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Professional networks, science ability, and gender determinants of three types of leadership in academic science and engineering

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ABSTRACT

This paper examines the factors associated with holding leadership positions among men and women academic scientists. We develop hypotheses for three determinants of leadership: professional networks, science ability, and gender. We test the resulting model on the likelihood of holding three different types of academic science leadership—research center leadership, university administrative leadership, and discipline leadership. Findings show that while science productivity and reputation are strongly associated with having either a center or discipline leadership position, they are less strongly associated with administrative leadership. Also, larger and more dense collaboration networks predict having a center leadership position, but the opposite is true for holding an administrative leadership position. Women are more likely to be in discipline leadership positions and less likely to be a leader of a research center or have an administrative university leadership position. Finally, having more women in the network reduces the likelihood of holding discipline or center leadership positions. Interpretations of findings and conclusions explore the potential implications for theory, practice and policy.

1. Introduction

Leadership is broadly recognized to be a key resource necessary to foster intended behavior among groups of people, raise organizational performance, and advance organizational objectives (DuBrin, 2012). Leadership positions are highly desirable in many professional contexts as they typically enhance recognition and visibility, and place the individual in a position of substantial authority from which he or she can allocate resources, influence decisions and alter directions (Burke, Sims, Lazzara, & Salas, 2007). Nonetheless, access to positions of leadership is often not accorded through an open, equitable, merit based process. Rather attainment of a leadership position occurs through a social process that values a confluence of different factors including ability and experience, preferential relationships and social structures, and attributes such as personality, gender or race (Bass & Bass, 2008; Judge, Bono, Ilies, & Gerhardt, 2002; Ridgeway, 2002; Van Vugt, 2006). Studies of leadership interested in predicting how and why people attain leadership positions must simultaneously examine multiple potential contributing factors. An integrated approach asks questions such as: What mixture of hard work and network structure favor attainment of a leadership position? What personal and professional attributes increase the probability that someone attains a leadership position? Do these attributes interact with social structure to increase the likelihood of attaining a leadership position?

Academic science is an important area of application for such research on leadership research. The practice of academic science has evolved from a profession dominated by single investigator working in a self-funded science lab to a highly collaborative, team based activity requiring tremendous resources, coordination, and interaction with various external

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organizations and multiple people (Hinds & McGrath, 2006; Jones, Wuchty, & Uzzi, 2008). The topic of science leadership concerns who controls the authority to allocate resources for development of human capital, research infrastructure, and intellectual endeavors designed to produce new knowledge. The science leader is also increasingly instrumental in harnessing the combined intellectual capacity of large groups and stimulating creative energy, and rationalizing research interests with social goals. In this paper, we adopt a concise definition of leadership that has been consistently accepted over time (especially in the context of higher education) and lends itself to direct measurement (Ahlquist & Levi, 2011; Bryman, 2007; Glatter, 2004; Pfeffer, 1977). Leadership is a formal position of authority that is officially conferred by an organization that includes the latitude to influence and direct a body of subordinates and make major decisions directly related to the organization's goals and mission.

This paper examines how three broad factors—professional relationships, scientific ability and gender—predict the likelihood that academic scientists hold a leadership position. Professional relationships comprise the structure and characteristics of the social networks that academic scientists have with the people in the scientific community. Scientific ability concerns the scientific productivity and academic reputation of the individual. The study of gender in science leadership provides a means of examining advancement of women into important positions within an important sector of the academic community. While professional relationships, scientific ability, and gender have been researched individually to understand their connections to science leadership, this research examines them in concert (Bozeman & Corley, 2004; Rosser, 2004; Xie & Shauman, 2003). Thus, our research question is as follows: how are professional relationships, scientific ability, and gender associated with holding leadership positions in academic science, technology, engineering and math (STEM) fields? Furthermore, we will apply our empirical analysis to three common types of academic leadership.

The paper first conceptualizes the three specific types of scientific leadership—STEM research center leadership, STEM administrative leadership, and STEM discipline leadership before building hypotheses predicting the associations between having a leadership position and the independent variables of interest: professional relationships, science productivity and recognition, and gender. Using data from a national survey of academic scientists in six fields of science and engineering, we empirically test the hypotheses using regression analysis. Findings show that science productivity and recognition, including grant production, publications, and awards received, are strongly positively associated with center and discipline leadership, while only grant production is associated with administrative leadership. Additionally, while many of the professional relationship variables are associated with leadership attainment, the effects of social network structure and network characteristics depend upon the type of leadership examined. For example, larger more dense networks of strong collaborative ties are positively related to STEM center leadership, while the opposite is true for STEM administrative leadership. Women are overall more likely to report holding a leadership position, although findings show that women are less likely to be a STEM center or administrative leader, but more likely to be a STEM discipline leader. Additionally, having more women in the collaboration network is negatively associated with holding any type of leadership position except administrative leadership.

The conclusion section of the paper discusses several implications of the findings. For the purposes of leadership research, conclusions point to the opportunity to more effectively integrate social network approaches to understanding how relationships matter for holding or attaining a leadership position. Conclusions also discuss implications for leadership development by identifying ways to facilitate preparation and positioning of future leaders. Finally, the paper also discusses the potential need for policies at both the national and university level to ensure adequate representation of females in science leadership positions. Table 1 summarizes the major findings and how they might be applied.

2. Academic science leadership

Academic science leaders are responsible for many different types of activities designed to facilitate and enable the production of knowledge. They attract and maintain a workforce of creative, motivated, and reputable faculty as well as manage the transfer and application of scientific knowledge within the university science setting to the external environment (Etzkowitz & Leydesdorff, 1997; Gieryn, 1983; Keller & Holland, 1975; Shapin, 2008; Siegel, Waldman, Atwater, & Link, 2004). They ensure that necessary equipment and resources are available and properly allocated. Academic science leaders are also responsible for creating and communicating organizational goals both internally (i.e. inside of the university) and to external stakeholders (Etzkowitz & Leydesdorff, 1997; O'leary, 1999; Sapienza, 2005; Shapin, 2008). Nevertheless, academia and academic science specifically are organized at many different levels including lab, center, department, university, and discipline. Accordingly, we conceptualize three different types of leadership positions for this study: STEM center leadership, STEM administrative leadership, and STEM discipline leadership. These leadership types are not exhaustive. There are other types of leadership prevalent in the academic context. For example, it is possible to consider intellectual leadership in STEM fields in which an intellectual leader is recognized by the ideas she produces not by a formal position. As the science research effort is increasingly distributed among researchers in different institutions, a research network or program leader is likely to exist. Additionally center, administrative and discipline leadership positions are not necessarily mutually exclusive or discrete end-points in a career. It is possible to hold more than one position at a time and holding one position may give an individual the experience and contacts necessary to seek another position at a future point in time. Leadership positions may also be held on a rotating basis such that an individual holding a leadership position at one point in time may go back to being a non-leader faculty member at another point in time. Nevertheless, the three types of leadership examined in this study are well recognized

Table 1
Summary table of study findings and possible applications.

For readers interested in…	Study findings indicate…	Possible implications of the study findings for practice and policy…
Multiple determinants of leadership	All three factors investigated—networks, ability, and individual characteristics—predict whether an individual is a leader or not.	Future research should further examine the interplay among the three factors in multiple contexts to advance leadership theory.
The role of networks on leadership	Different dimensions of the structure and characteristics of professional networks matter for different types of science leadership. Larger networks, structural holes, and strong ties are important for some types of leadership, while the reverse is true for other types. More women in the network is consistently negatively associated with being a leader.	Strategic approaches to enhancing networks may increase visibility and support necessary for obtaining a leadership position. Seniors and mentors can help junior scholars foster connections that enhance leadership opportunities. Effort should be made to reduce negative bias of having women in the network.
Gender disparities in leadership	Women are less likely to be in research leadership positions that directly control the research process and the production of knowledge. Women are less likely to hold department or college administrative positions. Women are more likely to be in highly visible discipline-level leadership positions.	University level policies could be developed to increase representation of women in research related leadership positions. Universities and funding agencies should establish institutions that foster a culture in academic science that leadership values that women favor.

formal positions that directly impact key functions in STEM fields, and as such, represent valid indicators of STEM-relevant academic leadership. A more in-depth discussion of these types follows.

2.1. STEM center leadership

STEM center leaders are individuals with formal positions (e.g. directors) at university labs and research centers or institutes. Among all three types of leadership studied, center leaders have the most direct impact on the production of scientific knowledge. In their extensive review of studies about leadership at research and development organizations, Elkins and Keller (2003) assert that leadership in the academic context is critical in that its outcomes directly influence idea generation process and the quality and value of final scientific outputs. Hollingsworth and Hollingsworth (2000) provide insight into the value of the visionary leadership in research labs, which they found to be integral in major discoveries and innovations. "Visionary leadership [is] the capacity for understanding direction in which scientific research is moving and integrating scientific diversity" (p. 220). While not all center lab directors are visionary, they are responsible for key activities and decisions including identifying areas of research (i.e. setting research agendas), securing proper resources and capital for research, facilitating research projects, serving as a buffer between scientists and non-scientists of the academic science environment, and managing the dissemination and communication of research outputs (Jain & Triandis, 1997; Kaplan, 1959; Keller & Holland, 1975; Shapin, 2008). STEM center research leaders must also effectively fulfill these responsibilities in ways that meet the demands of multiple stakeholders who consume and appropriate research outputs differently while simultaneously managing the scientists who actually do the work (Bland & Ruffin, 1992; Elkins & Keller, 2003; Sapienza, 2005).

2.2. STEM administrative leadership

STEM administrative leaders in universities include deans, department heads and chairs, provosts and other formal university administrative positions. They manage both the internal and external environments of universities in ways that facilitate the production of high quality science (Siegel et al., 2004; Siegel, 2003). STEM administrative leaders are charged with developing and managing organizational policies, culture, and institutions (Del Favero, 2006), and creating incentives and reducing barriers to encourage and facilitate research and teaching. Management activities include implementation of strategies that respond to government initiatives, development of policies that influence how universities practice and produce science (Morris, 2002).

STEM administrative leader actions impact the external reputation that institutions have as creative and resource rich environments that facilitate the production of knowledge. They communicate university goals both internally and externally, and develop programs to communicate what the university and its faculty accomplish. As universities have embraced entrepreneurship, administrative leaders have sought to bridge academia and industry (Siegel et al., 2004). And, within the increasingly complex fiscal climate, administrative science leaders must secure financial resources necessary to support the organization in conducting its work and at the same time compete with other universities for students and faculty. Administrative leaders are responsible for compliance with laws and regulations, creating standards for performance and evaluative activities that aim to continually improve the organization (Hagstrom, 1977; Hemphill, 1955; Hind, Dornbusch, & Scott, 1974; O'leary, 1999; Rindova, Williamson, Petkova, & Sever, 2005; Siegel et al., 2004). Essentially, administrative leaders are predominantly involved in managing the department, college, or university in ways that enable faculty to accomplish work that contributes to university goals (Etzkowitz, 1998).

2.3. STEM discipline leadership

STEM discipline leaders include individuals who have positions in professional science associations and regulatory organizations. They focus primarily on developing and enforcing standards and norms for the scientific community as a whole, which subsequently results in impacting the culture of science. Examples include elected or appointed duties in disciplinary organizations as well as roles in organizations such as the *American Association for the Advancement of Science*, the *National Academy of Science*, or the *American Medical Association*. Various responsibilities of discipline leaders include developing and administering overall professional practices such as peer review, helping to shape policies that impact science and technology development, enforcing codes of conduct, promoting insight into the benefits and limitations of science, facilitating and encouraging important policy changes in the scientific community and in government, improving the connection between professional scientists and the public, and encouraging assessments of the scientific field (Eagle, Garson, Beller, & Sennett, 2003; Fields, Greenwood, Suddaby, & Hinings, 2002; Frankel, 1989; Pellegrino & Relman, 1999; Swan & Newell, 1995). Overall, discipline science leaders promote the professionalization, communication, and institutionalization of science (Fields et al., 2002; Swan & Newell, 1995).

As can be implied from the discussion above, center, administrative, and discipline leaders have similar roles in resource appropriation and managing the visibility of their organizations for the purpose of advancing the production and application of scientific knowledge. However, each type of academic leadership may manifest those roles differently, have access to different types of resources, and have different needs for support. Table 2 provides a summary comparison of the three types of leadership.

3. Science leadership hypotheses: professional networks, science ability and gender

This section develops hypotheses for three general determinants of science leadership – professional networks, science capacity, and gender. We posit that these factors afford individuals with information, resources, reputational advantages, which enable the attainment of leadership positions. Other factors, such as personality traits and longitudinal patterns (i.e. career pathways overtime) are also important determinants, but we are not able to examine them due to data limitations. These should be explored in future studies.

3.1. Science leadership and professional networks

By addressing how professional networks, as well as other factors, determine whether an individual holds a leadership position, this research responds to recent literature calling for more integrated studies of leadership (Avolio, 2007). Social network research often invokes the theory of social capital, which is defined as “the aggregate of the actual or potential resources which are linked to possession of a durable network of more or less institutionalized relationships of mutual acquaintance or recognition” (Bourdieu, 1985, p. 248). Coleman (1988) asserts that social capital can be conceived of as the intangible resources, information, opportunities, and control that is gained through relationships with other people and is used as a means to achieve a particular end. Lin (2002) offers that social capital concerns the resources that can be attained through social connections such as personal and social resources.

In the field of leadership, social networks are recognized to enable the two-way flow or resources and information that are important for sustaining leader–follower relationships (Balkundi & Kilduff, 2005). Social networks form the basis of relational leadership approaches in which leaders are recognized to be embedded in a social structure that affects the leader's ability to act, control followers and attain outcomes (Treadway, Breland, Williams, Yang, & Williams, 2012). Many of these research efforts emanate from leadership-member exchange (LMX) theory, which posits that “effective leadership processes occur when leaders and followers are able to develop mature leadership relationships (partnerships) and thus gain access to the many benefits these relationships bring” (Graen & Uhl-Bien, 1995, p.225). Just as the leader can confer benefits, followers can also provide the information and support necessary to support the leader.

Given the two-way exchange, how might social networks explain why some people are leaders and others are not? In what ways do social networks provide access to leadership? Social capital that accrues from an individual's network structure provides advantages “that manifest in higher odds of proposing good ideas, more positive evaluations and recognition, higher compensation and faster promotions (Burt, Kilduff, & Tasselli, forthcoming, p. 3).” Professional networks that provide greater amounts of valuable information and resources may create opportunities for professional advancement and facilitate the productive activity (Brass & Krackhardt, 1999; Burke et al., 2007; Hansen, Podolny, & Pfeffer, 2001; Nahapiet & Ghoshal, 1998).

Social network structure helps to determine how information and resources are exchanged and is thus associated with advantages that enable individuals to attain and hold leadership positions (Balkundi & Kilduff, 2005; Burt, 1992; Burt & Celotto, 1992). An individual's position in the network is indicative of her power and influence (Brass & Krackhardt, 1999). Some positions enable greater control of information and resource flows, which translates into a source of influence and power for the boundary spanner (Aldrich & Herker, 1977; Russ, Galang, & Ferris, 1998; Spekman, 1979; Tushman & Scanlan, 1981a, 1981b). Thus, social

Table 2
Summary of academic science leadership types.

Types of academic science leadership			
	STEM center leader	STEM administrative leader	STEM discipline leader
Examples of leadership positions	Director of permanent science or engineering laboratory or center or research institute.	Dean or provost of science college/university, chair or head of science department	President or officer in professional science organization/association
Duties, activities, and scope of influence	• Encourages and inspires researchers, postdocs and students working in the center. • Directly oversees scientific research, manages allocation of funds on a science research project or set of projects, responsible for reporting and compliance for projects. • Sets research agendas, advises on and directs \research trajectories for the Center. Secures resources to conduct science and fund the people working in the lab.	• Represents the organization for official administration, policy and management activities. • Leads the development of academic goals (research, teaching and service) for the organization. Integrates goals at different levels of the organization. • Develops programs, policies and administrative systems to facilitate goal attainment. • Bridges university and external stakeholders (e.g. government labs, industrial R&D, community, etc.). • Promotes the reputation of the science department, college, or university.	• Directs and oversees the management of activities undertaken by the disciplinary association or organization (conferences, news events, etc.). • Represents the discipline at important events and meetings. • Seeks to influence government policy (national, state, granting agencies, etc.) to advance the discipline or profession. • Communicates perspectives, directions, values and goals of the discipline to the scientific community and to other stakeholders.

networks can enable the individual to generate, appropriate, and control information and resources, as well as attain positions of influence (Burt, 2000).

Visibility and reputational returns are also attained by individuals aligning themselves with other people that have valuable information and resources (Burt et al., forthcoming). Brass (1984, 1985) found that enhancing one's reputation by associating with powerful groups was a key factor in these individuals being placed in management positions. Cialdini et al. (1976) and Cialdini and Nicholas, (1989) were among the first to assess this as a common phenomenon and coined it as the ‘basking in the reflected glory of others’ phenomenon. Brass and Krackhardt (1999) further asserted that ‘basking’ individuals would be more likely to increase their own power reputation. This is because associating with powerful others can serve as a signal that an individual may be as resourceful, influential, and successful as those with whom she is associating. Consequently, the individual becomes more visible (Kilduff & Krackhardt, 1994) and higher visibility, whether attained through individual actions or alignment with powerful others, is more likely to help attain and hold formal leadership positions (Borins, 2002).

Four characteristics of networks are expected to be associated with being in a position of leadership: network size, network density, balance of external and internal ties, and strength of ties. The social network literature typically defines size as the number of alters in the ego's network (Wasserman & Faust, 1994). A larger number of alters in an ego's network indicate a larger potential set of individuals from which the ego can obtain resources. Larger networks provide greater number of channels through which more information and resources can flow (Cross & Sproull, 2004; Granovetter, 1973; Podoldy & Baron, 1997). Holding a leadership position requires substantial resources and support from a broad range of actors. Individuals who have higher numbers of alters in their network may be able to obtain the resources needed to hold a leadership position. In addition to providing more resources, a larger number of alters also increases the likelihood that an ego's reputation will be enhanced. This is because more people are knowledgeable about the ego's work and accomplishments and can communicate that knowledge to others.

The social network literature defines density as the connectedness among individuals in a network; it is measured as the number of connections among entities within the network relative to all possible connections (Burt, 1992; 2000). When networks are more dense, the higher connectivity among individuals results in greater redundancy of informational resources. This is because connected individuals are familiar with the same information, obtain information from the same sources, and communicate more with each other (Balkundi & Kilduff, 2005; Brass & Krackhardt, 1999). In networks that are less dense, individuals are more likely to be connected by weak ties across structural holes, which are defined as “a relationship of nonredundancy between contacts” (Burt, 1992, p.65). Weak ties can provide access to diverse sources of non-redundant information (Ahuja, 2000; Friedkin, 1982; Lin, 2002). Less dense networks may be advantageous for attaining a leadership position because an individual has access to a greater diversity of resources from which he or she can draw (Balkundi & Kilduff, 2005). Additionally, individuals that hold positions that bridge structural holes are better situated to broker the exchange of resources and information throughout the network (Burt, 1992). “More, the structural holes between his contacts mean that he can broker communication while displaying different beliefs and identities to each contact.” (Burt et al., forthcoming) Balkundi and Kilduff also note that the ego leader needs to have ties to other constituencies and access to secondary networks (2005). Hence, lower density may indicate that individuals have structural advantages that enable them to access and control the flow of dissimilar yet valuable resources.

Other findings indicate that women have fewer connections to power because they are less integrated into male dominated networks where men are in tightly held positions of authority and power (Brass, 1985). Balkundi and Kilduff note that leaders often interact with individuals in other organizations as a means of "affecting the flow of important information and resources, and, thereby, organizational survival." (2005, p. 436) Similarly, individuals that have more external ties may have access to more information and resources outside of the organization (in this case the university) that may provide advantages to their attainment of a leadership position. A higher number of connections with alters outside is likely to yield both resource advantages, and indicate greater visibility or reputation of the ego. Hence, all else equal, it is reasonable to posit that the ratio of external to internal ties will be associated with holding a leadership position. Seen the other way around, individuals holding a leadership position are likely to depend upon diverse sources of information and span organizational boundaries to carry out their work.

Network relationships lie on a continuum from strong to weak. Strong ties are often intimate or close, where communication is frequent and trust is high (Granovetter, 1973; Krackhardt & Stern, 1988; Uzzi, 1996). Individuals are more likely to mobilize resources from strong, high trust ties for attainment of a leadership position where sustained commitment and support is required (Lin, 2002). A common way that strength of ties is conceptualized in network research is emotional closeness (Granovetter, 1973; Lin, 2002). Greater emotional closeness—such as close friendship—is associated with higher levels of trust, which is critical for mobilizing social capital as indicated by willingness to share valuable information and resources (Krackhardt, 1992). Networks vary in terms of amount of strong ties. The more strong connections an individual has, the more likely he or she will be able to obtain necessary information and resources to attain and sustain a position of leadership.

Based on the above discussion it is possible to develop a set of hypotheses about how network size, density, external connections, and strength of ties may provide positional advantage to leaders:

H1. Science leaders will have larger collaboration networks than non-leaders.

H2. Science leaders will have less dense networks than non-leaders.

H3. Science leaders will have a greater proportion of external to internal network ties than non-leaders.

H4. Science leaders will have stronger network ties than non-leaders.

3.2. Science leadership and science ability

Science leaders need to possess strong technical skills since they are charged with working with group members in solving research problems and advancing the development of scientific knowledge (Jindal-Snape & Snape, 2006; Sapienza, 2005; Shapin, 2008). Similarly, strong scientific ability is likely to be an important indicator of reputation, and reputation has been shown to be an important determinant of having a leadership position. The link between academic science ability and reputation is especially evident in the literature (Ben-David & Sullivan, 1975; Crane, 1965; Hargens & Hagstrom, 1982; Merton, 1957; Stern, 2004). Success in science is typically measured in terms of productive outcomes and recognition. These include publishing journal articles, receiving grant awards and receiving prestigious awards that recognize scientific contributions (Allison, Long, & Krauze, 1982; Arora, David, & Gambardella, 1998; Boardman & Ponomariov, 2007; Mcmillan & Deeds, 1998; Merton, 1973; Sorenson & Fleming, 2004). This is consistent with the work of Rindova et al. (2005) who found that productive faculty contributed to the prominence of their academic institution. Furthermore, this is consistent with findings by O'leary (1999) who shows that science organizations typically use technical competence as primary criteria for promotion to management positions. Thus, overall, we can posit that positive scientific reputation, which often results from recognized productivity, skills and knowledge, will increase likelihood of holding a leadership position.

H5. Science leaders will have more scholarly awards than non-leaders.

H6. Science leaders will have more science outputs (grants awarded and journal articles) than non-leaders.

3.3. Science leadership and gender

Historically, the understanding of why women have tended not to attain leadership positions has focused on women's perceived lack of leadership ability. By contrast, more recent literature based in network theory and critical feminist theory has provided more nuanced understanding of the reasons why women are less likely to be in leadership positions. For example, some network based research finds that women are less likely to connect to people who have more power and authority (Agars, 2004; Ibarra, 1992; 1993a, 1993b; McGuire, 2000). Other findings indicate that women have fewer connections to power are because they are less integrated into male dominated networks where men are in tightly held positions of authority and power (Brass, 1985). Prior work has found that compared to men, women have fewer weak tie relationships that span otherwise unconnected groups across structural holes and are more likely to be embedded in denser, strong tie networks (Burt, 2000; Timberlake, 2005). These differences may mean that women are less likely to be positioned to bridge disconnected groups that could provide information important for getting and maintaining a leadership position.

Critical feminist theory has shown that in general, conceptions of leadership (particularly educational leadership) are commonly more masculine in nature such that they are infused with such qualities as paternalistic, dominant, charismatic, having a level of detachment from subordinates, self-seeking, and rational. This particular body of literature generally argues that leadership norms are less likely to recognize or promote values held by women such as fostering inclusion, building relationships, or promoting equitable outcomes. Because women's contributions as leaders do not fit entirely within the male-centric paradigm of leadership and because the more masculine paradigm of leadership predominates in society, there are fewer opportunities for women to pursue leadership positions (Bensimon, 1989; Blackmore, 1989; Dentith & Peterlin, 2011; Glazer, 1991; Grogan, 2000).

H7. Women will be less likely to be science leaders than men.

H8. Science leaders will have fewer women in their networks than non-leaders.

Based on the previous discussion Fig. 1 provides a conceptual model of the relationship between social networks, expertise, gender, and academic science leadership. Hypothesized relationships are in parentheses.

4. Data and methods

Data for this study is from a 2007 National Science Foundation funded survey on the role of social networks on the career success of women in science and engineering administered by the University of Illinois at Chicago and the Georgia Institute of Technology. The population of academic scientists and engineers at 150 Carnegie-designated Research I (or Research Extensive) universities was constructed by capturing relevant data—name, contact information, gender and rank—from university science department web pages and entering them into a database. A proportionate random sample of 3667 academic scientists stratified by sex, rank (assistant, associate and full), and discipline (biological sciences, chemistry, computer science, earth and atmospheric sciences, electrical engineering, and physics) was selected from the final population of 23,896 individuals. The six disciplines were selected based on the level of female representation in those fields (low, transitioning, and high fields) and women were oversampled because women represented a small percentage of the population of interest. Equal proportions of participants were selected from each discipline and the distribution of rank in the sample was approximately proportionate to that found in the population. Once the sample was chosen, work was done to finalize the collection and input of complete contact information. Post survey analysis showed that the distribution of responses across all three strata were no different than those selected in the random sample. As a result, sample weights were calculated using the inverse of the probability of selection and employed in calculating all results presented below.

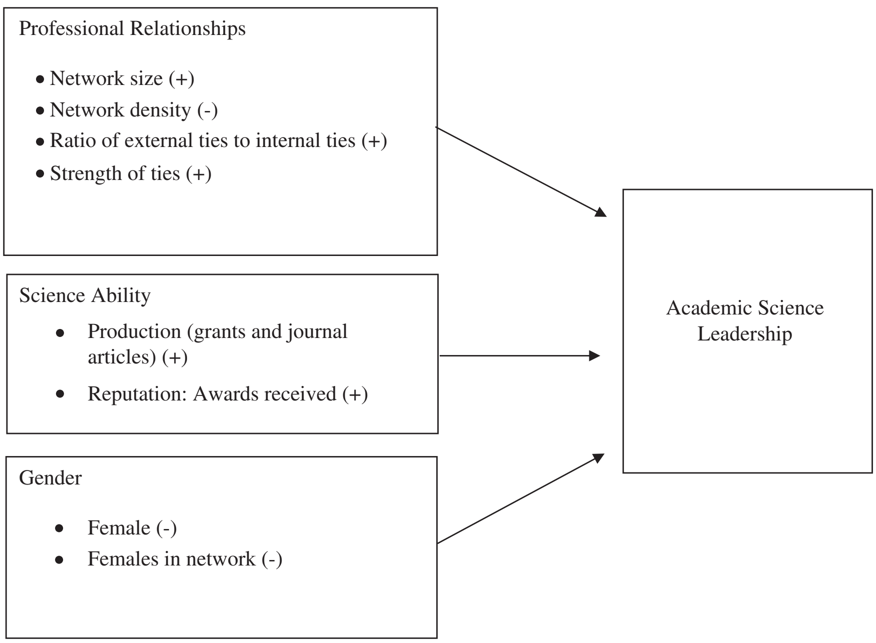

Fig. 1. Model depicting the relationship between science leadership, professional relationships, science ability, and gender.

The survey was administered online over the period of two and a half months in 2007 using Sawtooth Software®, which provided the necessary capacity to handle the complex nature of name generator and name interpreter questions. Postal and electronic mail invitations were distributed to individuals inviting them to participate in the survey. Both types of invitations provided a personalized username and password that allowed respondents to securely access the survey. Reminder emails were also sent to increase response rates. Overall, the survey took between 30 and 45 min to complete.

A total of 1774 complete survey responses were received. Because the study design called for only tenure track assistant, associate and full professors, 176 responses were removed due to ineligible rank or discipline. The resulting final sample size used for analysis was 1598. The overall response rate of the survey, calculated using the RR2 method from the American Association for Public Opinion Research (AAPOR) was 45.8%. The weighted response rate was 43.0% (AAPOR (The American Association for Public Opinion Research), 2009).

Several types of data were collected as part of the survey including: education and career experience, research and teaching responsibilities, productivity, leadership positions currently held, as well as information on respondents' professional networks. The survey is unique in that it collects detailed information about the aspects of individual's collaborative and advice networks (Wasserman & Faust, 1994). The ego-centric network data go beyond bibliometric approaches that use publication data to capture the complex nature of relationships and the resources exchanged across them. The value of this is that more insight can be gained into how specific networks and the relationships fostered within them are important for career outcomes and the production of scientific outputs (Burt & Minor, 1983; Marin, 2004; Straits, 2000).

Network data were collected using a series of name generator and name interpreter questions. Respondents were first asked to complete five different name generator questions asking them to provide the names of key collaborators or advisors. The names provided by the respondent were piped into a series of name interpreter questions that asked about the types of activities undertaken with the individuals named and the nature of the relationship between them. Specifically, the name interpreter questions inquired about such things as outputs produced, how they met, level of knowledge of the collaborator's research expertise, frequency of communication, and general demographics, among others. Data collected through the name interpreter questions (called alter-level data) were aggregated into sums and averages that were integrated as network variables into the respondent level dataset (ego-level data). In this way the final data set includes both ego-level data on leadership and productivity and summary alter-level network data.

4.1. Measures: dependent variables

Four main dependent variables capture leadership in this paper. Three operationalize each of the three types of leadership—STEM center, STEM administrative, and STEM discipline—while a fourth combines all three into a single indicator of science leadership. A STEM center leader is a faculty member that holds a current position as a director or co-director of a primary lab or a director of a research center or institute. To capture this variable we used responses to two questions. The first question asked respondents to indicate if they were a director or co-director of a permanent science or engineering laboratory or center (1 = yes). The second question asked respondents to indicate whether they currently hold a position as a director of a research center or institute (1 = yes). Because these questions may overlap, we created a new variable indicating center leadership (1 = yes) if the individual held at least one of the two positions.

STEM administrative leadership is a discrete variable in which the individual either currently held a position as dean or department head/chair (1 = yes). STEM discipline leaders are individuals who currently held a position as an officer in a professional science association. In the survey, individuals first named the set of associations in which they were members. A subsequent question piped the association names into a name interpreter questions that asked respondents to indicate whether were currently an office holder. In some cases, scientists held offices in more than one association. For the purposes of this study, we created a discrete one-zero variable indicating STEM discipline leadership (1 = yes) if the respondent held a minimum of one positions. Finally, we created a fourth variable by combining the three leadership variables into a discrete one-zero indicator of science leader (1 = yes).

4.2. Measures: independent variables

The independent variables of interest are grouped into three areas: structure and characteristics of the respondent's professional relationships, science ability, and gender. The profession relationship variables of interest include network structure (i.e. network size, network density, and ratio of external to internal ties), the strength of ties in the network, proportion of close friends, and the number of women in the network. As this is a study of academic scientists, professional relationships were measured using data on the respondent's collaboration network—the network of individuals inside and outside of the respondent's institution with whom he or she collaborated on research. Two name generator questions in the survey capture this: “Over the past two academic years, which individuals at your university have been your closest research collaborators” and “Over the past two academic years, who have been your closest research collaborators outside of your institution (including other academic institutions, government and industry”. Based on recommendations from the literature, respondents were limited to naming five individuals for each name generator such that respondents were able to name up to a total of ten collaborators (Marsden, 2006; Vehovar, Lozar Manfreda, Koren, & Hlebec, 2008).

We measure the total size of the collaboration network as the sum of the collaborators named by the respondent. The name of the variable measuring the total size is “network size”. Strength of ties is measured as the proportion of close friends in the respondent's collaboration network. This was captured by a name interpreter question in the survey where the respondent was asked to “please indicate if this person is a close friend”. The proportion of close friends in the network was then calculated. The name of the variable measuring the strength of ties is “proportion close friends”.

Network density reflects the extent to which alters in the respondent's network are connected to each other and is measured by dividing the total number of ties in the collaboration network by the total number of possible ties, as follows:

$$\text{Network Density} = (2 \times \text{Number of Ties})/((\text{Network Size}) \times (\text{Network Size} - 1)).$$

The name of the variable reflecting the density is called “network density”.

The E–I index measures the extent to which a respondent's network is situated more or less externally to his or her university. Krackhardt and Stern (1988) developed an E–I index to capture the relationship between external and internal links of an individual's network. For this study, external links comprise the collaborative ties between the respondent and named collaborators outside the respondent's university; internal links are collaborative ties between the respondent and named collaborators inside the respondent's university. The specific calculation for the E–I index is as follows:

$$\text{E} - \text{I index} = (ECL - ICL)/(ECL + ICL),$$

where ECL is the number of external collaborative links and ICL is the number of internal collaborative links. The E–I index ranges between −1.0 and +1.0; as it approaches +1.0, the ratio of external links to internal links increases and as it approaches −1.0, the ratio of internal links to external links rises. The name of the variable measuring this ratio is “ratio of external to internal ties”.

As science ability is a broad concept reflecting an individual's ability to produce scientific knowledge, it is captured using a variety of different variables. The first measure of productivity uses an open-ended question that asked respondents to estimate the average number of annual journal articles they had published in the last five academic years. The second variable representing science ability uses an open-ended question asking respondents to estimate the average number of research grant proposals submitted in the last five academic years. The third and final variable captures awards. It uses a survey question asking if respondents had received any of the following awards: dissertation or “best paper” award, a National Science Foundation career grant, a National Science Foundation fellowship, a young investigator award, or another science or engineering award. The final variable is the sum of awards (ranging from one to four) received by the respondent. The names of the variables reflecting each measure of science ability are as follows: “grant proposals submitted”, “journal articles published”, and “awards received”.

The gender of the respondent is measured as a dichotomous variable (1 = female). The variable reflecting the gender is called “female”. Additionally, to measure the women in the respondent's network, we summed the number of collaborators in each respondent's network who are female. The name of this variable is “number of females in network”.

Control variables include six discrete indicators of science field—biological sciences, chemistry, computer science, earth and atmospheric sciences, electrical engineering, and physics—as well as a discrete measure of minority if the individual is Black, Hispanic, or Native American (1 = yes), and continuous variables for age, and age squared. A table of the survey questions used for each of the dependent, independent, and control variables appear in Appendix A of this paper.

4.3. Methods and model

Because the dependent leadership variables are measured using discrete one-zero indicators, logistic regression analysis was used to predict the likelihood of having a leadership position. Sample weights were used and listwise deletion of observations due to missing values resulted in a sample size of 1317 used in the estimations.

Four regression estimations were developed and estimated using the logistic regression analysis. Three were used to predict the likelihood of discipline leadership, administrative leadership, and center leadership. A fourth model was used to predict the likelihood of total science leadership, which combines all three types of leadership. The final empirical model can be expressed as:

$$\begin{aligned}\text{Science Leadership} = f[&\text{Science Ability (grant proposals submitted, journal articles published, awards received)},\\ &\text{Social Relationships (network size, proportion close friends, network density,}\\ &\text{ratio external to internal ties, number of females in network), Female,}\\ &\text{Controls (minority, field, age, age squared)}]\end{aligned}$$

4.4. Descriptive statistics

Two types of descriptive statistics are provided in this section. Table 3 provides means and standard deviations for the dependent and independent variables while Table 4 presents ANOVA results for differences of means between men and women for the four different types of leadership.

Among the dependent variables shown in Table 3, it can be seen that slightly more than a fourth of all respondents (26%) are science leaders as measured in this study. As we measure it here, discipline leaders comprise the largest group (18%), followed by center leaders (7%), and administrative leaders (5%). Also in Table 3, academic scientist respondents reported submitting 2.55 grants and publishing 3.76 articles per year. Respondents report an average of five collaborators (network size), of which less than one is female (0.73) while approximately 23% are close friends (proportion strong ties). Respondents indicated that of all the possible connections that could exist among the people in their network, 47% already exist (network density). An E–I Index of zero indicates that on average scientists report an equal balance of internal and external close collaborators.

Among the control variables, very few respondents are minorities (4% or 63 respondents). There is a similar distribution of respondents having science leadership positions across the scientific fields with chemistry respondents reporting the highest percent (18%), followed by biological sciences and physics (17%), computer science (16%), and electrical engineering (13%). Respondents are approximately 48 years old and under half are women (46%).

The distribution of leadership types by gender (Table 4) shows that women are overall more likely to report being a science leader (male 23%; female 27%). Looking at gender differences across type of leadership, women are much more likely to report having STEM discipline leadership positions, while men are more likely to be STEM administrative leaders and STEM center leaders. These differences are statistically significant although the statistical significance is weak in the case of STEM center leadership.

5. Estimation findings

Tables 5 and 6 present the results from logistic regression estimations. Table 5 provides results for the total science leadership and STEM discipline leadership models. Table 6 provides results for the STEM center and STEM administrative leadership models. All models also provide odds ratios for each independent variable, which generally indicates how important each variable is in predicting science leadership.

First, we can examine the estimation results for the total science leadership model (Model 1). Findings for the professional relationship variables generally support three of our four hypotheses (H1, H2 and H4). Estimation results show that individuals who have larger networks are more likely to be in leadership positions ($p<0.01$). This likely indicates that on average, social capital returns from larger networks provide the information, resources and support necessary to hold a leadership position. Results also show that network density is negatively associated with science leadership ($p<0.01$), such that the more weak ties that exist in the network the more likely the individual will hold a leadership position. This is likely due to the advantage that bridging disparate groups of individuals has for a leader who must seek information, resources and support from a broad set of

Table 3
Descriptive statistics.

Variable name	N	Mean	Standard deviation
Dependent variables			
Science leadership	1598	0.26	0.44
STEM discipline leadership	1598	0.18	0.39
STEM center leadership	1598	0.07	0.26
STEM administrative leadership	1598	0.05	0.21
Independent variables			
Professional relationships			
Network density	1394	0.47	0.24
Ratio of external to internal ties	1436	0.00	0.53
Proportion of close friends in network	1435	0.23	0.28
Network size	1436	5.09	2.45
Number of females in network	1435	0.73	1.06
Science production and reputation			
Average grant proposals submitted	1554	2.55	2.39
Average journal articles published	1589	3.76	5.36
Awards received	1598	0.67	0.79
Gender			
Female	1598	0.46	0.54
Controls			
Minority	1598	0.04	0.21
Chemistry	1598	0.18	0.38
Computer science	1598	0.16	0.37
Electrical engineering	1598	0.13	0.34
Biological sciences	1598	0.17	0.38
Physics	1598	0.17	0.38
Age	1574	48.04	10.07
Age-squared	1574	2408.89	1010.57

Table 4
Difference of means, male and female leadership.

Leadership type	Male		Female		Significance
	N	Mean (SD)	N	Mean (SD)	
Science leadership	867	0.23 (0.42)	731	0.27 (0.44)	***
STEM discipline leadership	867	0.13 (0.34)	731	0.21 (0.41)	***,**
STEM center leadership	867	0.09 (0.29)	731	0.05 (0.22)	*
STEM administrative leadership	867	0.05 (0.22)	731	0.03 (0.18)	***

* p<.10.
** p<.05.
*** p<.01.

different groups. Strong ties are significantly and positively related to having a science leadership position ($p<0.01$) indicating that strong, trust-based relationships with others in the network likely enable the leader to more effectively access information and resources necessary to lead. The coefficient for the ratio of external to internal ties is negative, indicating that when there are more internal compared to external network ties among collaborators, the scientist is more likely to hold a leadership position ($p<0.01$). This finding is unexpected and may be a reflection of the dominance of center and university administrative leadership in the single discrete dependent variable. To hold a leadership position, local reputations and connections may be more advantageous sources of support than distant ones. As an example of the interpretation of the odds ratios for these variables, an increase by one unit of the proportion of close friends results in a 1.71 increase in the likelihood of being a science leader. Similarly, a one unit increase in the ratio of external to internal ties has the least impact by increasing the likelihood of leadership by only 0.68.

All of the independent variables representing science ability are positively related to science leadership and significant at the $p<0.01$ level supporting our H5 and H6. Receipt of awards, submission of grant proposals, and publication of journal articles are positively associated with the holding a leadership position. The findings indicate that leadership positions are more likely to be held by individuals who are more productive and formally recognized in their fields. Among the odds ratios related to science

Table 5
Estimation results: total science leadership and discipline leadership.

	Model 1: science leadership				Model 2: STEM discipline leadership			
	Coefficient	Standard Error	Significance	Odds Ratio	Coefficient	Standard Error	Significance	Odds Ratio
Professional relationships								
Network size	0.14	0.01	***	1.15	0.17	0.02	***	1.18
Network density	−0.39	0.13	**	0.68	−0.44	0.17	**	0.64
Ratio of external to internal ties	−0.38	0.06	***	0.68	−0.02	0.08		0.98
Proportion of close friends	0.54	0.10	***	1.71	0.67	0.11	***	1.96
Number females in network	−0.14	0.03	***	0.87	−0.07	0.04	**	0.93
Science production and reputation								
Grant proposals submitted	0.05	0.01	***	1.05	0.03	0.01	**	1.03
Journal articles published	0.04	0.00	***	1.04	0.02	0.00	***	1.02
Awards received	0.23	0.04	***	1.25	0.31	0.04	***	1.36
Female	0.46	0.08	***	1.59	0.72	0.09	***	2.06
Control variables								
Minority	0.46	0.14	***	1.59	0.65	0.14	***	1.91
Chemistry	−0.56	0.11	***	0.57	−0.58	0.12	***	0.56
Computer science	−0.44	0.11	***	0.65	−0.54	0.12	***	0.58
Electrical engineering	0.19	0.10	*	1.21	0.12	0.12		1.13
Biology	−0.30	0.09	***	0.74	−0.38	0.10	***	0.69
Physics	−0.26	0.10	***	0.77	−0.30	0.11	***	0.74
Age	0.41	0.03	***	1.51	0.25	0.03	***	1.28
Age-squared	0.00	0.00	***	1.00	0.00	0.00	***	1.00
Intercept	−13.56	0.79	***	1.00	−9.69	0.85	***	
Model summary								
n	1317				1317			
Likelihood ratio	875.60				583.98			
Prob > Chi-squared	***				***			

Significance: p<.10*, p<.05**, p<.01***; Reference category for science field is Earth and Atmospheric Sciences.

Table 6
Estimation results: center leadership and administrative leadership.

	Model 3: STEM center leadership				Model 4: STEM administrative leadership			
	Coefficient	Standard Error	Significance	Odds Ratio	Coefficient	Standard Error	Significance	Odds Ratio
Professional relationships								
Network size	0.19	0.02	***	1.20	−0.05	0.02	**	0.95
Network density	0.39	0.22	*	1.48	−0.62	0.24	**	0.54
Ratio of external to internal ties	−0.68	0.11	***	0.51	−0.26	0.11	**	0.77
Proportion of close friends	0.59	0.15	***	1.80	−0.39	0.20	**	0.67
Number females in collaboration network	−0.16	0.05	***	0.85	0.02	0.06		1.02
Science production and reputation								
Grant proposals submitted	0.12	0.02	***	1.13	0.09	0.02	***	1.10
Journal articles published	0.02	0.00	***	1.03	0.01	0.01		1.01
Awards received	0.24	0.06	***	1.27	0.01	0.08		1.01
Female	−0.27	0.15	*	0.77	−0.37	0.18	**	0.69
Control variables								
Minority	−0.02	0.23		0.98	0.24	0.24		1.27
Chemistry	−0.37	0.20	*	0.69	−0.37	0.17	**	0.69
Computer science	0.31	0.17	*	1.37	−0.54	0.18	***	0.58
Electrical engineering	0.61	0.17	***	1.84	0.03	0.17		1.03
Biology	0.65	0.15	***	1.92	−0.91	0.18	***	0.40
Physics	0.19	0.16		1.21	−0.98	0.19	***	0.38
Age	0.34	0.05	***	1.41	1.05	0.10	***	2.86
Age-squared	0.00	0.00	***	1.00	−0.01	0.00	***	0.99
Intercept	−15.15	1.35	***		−30.11	2.52	***	
Model summary								
N	1317				1317			
Likelihood ratio	589.10				363.96			
Prob > Chi-squared	***				***			

Significance: p<.10*, p<.05**, p<.01***; Reference category for science field is Earth and Atmospheric Sciences.

ability, the total awards given increases the likelihood of being a leader the most (1.25), while the average publications submitted has the least impact on increasing the odds of becoming a leader (1.04).

The number of women in the collaboration network is significantly, but negatively related to holding science leadership positions. In other words, having fewer women in one's collaboration network is more likely to lead to having science leadership positions. These findings tend to support our expectations regarding women in networks (H8). In examining the odds ratio for this variable, we see that an increase of one woman in the network reduces the likelihood of being a leader by 0.87. By contrast, we unexpectedly find that being a woman is positively and significantly related to holding a science leadership position. This means that being a woman increases the likelihood that one will hold a science leadership position. Odds ratios show that being a woman increases the likelihood of being a leader by a factor of 1.59. It seems as though there may be opportunities for women in leadership positions but they are more likely to be in a leadership position if they are connected to men. This finding can be explained by recognizing that: 1) the majority of scientists in these fields are male, 2) there are strong institutional demands for increasing diversity in STEM fields, and 3) the quality of women scientists who tend to survive and succeed in STEM fields is high (Hopewell et al, 2009; National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, 2006).

Among the control variables, we find that minorities are more likely to be science leaders, perhaps for the same reasons described above for women. Additionally, chemists, computer scientists, biologists and physicists are less likely than earth and atmospheric scientists (EAS) to be leaders. We can speculate that the wide array of different disciplines in the EAS field means that scientists are more likely to be involved in coordination activities. Coefficients for the age and age squared variables show that older scientists are more likely to be leaders than younger scientists. Example odds ratio results show that being a minority that increases the likelihood of becoming a leader the most (by 1.59), while being in the chemistry field increases the likelihood the least (by 0.57). Because findings for the control variables are similar for all four models, we will not repeat this discussion for the other three models.

Results from the estimation of STEM discipline leadership (Model 2) are similar to the overall leadership model (Model 1). Larger, less dense networks are positively and significantly related to discipline leadership. Also similar to Model 1, more awards, more publications and having fewer women in the network are positively and significantly related to STEM discipline leadership. The only substantive difference between the first two models is the lack of significance of the ratio of external to internal ties. This can be interpreted to indicate that STEM discipline leadership does not depend on the balance of external and internal collaborative ties. Possibly this is because internal and external ties both provide important advantages to an individual leader – for example internal ties could provide substantial resources to support a leadership bid, while external ties provide reputational and visibility support. Hence, for an individual who would like to become a STEM discipline leader, it is important to maintain a balance of internal and external ties. Moreover, focus on an external network strategy at the expense of internal relationships is likely to have low or potentially negative payoffs. Other network strategies, such as investing in stronger ties and bridging structural holes (whether internal or external the university), appear to be important considerations for potential leaders.

The STEM center administration leadership model (Model 3) demonstrates some similarities as well as some dissimilarity with the previous models. As found in the results for the network variables in Models 1 and 2, STEM center leadership results demonstrate that larger networks and strong ties are positively and significantly related to the dependent variable. However, unlike Models 1 and 2, denser networks and a higher ratio of internal to external ties are positively and significantly related to center leadership. We believe these findings are indicative of the particular context of STEM centers; because STEM centers are often locally organized and focused on a narrow range of tasks, center members are more likely to be at the same university and to know each other.

Also, similar to the first two models, more awards and more productivity are positively and significantly related to having a STEM center leadership position. In regards to gender, being a woman and having more women in the network are negatively and significantly related to STEM center leadership. This contrasts with the first two models where women are more likely to be leaders. Possibly this has to do with the lack of institutional efforts or polices at the university level for women STEM center leaders and a lack of explicit policy or willingness (both at the granting agency and in universities) to advance women as STEM center leaders.

Findings for the estimation of STEM administrative leadership (Model 4) show that ratio of external to internal ties and network density are significant and negative. This result is similar to the science leadership findings in Model 1. Our interpretation remains the same as with Model 1: local reputation and connections provide substantial advantages to STEM university administrative leaders. Contrary to prior models, coefficients for collaboration network size and close friends are negatively and significant. This may indicate that deans, department heads and chairs are less likely to engage in collaborative research or maintain strong research ties. Their networks likely include more administrators and fewer collaborators.

Additionally, STEM administrative leadership is not predicted by awards or journal publications. However, the coefficient for average annual grants submitted is positively and significantly related to administrative leadership. Perhaps grant getting ability demonstrates an important type of resource building skill that is valued at the university. Alternatively, administrative leaders may be submitting high numbers of education and infrastructure grants. Finally, similar to STEM center leadership, women are less likely to be university administration leaders. Our interpretation remains the same: lack of institutional efforts or policies may contribute to the reduced likelihood of women STEM scientists being administrative leaders in science. Overall, Model 4 diverges more than the other models from the expectations established in the hypotheses.

6. Discussion and conclusion

This study sought to understand how science ability, professional relationships, and gender are associated with science leadership. We find that all three are associated with leadership, but in different ways depending upon the type of leadership position. Science production is generally positively associated with holding a science leadership position. STEM center and discipline leaders are more likely to seek grant funding and produce papers, and receive awards. STEM discipline leaders continue to exhibit large networks of strong ties, but the ties are less likely to know each other than individuals who are not discipline leaders. This makes sense for discipline leaders because they likely need to bridge a variety of disconnected others both to obtain resources and support and to govern. STEM center leaders have larger, denser networks and stronger ties. These factors are likely important for a high trust collaborative research environment. STEM administrative leaders have smaller, less dense networks containing fewer close friends than non-administrative leaders. As with discipline leaders, administrative leaders may need to bridge disparate groups to be able to gain the resources necessary to lead. Additionally, it is likely that STEM administrators have difficulty forming strong ties due to their positions as decision makers and resource allocators.

We also found interesting results as it relates to gender. Being a woman is significantly associated with the likelihood of having science leadership positions overall (based on the total leadership regression model), but this is primarily because the total model combines all three types of leadership and hides the important negative relationships found in other models. Women are less likely to be center or administrative leaders: positions that are more likely to control resources and to have direct effects on knowledge production and the conduct of science. There are least several reasons why women are more likely to be discipline leaders: women are more willing to provide service to the discipline; women are fewer in number and are therefore more likely to be asked to serve; and there may be high demand for female representation in professional associations (Chamberlain, 1988; de Melo-Martín, 2012; Twale & Shannon, 1996). Having more women in one's collaboration network decreases the likelihood of having a science leadership position. This is consistent with literature indicating that while women are assets as leaders, their presence in social networks can be detrimental because they do not generate as much social capital for those possibly wanting a leadership position (Carless, 1998; Day, 2001; Ibarra, 1993a, 1993b; Smith-Doerr, 2004; Vecchio, 2002).

There are limitations to this study that could shed more light on leadership in science organizations. First, we were limited to survey data that measured formal leadership positions currently held among faculty. Hence, we know little to nothing about faculty members' informal leadership positions or activities. Furthermore, the study is limited by the cross sectional nature of the data. A longitudinal analysis would be able to examine how change in networks and productivity over time would predict leadership attainment. Another limitation is the type of networks that were used. We only use a particular type of faculty members' networks. Using networks that pertain to teaching, service, advice or other activities may provide additional insights into why some people have leadership positions and others do not. Other limitations in this study are the lack of data on the respondents' personality traits or willingness to lead. Additionally the study is limited by its focus on collaborative networks and the limited number of names (five for each name generator) that individuals were able to enter. Future work should address these short comings. For example, future work could cover a larger range of relevant professional networks such as advice or mentoring networks. Finally, our study examines six fields of science, and although these fields were purposively selected for the differences in the proportion of women represented in each field, care should be taken when generalizing our findings to other fields of science and to other professions.

Despite these limitations, the current study has implications for future research in that it underscores the complex nature of leadership in which multiple factors—ability, networks and individual characteristics—provide advantages that explain why some people are able to attain and hold leadership positions and others are not. The findings generally support expectations developed from the social capital literature that connections with others are critical for explaining who is a leader. Informational, resource and reputational advantages are provided through the structures and characteristics of networks within which academic scientists are embedded. The empirical support for this observation implies that individuals may be able to proactively and strategically develop structures for themselves or assist in the development of structures for others through advice and guidance. For example, senior faculty or student mentors may be able to recognize opportunities to proactively expand the networks of colleagues or mentors in ways that help them pursue leadership positions either through access to resources or through greater visibility.

However, it is also important to recognize that network structures can also create disadvantages and promote negative outcomes. Findings show that individuals who have more women in their networks are less likely to be in leadership positions, implying that there is also a role for policy as it relates to leadership. Currently leaders who have significant impact on faculty promotion and development need to pay particular attention to the potential for biased selection of leaders. Policy must also anticipate potential for inequitable distribution of leadership positions among men and women. Practices need to be devised at the department, university and national levels (e.g. federal granting agencies) such that women receive greater opportunity and encouragement to obtain research-related leadership positions. It is no longer enough to provide grant funding opportunities for women as single investigators or primary investigators on projects. This research shows that greater attention needs to be placed on intentional creation of STEM center leadership positions for women.

Additionally, given the feminist theory literature, a more expansive conception of leadership that is less male-centric could be fostered in the academic STEM culture in ways that broaden the boundaries within which leadership positions are decided. While such change in the culture of leadership in STEM fields is likely to be slow, senior faculty and mentors can recognize and correct the nuanced biases that currently exist, as shown in this study, in two ways. First, a broader definition of leadership should be adopted; one that stresses inclusion, equity and other values that are recognized as salient in the feminist literature. Selection panels for new leaders should include greater female representation and leader selection criteria (including job descriptions) should include criteria that are less traditionally male oriented. Second, senior faculty and mentor efforts to further the careers of men and women junior scholars should endeavor to introduce more established female scholars.

Beyond academic science, this research has important implications for the study of leadership more generally that underscores the relationship between leadership attainment, human capital, social capital and attributes. Certainly, one of the most important lessons concerns the finding that professional network ties matter for holding a leadership position. Relationships provide resources and information, but their structures may also create inherent biases that limit access to leadership positions. Focusing only on the combined science leadership findings (Model 1), results show a powerful combination of 1) larger networks of strong ties that enable access to greater amounts of social capital, and 2) weak tie connection to otherwise unconnected groups and greater connections outside the university that allow leaders to access a wide range of non-redundant information across multiple institutions. This structural advantage is likely developed and nurtured over time and strategic leadership development efforts can seek to build these capacities. Additionally, findings show that more women in the network reduce the likelihood that an individual holds a leadership position. While this may be due to lower capacity or lower social capital of female networks, it likely is not as women who succeed in professions in which they are underrepresented are highly capable and connected. Furthermore, the finding that ability is closely related to having a leadership substantiates the long-held recognition of the value of human capital for leadership. This reflects the necessity of the leader to be knowledgeable of the environment, people, political and work processes, culture and other facets of the organization they manage and shape. Taken together, leadership research and development efforts should recognize the importance of both social and human capital to explain individuals' advancement into leadership positions. In combination with other factors such as personality and individual characteristics, future work should continue to investigate how social capital available through social structures and relationships provide advantages for the attainment, sustainment and practice of leadership. Leadership research should also undertake work that examines how trade-offs identified in this paper, such as whether or not to include more women into the professional structure, are related to effective leadership and how they may be addressed. Given the two-way relationship between leader and follower, there are clear equity considerations embedded in these trade-offs because professional structures that are beneficial (or not) for promoting a leader are also likely to be effective (or not) for promoting the interests and needs of followers. Finally, there is also a role for policy and proactive leadership to recognize possible structural inequalities and develop new guidance and advice to reduce them. For the larger leadership community—both researchers and practitioners—our findings provide the foundation for understanding more about the pathways to leadership that involve a balance of strategic relationships that considers potential gender bias and developing the skills and knowledge.

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Appendix A. Variables and measurements

Factors	Variables	Related survey questions/Transformed variables	Measurement
Science leadership	STEM discipline leadership	Please list the academic and professional associations in which you are most active. (Association name generator question) For the associations that you named, please indicate if (you are a current office holder).	1 = Yes
	STEM center leadership	Are you a member or have a formal affiliation with a permanent science or engineering laboratory or center? If responded "yes": Please indicate your affiliation with this laboratory: (Director or Co-Director, Researcher); and Do you currently hold any of these positions: (Director of a Research Center or Institute)	1 = Yes
	STEM administrative leadership	Please tell us whether you currently hold, or have ever held, any of these positions: (Department Chair/Head or Dean)	1 = Yes
	Science leadership	An individual is either a STEM Discipline, STEM Center, or Administrative Leader	1 = Yes
Science production and reputation	Submitted grants	Over the past five academic years, on average how many grants have you submitted per year?	Number
	Submitted publications	Over the past five academic years, on average how many peer-reviewed journal articles have you published per year?	Number
	Awards received	Have you ever received a dissertation or "best-paper" award?; NSF Career Grant; NSF Fellowship?; Young Investigator award?; Other science or engineering fellowship or award?	Sum of awards
Professional relationships	Network size Network density E–I Index	Over the past two academic years, which individuals at your university have been your closest research collaborators? Over the past two academic years, who have been your closest research collaborators outside of your institution	Network size is the sum of the names provided in these two questions (Max 10) Network Density is calculated according to the equation in methods section. E–I Index is calculated according to the equation in methods section
	Proportion of strong ties	Please indicate if this person is a close friend.	Number of close friends divided by the total number of collaborators.
	Number of females in network	Please indicate if this person is female.	Sum of collaborators that are female divided by total number of collaborators
Controls	Female	Are you? (female, male)Please indicate if this person is: (female)	1 = Yes
	Minority	What is your race/ethnicity? (Blacks/African American, Latino/Hispanic, and Native American)	1 = Yes
	Minority female	Female*Minority	1 = Yes
	Science field	What is your discipline? (biology, chemistry, physics, earth and atmospheric sciences, electrical engineering, and computer science)	Six dummy variables, 1 = Yes
	Age	What is the year of your of birth?	2007 minus year of birth.
	Age squared	What is the year of your of birth?	Age*Age

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