

Effects of Network Size and Gender on PI Grant Awards to Scientists and Engineers: An Analysis from a National Survey of Five Fields

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Presented at the 2006 Annual Meeting of the Association for Public Policy and Management (APPAM).
Madison, Wisconsin, November 2-4, 2006.

“Data analyzed in this paper were collected under the auspices of the 2005-09 project, “Women in Science and Engineering: Network Access, Participation, and Career Outcomes,” (NETWISE 2006) a project funded by the National Science Foundation (Grant # REC-0529642) (Co-PI’s Dr. Julia Melkers and Dr. Eric Welch). Opinions expressed in this paper are not necessarily shared by the NETWISE 2006 project leadership and/or the University of Illinois at Chicago.”

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INTRODUCTION

In the research setting, networks are recognized as critical in the development and diffusion of knowledge (Newman, 2001; Frenken, Holzl and de Vor, 2005; Mote, 2004, among others). Network ties are believed to represent social and professional resources that can be accessed and put to use in the creation of new scientific outputs and outcomes. However, most of these studies rely on the examination of networks as evidenced by co-authorship linkages on journal articles, despite the fact that there are many different outcome indicators that can serve as outcome measures: grant getting ability, awards and other types of recognition, and satisfaction, are a few. Moreover, research to date has not empirically examined the more complex and integrative questions concerning (1) the effects that antecedent factors have on network size, and (2) how these factors, along with network size determine research outcomes.

In the field of science policy, studies have show that despite increases in university enrollment and graduation levels in most science and engineering subfields, women academic faculty continue to be underrepresented and have lower salaries, rank or position, and productivity (e.g. Xie and Shauman, 2003). Prior research has identified some of the barriers that women face: discrimination, work-family imbalances, and ineffective mentoring (Rosser 1988, 1990, 1997; Tobias 1992). However little is known about how men and women scientists network structures differ. Is not clear, for example, whether men and women have similar sized networks at comparable stages of their careers. Less is known about the roles that social and professional networks play in fostering different outcomes – hiring, advancement, publication, funding, and satisfaction – for men and women. The broader policy question that we would like to address is: Do women faculty have lower access to resources and to critical networks that potentially control resources necessary for success?

This paper addresses both of these gaps in the literature by comparing and contrasting network size and production of men and women in five fields of science. We briefly assess gender differences in formal collaborative networks, informal advice networks, and across a variety of different measures of productivity. We then focus on one specific outcome, receiving a research grant as primary investigator, to better understand how size of collaborative network, gender and productivity are related. Our rationale for choosing PI grant award as a focus for analysis is that these awards are often critical determinants of promotion and tenure in science and engineering. As a result the paper address the following research questions:

- In what ways do women's and men's networks differ?
- In what ways does the productivity of women and men differ?
- How are network size and production related?
- If there is a relationship between networks and production, to what extent does gender matter?

We first present prior literature in this area paying particular attention to network size and production. We then develop a theoretical model and present a few hypotheses to guide the study. Then using survey data collected from a pretest for national network survey of men and women faculty in science and engineering, we present an exploration of descriptive statistics and from an endogenous probit regression model that simultaneously estimates network size and award of a research grant as a PI. Findings help specify the interplay of networks, gender and grant success.

PRIOR RESEARCH

Using Social Network Data in the Study of Science

The data reported in this paper are drawn from a large study heavily reliant on social network data collection methods and related analysis. A social network is the set of relationships that exist among individuals, groups or organizations that enable the flow of data, information, knowledge, and other resources. Social network analysis (SNA) comprises a set of methods that can be used to examine the relationship or tie between two or three actors (or nodes), or an entire set of actors. Social network analysis is distinguishable from other types of analysis in the social sciences because it focuses on the relationships among network members, rather than on their characteristics or attributes (Wasserman and Faust, 1999; Monge and Contractor, 2003). As such, it provides the potential for an additional dimension of explanation for behaviors, processes, and outcomes. The method of network analysis has been applied from diverse perspectives for a variety of purposes including communication among individuals and across organizations (Monge and Contractor, 2003), spread of disease (Hartigan, 1980), diffusion and transfer of knowledge (Collins, 1974), economic performance (Uzzi, 1996), and scientific collaboration (Newman, 2001), among others.

Social network research involves not only the identification, but also the valuation of relationships. For example, even though a tie exists between two individuals, the directionality of the tie may exist in either one or two directions (Monge and Contractor, 2003; Wasserman and Faust, 1999). SNA can also be applied to different levels of analysis. At the individual (ego-centric) level, the analysis focuses on the relationships and attributes of nodes in the network (individuals, groups or organizations), while a global level of analysis centers on the network as a whole. An ego-centric perspective (as is used in this paper) can be used to examine how the characteristics of individual networks, and related ties, are related to ego characteristics as well as outcomes. A global perspective would be used for research that compares the structure of fields of science, as has been often done in network studies of bibliometric and citations links between researchers and institutions.

Research on social network size has demonstrated the social capital value of network participation and also shown linkages between network size and outcomes. A larger network increases possibilities of receiving diversified information and securing information regarding complementary assets (Greve, 1995). For scientists, large networks can facilitate the discovery of opportunities as well as the identification, collection and allocation of scarce resources (Birley, 1985; Nicolaou & Birley, 2003). Other social network research has been conducted on academic collaboration among scientists in physics

and biology (Newman 2001a,), physics, biomedicine, and computer science (Newman 2001b,) mathematics and biomedicine (Albert & Barabasi 2002), and mathematics and neuroscience (Barabasi et al., 2002). Studies of collaboration show that larger networks tend to produce higher quality research as measured by citation impacts (Oliver, 2004; Herbertz and Muller-Hill, 1995; Godin and Gringras, 2000; Narin et al., 1991; Diamond, 1985). Models of science and technology human capital (Dietz et. al, 2000, Bozeman et al, 2001, and Bozeman and Corley, 2004) also point to the shared learning and enhanced productivity that occurs in the knowledge exchange of collaborative work. The increased likelihood of common co-collaborators continuing their collaboration with one another demonstrates the potential for academic collaboration networks to generate significant amounts of career-related social capital and enhances access to greater numbers of networks (Ahuja 2000).

H1: Individuals with larger collaborative networks are more likely to produce higher quality outputs.

Prior research has addressed the barriers that women face in the sciences and engineering, from discrimination, to work-family imbalances, to ineffective mentoring (Rosser 1988, 1990, 1997; Tobias 1992, 1995; Morse 1995; Nelson Report 2005, Fox, 1982; among others). Much of the prior research is rich with anecdotal evidence that explains the circumstances and conditions of women scientists as they progress in their careers. It suggests that women's advancement and success depends on early identification of, participation in, and adequate access to, networks. Building dense, interconnected networks and participating in them produces social structure and social capital from which members may then benefit (Coleman 1988). However, some evidence suggests that women have significantly different access to career-related social capital: the features of social organization such as networks, norms, and social trust that facilitate coordination and cooperation for mutual benefit (Putnam 1995). However, research has also provided evidence that men and women's networks differ (Moore, 1990) and that women are not as effective in creating social capital through network participation (Emmerick, 2006) Bozeman and Corley also show that women have smaller networks than men across their career (2004).

H2: Women have smaller collaborative networks than men.

Collaboration networks provide all scientists with access to career-related social capital networks that increase the likelihood of success in their fields, but women's participation as collaborators has been analyzed to a far lesser extent than has the effect of collaboration on academics in general. Long, McGinnis, and Allison (1980) further underscore the importance of collaboration networks to women scientists in their analysis of productivity using citation counts. However, it is less clear whether there are gender based differences in the positive outcomes of collaborative participation. In terms of some of the different outputs or opportunities that exist in science and engineering, such as grant opportunities and awards, it is possible that because women's networks are smaller, due perhaps to lower access and participation, they may be less likely to receive opportunities and awards than men. Moreover, it is possible that there is some level of system bias that favors scientific outputs by men over those produced by women.

Because this paper is primarily interested in the determinants of PI grant awards, we posit the following exploratory hypothesis:

H3a: Women are less likely to receive PI grant awards than men.

Aside from the nature of the networks themselves, what aspects of the academic work environment contribute to, or detract from the creation of social capital? Prior research has shown that the time that faculty have available for research has important effects on productivity and the quality of that production (Creswell, 1985, Boyer and Cockriel, 2001; Levitan and Ray, 1992.) Studies of academic productivity have demonstrated significant links between service and teaching commitment, and resulting lower productivity. Further, this has been demonstrated not only in raw numbers, but also in the quality of those products. For example, Fender, et al. (2005) found significant relationships between teaching and service responsibilities of academic faculty and the extent to which they published in elite journals. To what extent does the nature of academic work obligations and work opportunities enhance, or deter academic productivity and the ability to access networks? To address this, we generate the following hypotheses:

H4: The propensity of receiving a PI grant award declines as the level of competing activities (course instruction and committee membership) increases.

In addition, numerous human capital factors may contribute to the creation science and engineering outputs. The emphasis in some areas of science on postdoctoral appointments provides important access to new sets of collaborative networks and relationships. Evidence has shown important linkages between postdoctoral experiences and future academic productivity rates (McGinnis et. al, 1982, Robin and Cahuzac, 2003, Carayol and Matt , 2003). Therefore, we posit:

H5: Experience in skill building activities, such as postdoctoral experiences will increase the propensity of an individual to receive a PI grant award.

DATA, MEASURES, AND METHODS

Data

The data reported in this paper comes from the first stage of a large three-year study of social and collaborative networks of scientists and engineers.¹ The multi-year effort include a large national two-stage survey of academic scientists and engineers, as well as additional surveys of postdoctoral fellows, faculty mentors and scientists working in government laboratories. The data reported here are drawn from the pretest of a large

¹ "Women in Science and Engineering: Network Access, Participation, and Career Outcomes," (NETWISE 2006) a project funded by the National Science Foundation (Grant # REC-0529642) (Co-PI's Dr. Julia Melkers, Dr. Eric Welch and Dr. Sharon Mastracci.).

national two-stage survey of academic scientists and engineers.² This survey is unique in that it captures the structure of collaborative and advice networks that are not accessible through existing data.

The survey included three major categories of questions. First, the most extensive of these questions was a series of name generator and name expander questions based on research methods typical to sociological studies of social networks. The name generator questions were used to identify key collaborators or advisors in several key categories, including formal as well as research advice networks. Because an important focus of the study is on the social aspects of the academic enterprise, two name generators were used to identify “advice” networks,” including addressing career issues as well as institutional issues. While the name generators are useful for identifying collaborators, it was also important to understand characteristics of these individuals. To do this, a series of “name expander” questions were used to capture the nature of the collaboration (nature of research product), details about the level of relationship and origin of acquaintance, closeness of research expertise, communication frequency, grant activity, and general demographics.

The survey was implemented online using Sawtooth Software®. Individuals were alerted to the survey via personal email or traditional mail (split sample)³ and provided with a unique userid and password (and directed to the website.) Three reminders were sent, with a combination of email and postcard reminders. One of the advantages of conducting the survey online is that questions could be electronically branched depending on respondent characteristics (e.g. faculty rank.) The electronic platform was also critical to the name generator and corresponding name expander questions (names were “piped into” the name expander questions.)

The survey sample was drawn from the population of academic scientists and engineers in five disciplines in Carnegie-designated Research I universities (151 universities.) The disciplines were selected based on the level of female representation in order to allow for comparison across male-dominated versus gender balanced fields of study. The fields were chemistry, biological sciences, agricultural sciences, electrical engineering, and math⁴. Overall, one hundred and fifty individuals (equally split by gender) were invited to the survey in each field, for a total sample size of seven hundred and fifty. Prior to the mailing, contact information was confirmed. However, a portion of the emails were not workable. Overall, two hundred and fifty usable responses were received for an overall response rate of 33.3%. Responses were fairly evenly distributed across the five fields, gender (55% women) and rank (23 % assistant professor, 34 % associate professor, and 42 % full professor.)

Measures and Methods

The primary interest of the modeling section is to determine what factors affect the propensity of scientists to receive a primary investigator grant award. The importance of a PI award cannot be understated. Prior to the development of the survey instrument,

² The full study will be implemented in November 2006, with data ready for analysis in March 2007.

³ This split sample was used to determine response rate differences between email-only contacts versus a mixed contact of traditional mail and email (the later produced a 10% higher response rate.)

⁴ Chemistry and biological sciences will also be included in the full national survey, along with other fields similar to those selected for the pretest, but with insufficient numbers of women to include in the pretest.

ad hoc interviews with scientists revealed that promotion and tenure decisions are heavily dependent upon evidence of grant-getting ability. Faculty members, especially assistant professors, are evaluated based on their ability to obtain grants. While universities may vary dramatically in the extent to which grants are weighted in the tenure and promotion decisions, among Carnegie I designated institutions grants are a primary consideration. To measure grant awards, we converted a question asking researchers to indicate how many PI grants they received over the past two years. We then recoded this variable into a discrete dependent variable in which awardees were coded 1 and non-awardees were coded 0. As shown in Table 2, 78 percent of all respondents were awardees.

A secondary focus of this research is the effect of collaborative network size on the probability of receiving a PI award. In addition, we are interested in understanding how other structural factors, such as faculty rank, gender, and age, are associated with collaborative network size. To measure network size, we summed the number of unique network ties from three network name generation questions that asked respondents to name up to five individuals in their research laboratory, up to five individuals in their university and up to seven individuals outside their university with whom they have collaborated over the past two years (see Appendix for the specific measures). Individuals were not forced to fill in names for any of these questions. Although the survey provided entry spaces for 17 names, the number of names nominated ranged from 1 to 11, with an average of 4.7 individuals. This finding falls somewhere in the middle of network sizes found in the literature (Bozeman and Corley, 2004; Moore, 1990).

To capture some of the experiences that might affect networks size and grant awards, we utilize two discrete variables: one that codes whether they individual has ever had a position as a post-doctoral researcher and one that controls for the extent to which faculty are jointly appointed to two different departments. Table 1 shows that 63 percent of respondents have had a post-doc and 15 percent report having joint appointments. In addition, we incorporate two measures to assess the extent to which faculty engage in work-related activities that might compete with their ability to obtain grants: total number of courses taught or co-taught and total number of committees served on during the past year. As Table 1 indicates, faculty respondents teach an average of 3.5 courses, while they serve on an average of approximately six committees.

Other measures used in the model include rank, gender, age and field. Although measurement of the first three is straightforward based on specific questions asked in the survey, the field variable was part of the sample design. As mentioned above, the pre-test survey was administered to five different fields: chemistry, biology, civil engineering, agricultural sciences, and math. While we recognize that these fields differ substantially from each other, in this study we have only coded the biology field as a discrete variable, which we compare against all other fields in the sample. Our decision in this regard is justified on the basis that the field of biology is more different than the other fields than the other fields are from each other; biology has the highest percentages of women in the five fields surveyed and based on the data, faculty member in biology have substantially larger networks. In this sample, approximately 18% are from biology. The average age is around 48 and assistant, associate and full professors make up 24, 33, and 43 percent of the respondents respectively.

Table 1. Descriptive Statistics for Endogenous Probit Model

	n	Mean (Standard Deviation)
Collaborative Network Size	221	4.70 (2.59)
PI Grant Ever	246	0.78 (0.41)
Associate Professor	246	0.33 (0.47)
Full Professor	246	0.43 (0.49)
Female	246	0.54 (0.50)
Postdoc	246	0.63 (0.48)
Number of Courses Taught	243	3.46 (1.32)
Number of Department and University Committees	233	5.74 (2.14)
Age	242	48.47 (10.87)
Joint Appointment	241	0.15 (0.36)
Biology	246	0.18 (0.39)

Aside from the variables that we use in the regression model (Table 1), we have also examined a broader range of network size and academic production measures. These additional variables include collaborative network size inside and outside the university, size of advice network, number of journal articles, review proceedings, book chapters, electronic pre-prints, invited presentations, total grants submitted, PI grants submitted, Co-PI grants submitted, total grant success, PI grant success, Co-PI grant success, and number of federal grants received. All of the network variables are counts of individuals nominated, all grant related variables are measured as counts and all of the other production related variables are measured on an ordinal scale of narrow ranges (see Appendix for specific questions). As will be discussed in the findings section, we present the means of these variables by gender and conduct difference of means tests on each to determine if networks size and work outputs are different for men and women.

Method

There are two parts to our data analysis. First, we conduct an exploratory analysis of descriptive statistics broken out by gender. We conduct difference of means tests on all categories of variables to determine if there are statistically significant differences in network size and academic outputs for men and women. Second, using the *ivprobit* function in STATA, we apply an endogenous dependent variable model to a nested pair of equations: one that predicts network size and the other that predicts the probability of receiving a PI grant award.

Endogeneity is a primary concern when attempting to establish the direction of relationship between network structure and outcomes. How do we know, for example, that network ties actually determine some type of output, rather than the other way around? As an empirical problem, endogeneity arises when an independent variable in a linear regression equation, for example, is correlated with the residuals of the regression equation. Endogeneity results in inconsistent estimators. There are two primary solutions. First, it is possible to examine changes in network ties and outcomes over

time, using panel data analysis techniques. Since this option is not available to us, we utilize the second; to employ a nested or simultaneous equation model such that the predicted values of one equation are utilized in the second equation. The STATA *ivprobit* tool is a maximum likelihood estimation technique that can be expressed in the following two equations:

$$\begin{aligned} y_{1i}^* &= y_2\beta + x_{1i}\gamma + u_i \\ y_{2i} &= x_{1i}\Pi_1 + v_i \end{aligned}$$

where i is a set of individuals that runs from $i = 1, \dots, N$, y_{2i} is a $1 \times p$ vector of endogenous variables, and x_i is a $1 \times k_1$ vector of exogenous variables. The equation for y_{2i} is written in reduced form and both equations are solved simultaneously. By assumption $(u_i, v_i) \sim N(0, \Sigma)$ where σ_{11} , the variance, is normalized to one in order to identify the model. β and γ are vectors of structural parameters, and Π_1 is a matrix of reduced-form parameters. As with all discrete choice models, y_{1i}^* is not observed; instead, the model fits the following observations:

$$y_{1i} = \begin{cases} 0 & y_{1i}^* < 0 \\ 1 & y_{1i}^* \geq 0 \end{cases}$$

It is possible to rewrite the above equation using the variable names that represent the measures discussed above:

Probability of PI Grant = (number of collaborative ties, female, associate professor, full professor, postdoctoral experience, number of courses, number of committees)

Number of Collaborative Ties = (age, joint appointment, biology field, never married)

Number of collaborative ties is the instrumented variable, while all other right side variables are the instruments for the estimation. The above equation is estimated two times: for all assistant, associate and full professors and for assistants only. Although we recognize that the sample size is small for the assistant only regression, it is these individuals' careers that are most affected by a PI grant award. The discrete variables for associate and full professors are dropped for the assistant only regression estimation. We report both the first and second stage regressions. The first stage provides the reduced-form equations that specify the relationships between the endogenous variables and the instruments. We also report the Wald statistic for the equation that tests the hypothesis that all of the slope coefficients are jointly zero, and the Wald test of exogeneity which tests whether there is enough information in the equation to reject the null that there is endogeneity. If the p values for these statistics are not significant, then a normal probit estimation may be more appropriate.

FINDINGS

To first explore reported differences between men and women in the pretest dataset, Table 2 presents the means and difference of means results for reported network size and academic production measures by gender. Two striking findings deserve discussion. First, women report larger networks across all measures and women also report higher averages in eight of the twelve production categories. Second, few of these differences are statistically significant at the 0.05 probability level. The exceptions, at different levels of significance, are total size of collaborative network, size of university network, book chapters, co-PI grants submitted and co-PI grant success. In each of these, women report higher levels than men do.

Consistently higher overall reporting for all variables by women may indicate some level of response bias. Future work will compare these findings with associated bibliometric and CV data to determine their accuracy. Nevertheless, if the network differences are accurate, our findings contrast sharply with those of Bozeman and Corley who find that men's networks are larger than women's networks (2004). The difference appears to be in the time frame considered. Bozeman and Corley look at collaboration over career, while the name generators used here ask respondents to consider only the last two years. The contrast in findings may indicate that while women's career-length networks are smaller, at any one point in time women may have larger active networks. If these findings become substantiated with the larger survey or with bibliometric data, it may indicate that women and men have fundamentally different collaborative strategies or structures in science and engineering. Men may create more overall collaborative ties than women, but they may also switch ties more often and manage fewer at one time than women. A substantiated finding would also support Emmerick (2005) who found that men were more effective than women in using collaborative/team resources to create social capital. Whether this pattern holds and whether the pattern varies across academic ranks and fields of science and engineering remains to be seen. Similarly, the effects that these different networking structures or strategies have on success remain to be seen.

Women clearly report higher levels of output in all categories except conference proceeding, electronic pre-prints, and PI grant success. The largest differences in means are for co-PI grants submitted and for federal grants received. However, due to the high standard deviation for women, these differences are not statistically significant. Women report that they are co-PI on approximately one more grant submitted and one more federal grant received in the last two years than men do. Both of these differences are statistically significant. We might interpret the grant submission effort in light of the findings on size of collaborative networks: women may be involved in more grants as co-PIs, which might have a positive effect on their short-term network size. The finding that women receive more federal grants (albeit not statistically significant at this point) than men (albeit not statistically significant at this point) may be linked to NSF Career grant awards for women), a policy effect. Alternatively, it may represent bias in the overall federal granting system, bias in respondent reporting, or different levels of grant seeking behavior of men and women related to federal grant. However, we believe these alternative explanations are less likely.

Table 2. Network Size and Academic Production for Men and Women

	Men		Women		Sig.
	n	Mean	n	Mean	
Network Size Measures					
Size of Collaborative Network	100	4.41 (2.68)	121	4.94 (2.51)	*
Size of Collaborative Network, Outside of University	113	2.06 (1.93)	133	2.32 (1.93)	
Size of University Network	113	1.58 (1.44)	133	1.90 (1.40)	**
Size of Research Discussion Network	113	1.11 (1.26)	133	1.21 (1.41)	
Production Measures					
Journal Articles	113	3.40 (1.76)	133	3.54 (1.520)	
Reviewed Conference Proceedings*	113	1.99 (1.34)	133	1.92 (1.28)	
Book Chapters	113	1.29 (0.61)	133	1.51 (0.85)	**
Electronic Pre-print Articles*	113	1.45 (1.13)	133	1.34 (0.87)	
Invited Conference Presentations	104	2.70 (1.52)	127	2.94 (1.61)	
Total Grants Submitted (PI and Co-PI)	113	6.42 (8.74)	133	7.47 (7.58)	
PI Grants Submitted	108	4.91 (6.83)	129	4.98 (5.47)	
Co-PI Grants Submitted	108	1.87 (2.65)	129	2.74 (3.42)	**
PI Grant Success*	101	2.14 (2.66)	121	2.06 (2.32)	
Total Grant Success	113	2.43 (3.39)	133	2.81 (3.97)	
Co-PI Grant Success	94	0.95 (1.26)	112	1.30 (2.24)	*
Number Federal Grants	99	1.86 (2.51)	113	2.82 (9.50)	

Tables 3 and 4 present the endogenous probit regression results for all faculty and assistant professors, respectively. Results for the two estimations reveal high strongly significant p values for the Wald tests for the equation and for the Wald test for exogeneity. Therefore we know that the estimation method and model are appropriate for examining the factors that affect PI grant success. In the first three columns of each table we report the first stage results in which collaboration network size is regressed on all instrumental variables. The last three columns of Tables 3 and 4 present the findings for the probit model. The sample size for the estimations dropped due to missing values.

First stage regression results for all faculty show that individuals in the biology field and those with joint appointments are more likely to have larger networks, while older people and a postdoc experience are negatively related to network size. Number of committees is also positively related to network size, indicating that committee involvement may bring researchers in contact with potential collaborators. Most

importantly, women are more likely to have larger networks. While this result was shown in difference of means tests above, controlling for other factors, the variable for female becomes highly significant.

Probit regression results show collaboration size to be a strongly significant determinant of PI grant success, which supports our hypothesis that network size matters for this measure of success. In addition, the postdoc experience is positively associated with PI grant success while committee work is negatively associated with PI awards. Both of these findings make intuitive sense and support our hypotheses that skills learned as a postdoc do much to prepare the individual for a successful academic career, and that individuals who are saddled with competing responsibilities, such as committee work, are less likely to produce highly desired outcomes. In general, these findings indicate that women have larger short-term networks and that these networks matter for PI grant success.

Table 3. Endogenous Probit Regression Results for All Faculty

	Collaboration Network Size			PI Grant Success (1/0)		
	Coefficient	Standard Error		Coefficient	Standard Error	
Collaboration Network Size				0.37	0.04	***
Female	0.74	0.36	**	-0.19	0.17	
Associate	-0.34	0.49		0.20	0.22	
Full	-0.01	0.58		0.26	0.21	
Postdoc	-0.84	0.38	**	0.31	0.17	*
Number of Courses	0.09	0.13		-0.01	0.06	
Number of Committees	0.15	0.08	*	-0.07	0.04	**
Age	-0.04	0.02	**			
Joint Appointment	1.36	0.44	***			
Biology Field	0.89	0.36	**			
Observations	210					
Constant	5.32	1.10	***	-1.11	0.44	***
Log Likelihood	-595.34					
Wald Chi Square	94.15		***			
Wald Test Exogeneity	11.60		***			

* p<0.10; ** p<0.05, *** p<0.01

Turning to assistant professors we see similar effects of gender on network size and of network size on outcomes: women are more likely to have larger networks and larger networks are positively associated with PI grant success. The first stage regression results in Table 4 show similar results to those reported in Table 3, except that biology, postdoc experience, and number of courses are no longer statistically significant determinants of collaboration network size.

In the probit model, the significance of a postdoc experience and the number of committee memberships disappear. However, the female variable shows a significant negative effect on PI grant success. These findings tend to support our hypotheses that women are less likely to receive PI grant awards than men. Moreover they indicate that

one of the strategies of women that women have, in the face of lower likelihood of receiving PI grant awards, is to develop larger networks, that can provide them with substantial inputs of knowledge on and advice about proposal development that then redresses the bias that may exist in the system.

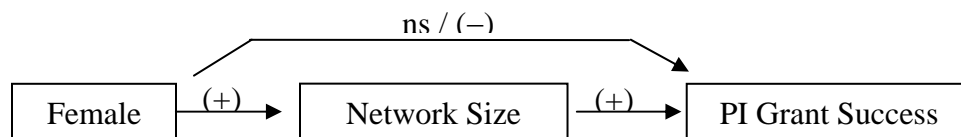
Table 4. Endogenous Probit Regression Results for Assistant Professors

	Collaboration Network Size			PI Grant Success		
	Coefficient	Standard Error		Coefficient	Standard Error	
Collaboration Network Size				0.44	0.05	***
Female	1.87	0.68	***	-0.67	0.33	**
Postdoc	-0.31	0.78		-0.09	0.41	
Number of Courses	0.43	0.29		-0.09	0.13	
Number of Committees	0.23	0.18		-0.14	0.09	
Age	-0.12	0.06	**			
Joint Appointment	1.55	0.80	**			
Biology Field	0.67	0.42				
Observations	49					
Constant	5.55	2.20	***	-0.38	0.82	
Log Likelihood	-122.97					
Wald Chi Square	76.09		***			
Wald Test Exogeneity	24.46		***			

p<0.10; ** p<0.05, *** p<0.01

CONCLUSIONS

We propose the following model to integrate the interrelated effects of network size and gender on PI grant success. In this model, women are more likely to have larger networks than men and larger networks are positively related to PI grant success. Moreover, depending upon the population women may or may not be more likely to receive PI grants. For assistant professors, we see that the direct effect of female on PI grant success is negative, while for faculty at all stages of their careers, gender is not a direct determinant of PI grant success.



Although it is beyond this data and the scope of this paper to determine why women have larger networks, we offer some possible interpretations. First, it is possible that women prefer larger active networks than men. Various research findings in the literature show that women's kinship networks are larger, but that their professional networks are smaller (Moore, 1990). Moreover, research in academic science and engineering indicates that women's career networks are smaller (Bozeman and Corley, 2004) or may be navigated differently (Emmerick, 2005.). Nevertheless, context matters

and in this case two contextual factors may explain our findings. First, short-term networks as measured by the questions used in this analysis may be different than career networks evident from CV and bibliometric data. Women may prefer to maintain a larger number of active ties at any one point in time than men, but their network structures may be more stable than men, who may change their collaborative networks more frequently.

Second, it is possible that women's networks are larger because they are more willing to contribute to or more likely to be asked to contribute to grant proposals as a co-PI. Women report much higher levels of grant funding than men, and higher number of co-PI grant submissions and success. Hence, it is possible that either (1) co-PI grant opportunities result in larger networks, or (2) the larger networks that women maintain lead to more opportunities, or (3) both factors happen simultaneously. Regardless the directionality here, if there is a relationship between co-PI grant submissions and network size, this may then be one of the generating factors that helps inform and train women, enabling them to obtain a PI grant award. Future work will address this possibility.

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APPENDIX

Survey Questions Used in Analysis

Do you hold a formal joint appointment with another academic department? (1 yes, 0 no)

What is your year of birth? [yyyy]

Have you held a post-doc appointment?

Are you currently an assistant professor, associate professor or full professor?

Are you a member or have a formal affiliation with a permanent science or engineering laboratory or center?

Are you: female; male

During the past academic year how many (0; 1; 2; 3; 4; 5 or more):

- courses did you teach or co-teach?
- department committees did you serve on?
- college/university committees did you serve on?

Name Generators for Network Size

- Over the past two academic years, which individuals in your lab or center have been your closest research collaborators? (five open text spaces for names)
- Over the past two academic years, which individuals at your university have been your closest research collaborators? (five open text spaces for names)
- Over the past two academic years, which individuals in your outside your university have been your closest research collaborators? (seven open text spaces for names)
- While some individuals may only seek advice and information from colleagues, others may go beyond their professional network. With which individuals (professional colleagues or other) do you seek advice about your career and/or professional development? (five open text spaces for names)

How many external grant proposals have you submitted where you have been **PI**?

Of these, how many were successful?

How many external grant proposals have you submitted where you have been **Co-PI**?

Of these, how many were successful?

Of the grants you received as PI or Co-PI, how many were federally funded?

What is the total amount of your external grant support (direct and indirect costs) for this and last academic year combined?

- \$0-\$100K “1”
- \$100,001-\$500K “2”
- \$500,001-\$1million “3”
- \$1,000,001-\$5 million “4”
- more than \$5 million “5”

Please tell us about your peer reviewed academic publications (accepted or published) and presentations in the past two academic years. (Range: 0; 1-2; 3-4; 5-6; 7-9; 10-14; 15 or more)

- Journal articles
- Reviewed conference proceedings
- Book chapters
- Electronic preprints
- Invited conference presentations
- Other conference presentations

