but with smaller effect magnitudes. For example, Hallinan and Williams (1989) found that friendship ties in secondary schools persisted longer for same-gender and same-race relationships than for other ties. Given the uncertainty in tie formation contexts, it seems reasonable to believe that attribute homophily (based on phenotypic comparisons) will be an efficient search strategy and means of reducing uncertainty, but it will be less salient in a familiar context of preexisting ties that transcend these initial scope conditions.

> **Hypothesis 2a (H2a):** Status homophily as manifested in similar attributes has a positive effect on tie formation but not tie persistence.

Value homophily. Lazarsfeld and Merton (1954: 25) noted how ''the dynamic role of similarities and differences of these values in forming, maintaining, or disrupting friendships . . . requires notice in its own right.'' But measuring value homophily has been inherently difficult (Ingram and Morris, 2007). A great deal of research has measured it via attitudinal similarities, but others have highlighted similarities in knowledge and shared experiences (McPherson, Smith-Lovin, and Cook, 2001). We consider how tie formation and tie persistence correspond with individuals reading the same research. When two individuals read similar work and engage in similar research topics, the challenges of communicating with and comprehending one another decrease, and this

likely increases the chances of tie formation and tie persistence. At very high levels, however, there may be a cost to too much knowledge overlap. The marginal benefit of shared knowledge decreases because there is a risk of redundant ideas and few opportunities for complementarities between individuals. At the extreme, one could even expect negative returns to value homophily—individuals who are too similar have no new information to exchange and explore, and they begin to encroach on each other's turf. In the world of academia, scholars often seek a niche for their own work by differentiating it from their colleagues'. To collaborate with someone who is too similar may be undesirable.

We thus expect that shared knowledge will have an inverted U-shaped relationship with tie formation and tie persistence. The benefits are likely to have a greater effect at low levels because shared knowledge establishes a degree of common ground and mutual interest while preserving room to explore unique new experiences and perspectives. When two individuals read the exact same texts and are substitutable, they have nothing new to exchange and are likely to assume a competitive relationship. Given these arguments, a balance between similarity and difference of work should be most conducive to producing new and persistent ties.

Hypothesis 2b (H2b): Value homophily, as manifested in intellectual similarity, has an inverted U-shaped relationship with tie formation and persistence.

Cumulative Advantage

Research on the Matthew effect maintains that popular individuals attract more overtures from others for ties (Merton, 1973; Bothner, Podolny, and Smith, 2011) and thereby have greater returns to research productivity (Azoulay, Graff Zivin, and Wang., 2010; Oettl, 2012; Waldinger, 2012). In the context of academia, there are two especially salient sources of cumulative advantage: the number of ties an individual maintains and the amount of financial resources available to that person. Grant funding is an important source of power in universities (Pfeffer and Moore, 1980).

The halo effect of cumulative advantage through approaching sought-after individuals is especially attractive for tie formation, but it may be less pronounced for tie persistence. By virtue of collaborating with many other individuals, a popular individual has greater social capital to draw on, but his or her time is also more in demand and scarcer. There is a tension between the access to fungible resources from working with people of great social standing and the danger of not getting sufficient attention from them (Burt, 1992). This creates a situation in which individuals with some ties are likely to be attractive collaborators, while those with too many ties are less attractive.

This speaks to the general assertion that there is a finite number of ties an individual can credibly maintain (Jackson, 2008). Each tie requires attention, and individuals have limited attention to distribute (March and Simon, 1958). Simon (1971: 41) noted that ''a wealth of information creates a poverty of attention and a need to allocate that attention efficiently among the overabundance of information sources that might consume it.'' This points to an upper limit of ties an individual can credibly maintain, because each tie requires communication and effort (Ahuja, 2000). This is particularly evident for collaborations that involve substantial dialogue and regular meetings. To the extent that

one can only maintain a finite number of ties, individuals have to select among different credible options. The relative importance of any given tie decreases with the number of ties one must attend to. At some point, too many partners can decrease the advantage derived from any particular tie (see Koput, 1997, for a simulation model).

For forming ties, it is attractive to go after the most sought-after individuals, but persistent returns from such a relation may be untenable in the long run. Popular individuals seldom reciprocate all tie overtures equally, and they are likely to contribute less time to most collaborations. Therefore, popular individuals will be less able to sustain their ties, and their partners may see little value in doing so. People with a few ties are likely to sustain their ties longer because they see learning benefits in multiple collaborations and have time to commit to them. But people with too many ties may find that coordination costs increase with each additional tie. This leads us to hypothesize an inverted U-shaped relationship between the number of ties an individual maintains and the likelihood of tie persistence. The tendency for well-connected individuals to affiliate should be stronger for new tie formation than for persistence, as new ties are cheap to produce, have few obligations, and additional rewards have yet to be sought.

Hypothesis 3 (H3): Individuals who are more connected and have more resources will facilitate tie formation and have an inverted U-shaped relation with tie persistence.

Triadic Closure

Sociologists have long described how the commitment to a relationship is contingent upon the broader network of ties in which it is embedded (Simmel, 1950). One of Coleman's (1988) observations was that dense, cohesive communities establish cooperative norms through an increased capacity for monitoring and sanctioning behaviors. From this, we infer that ties are more likely to form between individuals with shared friends but will also persist when they exist in a closed triad or group. This argument is rooted in Simmel's (1950: 136) observation that ''the sociological structure of the dyad is characterized by . . . the intensification of [the] relation by a third element, or by a social framework that transcends both members of a dyad.'' A completely connected triad transforms dyadic ties by mitigating the pursuit of an individual's self-interests, reducing the bargaining power of single individuals, and facilitating cooperation and conflict resolution (Krackhardt, 1999). This is supported in Krackhardt's (1998) study of a college dorm, in which he found that ties are more ''sticky'' if they have mutual friends. Reagans and McEvily (2003) proposed that social cohesion around a relationship affects the willingness and motivation of individuals to invest time, energy, and effort in sharing knowledge with others. Even in the extreme case, in which two individuals face obstacles to collaborate because of conflicts of interests, it can be difficult to disengage because the relationship is embedded in a larger group, such as a lab.

Hypothesis 4 (H4): Individuals who are connected by indirect ties are more likely to form and maintain ties.

Tie Inertia

Some view tie dissolution as the inverse of tie formation, and this approach suggests that two individuals would end their relationship when the tie could no longer stimulate the necessary interest to produce future outcomes, but this view of tie dissolution ignores the concept of attachments (Seabright, Levinthal, and Fichman, 1992). Attachment is a commitment that emerges from shared experiences and investments in a relationship. This may lead to people maintaining relationships that are no longer fruitful, despite their having more attractive alternatives. When a relationship is in place, the two partners have more information available about one another than about unaffiliated individuals, and they have accumulated a variety of shared experiences. The factors of tie persistence are logically independent of those from tie formation because they require a tie to already exist. In particular, inertia and attachment correspond with two qualities of ties: tie strength and tie multiplexity.

Characteristics of ties afford participants motives to sustain a relationship. Prior work has found that strong ties are proximate, entail frequent interaction and shared experiences, and correspond with a sense of attachment or feelings of closeness (Marsden and Campbell, 1984). A great deal of research has elaborated on the qualities of strong ties, making its further elaboration unnecessary here (Granovetter, 1973, 1983).

Another tie quality—multiplexity—suggests that greater dimensionality in a tie corresponds with greater value. Multiplexity refers to the number of different types of relationships two persons share (Burt, 1980; Wasserman and Faust, 1994). Although network scholars typically focus on a single activity (Brass et al., 2004), there has been recent interest in multiple networks and multiple ties, which can serve more than one purpose (Gould, 1991; Lomi and Pattison, 2006). For example, in some of these studies ties from marriage are often used for the purposes of business (Padgett and McLean, 2006). As such, a unidimensional tie can be expanded and layered further for other purposes, extending its value and persistence. Elsewhere, studies find that multiplex ties act much like strong ties and have greater influence on productivity (Marsden and Campbell, 1984; Rawlings and McFarland, 2011).

Multiplex ties are rare because they require greater investment to establish interactions in multiple domains (Burt, 1980), but they are particularly valuable for career outcomes (Ibarra, 1992). For example, Coleman (1988) argued that multiplexity increases the overall resources available because resources in one dimension of the relationship can be appropriated for use in another. Uzzi (1997) built on this argument and described how multiplexity not only increased the pool of resources but afforded flexibility and adaptation in the face of uncertainty. Multiplex ties therefore enable people to transpose one type of association to another and to overcome challenges that arise in any one type of association. In addition, the breadth of association brings experiential ''variety'' to the dyad, making it less stale and more interesting over the long term. Last, multiplex ties afford greater certainty about and understanding of interaction partners (Padgett and Ansell, 1993). When we observe one another's behaviors in multiple settings, we forge a deeper understanding of a person and the stylized habits shaping his or her behavior across contexts (Blau, 1964). Therefore, even though multiplex ties are less common, they are a relevant factor in tie persistence because they afford adaptability in the face of uncertainty, bring

the thrill of variety, and afford greater certainty. This claim is supported at the organizational level, where Palmer (1983) argued that overlapping ties will be disbanded at a slower pace.

Hypothesis 5 (H5): Characteristics of ties, such as multiplexity and tie strength, influence the probability that ties will persist. This effect is only available after the tie has formed.

Means-ends Rationalization

It is reasonable to assume that the products of a tie would have feedback effects on the tie's persistence, but this effect has been unexplored. Burt (2002: 343) acknowledged that "people in . . . relationships often discover that they do not enjoy one another, or cannot work well together, so they disengage in favor of more compatible contacts." Missing from his remark, however, is a reflection on the outcome of a collaboration and whether that is the reason for the tie's continuation. Independent of whether two individual scholars enjoyed collaborating, they would be more positively inclined to continue collaborating if their paper submissions successfully reached publication and were widely cited.

The range of products that can arise from a social tie is quite broad—from babies and ideas to meanings and problems—and each product has socially recognized qualities and value. Most judgments of tie outcomes are only available in hindsight. Hence, individuals should repeat ties whose products have resulted in success. They should drop ties when the product was a failure (Levitt and March, 1988). For the collaborations of interest here, the tie products are articles, and they vary in how much recognition they receive. This reflects how the wider social reinforcement for the activity being performed affects the persistence of the tie. These factors feed back into decisions of tie persistence such that more recognized collaborations will associate a sense of reward with the shared activity. This links into March's (1999: 141) observation that "each node in a network learns from local experience, thereby adjusting the local linkages. . . . Local learning depends on local judgments about the 'success' or 'failure' of experience with particular local links."

Hypothesis 6 (H6): Successful tie outcomes will facilitate tie persistence. This effect is only available after the tie has formed.

Table 1 summarizes the factors involved in tie formation and persistence and the hypotheses we developed about their effects.

METHODS

Data

We tested our hypotheses using data from a variety of different archival resources covering fifteen years of data on Stanford University's faculty members, from 1993 to 2007. Collaborations in academia have become more popular over the last few decades for a variety of reasons (see, e.g., Wuchty, Jones, and Uzzi, 2007). In academia, individuals can self-select whom they work with, it is time consuming to develop the research, and there are significant rewards to producing influential publications. By extension, choosing to collaborate with

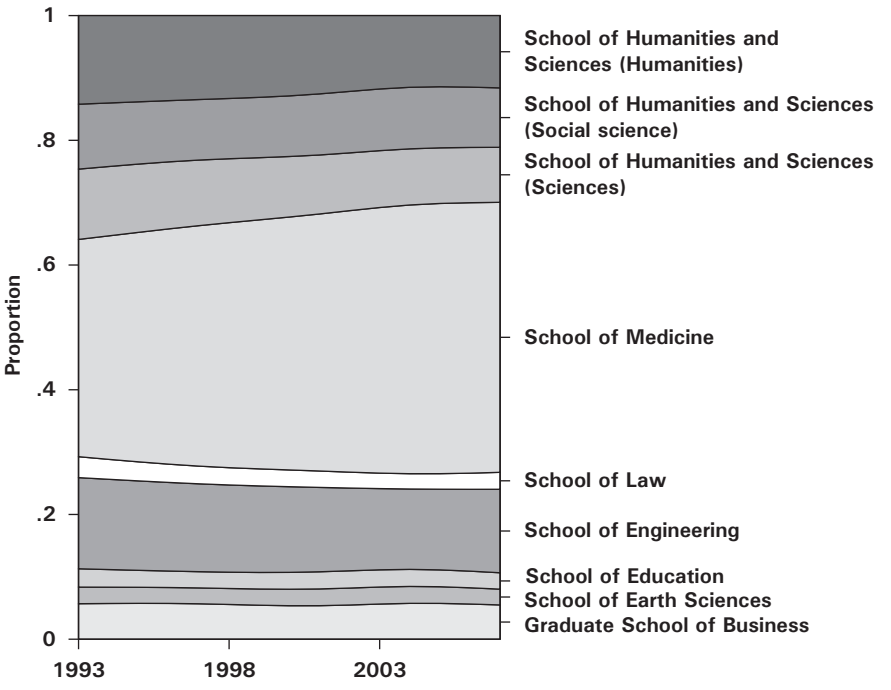
Table 1. Six General Factors for Tie Formation and Persistence

Factor	General claims	Tie formation	Tie persistence	Hypotheses
Organizational foci	Individuals who share organizational foci are more likely to be exposed to one another and thus more likely to collaborate.	Strong positive effect. The initial exposure causes individuals to form ties.	No effect. The exposure has already occurred, so shared foci means less once the tie is established.	H1: Organizational foci have positive effects on tie formation but not on tie persistence.
Status *and* value homophily	Individuals who share status *and* interest homophily have more in common and are more likely to collaborate.	Strong positive effect for status homophily. Shared social attributes cause individuals to affiliate.	No effect. Ties become less stereotypical once the tie is established.	H2a: Status homophily as manifested in similar attributes has a positive effect on tie formation but not tie persistence.
		Inverted U-shape relationship between interest homophily and tie formation. Shared interests and similar styles of work are more compatible.	Inverted U-shape relationship between interest homophily and tie persistence. A sense of comple-mentarity grows stronger once the tie is established.	H2b: Value homophily, as manifested in intellectual similarity, has an inverted U-shaped relationship with tie formation and persistence.
Cumulative advantage	Individuals who are influential in terms of past ties and resources are attractive collaborators and more likely to collaborate.	Strong positive effect. Cumulative advantage suggests that individuals with status will be attractive collaborators.	Strong curvilinear effect. The status effect of collaborating with a ''star'' diminishes once the tie is established.	H3: Individuals who are more connected and have more resources will facilitate tie formation and have an inverted U-shaped relation with tie persistence.
Triadic closure	Individuals with shared colleagues have more detailed information and are more likely to collaborate.	Strong positive effect. Individuals with shared friends are more likely to be aware of one another and close triads.	Strong positive effect. Individuals that have shared collaborators are more likely to stick to those relationships.	H4: Individuals who are connected by indirect ties are more likely to form and maintain ties.
Tie inertia	Individuals who are connected by ties that are expandable for different activities and stronger are more likely to continue collaborating.	*Not logically feasible. The tie needs to be in place.*	Strong positive effect. Experiences about the collaboration itself affect its future continuation.	H5: Characteristics of ties, such as multiplexity and tie strength, influence the probability that ties persist. This effect is only available after the tie has formed.
Means-ends rationalization	The outcome quality of collaborations influences the probability a collaboration will continue.	*Not logically feasible. The tie needs to be in place.*	Strong positive effect. Collaborations that are deemed successful by relevant observers affect the continuation of the collaboration.	H6: Successful tie outcomes will facilitate tie persistence. This effect is only available after the tie has formed.

another individual is a big commitment that can have serious implications for careers. Individuals learn from their experiences working together, and if they decide to collaborate repeatedly, they will likely produce a stream of successful publications. These in turn help individuals achieve indefinite tenure and advance their research area. For this reason, we study the first instance of collaboration and the factors leading to collaborations persisting over time.

The data we used for this paper were retrieved from several sources at Stanford's central office and include complete information about appointment dates, department, courtesy and joint appointments, tenure status, ethnicity, gender, and age. We also collected information from CVs and websites about what year and from which university faculty members received their highest degrees. This resulted in detailed longitudinal information for all 3,052 faculty members who were in the faculty for the whole or some part of the study period. These faculty are academic council members, meaning they have voting privileges in their departments. This includes teaching professors, research professors, and clinical line faculty at the Medical School, all of whom can vote in their departments. We disregarded lecturers, acting assistant professors, visiting professors, consulting professors, and outside members of dissertation committees. In this way, we bounded the network of faculty at those who are more permanent members of the faculty (not as temporary as yearly appointments) and who have a say in departmental decisions. This reduces the list of faculty to some extent but mostly removes peripheral individuals who occasionally show up and have little effect on all of the other network statistics. Wang et al. (2012) showed that such people have little effect on measurement error. Figure 1 shows the proportion of faculty included in our sample and how

Figure 1. Distribution of faculty in different schools over time between 1993 and 2007.



they are associated with each of the schools at Stanford. We divided the School of Humanities and Sciences into three different areas of humanities, social sciences, and natural sciences because they conduct distinctive forms of research (Kagan, 2009). Appendix A describes all of the schools and their associated departments.

We used departments to calculate the shared foci variable, but we report schools in figure 1 to show trends visually (there are more than sixty departments at Stanford). We separated the School of Humanities, Social Science, and Sciences as shown in the figure. As the graph shows, the School of Medicine is the largest school and has also grown over our study period. In our analyses, we accounted for departmental differences using fixed individual-level effects and also included time dummies to capture time trends in collaboration patterns.

We obtained records on several types of faculty work activities to construct different types of collaboration networks. First, we obtained records on all dissertations defended at the university. These records include information about each dissertation, including the year filed, name of the student, department affiliation, and the names of dissertation committee members. We used these data to construct affiliation networks showing how faculty members were connected through co-advising of doctoral students. Second, we collected yearly data from the university's sponsored project office that tracks all successful and unsuccessful grant applications submitted by the faculty. We used this information to investigate faculty members' collaboration in writing grants. Third, we obtained a license and downloaded the full content of all publications listed in Thomson's ISI Web of Knowledge database with Stanford in the address field. ISI is generally considered the most comprehensive database for scholarly work and includes thousands of scholarly journals and reports. One obvious problem noted by earlier researchers (Newman, 2008; Azoulay, Ding, and Stuart, 2009) is that some individuals use different spellings in their publication record, and there are several different individuals with the same name. Through a series of matching rounds, we matched each faculty member with his or her publications. We evaluated false positives and false negatives for each round of matching and reestimated our regressions using networks with different precision for matching faculty members and their publications (see Appendix B for details). We used these data to create networks of faculty members collaborating on publications over time.

The records for each type of work activity are initially represented as an affiliation network in which multiple individuals share events in the form of publications, grants, and dissertations. We multiplied the affiliation matrix $\boldsymbol{M}$ with its transpose $\boldsymbol{M'}$ to create a collaboration network of how many times each faculty member collaborated with another in a given year.

Dependent Variables

Tie formation. For our first analysis, we developed a yearly dataset of each tie created between two individuals through coauthoring publications or applying for a grant together. We focused on these types of collaborations because they reflect the faculty member's instrumental efforts at knowledge creation,

whereas other forms of collaboration (like student co-advising) may be driven by exogenous factors (e.g., the students select advisors). To avoid problems of left-censoring, we analyzed how newly hired, untenured faculty members with a Ph.D. they defended in the three years prior to their arrival at Stanford forged ties with other Stanford faculty when they arrived. When manually checking CVs, we found that these individuals had no or very little prior history of collaboration with Stanford faculty members. This variable was coded as a dummy taking the value of 1 if a tie between individuals *i* and *j* is formed in year *t*. Most academics know all too well that some paper projects fail to get published, just as some alliance efforts between organizations do not materialize. Because it is virtually impossible to get data on papers that were rejected from journals and never made it to print, we undertook a complementary analysis in which failed attempts are observable. The second dependent variable takes the same approach as above, but it distinguishes between successful grants that won a financial award and unsuccessful grant applications that never received funding. This allowed us to examine if there were any differences across types of ties and assess whether counting publication ties as manifested in publications is problematic and subject to a potential success bias.

Tie persistence. Our second analysis focused on the survival of the *first* tie initiated between *i* and *j* during the course of our study. We can directly observe when different ties come into being, but not when a tie ceases to exist. A tie between individuals *i* and *j* created in year *t* takes the value of 1 in $t+n$ (Singer and Willett, 1993). Given our analytical approach, a tie that is never repeated is treated as right-censored. This approach allowed us to estimate the likelihood of a tie being repeated between two academics, conditional on the tie being at risk. We coded this dummy variable to take the value of 1 if the tie between individuals *i* and *j* was repeated in year *t*. We did this for both publication and grant ties.

Independent Variables

Organizational foci. To assess hypothesis 1, we assessed how shared organizational foci differ for tie formation and persistence. An often-cited barrier to tie formation in academia is departmental boundaries that represent formal, jurisdictional boundaries within the modern university (Abbott, 2001). University departments constitute different units in which members have similar cultures and intellectual heritages. As Blau (1973) said, one consequence is that ties across departmental boundaries are rare and more difficult to form because there are different underlying logics of doing work and assessing its importance. Other scholars have a more optimistic view of the rate at which we will observe interdisciplinary ties. For instance, Friedkin's (1978) analysis of the physical sciences showed that university networks sometimes span departments through interdisciplinary collaborations. To control for these explanations, we controlled for two forms of propinquity in departments and centers.

We developed a dummy that measured whether individuals *i* and *j* are from the same or different departments in year *t*. A few departments merged or changed names during our study period, which we accounted for in our

analysis. We have divided the School of Humanities and Sciences into three sub-schools (Humanities, Sciences, and Social Science), as they deal with different types of research. Because there are no departments in three of the professional schools (Law, Education, and the Graduate School of Business), we treated those schools as departments.[1] Universities have also undergone major transformations to incorporate interdisciplinary centers that bring researchers together to solve pressing societal problems. We thus constructed a dummy variable that captured whether individuals *i* and *j* belonged to the same center at Stanford in year *t*.

Homophily. We tested the homophily factor by measuring both status homophily and value homophily (Lazarsfeld and Merton, 1954). We tested the status attribute homophily argument in H2a using several variables that are especially salient in the context of collaboration among academics (Burt, 2000; McPherson, Smith-Lovin, and Cook, 2001). The first three—gender, age, and ethnicity—are ascribed status characteristics, and the last two—education and tenure status—are achieved status characteristics.

Ascribed status. Individuals with the same gender are more likely to affiliate (Hallinan and Williams, 1989), and same-gender ties are more likely to persist (McPherson, Smith-Lovin, and Cook, 2001). We therefore used a dummy variable, *same gender,* that captures whether *i* and *j* are the same gender. Another homophily variable that causes ties to persist is *age difference*. Here we measured whether similarly aged individuals—by their absolute difference in age—are more likely to have persistent ties. Individuals who share the same ethnicity are also more likely to associate. We measured *ethnicity similarity* with dummies indicating whether *i* and *j* had the same ethnicity or different ethnicities. The following classes of ethnicity are in the data: (1) African American, (2) Asian, (3) Caucasian, (4) Hispanic, and (5) Native American. We tested the effect of ethnic homophily with a dummy variable that takes a value of 1 for the same ethnicity and 0 otherwise.[2]

Achieved status. We used two measures of achieved status: educational background similarity and tenure status similarity. Although the job market induces disciplinary boundaries (Abbott, 1988), scientists can apply for jobs in different departments. For instance, a trained sociologist could potentially apply for jobs in sociology departments, business schools, and schools of education. To measure educational background similarity for each faculty member, we collected information about the subject area of the individual's highest degree. For each of these degrees, we used the taxonomy of subjects developed by the U.S. Department of Education's National Center for Education Statistics (NCES). This classification was developed to facilitate assessment and reporting of educational programs. We coded a dummy variable as 1 if *i* and *j* had the

[1] In supplementary analysis not reported here we reran the analysis with schools as the relevant organizational foci. This did not affect the substantive results, although the effect of same school was slightly weaker than same department.

[2] To investigate whether there are differences across ethnicities, we also developed separate dummies for the different possible combinations of ethnicity. In the regressions reported, we report whether the two individuals have the same ethnicity, but alternative estimations with different combinations of ethnicity are available upon request. They do not change the results relevant to our hypotheses.

same two-digit degree code.[3] Our second measure of achieved status is *tenure status similarity.* Individuals who are at similar stages of their careers may be more likely to collaborate. For instance, untenured professors are pressured to publish in certain journals to be promoted. A related argument refers to the career logics of faculty members. Untenured scholars need to build a reputation within their discipline. Junior and senior colleagues have symbiotic relations in which the junior person brings the senior colleague new methodological skills and the senior person brings the junior colleague access to resources.

Value homophily. To test our hypothesis 2b that intellectually similar individuals form and sustain ties, we compared the citations used in their publications at *t*-1. Citations have commonly been regarded as good indicators of intellectual similarity (Zuckerman and Merton, 1972). The underlying logic is that shared citations demonstrate that scholars are building on similar kinds of prior work and define the audience they are trying to approach. A greater proportion of shared cites is therefore an indicator that two individuals work in the same intellectual space. To measure *reference similarity* for each individual *i* and *j* in year *t*, we measured the extent to which two individuals cite the same references. Consider faculty member *i*'s references as a set A. To compare with another faculty member *j*'s set B, we calculated the intersection of $A \cap B$ over the union $A \cup B$. This allowed us to capture the similarity of sets *i* and *j* while acknowledging the fact that faculty differ with respect to how much they have referred to prior work in the past or more formally, that the sets are of different sizes. We ignored publications that *i* and *j* had done jointly (as that would imply that *i* and *j* have a perfect overlap). We hypothesized that there are diminishing returns to similarity; there is a greater effect from an increase in similarity at lower levels than at higher levels. To test this, we included a squared term for reference similarity.

Cumulative advantage. We expected individuals to have a cumulative advantage as a result of collaboration centrality and amount of grant funding. We argued that individuals with high collaboration centrality are likely to attract further associations. We would expect this effect to taper off when people get overwhelmed by a too-large number of ties; even the most extroverted scholars will be unable to sustain huge numbers of collaborations. To measure *collaboration centrality*, we calculated the respective degree centrality in the network for individuals *i* and *j* in year *t*-1, using a decay time of three years for ties. We included a squared term to test for a possible curvilinear association with tie formation and tie persistence. To assess whether ties form between individuals who occupy similar positions in networks, we also calculated the absolute differences between *i* and *j*'s collaboration centrality in year *t*-1 (*collaboration centrality difference*). This allowed us to capture the possibility that highly central individuals may be suspicious of reaching out to peripheral ones, so that ties form between individuals with a

[3] All two-digit codes can be found at http://nces.ed.gov/pubs2002/cip2000/. We merged categories 51, Health Professions and Related Clinical Sciences, and 60, Residency Programs, into one category because they are closely interrelated for researchers at the Medical School and separating them would overestimate collaborations between researchers with different educational backgrounds.

similar social standing. Grant funding is an important source of power within universities (Pfeffer and Moore, 1980). We calculated the *amount of grant funding* that faculty *i* and *j* raised, respectively, in *t*-1. People with grants are often attractive collaborators as they can build groups around themselves. We calculated the absolute differences between funding for *i* and *j* to capture whether faculty form ties with people in a similar funding position (*grant resource difference*).

Triadic closure. We posited that shared third parties constrain individuals from breaking up (Simmel, 1950; Coleman, 1990: 318–319). To test H4, we measured this effect by coding a dummy variable taking the value of 1 when an indirect tie linked *i* and *j* in year *t (indirect ties)*. A common problem in studies of networks is the ''boundary problem,'' as one is forced to make an assumption of where the network ends. To assume that ties end at Stanford is obviously not realistic, and thus we searched extensively for information about external collaborators. This allowed us to analyze how triadic closure may occur through a shared collaborator inside *and* outside of Stanford.

Tie inertia. We proposed in H5 that ties, once in place, get a life of their own. This creates inertia, a tendency to stick to ties that are already formed, an effect that will carry depending on the strength of the ties and its multiplexity. We measured *tie strength* by counting the number of times *i* and *j* collaborated on a publication in year *t*. To measure *multiplexity*, we investigated three networks: mentoring in dissertation committees, resource acquisitions in grant teams, and knowledge creation in coauthored publications. We counted whether *i* and *j* had ties in the grant and dissertation network in year *t*. For instance, a tie between two individuals in the publication network gets a score of 1 if they had a tie in the dissertation or grant network and a score of 2 if they had a tie in both networks.

Means-ends rationalization. After the first tie has formed, there are social cues that individuals can use to decide whether to continue the relationship. We argued in H6 that the success of an intellectual collaboration affects its persistence. Hence, we formulated an experiential learning hypothesis that individuals repeat activities that are deemed successful. We measured the *outcome success* of a collaboration by counting the annual number of forward citations per team member.

Control variables. We accounted for individual differences by controlling for individual *i's* and *j*'s *tenure status, gender*, and *ethnicity*, all of which may influence the likelihood of collaborating. To account for individual unobserved heterogeneity, we built the models stepwise and included individual fixed effects. Also, the number of papers produced every year has increased over time because there are more scholars pursuing research, and the competition has increased productivity. We therefore included separate year dummies to account for this trend.

Table 2 summarizes the variables used in the study, their definitions, and the data sources used to construct them.

Table 2. Definition of Variables and Their Data Sources

Variable	Description	Data sources
Tie formation (publication)	Dummy = 1 if the first publication tie forms between individual *i* and *j* in year *t*.	ISI Web of Knowledge
Tie persistence (publication)	Dummy = 1 if the publication tie between *i* and *j* is repeated in year *t*.	ISI Web of Knowledge
Tie formation (grant application)	Dummy = 1 if the first grant application tie forms between individual i and j in year *t*.	University's sponsored project office
Tie persistence (grant application)	Dummy = 1 if the tie grant application between *i* and *j* is repeated in year *t*.	University's sponsored project office
Organizational foci		
Same department	Dummy = 1 if *i* and *j* are both in the same department.	Official university records
Same center	Dummy = 1 if *i* and *j* are both affiliated with the same center.	Official university records and manual coding
Status homophily		
Same educational background	Dummy = 1 if *i* and *j* received their highest degree in the same two-digit degree code.	Coded data on the subject area of the highest degree
Gender similarity	Dummy = 1 if *i* and *j* are the same gender.	Official university records
Age difference	Absolute difference in age between *i* and *j*.	Official university records
Same ethnicity	Dummy = 1 if *i* and *j* have the same ethnicity.	Official university records
Same tenure status	Dummy = 1 if *i* and *j* have the same tenure status in year *t*-1.	Official university records
Value homophily		
Reference similarity	The intersection of *i* and *j*'s previous references over the union in year *t*-1.	All references included in the ISI publications
Cumulative advantage		
Collaboration centrality difference	Absolute difference in degree centrality in and outside Stanford between *i* and *j* in year *t*-1.	Official university records and ISI Web of Knowledge
i/j's collaboration centrality	*i/j*'s degree centrality in year *t*-1.	
Amount of grant resources difference	Absolute difference in grant resources between *i* and *j* in year *t*-1.	University's sponsored project office
i/j's grant resources	*i/j*'s grant funding in year *t*-1.	University's sponsored project office
Triadic closure		
Indirect ties	Dummy = 1 if there is at least one indirect tie between *i* and *j* in year *t*-1 through having a shared collaborator at Stanford or at another university.	ISI Web of Knowledge
Tie inertia		
Tie strength	Number of published papers or applied grants that *i* and *j* did together in year *t*-1.	
Tie multiplexity	Number of different networks in which *i* and *j* have a tie (dissertation, grant, and publication network) in year *t*-1.	Official university records on dissertation committees and grant data from university's sponsored project office

(continued)

Table 2. (continued)

Variable	Description	Data sources
Means-ends rationalization		
Outcome success	Number of forward cites of the articles produced by *i* and *j* in year *t*.	ISI Web of Knowledge
Controls		
Individual characteristics		
i/j's gender	Dummy = 1 if *i/j* is male.	Official university records
i/j's tenure status	Dummies = 1 if *i/j* for each tenure status in year *t*-1.	Official university records
i/j's ethnicity	Dummies = 1 for each ethnicity of *i* and *j*.	Official university records
Exclusion restriction		
Appointment year difference	Absolute difference in appointment year at Stanford between *i* and *j*.	Official university records

Estimation Technique

To understand why some ties form and persist, we used a longitudinal dataset in which we could observe the formation of new ties and their repetition over time. We considered all ties created between individuals *i* and *j* in year *t*. To avoid problems of left-censoring, we investigated newly hired, untenured faculty members who arrived at Stanford fresh out of their Ph.D. programs. We thus constructed all possible ties these faculty members could form with other faculty members during our observation period. This resulted in a little more than 5 million possible ties, though only a small fraction of these possible ties actually formed.

We used a discrete-time survival analysis to estimate time to the first collaboration and, among those collaborations that did form, time to the second collaboration. In this approach, a possible dyad enters our analysis when both faculty members were present at the university. They are considered ''at risk'' to collaborate in subsequent time periods. We included dummies for each year following the initial exposure. For the tie persistence analysis, we used a similar approach, but here we included dummies for each year after the tie was formed. The time period in which a potential tie first exists in the data is set at 0, independent of the year it was formed. Here a tie enters the analysis conditional upon its being formed. To analyze tie formation and tie persistence, we used discrete-time survival models using logistic regression with indicator variables for each of the time periods. The discrete time hazard rate is the unobserved rate at which events occur in the data (Singer and Willett, 1991, 2003). Thus discrete-time hazard h_j is the conditional probability that a tie will be formed or repeated in time period *j*, given that the respective event has not occurred prior to *j*:

$$h_j = P[T = j | T \geq j]$$

where T is the discrete random variable that indicates the time period *j* when the event occurs.

The discrete-time model does not directly measure the duration to a termination event. The models are estimated by constructing datasets in which each tie has a separate observation for each year that it was deemed part of the risk set. Ties that were never repeated are considered right-censored. We dropped ties after either faculty member *i* or *j* left the university because after they left we lacked information about their ties. We used a logistic regression with separate time dummies to allow for disjunctures in the hazard rate. In our models, we suppressed the constant in order to be able to include all time dummies (Singer and Willett, 2003).[4] Burt (2000) used a similar approach in his analysis of tie decay among managers within a firm, but with fewer time periods at his disposal.

The analysis has two parts: one predicting tie formation, and another one predicting tie persistence. The tie formation analysis obviously includes more ties because it includes all potential ties that could form in any given year. The tie persistence analysis was conditional upon the tie being formed and included fewer ties.[5] In one of our models, we also accounted for the fact that the tie persistence analysis is conditioned upon a tie being formed: ties have to form to persist. We accounted for this by developing the inverse Mills ratio as a selection parameter (see Polidoro, Ahuja, and Mitchell, 2011). To estimate this, we used one exclusion restriction variable that affected tie formation, but not persistence: the absolute difference in year of arrival at Stanford. When people join organizations, networks are initially more open to collaborations, so people who arrive at the same time are more likely to collaborate. This, however, had no effect on the persistence of ties.

Our analysis used two different empirical strategies to overcome some inherent challenges to studying networks. We first used an approach developed by Cameron, Gelbach, and Miller (2011) that allows for clustering of standard errors based on more than one variable. So rather than using Huber-White standard errors clustered by each untenured faculty member *i*, this approach allowed us to cluster standard errors on *both* faculty members *i* and *j*. Kleinbaum, Stuart, and Tushman (2013) applied this approach when analyzing e-mail exchange between people within an organization. This approach calculates standard errors in three separate covariance matrices: one clustering on faculty member *i*, one on *j*, and one on the intersection. The reported standard errors are clustered on both *i* and *j* and estimated on a matrix formed through adding the first two covariance matrices and subtracting the third (Kleinbaum, Stuart, and Tushman, 2013). Although this is a significant methodological advancement, a potential concern about unobserved heterogeneity remains at the individual level, including disciplinary differences in where the individuals received their degrees and the possibility that some partners may be more attractive. We coped with these challenges by using fixed individual effects for all faculty members *i* and *j*, an estimation strategy that also accounts for nonindependence of the observations. The fixed-effects estimations drop observations when there is no underlying variation in the dependent variable (when *i* or *j* is not collaborating).

[4] Models without the constant but with all of the time dummies are equivalent to models with the constant dropping one dummy; they are merely different parameterizations of the same model.
[5] We estimated tie persistence in two ways. Ties that are repeated in $t+1$ were left out of the analyses in subsequent time periods and when all repetitions of collaborations were considered.

RESULTS

Tables 3 and 4 show the descriptive statistics for the main variables concerning tie formation and tie persistence, respectively. It is worth noting that there are only modest correlations between our variables. Table 5 shows the results for the tie formation analysis. We estimated tie formation with a discrete-time survival analysis of the time members of a given dyad had jointly worked at Stanford (time hazard dummies are suppressed in the table).

Models 1 through 3 report the results predicting a publication tie being formed between two faculty members. Model 1 is the baseline and model 2 includes all the independent variables, both using two-way clustered standard errors for faculty member *i* and *j*. Model 3 includes the same variables as model 2, but it estimates this with fixed individual effects to account for unobserved heterogeneity. Model 3 thus drops observations consisting of individuals never forming ties and variables that are time invariant (such as gender and ethnicity). Note that when we compare the coefficients in model 2 and model 3, the signs and magnitudes remain similar. To further analyze why ties form, and whether publication ties are subject to a success bias because we only observe published papers, we used the same factors to predict grant application ties between faculty members. These grant ties include both attempts that received funding and those that failed. We used the same strategy as explained above and report the results in models 1B–3B.

Table 6 shows results from the tie persistence analyses. Again we used discrete-time survival models in which the time hazard dummies (suppressed in the table) of years since first collaboration estimate tie persistence. Because this analysis is conditional upon a tie being formed, we first developed the inverse Mills ratio in which we have an exclusion restriction variable. The first three models used two-way clustered standard errors, and the last used individual fixed effects. In models 4 and 5, we mimicked the approach for tie formation. In model 6, we tested the idea that features of the tie itself affect its

Table 3. Descriptive Statistics for the Main Variables in Tie Formation Analysis of Publication Ties*

Variable	Mean	S.D	1	2	3	4	5	6	7	8	9	10	11	12
1. Tie formation	0.00													
2. Same department	0.02		.08											
3. Same center	0.00		.01	.01										
4. Same educational background	0.09		.03	.20	.01									
5. Same gender	0.62		.01	.01	−.01	.01								
6. Same ethnicity	0.66		.00	−.01	.02	−.01	.05							
7. Same tenure status	0.20		.00	.01	.03	.00	.03	.05						
8. Reference similarity	0.00	0.00	.11	.10	.02	.07	.00	−.01	.01					
9. *i*'s degree centrality	25.70	68.25	.02	.00	.02	.05	.04	−.05	.08	.05				
10. *j*'s degree centrality	34.80	76.92	.02	.01	.01	.01	.02	−.03	−.03	.04	.00			
11. *i*'s grant amount	1302519	2913314	.00	.02	.03	.07	.03	.08	.23	.02	.13	.02		
12. *j*'s grant amount	2884113	6100788	.00	.00	.02	.00	.02	.02	.01	.02	.01	.12	.01	
13. Indirect tie	0.01		.14	.11	.02	.11	.02	.00	.10	.17	.18	.15	.07	.02

* The descriptive statistics for grant application ties are not reported to conserve space.

Table 4. Descriptive Statistics for the Main Variables in the Tie Persistence Analysis of Publication Ties

Variable	Mean	S.D	1	2	3	4	5	6	7
1. Tie persistence	0.23								
2. Same department	0.34		.10						
3. Same center	0.03		−.01	−.02					
4. Same educational background	0.44		.02	.22	−.02				
5. Same gender	0.76		.01	−.02	.00	−.05			
6. Same ethnicity	0.66		−.06	.01	.06	.05	.07		
7. Same tenure status	0.38		−.09	.02	.06	−.02	.03	.08	
8. Reference similarity	0.02	0.03	.08	.18	.04	.05	−.06	−.01	.04
9. *i*'s degree centrality	117.28	140.20	.17	−.08	−.05	−.08	.04	−.16	−.04
10. *j*'s degree centrality	125.99	152.51	.15	−.11	−.03	−.17	.03	−.10	−.02
11. *i*'s grant amount	392334	4846659	−.09	−.06	.02	.01	.02	.14	.27
12. *j*'s grant amount	7029847	14602201	−.03	−.08	.10	−.05	.03	.07	.14
13. Indirect tie	0.89		.07	−.02	−.05	.00	.05	−.04	.01
14. Cites per year by author	10.06	41.12	−.05	−.08	−.02	−.04	.06	.03	−.02
15. Multiplex tie	0.47	0.66	.11	.22	.14	.06	.02	.09	.22
16. Tie strength	2.9	9.3	.29	.06	−.02	−.04	.00	−.09	.02

Variable	8	9	10	11	12	13	14	15	16
9. *i*'s degree centrality	.01								
10. *j*'s degree centrality	.05	.55							
11. *i*'s grant amount	.01	−.08	−.09						
12. *j*'s grant amount	.01	−.10	.17	.10					
13. Indirect tie	.04	.17	.15	.09	.04				
14. Cites per year by author	.01	.07	.13	−.03	.03	.05			
15. Multiplex tie	.17	−.15	−.09	.24	.15	−.03	−.06		
16. Tie strength	−.03	.34	.28	−.08	−.05	.07	−.02	−.03	

future continuation, namely, the strength of ties and their multiplexity and whether successful collaborations are more likely to persist. Finally, model 7 includes fixed effects for individuals *i* and *j*. We also repeated this analysis for grant application ties reported in models 4B–7B. In previous sections we theorized about the differences between tie formation and tie persistence, so we drew on the final models from tables 5 and 6 to interpret our findings.

Organization foci. We argued that people who are exposed to shared organizational foci are more likely form a tie and persist in a relationship. Two such foci are particularly salient in the context of universities: departments and research centers. We theorized in H1 that this effect would be salient for tie formation but not for tie persistence. Our results partly confirmed this hypothesis. The coefficients for both the same department and research center were significant for tie formation. But only same department had a positive effect (although smaller) on tie persistence. The results are consistent across both publication and grant application ties. This suggests that shared organizational foci expose individuals to one another but do not necessarily promote persistent ties. In many regards these results suggest that work collaborations follow the golden rule of ''out of sight, out of mind.'' They are also consistent with Reagans' (2011) finding that foci create significantly

stronger ties. The magnitude of the effect on tie persistence is weaker than it is for tie formation, however, suggesting that people are willing to walk farther to sustain an existing collaboration than they are to form a new one.

Status homophily. In line with our reasoning, we found that status homophily appears to be a stronger predictor for explaining why ties form initially than for explaining subsequent interactions. The coefficients for same Ph.D. training, same gender, and same ethnicity had positive effects on a publication tie being formed. The exception was same-tenure status, which was insignificant. These findings are largely consistent with McPherson, Smith-Lovin, and Cook's (2001) argument that similar social attributes breed association. For tie persistence, the coefficients for the status homophily variables were all insignificant. The only significant variable was same educational background, which has a negative sign, suggesting a pattern of heterophily rather than homophily. For grant application ties, same educational background was significant, but same gender and ethnicity had no effect. Lending support to hypothesis 2a, these results show that while status homophily predicts a tie's formation, it has no correlation with whether that tie persists.

Value homophily. We argued in hypothesis 2b that intellectual similarity between individuals has a curvilinear relationship to tie formation and persistence. In support of this argument, the main effect of reference similarity was positive and significant, and reference similarity squared was negative and significant. Although the negative squared term suggests that too much intellectual similarity can be detrimental to tie formation and persistence, there were relatively few observations in this part of the distribution. We are therefore cautious about the negative returns to similarity. Our results do support the hypothesis of *diminishing* returns to intellectual similarity on tie formation and persistence. The pattern is consistent across both publication and grant application ties.

Cumulative advantage. We assessed hypothesis 3, the cumulative advantage hypothesis, by looking at individuals' collaboration centrality (in the publication and grant network, respectively) and amount of grant resources. We argued that learning benefits could be outweighed by coordination costs created by having too many ties. Each additional collaboration has a potential downside: it increases coordination costs and the difficulty of credibly maintaining each relationship. In support of this argument, we found that the coefficients for collaboration centrality for individuals *i* and *j* were positive, and collaboration centrality squared was negative and significant. This suggests that the initial benefits of a collaboration experience can turn into a disadvantage. We also investigated the absolute difference in collaboration centrality for individuals *i* and *j* and found that new ties were more likely to form between individuals of similar positions. In other words, a well-connected individual is more likely to collaborate with other well-connected individuals than to reach out to someone who is more peripheral. The signs of the coefficients for tie persistence were similar to those for tie formation, but the magnitudes of the main effects were smaller. This implies that, for tie persistence, junior faculty

Table 5. Tie Formation Results for Different Estimation Methods*

Variable	Publication Tie			Grant Application Tie		
	Model 1: Two-way clustered standard errors	Model 2: Two-way clustered standard errors	Model 3: Fixed individual effects	Model 1B: Two-way clustered standard errors	Model 2B: Two-way clustered standard errors	Model 3B: Fixed individual effects
Hypothesis 1						
Same department		1.800•••	2.260•••		2.179•••	2.474•••
		(0.123)	(0.064)		(0.122)	(0.054)
Same center		1.334•••	0.904•••		1.072•••	0.649•••
		(0.285)	(0.184)		(0.317)	(0.156)
Hypothesis 2a						
Same educational background		0.735•••	0.611•••		0.691•••	0.829•••
		(0.114)	(0.059)		(0.087)	(0.046)
Same gender		0.308•••	0.168••		0.117•	−0.041
		(0.062)	(0.078)		(0.064)	(0.063)
Same ethnicity		0.466•••	0.119		0.511•••	0.109
		(0.065)	(0.074)		(0.074)	(0.070)
Same tenure status		−0.460•••	0.0820		−0.363•••	0.126•
		(0.119)	(0.088)		(0.110)	(0.071)
Hypothesis 2b						
Reference similarity		0.245•••	0.232•••		0.299•••	0.303•••
		(0.040)	(0.010)		(0.023)	(0.012)
Reference similarity squared		−0.004•••	−0.004•••		−0.006•••	−0.006•••
		(0.001)	(0.000)		(0.001)	(0.000)
Hypothesis 3						
i's collaboration centrality		1.060•••	0.672•••		1.431•••	1.356•••
		(0.109)	(0.078)		(0.196)	(0.039)
j's collaboration centrality		1.253•••	1.000•••		1.381•••	1.301•••
		(0.083)	(0.084)		(0.103)	(0.037)
Collaboration centrality difference		−0.627•••	−0.582•••		−0.820•••	−0.866•••
		(0.067)	(0.026)		(0.115)	(0.022)
i's grant resources		−0.011	0.041		0.130•••	0.096•••
		(0.069)	(0.043)		(0.045)	(0.031)
j's grant resources		0.455•••	0.437•••		0.477•••	−0.255••
		(0.132)	(0.143)		(0.175)	(0.104)
Grant resource difference		−0.443•••	−0.315•••		−0.429••	0.150
		(0.131)	(0.122)		(0.179)	(0.096)
i's collaboration centrality squared		−0.110•••	−0.053•••		−0.135•••	−0.097•••
		(0.017)	(0.012)		(0.049)	(0.006)
j's collaboration centrality squared		−0.127•••	−0.075•••		−0.093•••	−0.065•••
		(0.016)	(0.014)		(0.030)	(0.005)
Hypothesis 4						
Indirect tie		1.577•••	1.032•••		1.220•••	1.247•••
		(0.175)	(0.072)		(0.125)	(0.077)
Control variables						
i is untenured	−1.633•••	−1.357•••	−0.124	−1.671•••	−1.380•••	−0.102
	(0.139)	(0.161)	(0.104)	(0.130)	(0.146)	(0.094)
i is clinical faculty	−0.754••	−0.566•	0.0995	0.016	−0.301	0.277
	(0.345)	(0.336)	(0.242)	(0.282)	(0.190)	(0.200)
i is male	0.189	−0.126		0.177	−0.106	
	(0.159)	(0.149)		(0.155)	(0.124)	
j is untenured	−0.635•••	−0.243•	−0.232	−0.453•••	−0.091	−0.629•••
	(0.131)	(0.125)	(0.170)	(0.119)	(0.110)	(0.134)

(continued)

Table 5. (continued)

Variable	Publication Tie			Grant Application Tie		
	Model 1: Two-way clustered standard errors	Model 2: Two-way clustered standard errors	Model 3: Fixed individual effects	Model 1B: Two-way clustered standard errors	Model 2B: Two-way clustered standard errors	Model 3B: Fixed individual effects
j is clinical faculty	−0.0735	−0.165	−0.148	−0.559•••	−0.352•••	−1.138•••
	(0.127)	(0.124)	(0.282)	(0.128)	(0.112)	(0.203)
j is male	−0.327•••	−0.470•••		−0.321•••	−0.429•••	
	(0.089)	(0.085)		(0.087)	(0.091)	
i's ethnic dummies	Yes	Yes		Yes	Yes	
j's ethnic dummies	Yes	Yes		Yes	Yes	
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	5883315	5883315	1455515	5864637	5864637	1306475

•$p < 10$; ••$p < .05$; •••$p < .01$; two-tailed tests.
* Standard errors are in parentheses. Time-hazard dummies are suppressed.

members are on the lookout for well-connected individuals, but this is more important for tie formation than for tie persistence.

Grants are important sources of power within universities (Salancik and Pfeffer, 1974). We proposed that individuals with grant resources would be attractive collaborators. In support of this reasoning, we found that individuals with grants were more likely to form ties. The same effect did not apply for persistence, however, suggesting that grant resources attract people to collaborate, but not necessarily to build persistent ties. The exception is junior faculty members' collaborators in the publication network. Our results were consistent for both publication and grant application ties.

Triadic closure. We hypothesized in H4 that indirect ties positively affect both the formation and persistence of ties (Simmel, 1950; Coleman, 1990: 318–319). These indirect ties include collaborators who are at Stanford *and* other campuses. Our results suggest that triads have a tendency to close, and that indirect ties are an important means to discover potential partners, but the presence of an indirect tie between individuals *i* and *j* had no effect on the persistence of ties. The results were similar for both publication and grant application ties.

Tie inertia. We next theorized in H5 that once a tie forms, it gets a life of its own (Stinchcombe, 1965). When two persons are in a relationship, they have more information with which to evaluate that relationship and weigh its future. With regard to tie inertia, we proposed that, because multiplex ties span several different activities, they are more likely to be repeated. Our results supported this hypothesis: the coefficient for multiplex ties was positive and significant (net of strength). As a tie changes from being uniplex to being multiplex, the probability that it repeats increases. Our results also confirmed our assertion that strong ties are more likely to be renewed. We separated tie strength with dummies (baseline is one publication or grant), to see if there is an optimal number. For publication and grant collaborations, stronger ties

Table 6. Tie Persistence Results for Different Estimation Methods*

Variable	Publication Tie with Repeated Events				Grant Application Tie with Repeated Events			
	Model 4: Two-way clustered standard errors	Model 5: Two-way clustered standard errors	Model 6: Two-way clustered standard errors	Model 7: Fixed individual effects	Model 4B: Two-way clustered standard errors	Model 5B: Two-way clustered standard errors	Model 6B: Two-way clustered standard errors	Model 7B: Fixed individual effects
Hypothesis 1								
Same department		0.417•••	0.333••	0.545••		0.868•••	0.811•••	0.835•••
		(0.115)	(0.130)	(0.215)		(0.131)	(0.134)	(0.134)
Same center		0.293	0.159	−0.184		0.078	0.076	−0.013
		(0.224)	(0.243)	(0.370)		(0.264)	(0.274)	(0.211)
Hypothesis 2a								
Same educational background		−0.053	−0.101	−0.837•••		−0.009	−0.010	−0.127
		(0.128)	(0.122)	(0.206)		(0.128)	(0.123)	(0.103)
Same gender		0.224	0.219	0.405		0.123	0.119	−0.162
		(0.158)	(0.166)	(0.287)		(0.120)	(0.128)	(0.141)
Same ethnicity		−0.140	−0.082	−0.017		0.120	0.078	−0.011
		(0.155)	(0.173)	(0.293)		(0.133)	(0.137)	(0.162)
Same tenure status		−0.173	−0.197	−0.099		−0.134	−0.149	−0.169
		(0.138)	(0.144)	(0.185)		(0.123)	(0.124)	(0.108)
Hypothesis 2b								
Reference similarity		0.065•••	0.056•••	0.039••		0.080•••	0.077•••	0.087•••
		(0.021)	(0.020)	(0.019)		(0.018)	(0.018)	(0.012)
Reference similarity squared		−0.002•••	−0.001••	−0.002•••		−0.001••	−0.001••	−0.001•••
		(0.000)	(0.000)	(0.000)		(0.000)	(0.000)	(0.000)
Hypothesis 3								
i's collaboration centrality		0.479•••	0.500•••	0.783•••		0.966•••	0.973•••	1.386•••
		(0.104)	(0.097)	(0.205)		(0.114)	(0.113)	(0.047)
j's collaboration centrality		0.441•••	0.444•••	0.552•••		0.907•••	0.912•••	1.408•••
		(0.103)	(0.109)	(0.182)		(0.080)	(0.080)	(0.052)
Collaboration centrality difference		−0.311•••	−0.282•••	−0.225•••		−0.894•••	−0.896•••	−0.895•••
		(0.067)	(0.077)	(0.067)		(0.147)	(0.147)	(0.037)
i's grant resources		−0.073	−0.112•••	−0.056		−0.083	−0.091	0.016
		(0.044)	(0.044)	(0.087)		(0.059)	(0.057)	(0.040)
j's grant resources		0.351•	0.157	0.544••		−0.114	−0.123	−0.111
		(0.188)	(0.161)	(0.278)		(0.158)	(0.156)	(0.139)
Grant resource difference		−0.383•	−0.182	−0.115		0.040	0.042	0.191
		(0.203)	(0.169)	(0.240)		(0.161)	(0.158)	(0.121)
i's collaboration centrality squared		−0.050•••	−0.065•••	−0.088•••		−0.059•••	−0.059•••	−0.079•••
		(0.017)	(0.019)	(0.033)		(0.018)	(0.018)	(0.006)
j's collaboration centrality squared		−0.056•••	−0.060•••	−0.050		−0.027•	−0.028•	−0.061•••
		(0.021)	(0.023)	(0.031)		(0.015)	(0.015)	(0.007)
Hypothesis 4								
Indirect tie		0.284•	0.225	−0.308		−0.185	−0.204	0.085
		(0.158)	(0.158)	(0.309)		(0.123)	(0.152)	(0.102)
Hypothesis 5								
Tie multiplexity			0.502•••	0.923•••			0.505•••	0.820•••
			(0.166)	(0.200)			(0.184)	(0.144)
Tie strength = 2 shared events			0.872•••	1.123•••			0.787•••	1.056•••
			(0.139)	(0.202)			(0.134)	(0.129)
Tie strength = 3 shared events			0.959•••	0.018			1.339•••	1.915•••
			(0.291)	(0.395)			(0.420)	(0.339)
Tie strength = 4 or more			2.070•••	3.137•••			0.712	0.361
			(0.241)	(0.402)			(0.450)	(0.475)

(continued)

Table 6. (continued)

Variable	Publication Tie with Repeated Events				Grant Application Tie with Repeated Events			
	Model 4: Two-way clustered standard errors	Model 5: Two-way clustered standard errors	Model 6: Two-way clustered standard errors	Model 7: Fixed individual effects	Model 4B: Two-way clustered standard errors	Model 5B: Two-way clustered standard errors	Model 6B: Two-way clustered standard errors	Model 7B: Fixed individual effects
Hypothesis 6								
Cites per year			−0.147	−0.225			−0.025	0.014
			(0.106)	(0.144)			(0.023)	(0.030)
Control variables								
i is untenured	0.451•••	0.273•	0.218	−0.007	0.072	−0.159	−0.201	−0.029
	(0.127)	(0.146)	(0.146)	(0.212)	(0.142)	(0.175)	(0.179)	(0.138)
i is clinical faculty	0.264	0.482••	0.419••	1.183•••	0.282	−0.325	−0.326	−0.140
	(0.276)	(0.199)	(0.184)	(0.382)	(0.383)	(0.243)	(0.248)	(0.333)
i is male	0.110	−0.057	−0.122		−0.141	−0.321	−0.297	
	(0.235)	(0.255)	(0.180)		(0.142)	(0.207)	(0.214)	
j is untenured	0.408•	0.447••	0.415•	0.458	−0.141	0.028	0.022	−0.003
	(0.212)	(0.214)	(0.233)	(0.379)	(0.134)	(0.154)	(0.153)	(0.215)
j is clinical faculty	0.042	0.062	0.031	−0.278	−0.361•••	−0.124	−0.139	−0.752•
	(0.133)	(0.125)	(0.127)	(0.645)	(0.138)	(0.139)	(0.139)	(0.411)
j is male	0.091	−0.108	−0.190		−0.102	−0.371•••	−0.380•••	
	(0.160)	(0.156)	(0.173)		(0.091)	(0.138)	(0.144)	
i's ethnic dummies	Yes	Yes	Yes		Yes	Yes	Yes	
j's ethnic dummies	Yes	Yes	Yes		Yes	Yes	Yes	
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of observations	6430	6430	6430	4407	25158	25158	25158	20517

•$p < 10$; ••$p < .05$; •••$p < .01$; two-tailed tests.
* Standard errors are in parentheses. Time hazard dummies are suppressed. The results account for fact that tie persistence is conditioned upon a tie being formed by including the inverse Mills ratio.

appear to be more persistent. This finding is consistent with prior work on tie persistence (Levi Martin and Yeung, 2006), and the results are robust for both publication and grant application ties.

Outcome success. By distinguishing between tie formation and tie persistence, we were able to evaluate the success of the event that brought two individuals together. Hypothesis 6 proposed that successful publications would lead to repeated collaboration because participants learn from the successes and failures of their past collaboration (March, 1999), but we found no support for this relation, as all coefficients are non-significant (and we tried various polynomial forms). The effect of prior collaboration success is not a factor in tie persistence. This association is likely ambiguous because success can reinforce a tie and/or lead others to invite people into new collaborations. The latter likely reduces their chance of repeating any single collaboration, while the former increases it.

Robustness Checks

We conducted several robustness checks to strengthen our inferences. First, we varied the precision of our name-matching procedures for publications

(Newman, 2001) and assessed the results, without finding any significant differences (see Appendix B). Second, we estimated our models with complementary log-logistic regressions, without any substantial change in the results. Third, we tackled a methodological issue that arises when converting affiliation networks to one-mode data. Specifically, when large teams of individuals collaborate together, the conversion to one-mode network data suggests there is a fully connected clique even though it is likely that all of these people did not work together very closely. For instance, norms in physics are such that teams sometimes involve dozens of researchers. It is unclear how much the *n*'th individual contributes. Our approach was to reconstruct networks by ignoring those events with more than 15 faculty members. Some work compares team assembly mechanisms with randomly assembled teams that could have formed but did not (see, e.g., Ruef, Aldrich, and Carter, 2003; Ingram and Torfason, 2010), and as another robustness check, we therefore separated the analysis into collaborations formed between two faculty members versus collaborations formed among three or more. Had we missed something fundamental when converting the two-mode data to one-mode data, we would expect differences between the analysis of dyads and larger teams. Instead, all of our robustness checks rendered remarkably consistent results, which strengthened our inferences. All of our alternative estimations are available upon request from the first author. Some of these precautions also have implications for future research, which we elaborate on in the discussion.

DISCUSSION

We began this paper with a simple observation. A large body of research attributes positive outcomes to collaborations (Brass et al., 2004). In response, research has begun to explore where new ties come from, but it has paid significantly less attention to how those ties persist. Although some research has examined tie formation and persistence between organizations (Gulati and Gargiulo, 1999; Broschak, 2004; Powell et al., 2005) and even nations (Ingram and Torfason, 2010), there has been considerably less research on how intraorganizational collaborations form and persist. To address this gap, we focused on intraorganizational collaborations occurring within universities as faculty publish articles and apply for grants. We developed a range of different explanations for the formation and persistence of these task relationships, and we were able to empirically test and compare them using a unique dataset on faculty collaborations. While it has been suggested that similar factors shape tie formation and persistence (McPherson, Smith-Lovin, and Cook, 2001), our contribution has been to identify multiple reasons why this is not necessarily the case. Some cues relevant to persistence are not available for tie formation. Tie formation and tie persistence are only partly characterized by the same features and with different magnitudes and patterns of association.

Tie formation is the result of multiple factors: shared organizational foci, status homophily (same ascribed and achieved traits), value homophily (intellectual similarity), and characteristics of cumulative advantage (centrality and resource richness). Tie persistence results from some of the same factors, such as shared organizational foci and value homophily, but they have less relevance. Moreover, tie persistence does not correspond with status homophily or cumulative advantage. People do not look to individual traits and grant resources when

deciding whether collaborations are worth repeating or not. Instead, they focus on their experiences in the dyad. If the dyad entails sunk costs and layered social obligations (strength of tie, multiplexity), they are more likely to sustain it. This pattern of results helps explain the difference between processes of tie formation and tie persistence. Collaborations form in a context in which people approach a broad assortment of unfamiliar potential partners and select those who are proximate, have identical traits and similar knowledge, and who exhibit a degree of social success and evidence of interpersonal trust. That is, tie formation is mostly a function of opportunity and preference. By contrast, collaborations persist in a context of familiar partners, and they are sustained when the individuals are somewhat proximate (not too far apart), have similar knowledge (but not identical), and a shared sense of dyadic history. That is, tie persistence is more a function of obligation and complementary experience than opportunity and preference selection. With formation, the results identified a context that is more uncertain because there is less firsthand information. With persistence, the results identified a context that is more certain and in which people make substantive reflections on experience from the tie itself (strength and multiplexity). People tend to stick to the ties they have formed, for better or worse, especially stronger ties that are multiplex and span multiple types of association.

These findings are important when we consider the effects or returns that new and persistent ties have on salient outcomes in organizations. In supplemental analyses, we found that persistent ties had greater returns on the rate of productivity and quality of performance than did new ties. That said, it is self-evident that tie formation *and* tie persistence are important aspects of organizational life. A successful portfolio of ties likely includes a mix of new and persistent ties, but research has been slow to specify their differences, and in turn, the different ways to manage their occurrence. Our baseline expectation was that ties are likely to be repeated over time (Kollock, 1994). But as Larson (1992: 99) noted, ''the relative stability of . . . ties should not obscure their inherent vulnerabilities,'' and ''subsequent research should include analyses of how and why these organizational forms disappear.'' This article reveals that not only is tie persistence valuable, it is problematic and worth study on its own.

Our results are partly a function of the pool of potentially repeatable ties being different from the overall pool of potential ties (March and March, 1977). When forming collaborations, individuals winnow down the pool of potential ties, resulting in a narrow pool of collaborations that one decides whether to sustain or not. By implication this means that some individuals are locked out of fruitful collaborations, while others become less open to collaborations with attractive potential partners (Uzzi, 1996). For instance, we saw that two individuals will choose to collaborate based on propinquity and homophily. This means that the remaining pool of ties that have the potential to be repeated will be more proximate and homogenous to begin with. We also saw that people tend to select individuals who are central and well connected. This means that the pool of repeatable ties is not only more local and homogenous but is also geared toward established members. Both of these factors make it inherently difficult for newcomers to establish ties. Young faculty members will likely struggle to find partners because the most productive ones are already too busy with their current collaborations. Academics therefore face a trade-off between attaching themselves to those perceived as desirable partners and attaching themselves to those who are available (Gould, 2002).

A similar implication follows for interdisciplinary collaborations. Studies in the sociology of science have documented a sharp rise in research collaborations across the disciplines in recent decades (e.g., Wuchty, Jones, and Uzzi, 2007). Many have even propounded the benefits of highly collaborative team science (see Rawlings and McFarland, 2011, for a review). Despite the virtues of interdisciplinary collaborations, many of them fail to form, and those that do form often fall apart. Our results show that interdisciplinary collaborations are often distant ties involving different types of academics. To form and sustain these ties, pairs of colleagues must interact frequently to share knowledge. And even then, the collaboration will need to be layered with multiple work activities (grants, student training, co-teaching, and publishing) and experience some success if it is to continue. Should this be accomplished, sustained interdisciplinary collaborations may have their proclaimed returns (Stokols et al., 2008). This is perhaps why interdisciplinary centers may be useful organizational means of corralling faculty and promoting continued distant collaborations.

Our findings on tie formation and tie persistence also have implications for how managers can generate persistent ties in their firms. Mixers, speed dates, and special forums have been explored as methods to encourage previously unconnected actors to affiliate (Ingram and Morris, 2007). The study by Ingram and Morris showed the inherent difficulty of establishing new ties because individuals fall back on existing relationships. Given the returns of persistent ties, our study suggests that organizations should encourage tie persistence by adopting activities that look less like mixers and more like team-building exercises. Extended retreats at off-site locations, ropes courses, and the like are all designed to encourage communication and interdependence, get past initial surface problems, forge trust, and develop dyadic and team identities (Hackman and Katz, 2010). The literature on teams frequently draws on classic social psychology to describe how stable, cohesive teams can form: to become stable teams, groups need time and interaction to work out surface problems and come to agreed-upon goals; they need to perform activities that require interdependent roles, afford collective rewards, and form a shared identity; and the interactions need to encourage members to learn how to coordinate their individual abilities so as to maximize team performance (Forsyth, 1990: 104–105). Many of the work activities we list concern shared endeavors (e.g., co-writing or advising), and our analyses of persistent ties highlight the effects of repeated interaction (strong ties) and complementarity (multiplexity and value homophily). The social psychological literature on teams, however, is more focused on establishing affective bonds than instrumental, trusted collaborations that are mutually fulfilling. As such, retreats for collaborators may need to include activities in which participants learn about different sides of their colleagues and thereby generate a more varied sense of value in one another. It may require asking collaborators to perform an assortment of different types of collaborative activities (e.g., designing a program, a party, or a research project). One might also find ways to reward collaborations that often go unnoticed or unrewarded. In some sense, interdisciplinary centers do this by bringing visibility to collaborations that may span groups and do not get the recognition of disciplinary journals.

Limitations and Future Studies

We have presented a thorough effort to analyze the formation and persistence of faculty collaborations. While this focus limits our empirical claims to intraorganizational task relationships, we believe they extend readily to informal and unplanned work relations that emerge in the context of organizations. The network of informal work relations has long been found to correspond with personal ties like friendship, so we expect our findings will be consistent when extended to faculty friendship relations within the university and possibly friendships in firms more generally (Krackhardt, 1992). We leave it to future work, however, to reveal whether the same mechanisms of relational formation and persistence hold for these subtly different types of ties.

We have attempted to be thorough in our analyses and to consider multiple alternative explanations. But like all research, this paper entails certain empirical limitations. In some cases, these limitations point toward fruitful future lines of research. For example, our work examines collaborations at a single university from which we acquired rich, longitudinal data on multiple networks. Like prior work on this topic (see Burt, 2000, 2002), we were forced to draw boundaries around a network and sacrificed a degree of generalizability for a greater richness of detail. Regardless, we believe the factors elucidated are more broadly generalizable in the presence of the following scope conditions: (1) individuals can choose with whom to create a tie, (2) there are no norms that prevent individuals from having ties with more than one other individual, and (3) there are tangible or intangible benefits participants can draw from ties. These scope conditions are present for many types of ties in organizations but do not extend to all social ties. Marriage, for example, does not fulfill these conditions because most Western societies strongly support monogamous relationships.

By focusing on a single university we were unable to take into account the fact that the rate of tie formation and tie persistence differs across organizations and types of ties (e.g., research universities create more publications and coauthors at a faster rate than teaching universities), but this potential concern only moves the general cumulative survival function of ties up and down. In supplementary analyses, we conducted similar analyses of the formation and persistence of a different type of tie—dissertation collaborations—with remarkably similar results. Future work would do well to study our models of tie formation and persistence for multiple universities and firms when such data become available.

Our focus on the repetition of coauthoring papers may lead us to miss instances of failed ties, through which individuals repeatedly try to publish their papers and fail. But we also analyzed grant applications (failed and successful), and these show very consistent results with those on publication, lending support to the notion that published papers afford a visible trail of research collaborations we can follow. That said, future work could elaborate more on the asymmetries of collaboration, examining the conditions under which some scholars decline to collaborate with someone else.

Our analyses concern dyadic ties at the expense of collaboration in teams. Although most collaborations are pairwise, many entail three or more partners. Some research has moved in the direction of analyzing team assembly mechanisms (e.g., Ruef, Aldrich, and Carter, 2003; Ingram and Torfason, 2010), and there should be many opportunities to analyze this in the context of research

collaborations. Our robustness checks comparing dyads with larger teams suggest that these are similar, but using the team as the unit of analysis can produce additional theoretical leverage in future work. In future research, authors could focus specifically on teamwork and consider the different ways in which tie persistence operates in teams, given that the ''certainty'' generated from a collective may have different effects than the quality or products of dyadic ties.

A potential limitation of our network approach is that structural perspectives overlook the effects of individual personalities. Collecting psychological information on over three thousand people over fifteen years may be a desirable direction for future research, but we found it difficult to get decent response rates from faculty. Therefore we sought to account for personality effects using fixed individual effects. Psychologists who study personality consider traits as relatively stable over time. Costa and McCrae (1992), for example, showed that extroversion can be considered a trait that remains stable over time, with test-retest correlations of about .8. As such, our models that include fixed individual effects account for much, albeit not all, of these traits. While we controlled for unobserved individual heterogeneity, future research could theorize directly about individual differences. For instance, extroverted individuals are likely to form more ties, but are their collaborations also more persistent? In this stream of research, Mehra, Kilduff, and Brass (2001) gained important ground in understanding how high and low self-monitors can be integrated to understand structural advantages within organizations. There is room to develop these ideas even further, but to some extent, testing them will remain a difficult task because studies of tie formation and tie persistence require longitudinal data.

Although we measured tie strength and multiplexity, it is practically impossible to capture all factors affecting tie formation and persistence. It is thus important to consider the possibility of omitted variables. One area for future research is to theorize about relational histories and how conflict events and setbacks are dealt with in collaborations. This would likely require detailed ethnographic information about collaborations over time (see, e.g., Owen-Smith, 2001). More cultural perspectives would likely afford a more agent-centric and interactional view of tie formation and persistence than the structural one we provide (Emirbayer and Goodwin, 1994), though we do not believe they will be antithetical. In the aggregate, these moment-to-moment moves should align with structural conditions.

A limitation of our work is the difficulty of capturing the content of ties and interactional instances salient to their formation and persistence. For instance, it is plausible that rare violations of trust and confidence undermine a tie's persistence. In this study, we were unable to capture behaviors that color relationships or the interactions that guide the course of a tie's history. A fruitful venue for future empirical research is to examine how interactions within a dyad affect the formation and persistence of ties. This can also reveal the relative effect of interactions as compared with structural factors (Butts, 2008).

Some work has begun to integrate cultural and structural perspectives of networks (Ruef, 2002; Lizardo, 2006). Such studies unearth how the benefits associated with the structure and content of networks are contingent on the culture in which they are embedded (Xiao and Tsui, 2007; Morris, Podolny, and Sullivan, 2008). The most salient cultural dimension in our context is the discipline, which affects the questions people ask and how research is pursued and evaluated. While we accounted for disciplinary effects in our models using

fixed individual effects, future work could theorize more explicitly about these differences.

There are several promising areas for future research. Kilduff, Tsai, and Hanke (2006: 1039) proposed that ''the social network . . . exists as layers upon layer of relations, built up over time and space in the cognitions of members.'' Indeed, individuals who have left the network can still influence it by becoming examples for the remaining members of what can be achieved. Future studies would benefit from investigating what happens when individuals who were previously part of the same network are separated. What is the rate of decay of these ties compared with others? Shared organizational foci had a strong effect in our study, and there are reasons to believe that ties spanning universities are fragile. Such ties transcend institutional boundaries and require greater efforts of coordination and communications, placing them at higher risk of dissolution. In a world characterized by high mobility between universities, this appears to be an important facet for future work to consider.

Another area for future research may reside in the interaction between tie formation and tie persistence. We have shown that tie formation and tie persistence emanate from different factors, but our analysis downplayed the interaction between these two processes. For instance, in a context in which potential new collaborators are widely available, the obligation to maintain old ties may not be as strong. In contrast, when chances for new collaboration are low, old ties may become more salient. Tie formation and tie persistence are conceptually separated in our empirical analysis because an analysis of persistence requires that the tie has come into existence. A fruitful area for future research would be to theorize and analyze the mutual constraints between tie formation and tie persistence. This would be particularly fruitful in contexts with great variation in the availability of potential partners, as this would affect the interaction between tie formation and persistence.

We have focused on the persistence of ties, but persistent ties are not an organizational panacea. A strategy built on sustaining existing ties can deter people from forming new collaborations that are more beneficial. In fact, when it is difficult to locate attractive potential collaborators, people will stay in their current collaborations even when there are better available matches (Cohen, March, and Olsen, 1972). Hence, it is likely that most organizations will require a mixture of efforts aimed at exploring new ties and further exploiting the potential of current ones (March, 1991).

Finally, this paper concerns intraorganizational task relationships, such as work collaborations. In many instances, these collaborations reflect the informal organization of a firm (and invisible colleges for universities) and therefore resemble personal ties to a great extent. In fact, supplemental work in this paper showed that the more multiplex these collaborations, the more they are recognized as close contacts. Hence, many of the mechanisms identified here likely apply to personal relationships, but we leave it to future work to carefully disentangle how the mechanisms of informal work relations differ from those of personal relations and whether those mechanisms foster the persistence of the collaborative ties that become critical organizational resources.

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REFERENCES

Abbott, A.
1988 The System of Professions: An Essay on the Division of Expert Labor. Chicago: University of Chicago Press.

Abbott, A.
2001 Chaos of Disciplines. Chicago: University of Chicago Press.

Ahuja, G.
2000 ''Collaboration networks, structural holes and innovation: A longitudinal study.'' Administrative Science Quarterly, 45: 425–455.

Azoulay, P., W. Ding, and T. Stuart
2009 ''The effect of academic patenting on the rate, quality, and direction of (public) research output.'' Journal of Industrial Economics, 57: 637–676.

Azoulay, P., J. Graff Zivin, and J. Wang
2010 ''Superstar extinction.'' Quarterly Journal of Economics, 125: 549–589.

Baker, W. E., R. R. Faulkner, and G. A. Fisher
1998 ''Hazards of the market: The continuity and dissolution of interorganizational market relationships.'' American Sociological Review, 63: 147–177.

Baldassari, D., and M. Diani
2007 ''The integrative power of civic networks.'' American Journal of Sociology, 113: 735–780.

Basalla, G.
1988 The Evolution of Technology. Cambridge: Cambridge University Press.

Blau, P. M.
1964 Exchange and Power in Social Life. New York: Wiley.

Blau, P. M.
1973 The Organization of Academic Work. New York: Wiley.

Bothner, M., J. M. Podolny, and E. B. Smith
2011 ''Organizing contests for status: The Matthew vs. the Mark effect.'' Management Science, 57: 439–457.

Brass, D. J., J. Galaskiewicz, H. R. Greve, and W. Tsai
2004 ''Taking stock of networks and organizations: A multilevel perspective.'' Academy of Management Journal, 47: 795–817.

Broschak, J. P.
2004 ''Managers' mobility and market interface: The effect of managers' career mobility on the dissolution of market ties.'' Administrative Science Quarterly, 49: 608–640.

Burt, R. S.
1980 ''Models of network structure.'' Annual Review of Sociology, 6: 79–141.

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

Burt, R. S.
2000 ''Decay functions.'' Social Networks, 22: 1–28.

Burt, R. S.
2002 ''Bridge decay.'' Social Networks, 24: 333–363.
Butts, C. T.
2008 ''A relational event framework for social action.'' Sociological Methodology, 38: 155–200.
Cameron, A. C., J. B. Gelbach, and D. L. Miller
2011 ''Robust inference with multi-way clustering.'' Journal of Business and Economic Statistics, 29 (2): 238–249.
Cohen, M. D., J. G. March, and J. P. Olsen
1972 ''A garbage can model of organizational choice.'' Administrative Science Quarterly, 17 (1): 1–25.
Coleman, J. C.
1974 Power and the Structure of Society. New York: Norton.
Coleman, J. C.
1988 ''Social capital in the creation of human capital.'' American Journal of Sociology, 94: 95–120.
Coleman, J. C.
1990 Foundations of Social Theory. Cambridge, MA: Belknap Press of Harvard University Press.
Coser, L. A.
1974 Greedy Institutions: Patterns of Undivided Commitment. New York: Free Press.
Costa, P. T., and R. R. McCrae
1992 ''Normal personality assessment in clinical practice: The NEO personality inventory.'' Psychological Assessment, 4: 5–13.
De Solla Price, D.
1963 Little Science, Big Science. New York and London: Columbia University Press.
Emirbayer, M., and J. Goodwin
1994 ''Network analysis, culture, and the problem of agency.'' American Journal of Sociology, 99: 1411–1454.
Feld, S.
1981 ''The focused organization of social ties.'' American Journal of Sociology, 86: 1015–1035.
Festinger, L., S. Schacter, and K. Bach
1950 Social Pressure in Informal Groups. New York: Harper.
Fischer, C. S.
1982 To Dwell Among Friends. Chicago: University of Chicago Press.
Forsyth, D. R.
1990 Group Dynamics. Pacific Grove, CA: Brooks/Cole Publishing.
Friedkin, N. E.
1978 ''University social structure and social networks among scientists.'' American Journal of Sociology, 83: 1444–1465.
Gould, R. V.
1991 ''Multiple networks and mobilization in the Paris Commune, 1871.'' American Sociological Review, 56: 716–729.
Gould, R. V.
2002 ''The origins of status hierarchies: A formal theory and empirical test.'' American Journal of Sociology, 107: 1143–1178.
Granovetter, M.
1973 ''The strength of weak ties.'' American Journal of Sociology, 78: 1360–1380.
Granovetter, M.
1983 ''The strength of weak ties: A network theory revisited.'' Sociological Theory, 1: 201–233.
Gulati, R., and M. Gargiulo
1999 ''Where do interorganizational networks come from?'' American Journal of Sociology, 104: 1439–1493.

Hackman, J. R., and N. Katz
2010 ''Group behavior and performance.'' In S. T. Fiske, D. T. Gilbert, and G. Lindzey (eds.), Handbook of Social Psychology, 2: 1208–1251. Hoboken, NJ: Wiley.

Hallinan, M. T., and R. Williams
1989 ''Interracial friendship choice in secondary schools.'' American Sociological Review, 54: 67–78.

Ibarra, H.
1992 ''Homophily and differential returns: Sex differences in network structure and access in an advertising firm.'' Administrative Science Quarterly, 37: 422–447.

Ibarra, H.
1993 ''Network centrality, power, and innovation involvement: Determinants of technical and administrative roles.'' Academy of Management Journal, 36: 471–501.

Ingram, P., and M. W. Morris
2007 ''Do people mix at mixers? Structure, homophily, and the 'life of the party'.'' Administrative Science Quarterly, 52: 558–585.

Ingram, P., and M. T. Torfason
2010 ''Organizing the in-between: The population dynamics of network-weaving organizations in the global interstate network.'' Administrative Science Quarterly, 55: 577–605.

Jackson, M. O.
2008 Social and Economic Networks. Princeton, NJ: Princeton University Press.

Jacobs, J., and S. Frickel
2009 ''Interdisciplinarity: A critical assessment.'' Annual Review of Sociology, 35: 43–65.

Kagan, J.
2009 The Three Cultures: Natural Sciences, Social Sciences, and the Humanities in the 21st Century. New York: Cambridge University Press.

Katz, R.
1982 ''The effects of group longevity on project communication and performance.'' Administrative Science Quarterly, 27: 81–104.

Kilduff, M., W. Tsai, and R. Hanke
2006 ''A paradigm too far? A dynamic stability consideration of the social network research program.'' Academy of Management Review, 31: 1031–1046.

Kleinbaum, A. M., T. E. Stuart, and M. L. Tushman
2013 ''Discretion within the constraints of opportunity: Gender homophily and structure in a formal organization'' Organization Science (forthcoming).

Kollock, P.
1994 ''The emergence of exchange structures: An experimental study of uncertainty, commitment, and trust.'' American Journal of Sociology, 100: 313–345.

Koput, K. W.
1997 ''A chaotic model of innovative search: Some answers, many questions.'' Organization Science, 8: 528–542.

Krackhardt, D.
1992 ''The strength of strong ties: The importance of philos in organizations. '' In N. Nohria and R. Eccles (eds.), Networks and Organizations: Structure, Form, and Action: 216–239. Boston: Harvard Business School.

Krackhardt, D.
1998 ''Simmelian ties: Super strong and sticky.'' In R. M. Kramer and M. A. Neale (eds.), Power and Influence in Organizations: 21–38. Thousand Oaks, CA: Sage.

Krackhardt, D.
1999 ''The ties that torture: Simmelian tie analysis in organizations.'' In S. B. Andrews and D. Knoke (eds.), Research in the Sociology of Organizations, 16: 183–210. Greenwich, CT: JAI Press.

Lamont, M.
2009 How Professors Think: Inside the Curious World of Academic Judgment. Cambridge, MA: Harvard University Press.

Larson, A.
1992 ''Network dyads in entrepreneurial settings: A study of the governance of exchange relationships.'' Administrative Science Quarterly, 37: 76–104.
Lazarsfeld, P. F., and R. K. Merton
1954 ''Friendship as a social process: A substantive and methodological analysis.'' In M. Berger, T. Able, and C. Page (eds.), Freedom and Control in Modern Society: 18–66. New York: Octagon.
Levi Martin, J., and K-T. Yeung
2006 ''Persistence of close personal ties over a 12-year period.'' Social Networks, 28: 331–362.
Levitt, B., and J. G. March
1988 ''Organizational learning.'' Annual Review of Sociology, 14: 319–340.
Lizardo, O.
2006 ''How cultural tastes shape personal networks.'' American Sociological Review, 71: 778–807.
Lomi, A., and P. Pattison
2006 ''Manufacturing relations: An empirical study of the organization of production across multiple networks.'' Organization Science, 17: 313–332.
March, J. C., and J. G. March
1977 ''Almost random careers: The Wisconsin school superintendancy, 1942–1978.'' Administrative Science Quarterly, 22: 377–409.
March, J. G.
1991 ''Exploration and exploitation in organizational learning.'' Organization Science, 2: 71–87.
March, J. G.
1999 ''A learning perspective on the network dynamics of institutional integration.'' In M. Egeberg and P. Lægreid (eds.), Organizing Political Institutions: 129–155. Oslo: Scandinavian University Press.
March, J. G., and H. A. Simon
1958 Organizations. New York: Wiley & Sons.
Marsden, P. V., and K. E. Campbell
1984 ''Measuring tie strength.'' Social Forces, 63: 482–501.
McPherson, J. M., and L. Smith-Lovin
1987 ''Homophily in voluntary organizations: Status distance and the composition of face to face groups.'' American Sociological Review, 52: 370–379.
McPherson, M., L. Smith-Lovin, and J. Cook
2001 ''Birds of a feather: Homophily in social networks.'' Annual Review of Sociology, 27: 415–444.
Mehra, A., M. Kilduff, and D. J. Brass
2001 ''The social networks of high and low self-monitors: Implications for workplace performance.'' Administrative Science Quarterly, 46: 121–146.
Merton, R. K.
1973 The Sociology of Science: Theoretical and Empirical Investigations. Chicago: University of Chicago Press.
Merton, R. K.
1976 Sociological Ambivalence and Other Essays. New York: Free Press.
Morris, M. W., J. Podolny, and B. Sullivan
2008 ''Culture and coworker relations: Interpersonal patterns in American, Chinese, German and Spanish divisions of a global bank.'' Organization Science, 19: 517–532.
Newman, M. E. J.
2001 ''The structure of scientific collaboration networks.'' Proceedings of the National Academy of Sciences, 98: 404–409.
Newman, M. E. J.
2008 ''The physics of networks.'' Physics Today, November: 33–38.

Oettl, A.
2012 ''Reconceptualizing stars: Scientist helpfulness and peer performance.'' Management Science, 58: 1122–1140.
Owen-Smith, J.
2001 ''Managing laboratory work through skepticism: Processes of evaluation and control.'' American Sociological Review, 66: 427–452.
Padgett, J. F., and C. K. Ansell
1993 ''Robust action and the rise of the Medici, 1400–1434.'' American Journal of Sociology, 98: 1259–1319.
Padgett, J. F., and P. D. McLean
2006 ''Organizational invention and elite transformation: The birth of partnership systems in Renaissance Florence.'' American Journal of Sociology, 111: 1463–1568.
Palmer, D.
1983 ''Broken ties: Interlocking directorates and intercorporate coordination.'' Administrative Science Quarterly, 28: 40–55.
Peterson, M. W.
2007 ''The study of colleges and universities as organizations.'' In P. J. Gumport (ed.), Sociology of Higher Education: Contributions and Their Contexts: 147–186. Baltimore, MD: Johns Hopkins University Press.
Pfeffer, J., and W. L. Moore
1980 ''Power in university budgeting: A replication and extension.'' Administrative Science Quarterly, 25: 637–653.
Polidoro, F., G. Ahuja, and W. Mitchell
2011 ''When the social structure overshadows competitive incentives: The effects of network embeddedness on joint venture dissolution.'' Academy of Management Journal, 34: 203–223.
Powell, W. W., D. R. White, K. W. Koput, and J. Owen-Smith
2005 ''Network dynamics and field evolution: The growth of inter-organizational collaboration in the life sciences.'' American Journal of Sociology, 110: 1132–1205.
Rawlings, C. M., and D. A. McFarland
2011 ''Influence flows in the academy: Using affiliation networks to assess peer effects among researchers.'' Social Science Research, 40: 1001–1017.
Reagans, R.
2011 ''Close encounters: Analyzing how social similarity and propinquity contribute to strong network connections.'' Organization Science, 22: 835–849.
Reagans, R., and B. McEvily
2003 ''Network structure and knowledge transfer: The effects of cohesion and range.'' Administrative Science Quarterly, 48: 240–267.
Robins, G., P. Pattison, Y. Kalish, and D. Lusher
2007 ''An introduction to exponential random graph (p*) models for social networks.'' Social Networks, 29: 173–191.
Ruef, M.
2002 ''Strong ties, weak ties, and islands: Structural and cultural predictors of organizational innovation.'' Industrial and Corporate Change, 11: 427–449.
Ruef, M., H. E. Aldrich, and N. M. Carter
2003 ''The structure of founding teams: Homophily, strong ties, and isolation among U.S. entrepreneurs.'' American Sociological Review, 68: 195–222.
Salancik, G. R., and J. Pfeffer
1974 ''The bases and use of power in organizational decision making: The case of a university.'' Administrative Science Quarterly, 19: 453–473.
Seabright, M., D. Levinthal, and M. Fichman
1992 ''Role of individual attachments in the dissolution of inter-organizational relationships.'' Academy of Management Journal, 35: 122–160.

Simmel, G.
1950 The Sociology of Georg Simmel. Glencoe, IL: Free Press.
Simon, H. A.
1971 ''Designing organizations for an information-rich world.'' In M. Greenberger (ed.), Computers, Communication, and the Public Interest: 37–52. Baltimore, MD: Johns Hopkins University Press.
Singer, J. D., and J. B. Willett
1991 ''Modeling the days of our lives: Using survival analysis when designing and analyzing longitudinal studies of duration and timing of events.'' Psychological Bulletin, 110: 268–290.
Singer, J. D., and J. B. Willett
1993 ''It's about time: Using discrete-time survival analysis to study duration and the timing of events.'' Journal of Educational Statistics, 18: 155–195.
Singer, J. D., and J. B. Willett
2003 Applied Longitudinal Data Analysis: Modeling Change and Event Occurence. Oxford: Oxford University Press.
Snijders, T. A. B.
2001 ''The statistical evaluation of social network dynamics.'' Sociological Methodology, 31: 361–395.
Stinchcombe, A. L.
1965 ''Social structure and organization.'' In J. G. March (ed.), Handbook of Organizations: 142–193. Chicago: Rand McNally.
Stokols, D., K. L. Hall, B. K. Taylor, and R. P. Moser
2008 ''The science of team science: Overview of the field and introduction to the supplement.'' American Journal of Preventive Medicine, 35 (2S): S77–S89.
Uzzi, B.
1996 ''The sources and consequences of embeddedness for the economic performance of organizations: The network effect.'' American Sociological Review, 61: 674–698.
Uzzi, B.
1997 ''Social structure and competition in interfirm networks: The paradox of embeddedness.'' Administrative Science Quarterly, 42: 35–67.
Waldinger, F.
2012 ''Peer effects in science: Evidence from the dismissal of scientists in Nazi Germany.'' Review of Economic Studies, 79: 838–861.
Wang, D., X. Shi, D. A. McFarland, and J. Leskovec
2012 ''Measurement error in network data: A re-classification.'' Social Networks, 34: 396–409.
Wasserman, S., and K. Faust
1994 Social Network Analysis: Methods and Applications. Cambridge: Cambridge University Press.
Weingart, P.
2000 ''Interdisciplinarity: The paradoxical discourse.'' In P. Weingart and N. Stehr (eds.), Practicing Interdisciplinarity: 25–42. Toronto: University of Toronto Press.
Wuchty, S., B. F. Jones, and B. Uzzi
2007 ''The increasing dominance of teams in production of knowledge.'' Science, 316: 1036–1039.
Xiao, Z., and A. Tsui
2007 ''When brokers may not work: The cultural contingency of social capital in Chinese high-tech firms.'' Administrative Science Quarterly, 52: 1–31.
Zuckerman, H., and R. K. Merton
1972 ''Age, aging, and age structure in science.'' In M. White Riley, M. Johnson, and A. Foner (eds.), Aging and Society, vol. 3: A Theory of Age Stratification: 292–356. New York: Russell Sage Foundation.

APPENDIX A: Description of Schools and Their Associated Departments

School	Description	Departments
Earth Sciences	The Earth Sciences house departments that focus on studying the planet Earth. Scholars conduct research on the environment, oceans and climate, fresh water, and geology.	Applied Earth Sciences Geology and Environmental Sciences Geology Geophysics Petroleum Engineering
Education	The School of Education researches educational practice and policy. The school's faculty includes scholars from social science disciplines as well as schools of education.	No departments, but three academic programs: Psychological Studies in Education Social Sciences, Policy and Practice Curriculum Studies, and Teacher Education
Engineering	The Engineering School conducts research on different types of engineering. It also offers entrepreneurship research through the Stanford Technology Ventures Program.	Aero/Astro BioEngineering Chemical Engineering Civil Engineering Computer Science EES&OR Electrical Engineering Engineering Eco Systems Industrial Engineering Management Science & Engineering Materials Science Engineering Mechanical Engineering Operations Research
Graduate School of Business	The school's faculty includes scholars with advanced degrees from business schools and social science disciplines.	No departments, but seven academic areas: Accounting Economics Finance Marketing Operations, Information, and Technology Organizational Behavior Political Economy
School of Humanities and Sciences (Humanities)		Art Asian Languages Classics Comparative Literature Drama English French & Italian German History Music Philosophy Religious Studies Slavic Studies Spanish and Portuguese
School of Humanities and Sciences (Sciences)		Applied Physics Biological Sciences Chemistry Food Research Mathematics Physics Progress in Human Biology Statistics

(continued)

APPENDIX A: (continued)

School	Description	Departments
School of Humanities and Sciences (Social Science)		Anthropological Sciences Communication Cultural Anthropology Economics Linguistics Political Science Psychology Sociology
Law	The great majority of faculty has advanced degrees from law schools.	No departments
Medicine	The School of Medicine is the largest at Stanford. It houses almost 800 faculty and more than 1000 postdoctoral students as well as M.D.s. Medical students can also gain clinical experience at Stanford Hospital and Clinics and at Lucile Packard Children's Hospital.	Anesthesia Biochemistry Cardiothoracic Surgery Cell Biology Comparative Medicine Radiology Dermatology Developmental Biology Functional Restoration Genetics Gyn & Obstetrics Health Research and Policy Medicine Microbiology and Immunology Molecular & Cellular Physiology Neurobiology Neurology Neurosurgery Ophthalmology Orthopedic Surgery Otolaryngology & HNS Pathology Pediatrics Pharmacology Psychiatry Radiation Oncology Surgery Urology

APPENDIX B: Name Matching Procedure

Faculty members were linked to ISI publications through an ordered list of heuristic rules for name matching. We ourselves were involved in the matching, but we also used research assistants. Accurate name matching is difficult because listed names often entail only a last name and first initial, and common names like ''Smith, M'' can match different persons. While statistical or machine-learning models have been used for automated clustering, we opted for the transparency and reliability of hand-written rules and manual review of difficult cases. We used a dozen heuristic rules for matching including restricting the search to ISI publications when at least one author had a Stanford mailing address; dropping all authors whose last name did not exactly match a Stanford faculty member; exact matches on first authors' last name, first initial, second initial, and whose

institution was Stanford; matching on last name and first initial for uncommon names, and so forth. To assess the accuracy of name matching, we randomly sampled 20 cases within each decision heuristic and manually assessed whether each match was correct by downloading the article and checking faculty members' CVs. In particular, we counted the number of true positives, false positives, true negatives, and false negatives. True positives are instances in which we believed the author of an article fit a Stanford faculty member and the match was done correctly, whereas false positives are cases in which the attribution to a faculty member was incorrect. True negatives are cases in which we correctly dropped a case that did not match a Stanford faculty member, and false negatives are cases in which we incorrectly dropped a case. From these counts, we derived two metrics for name-matching accuracy in the author database as a whole: precision and recall. Our precision and recall measures are significantly better than other papers that use ISI data and articulate their methods. We also reran our analysis using different precision and recall measures, with very similar results.

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