Science Leadership: Is it What You Know, Who You Know or Who You Are?

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***Abstract*— This paper examines the factors associated with the attainment of leadership positions of men and women academic scientists. Based on the literature, we develop hypotheses for three determinants of leadership: social relationships, reputation, and gender. Social relationships concern the importance of the network connections; reputation recognizes the importance of science ability; characteristics include individual traits such as gender. We test the resulting model on the likelihood of attaining three different types of academic science leadership – center leadership, university administrative leadership, and discipline leadership. Regression analysis uses data from a National Science Foundation funded survey of scientists in which social network, attitudinal and behavior data were collected to understand how social networks affect career trajectories of men and women. Findings show that while science reputation is strongly associated with center and discipline leadership, it is less strongly associated with administrative leadership. Also, large dense collaboration networks are important for center leadership, but the opposite is true for administrative leadership. 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 attaining discipline or center leadership positions. Conclusions interpret findings for policy and theory.**

***Index Terms*— Career development, educational institutions, social factors, sociology**

I. Introduction

WE live in a culture where leadership is a mainstay in discussions about how to move organizations forward. Good leadership is frequently viewed as the panacea that can cure the ails of organizational stagnation, poor performance, instability, and unprofitability, leading to the accomplishment of organizational objectives, growth, innovation, prosperity and more. To this end, much work has been done to understand the underpinnings of leadership--especially the contributors to the creation of a leader. However, leadership determinants continue to be a complex area of study and remain open for more inquiry. The evolution of the practice of science from a single investigator work to a highly collaborative, team based enterprise requiring tremendous resources, coordination, and interaction with various external organizations provides an interesting context for examining leadership determinants in academic science. Furthermore, increasingly the visibility of academic scientists as well as the administrative leadership at universities play significant roles in obtaining and allocating resources for the production of science. Leadership, defined here as a formal position of authority that is officially conferred by an organization that includes the latitude to influence and direct a body of subordinates [1], is an important topic in social studies of science because it concerns the acquisition of financial capital and the development of human capital for the production of scientific knowledge.

This paper explores the relevance of three factors typically linked to the attainment of academic science leadership positions: social connections, scientific ability, and gender. Social connections are reflected in the relationships that academic scientists have with the people in the scientific community. Scientific ability reflects the scientific productivity and reputation of the individual. The study of gender in science leadership provides a means of examining advancement of women into important positions within the scientific community. While social connections, scientific ability, and gender have been researched individually to understand their connections to leadership, this research examines them in concert. Thus, our research question is as follows: How are social connections, scientific ability, and gender associated with attainment of leadership positions in academia? We are also interested in understanding whether the three factors consistently predict different types of leadership.

The paper first conceptualizes three types of scientific leadership –center leadership, university administrative leadership and discipline leadership before building hypotheses predicting the associations between leadership and the independent variables of interest: social connections, science ability 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.

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Findings show that science reputation variables – grant ability, publications and awards obtained – are strongly associated with center and discipline leadership, while only grant production is associated with administrative leadership. Additionally, while many of the social relationship variables predict leadership attainment- large dense networks of strong collaborative ties are important for center leadership; but the opposite is true for administrative leadership. Women are more likely to attain leadership positions in general. Females are less likely to hold a leadership position in research centers, but more likely to be administration or discipline leaders. Finally, having more women in the collaborative network reduces the likelihood of holding any type of leadership position. Conclusions discuss implications for science administration and policy.

II. Science Leadership

Science leaders are responsible for many different types of activities designed to facilitate and enable the production of science. They attract and maintain a workforce of creative, motivated, and satisfied reputable scientists as well as manage the transfer, and application of scientific knowledge within the university science setting to the external environment [2]-[6]. They ensure that necessary equipment and resources are available and properly allocated. Science leaders are also responsible for creating and communicating organizational goals both internally (i.e. inside of the university) and to external stakeholders [7],[8]. Nevertheless, science is organized at many different levels: lab, center, department, university, and discipline. Accordingly, we conceptualize three different types of leadership positions for this study: center leadership, university administrative leadership, and discipline leadership. These leadership types are not exhaustive, nor are the mutually exclusive as it is possible to hold all three positions at once. A more in-depth discussion of these types follows.

Center Leadership

Center research leaders are individuals with formal positions (e.g. directors) at university labs and researcher centers or institutes. Among all three types of leadership, they 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 [13] assert that leadership in this context is critical in that its outcomes directly influence idea generation process and the quality and value of final scientific outputs. Hollingsworth and Hollingsworth [9] 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" [9]. The primary responsibilities of center leaders include 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 [10]-[12]. Most important and challenging for center research leaders is effectively fulfilling these responsibilities to meet the demands of multiple stakeholders who consume and appropriate research outputs differently while simultaneously managing the scientists who actually do the work [13],[14].

University Administrative Leadership

Administrative leaders in universities include deans, department heads and chairs, provosts and other formal administrative positions. They manage both the internal and external environments of universities in ways that facilitate the production of high quality science [15]. They are charged with developing and managing organizational policies, culture, and institutions [16], and developing incentives and reduce barriers to encourage and facilitate research and teaching. Management activities include implementation of strategies that respond to government initiatives and policies that influence how universities practice and produce science [17].

Leader actions impact the external reputation that institutions have as creative and resource rich environments that facilitate the creation 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 of administrative leaders have sought to bridge academia and industry [3],[4]. And, within the increasingly complex fiscal climate, administrative science leaders must secure financial resources necessary support the organization to conduct its work. Administrative leaders are responsible for compliance with laws and regulations, creating standards performance and evaluative activities that aim to continually improve the organization [7], [18]-[22]. Essentially, administrative science leaders are predominantly involved in managing the department or university in ways that enable faculty to accomplish work that contributes to university goals [23].

Discipline Leadership

Disciplinary 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 such 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, improving the connection between professional scientists and the public, and encouraging assessments of the scientific field [24]-[28]. Overall, discipline science leaders promote the professionalization and institutionalization of science [26], [28]

As can be implied from the discussion above, center, university 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, it can be seen that each type of leadership may manifest those roles differently.

III. Science Leadership Hypotheses: Social Relationships, Science Ability and Gender

This section develops hypotheses for three general associates of science leadership – social relationships, science capacity, and gender. We posit that these associates afford individuals with reputational benefits, which subsequently results in attaining formal leadership positions.

Science Leadership and Social Relationships

Leadership-member exchange (LMX) theory promotes the notion 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" [29]. These benefits can be viewed as the returns from social capital in the form of information and resources that can contribute to individual success and productivity [30]-[33]. Bordieu [34] defines social capital 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". Coleman [35] 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 [36] offers that social capital concerns the resources that can be attained through social connections such as personal and social resources. It is through social connections that individuals form their reputation by providing signals about their potential leadership ability [37]. It is this reputation for potential leadership that is crucial for individuals actually becoming leaders [1].

Characteristics of social networks contribute to how information and resources are created and are thus associated with the attainment of leadership positions [38]-[40]**.** An individual's position in the network is indicative of her power and influence [30]. Some positions enable greater control of information and resource flows, which translates into a source of influence and power for the boundary spanner [41]-[44]. As the boundary spanner attains more information and resource flows, she becomes more recognized and identifiable in her organization and network.

Thus, social networks can be advantageous by enabling the individual to generate, appropriate, and control information, resources, and influence [45]. Visibility and reputational returns are also attained by individuals aligning themselves with other powerful networks—networks with people having significant information and resources. Brass [46], [47] found that enhancing one's reputation by associating with powerful groups was a key factor in these individuals being placed in management positions. Cialdini [48], [49] was among the first to assess this as a common phenomenon and coined this as the "basking in the reflected glory of others" phenomenon. Brass and Krackhardt [30] further this in their study and assert that individuals "basking in the glory of prominent others" will be more likely to increase their own perceived reputation of power. This is likely because associating with powerful networks can serve as a signal that an individual may be as resourceful, influential, and successful as those she is associating with. Consequently, the individual becomes more visible [50]. Highly visible individuals—whether by way of individual actions or alignment with powerful other -- are more likely to attain formal leadership positions, especially in public institutions [51].

Four characteristics of networks are expected to be associated with attainment of a leadership position: network size, network density, balance of external and internal ties, and strength of ties. Network size refers to the number of alters in the ego's network. A larger number of alters in an ego's network indicates a larger potential set of individual from which the ego can obtain resources. Larger networks provide greater amounts of information and resources [52], [53]. Attaining 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 attain 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.

Network density reflects the number of connections among contacts within the network of the ego [39], [45]. When networks are more dense – more connections among alters, informational resources are highly redundant because the individuals who know each other are also familiar with similar information [30],[38]. Networks that are less dense may mean that alters may be connected. In this instance, alters are likely to be connected across structural holes, which are defined as "a relationship of nonredundancy between contacts" [39]. Weak ties provide access to diverse sources of information [54],[36]. In addition, the balance of internal versus external ties may matter for leadership attainment. Egos that have a greater ratio of external to internal ties (i.e. ratio of ties external to the organization to ties inside of the organization) may have access to more information and resources outside the organization (in this case the university). Individuals interested in attaining leadership positions are likely to depend up on diverse sources of information to be able to both span boundaries to carry out their work, but also position themselves strategically in ways that increase their likelihood of attaining a leadership position.

Relationships vary in terms of their strength of ties. Strong ties imply greater emotional closeness [36], [53] and higher levels of trust, which are likely to make people prone to sharing information and resources [55]. The more connections individuals has (i.e. larger networks), the information they have access to from various places. This also means that larger networks could provide access to more varied and less redundant information [39], [56]. Because leaders are charged with marshaling a wide range and variety of resources, it is advantageous for them to maneuver between less dense networks that are larger and more externally situated. Therefore, our hypotheses related to network structure, size, and strength of ties are:

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

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 [6], [8], [57]. Similarly, strong scientific ability is likely to be an important indicator of reputation, and reputation has been shown to be an important determinant of leadership attainment. The link between academic science ability and reputation is especially evident in the literature [58]-[62]. 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 [21], [63]-[68]. This is consistent with the work of Rindova [21] who found that productive faculty contributed to the prominence of their academic institution. Furthermore, this is consistent with findings by O'Leary [7] who shows that science organizations typically use technical competence as primary criteria for promotion to management positions. Overall, positive scientific reputation, which is linked to high productivity and recognition of skill and knowledge, increases visibility; which subsequently increases the likelihood of attaining 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.

Science Leadership and Gender

The literature generally finds that women are less likely to connect to people with more power and authority [69]-[72]. One possible reason is that women are less integrated into male dominated networks in which men are in positions of authority and power [46]. Another reason is that women are more likely to be in rather dense, tightly knit networks [73]. Women as compared to men have fewer weak ties which mean that they are less able to make connections across different types of networks that are located within and outside of the organization [45].

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

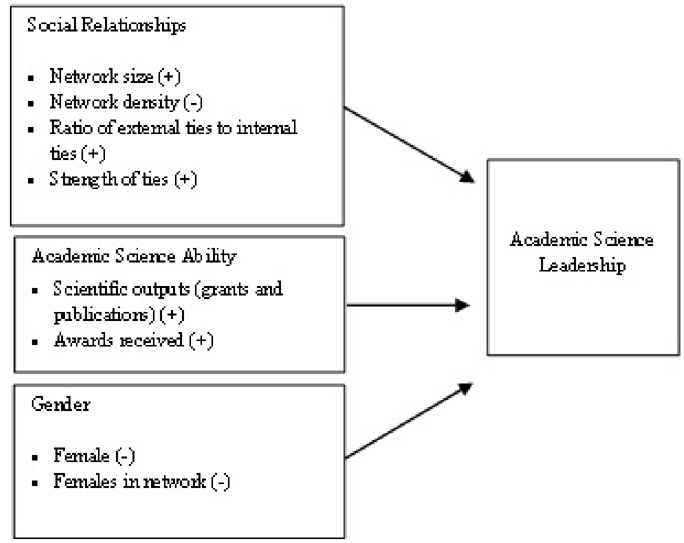

Fig. 1. Model depicting the hypothesized relationship between social relationships, academic science ability and gender and academic science leadership.

IV. Data and Methods

Data for this study is from a 2007 National Science Foundation funded survey administered by the University of Illinois at Chicago and the Georgia Institute of Technology. This was a national survey conducted among scientists and engineers at 150 Carnegie-designated Research I (or Research Extensive) universities. Several data points were collected: individual background, career timeframe and experiences, research and teaching responsibilities, productivity, and social networks. The survey is unique in that it collects detailed information about the aspects of individual's sub-networks and not the global network [74]. Detailed survey questions inquiring about the individual's activities and relationships within these network capture dimensions of the collaborative and advice networks that are not accessible through existing data such as bibliometrics. 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.

Network data was collected using a series of name generator and name interpreter questions. First, respondents were given five name generator questions asking them to provide the names of key collaborators or advisors in research collaboration as well as advice and support networks. These included closest collaborators within their own university, closest collaborators outside their university, individuals with whom “they talk about their research but have never collaborated. In addition, they were asked provide the names of individuals who provided them advice in two contexts– those with whom they talk about career advice and with whom they discuss departmental matters. It is important to note that while the research and advice networks are mutually exclusive, there is some overlap. Once the survey respondent provided names in each of the five name generator questions, the names were piped into a series of name interpreter questions focusing on the respondent’s activities with the individuals named and the nature of the relationship between the two. More specifically, these name interpreter questions inquired about the type of the collaboration undertaken with the collaborator, details about the level of relationship and how they met, closeness of research expertise, communication frequency, grant activity, and general demographics. Data collected through the name interpreter questions (i.e. alter-level data) were aggregated into sums and averages that were further aggregated into network variables for each respondent. This provided summary data about each of the respondent’s networks. In addition to the name generator and interpreter questions, respondents were asked about their research activities, including grant submission and success rate, teaching and committee responsibilities, attitudes about and involvement in interdisciplinary research, work environment, and detailed demographic and academic background questions.

A random sample of 3,667 participants stratified by sex, rank, and discipline was developed from the population of academic scientists and engineers in six scientific disciplines (biological sciences, chemistry, computer science, earth and atmospheric sciences, electrical engineering, and physics) in the Research I universities. The disciplines were selected based on the level of female representation in those fields (low, transitioning, and high fields). The population was constructed using a two step process. First, web pages of departments that best reflected the disciplines of interest and directories were found online. Second, information (i.e. name, gender, and individual websites) for faculty that could be clearly identified as assistant, associate, or full professors was copied into a population database. Sample weights were calculated using the inverse of the probability of selection and employed in calculating results for this study.

A total of 1,774 completed surveys were received. Of those, 176 were removed due to ineligible rank or discipline. There were 21 surveys where the respondents had responded to over 95% of the questions, and thus they were included as well. The resulting final sample size used for analysis was 1,598. 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% (American Association for Public Opinion Research 2009).

This was an online survey developed 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 minutes to complete.

Dependent Variables

Four main dependent variables capture leadership in this paper. Three operationalize each of the three types of leadership – center, administrative, discipline – while a fourth combines all three into a single indicator of science leadership. A 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 transformed this variable to a discrete one-zero indicator of center leadership (1=yes). A University Administrative Leader is operationalized as an individual responded that they either currently hold a position as dean or department head /chair. This is transformed into a discrete one-zero indicator of administrative leadership (1=yes). Discipline Leaders include all faculty respondents that indicated they currently hold a position as an officer in a professional 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 transformed this variable into a discrete one-zero indicator of discipline leadership (1=yes). Finally, we created a fourth variable by combining the three leadership variables into a discrete one-zero indicator of Science Leader (1=yes).

Independent Variables

The independent variables of interest are the respondent’s science ability, aspects of their social relationships, and gender. Science ability reflects an individual’s ability to produce scientific knowledge. Production of science publications and grants are a common way to assess scientific ability. Several questions on the survey captured this. One open-ended question asked respondents to estimate the average number of publications they had submitted in the last five academic years. Another open-ended question asked respondents to indicate the average number of research grants submitted in the last five academic years. Lastly, respondents were asked if they had been the recipient of any of the following awards: dissertation or “best paper, a National Science Foundation career grant, a National Science Foundation fellowship, a young investigator award, or another science or engineering award. The total number of awards was calculated, resulting in a final variable reflecting the sum of awards conferred to the respondent. The names of the variables reflecting each measure of science ability are as follows: "average grants submitted", "average publications submitted", and "total awards given". All of these variables measuring science ability are continuous.

For the purpose of this study, social relationships were measured using data on the respondent's collaboration network – the network of individuals both inside and outside of the respondent's institution with whom they 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". Respondents were limited to naming five individuals for each name generator such that respondents were limited to a total of ten possible close collaborators.

As mentioned previously, network structure (i.e. density and ratio of external to internal ties), network size, the strength of ties in the network, and the number of women in the network are the variables of interest. 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:

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

The name of the variable reflecting the density is called "density of network".

The E-I index assesses the extent to which a respondent's network is situated more or less externally to his or her university. Krackhardt and Stern [76] developed an E-I index to capture the relationship between external and internal links of an individual's network. For this study, external links are specifically the collaborative ties between the respondent and named close 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:

$$\text{E-I index} = (ECL - ICL) / (ECL + ICL). \quad (2)$$

where ECL is the number of external collaborative links and ICL is the number of internal collaborative links. Scores the E-I index range between -1.0 and +1.0. As the E-I index approaches +1.0, the ratio of external links to internal links increases. As the E-I index 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".

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 "size of collaboration network". The strength of ties is measured by the average number close friends in the respondent's collaboration network. This was captured by a name interpreter question in the survey where the respondent to "please indicate if this person is a close friend". The name of the variable measuring the strength of ties is "average number of close friends".

To measure the women in the respondent's network, we summed the number of collaborators who were identified by the respondent as being female. The name of this variable is "total females in collaboration network". The gender of the respondent is measured as a dichotomous variable (1=female). The variable reflecting the gender is called "female". Control variables include biological sciences, chemistry, computer science, earth and atmospheric sciences, electrical engineering, and physics, minority, age, and age squared. A summary of the dependent, independent, and control variables is in Appendix A at the end of this paper.

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 leadership. Sample weights were used and listwise deletion of observations due to missing values resulted in a sample size of 1,317 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:

> Science Leadership = *f*[Science Ability (grants submitted, publications submitted, awards earned), Social Relationships (collaboration network size, density, EI Index, close friends, number of women in collaboration network), Female, Controls (minority, field, age, age squared]

Descriptive Statistics

Descriptive tables are provided below. Table 1 provides descriptives for the dependent and independent variables. Table 2 presents ANOVA results for differences of means between men and women for the different types of leadership.

TABLE I
DESCRIPTIVE STATISTICS

Variable	N	Mean	Standard Deviation
Dependent Variables			
Total Science Leadership	1598	0.26	0.44
Center Leadership	1598	0.07	0.26
Administrative Leadership	1598	0.05	0.21
Discipline Leadership	1598	0.18	0.39
Independent Variables			
Science Capacity			
Average Grants Submitted	1554	2.55	2.39
Average Publications Submitted	1589	3.76	5.36
Total Awards Received	1598	0.67	0.79
Social Relationships			
Density of Network	1394	0.47	0.24
E-I Index	1436	0.00	0.53
Average number of close friends in network	1435	0.23	0.28
Total Size of Network	1436	5.09	2.45
Total Number of Females in Network	1435	0.73	1.06
Gender			
Female	1598	0.46	0.50
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

Among the dependent variables, it can be seen that slightly more than a fourth of all respondents are science leaders (0.26).As we measure it here, discipline leaders comprise the largest group (0.18), followed by center leaders (0.07), and administrative leaders (a mean of 0.05). Distribution of leadership types by gender in Table 2 shows that women are more likely to report being a science leader (male 0.23; female 0.27), while men are generally more likely to be administrative and center leaders. Among the control variables, very few respondents are minorities (four percent or 63 respondents). There is almost equal distribution of respondents among the scientific fields. Most of them are in chemistry (18 percent), followed by biological sciences and physics (both represented by 17 represented), then computer science (16 percent), and finally electrical engineering (13 percent). Age-squared is approximately 2409.

TABLE 2
DIFFERENCE OF MEANS, MALE AND FEMALE LEADERSHIP

	Male		Female		
Leadership Type	N	Mean (SD)	N	Mean (SD)	Significance
Discipline Leadership	867	0.13(.34)	731	0.21(.411)	***
Administrative Leadership	867	.05(.22)	731	.03(.18)	***
Research Leadership	867	.09(.29)	731	.05(.22)	*
Total Science Leadership	867	.23(.42)	731	.27(.44)	***

Significance: p<.10*, p<.05**, p<.01***

On average, scientists submit 2.55 grants, publish 3.76 articles per year, and receive .67 awards per year. The average age of the respondents is 48 years old and approximately half of the respondents are women (mean of 0.46).Respondents report an average of five collaborators (network size), less than one in five of which are female. Approximately 23 percent of all collaborators named in the survey are close friends (strong ties) of the respondent and 47 percent of all possible ties among collaborators. . An E-I Index of zero indicates that on average scientists have report as many internal as external ties.

V. ESTIMATION FINDINGS

Tables 3 and 4 present the results from the model estimations from the logistic regression analysis. Table 3 provides results for the total science leadership and discipline leadership models. Table 4 provides results for the center and 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). All of the measures for science ability are significant at the p<.01 level and are positively related to total science leadership. More awards, submitted grants, and publications are positively associated with the attainment of leadership positions and support our hypotheses H5 and H6 that science ability is associated with leadership attainment. Additionally, all of the social relationship measures related to collaboration networks are significant at the p<.01 level, except for density which is significant at the p<.05 level. Also, all of these measures except for the network density, number of women in the network and the E-I index are positively related to total science leadership supporting our expectations that larger, less dense collaboration networks with strong ties contribute to the attainment of science leadership(H1, H2 and H4). It is possible that dense networks are more important for some kinds of leadership than for others. Additional analysis of different types of leadership will provide further clarity for this finding.

The number of women in the collaboration network and the ratio of external to internal ties in the collaboration network are significantly, but negatively related to the attainment of science leadership positions. In other words, having fewer women in one’s collaboration network and having fewer external ties in one’s collaboration network is more likely to lead to the attainment of science leadership positions. The findings tend to support our expectations regarding females in networks (H8), but are again opposite of the expectations stated in H3 that external ties would be more important for leadership. This may be due to the dominance of center and university administrative leadership in the measure. To obtain these positions of leadership, local reputations and connections are likely more important than distant connections.

Examining the odds ratio we see that an increase of one woman in the network reduces the likelihood of being a leader by 0.87. Further analysis below will explore this. Finally, we find that being a female is positively and significantly related to the attainment of science leadership positions; being a woman increases the likelihood that one will attain a science leadership position. Odds ratios show that being a woman increases the likelihood of being a leader by a factor of 1.59. Among the odds ratios related to science ability, the total awards given increases the likelihood of being a leader the most (by 1.25), while the average publications submitted has the least impact on increasing the odds of becoming a leader (1.04). When examining the social relationship variables, it is the average number of close friends that increases the likelihood of becoming a leader the most (by 1.71), while the density of the network and the ratio of external to internal ties has the least impact by increasing the likelihood by only 0.68. Among the control variables, it is 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).

Results from the 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 and publications and having fewer women in a network is positively and significantly related to discipline leadership. In fact, the only substantive difference between the first two models is the lack of significance of the EI Index. This should be interpreted to indicate that neither a greater proportion of external nor internal collaborative ties is associated with leadership. Perhaps the balance of other types of ties matters, or leaders in their disciplines tend to have balanced networks.

Center administration leadership models (Models 3) demonstrates some similarities as well as some dissimilarities with the previous models. As found in the results for the network variables in Models 1 and 2, Model 3 (center leadership) demonstrates that larger networks with close connections are positively and significantly related to leadership. However, unlike Models 1 and 2, Model 3 shows that denser networks with greater proportion of internal ties are positively and significantly related to center leadership. We believe that it is likely that more dense networks are associated with center leadership as centers are often more local where most of the ego's collaborators would know each other. As for non-network variables, more scholarly awards and science outputs are positively and significantly related to center leadership. This is similar to the first two models. In regards to gender, being a woman and having women in one's network is negatively and significantly related to center leadership. This contrasts with the first two models where women are more likely to be leaders. Possibly this has to do with greater demand for women in more visible disciplinary leadership positions as well as the lack of institutional efforts or polices at the university level for women center leaders and a lack of explicit policy or willingness (both at the granting agency and in universities) to advance women as center leaders.

Findings for Model 4 (administrative leadership) are the most divergent. While the ratio of external to internal ties is again significantly negative and findings show a return to a negative sign on the significant density, there is a reversal of sign for tie strength and network size. This may indicate that deans, department heads and chairs are less likely to engage in research or maintain strong collaborative ties. Also, presumably, administrative leader networks are made up more of other administrators and less of collaborators. As for Science Ability, administrative leadership is not predicted by awards or journal publications. However, average grants submitted is positively and significantly related to administrative leadership. Perhaps grant getting ability may demonstrate an important type of resource building skill that is valued at the university. It should be noted here that the reverse may also be true: administrative leadership would tend to reduce ability of scientists to produce. Additionally, similar to center leadership, women are less likely to be university administration leaders. Overall, Model 4 diverges more than the other models from the expectations established in the hypotheses.

Finally, in terms of the control variables we see that minorities, like females, are more likely to hold discipline leadership positions. There are disciplinary distinctions related to leadership type, however all models tend to show that older people are more likely to be leaders but that there are non-linear limits to the relationship as age squared is negative in all models.

TABLE 3

ESTIMATION RESULTS: TOTAL SCIENCE LEADERSHIP AND DISCIPLINE LEADERSHIP

	Model 1: Total Science Leadership				**Model 2 : Discipline Leadership**			
	Coefficient	Standard Error	Significance	Odds Ratio	Coefficient	Standard Error	Significance	Odds Ratio
Science Ability								
Average Grants Submitted	0.05	0.01	***	1.05	0.03	0.01	**	1.03
Average Publications Submitted	0.04	0.00	***	1.04	0.02	0.00	***	1.02
Total Awards Given	0.23	0.04	***	1.25	0.31	0.04	***	1.36
Social Relationship								
Density of Network	-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
Average Number of Close Friends	0.54	0.10	***	1.71	0.67	0.11	***	1.96
Size of Collaboration Network	0.14	0.01	***	1.15	0.17	0.02	***	1.18
Total Females in Collaboration Network	-0.14	0.03	***	0.87	-0.07	0.04	**	0.93
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 4

ESTIMATION RESULTS: CENTER LEADERSHIP AND ADMINISTRATIVE LEADERSHIP

	Model 3: Center Leadership				Model 4 : Administrative Leadership			
	Coefficient	Standard Error	Significance	Odds Ratio	Coefficient	Standard Error	Significance	Odds Ratio
Science Ability								
Average Grants Submitted	0.12	0.02	***	1.13	0.09	0.02	***	1.10
Average Publications Submitted	0.02	0.00	***	1.03	0.01	0.01		1.01
Total Awards Given	0.24	0.06	***	1.27	0.01	0.08		1.01
Social Relationship								
Density of Network	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
Average Number of Close Friends	0.59	0.15	***	1.80	-0.39	0.20	**	0.67
Size of Collaboration Network	0.19	0.02	***	1.20	-0.05	0.02	**	0.95
Total Females in Collaboration Network	-0.16	0.05	***	0.85	0.02	0.06		1.02
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

VI. Discussion and Conclusion

This study sought to understand how science ability, social relationships, and gender are associated with science leadership. We find that leadership is associated with all three, but at different ways depending upon the type of leadership position. Science production is generally associated with holding a science leadership position. Although, university science leaders are less likely to have large, dense collaborative networks as their administrative roles probably limit their ability to conduct research. Center leaders continue to seek grant funding and produce papers, as do discipline leaders.

Findings on network structure indicate that individuals who take on different leadership positions also depend upon very different sources of resources and information. Center leaders have larger, denser networks and stronger ties: factors important for a high trust collaborative research environment. 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: they have a high degree of network betweeness, situated between trusted collaborators who do not know each other. This enables them to obtain and control the flow of resources, and enhance their influence. Administrative leaders have networks that are less dense, smaller, more internal and made up of a smaller proportion of close friends, than those of non-administrative leaders. Perhaps if we captured a different type of network, other than collaboration networks, we would see different structural patterns. Nevertheless, it is interesting to note that although administrative leaders guide universities, they are somewhat isolated from the research community they are supposed to lead.

We also found interesting results as it relates to gender. Being a woman is significantly associated with the likelihood of having science leadership positions in general, but this is primarily because of the higher likelihood that women are in positions discipline leadership positions. Women are less likely to be center or university leaders: positions that are more likely to control resources and more likely to have direct effects on the conduct of science. There at least two reasons why women are more likely to be discipline leaders: women are more willing to provide service to the discipline and there are fewer women available and a higher demand for female representation in professional associations [77], [78]. Having more women in one’s collaboration network decreases the likelihood of having a science leadership position. While this seems paradoxical on the surface, it is consistent with literature indicating that while women are assets as leaders, their presence in social networks can be detrimental because they cannot generate as much social capital for those possibly wanting a leadership position [71]-[81], [82].

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 networks and productivity change over time as a result of being a leader. Nonetheless, the current study does have implications for research in that it underscores the very complex nature of leadership and that even in one context, multiple dimensions are present that deserve careful attention.

Overall, we have demonstrated that academic science leadership is associated with both academic reputation and on network structure. These effects vary across different types of leadership, but in explainable ways. Future work should further explore the specific case of female leadership in science.

APPENDIX A
VARIABLES AND MEASURES

Factors	Variables	Related Survey Questions/Transformed Variables	Measurement
Leadership	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
	Center Leadership	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
	Administrative Leadership	Please tell us whether you currently hold, or have ever held, any of these positions: (Department Chair/Head or Dean)	1= yes
	Total Science Leadership	All three above questions	1=Leader
Science Ability	Submitted Grants	Over the past five academic years, on average how many grants have you submitted?	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.
Social Relationships	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?	Density equation in methods section. EI Index equation in methods section
	Network Size	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?	Sum of all people named.
	Strength of Ties	Please indicate if this person is: (in government, female, a close friend, senior to you, junior to you, neither senior nor junior to you)	Averaged number of 'close friend' selected
	Number of Females in Network	Please indicate if this person is: (female)	Sum of females
Gender	Female	Are you? (female, male)	1=Yes
Controls	Minority	What is your race/ethnicity? (Blacks/African American, Latino/Hispanic, and Native American)	1=Yes
	Science Field	What is your discipline? (biology, chemistry, physics, earth and atmospheric sciences, electrical engineering, and computer science)	Six Dummy Variables
	Age	What is the year of your of birth?	2007 minus response
	Age squared	What is the year of your of birth?	Age squared

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