A network's gender composition and communication pattern predict women's leadership success

Yang Yang[a,b], Nitesh V. Chawla[c,d], and Brian Uzzi[a,b,1]

[a]Northwestern Institute on Complex Systems, Northwestern University, Evanston, IL 60208; [b]Kellogg School of Management, Northwestern University, Evanston, IL 60208; [c]Computer Science and Engineering, University of Notre Dame, Notre Dame, IN 46556; and [d]Interdisciplinary Center for Network Science and Applications, University of Notre Dame, Notre Dame, IN 46556

Many leaders today do not rise through the ranks but are recruited directly out of graduate programs into leadership positions. We use a quasi-experiment and instrumental-variable regression to understand the link between students' graduate school social networks and placement into leadership positions of varying levels of authority. Our data measure students' personal characteristics and academic performance, as well as their social network information drawn from 4.5 million email correspondences among hundreds of students who were placed directly into leadership positions. After controlling for students' personal characteristics, work experience, and academic performance, we find that students' social networks strongly predict placement into leadership positions. For males, the higher a male student's centrality in the school-wide network, the higher his leadership-job placement will be. Men with network centrality in the top quartile have an expected job placement level that is 1.5 times greater than men in the bottom quartile of centrality. While centrality also predicts women's placement, high-placing women students have one thing more: an inner circle of predominantly female contacts who are connected to many nonoverlapping third-party contacts. Women with a network centrality in the top quartile and a female-dominated inner circle have an expected job placement level that is 2.5 times greater than women with low centrality and a male-dominated inner circle. Women who have networks that resemble those of high-placing men are low-placing, despite having leadership qualifications comparable to high-placing women.

gender inequality | leadership | social network | computational social science | STEM

On July 20, 1969, Neil Armstrong became the first human to set foot on the moon, marking one of the most celebrated scientific achievements in history. However, his immortal words, "That's one small step for man, one giant leap for mankind," would never have been possible without Susan Finley. Finley, a NASA engineer, rewrote the moon-landing code of Apollo 11's failed computer minutes before the spacecraft touched down, averting what would have been a catastrophic crash landing (1). In the 50 y since Finley's outstanding impact on the world, research has documented how the gender makeup of leaders impacts both organizational performance and equality (2–5). Leaders in organizations play a large role in filling job openings and establishing workplace cultures (2, 6). Female leadership has been associated with lower levels of gender discrimination (2, 7–9), supportive work–family-balance policies (6, 10–12), smaller gender-pay and -promotion gaps (13–15), and, in certain fields like science, technology, engineering, and mathematics (STEM), better retention among women employees (16, 17).

Women's and men's leadership attainment has been linked to high-school academic training, gender norms, and mentorship relationships that differentially shape men's and women's aspirations and preparation for leadership (2, 7, 18). Nonetheless, research continues to explore reasons behind gender imbalances in leadership (6, 19–21). A new channel into leadership positions that diverges from traditional "up-through-ranks" channels is through placement into leadership positions directly out of graduate-school programs that are designed to provide future men and women leaders with indistinguishable levels of managerial and technical training required for leading. While these programs are fast-growing (22), knowledge about their link with men's and women's placement into leadership positions is nascent (23–25).

In programs that prepare graduates for leadership positions, a factor that is hypothetically related to a student's placement is the student's social network (21, 26), which can provide a job-seeker with key job-market information (21, 27, 28). Job-market information is of two types—public and private (21, 27, 29). Public information tends to include facts on who's hiring and who has been hired, salaries across firms, company reputations, and other publicly available information important to job search and negotiations. By contrast, private information benefits job seekers by conveying personalized knowledge about an organization's culture, unwritten rules, or sensitive and confidential impressions on how to present to recruiters or manage relationships (27, 28).

Different types of social-network ties access public and private information (30–32). Because public information generally involves diverse market-wide data, it tends to be scattered among students in the school-wide network (33). In such cases, weak ties ("acquaintances") can be a primary source of public information because they are sufficient for passing on more or less fact-based information that requires little clarification to use effectively (30, 33). Conversely, because private information involves personal experiences and biases, it is more likely to be passed

along by strong ties ("close friends") who socially support each other and can interpret and trust one another's information (29, 30, 32).

To study the link between the graduate-school network and leadership attainment, we collected data from a top-rated graduate program. The program, and others like it, trains men and women to be equally attractive technically and managerially for leadership positions. The sample included all $n = 728$ graduates, 542 men (74.5%) and 186 women (25.5%). Students' social and communication networks were constructed from all 4.55 million anonymized, content-free emails sent among all students in the 2006 and 2007 classes. At this time, students used their school's email service almost exclusively for their email correspondences. Students' official transcripts provided data on gender, entrance-exam scores, grade point average (GPA), years of work experience, undergraduate major, nationality, class year, and sociability (34) (*SI Appendix*, section 2). Our modeling triangulates multiple methods. First, we use fixed-effects regressions to find correlations between job attainment and student human capital and network characteristics. Second, we use instrumental variable (IV) regression and coarsened exact matching (CEM) within the context of a quasi-experiment to conduct causal inference tests (35, 36).

Variables in our analyses are defined as follows. The dependent variable is women and men's "ranked job placement in leadership positions." All graduates took leadership-level positions. Because actual job-title data violate privacy guidelines, the institution provided a ranked percentile score [0.0–100] for each position based on the position's normalized industry and region-specific salary (37). We followed standard practice and converted each job rank to a corresponding Z score, which is interpreted like the original ranked-percentile score (38).

Three variables—centrality, communication equality, and gender homophily—measured different aspects of a student's network. For all network measures, nodes i and j were defined as connected if her or his email was reciprocal and greater than expected by chance (39–42) (group emails were omitted). Centrality in the school-wide network was measured by using Pagerank. Centrality scores were logged and standardized. Consistent with research, students displayed a median number of contacts of 12 (95%, CI = 11–13) (41, 42). Persons with the same centrality often have different network communication patterns and gender compositions (31). For example, students can email their network contacts relatively equally or unequally. Communication equality was measured by using Shannon entropy (43). When communication equality is low, a subset of i's alters receive an incommensurate share of i's email and stand out as relatively "strong" network ties (30, 39). When communication equality is high, i's alters receive roughly equivalent shares of i's email (all j's are relatively "weak" ties). Communication equality is normally distributed (mean = 1.93, SD = 0.65). Gender homophily was measured as a student's proportion of same-sex contacts compared with what was expected by chance using a Z score (44) (mean = 0.91, SD = 1.54). Compositionally, 76.2% of students had mixed-gender networks, 22.3% had all-male networks, and 1.3% had all-female networks (*SI Appendix*, Table S1). Detailed definitions of network variables can be found in *SI Appendix*, section 2.

Results

Fig. 1 presents the coefficients and standard errors of a regression of students' ranked leadership-job placement on social-network characteristics and controls for student characteristics and performance, an industry-category dummy variable (*SI Appendix*, section 2), and an interaction between the dummy variable and all of the network variables.

Examining the associations between person-level variables and placement, Fig. 1 indicates that examination scores, GPA, work

experience, and sociability show no statistically significant relationships with leadership-job placement. An explanation for the fact that employers do not seem to differentiate students on their personal traits is that graduate programs, unlike undergraduate programs, select relatively small numbers of students of nearly equivalent qualifications. Also noteworthy is the finding that patterns of leadership attainment do not appear to differ in STEM and non-STEM jobs ($P = 0.943$ and $P = 0.993$ for men and women) or display any significant variation across industries (see expanded table in *SI Appendix*, Table S2). This finding suggests that research that has speculated that STEM leadership positions are unique (20, 45) may nonetheless be able to draw on insights about women leaders found in non-STEM fields.

Controlling for other factors, we observe that students' networks strongly predict the placement level for both women and men. For men, only centrality is significantly related to job attainment. Roughly, a 10% increase in centrality on average for a man corresponds to an ~29% unit increase in ranked job placement. Beyond centrality, neither communication patterns nor gender homophily predicts placement level for men. This finding suggests that male students who equally or unequally distribute their communications among their contacts have no difference in placement rank. Similarly, for men, an underrepresentation or overrepresentation of same-gender contacts is uncorrelated with placement level. Together, these patterns suggest that men's networks relate to placement level principally via network centrality, which conceivably increases their access to diverse, publicly available job-market information in the school-wide network (21).

For women, centrality positively correlates with placement level. A 10% increase in centrality corresponds to an ~59% unit increase in ranked job placement, suggesting that wide access to public information about the job market is also essential for women. The regression also indicates that communication patterns and gender compositions significantly predict women's
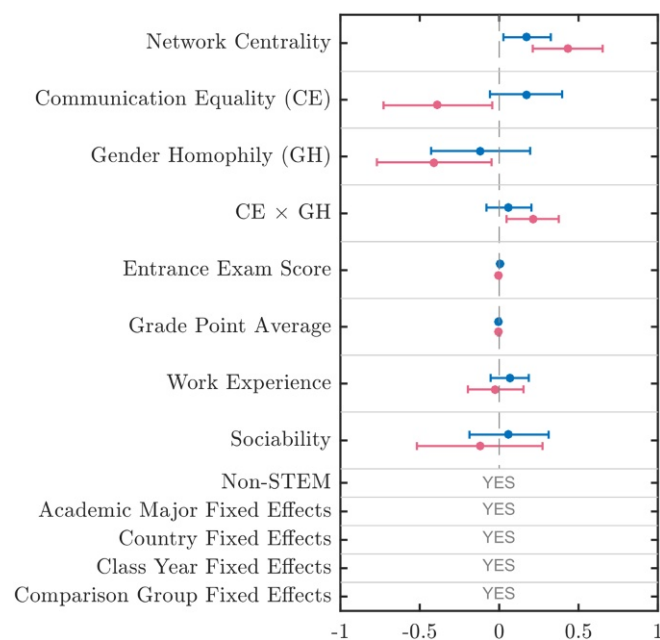
Fig. 1. Fixed-effects regression of ranked job-level placement in leadership positions. Job-level placement is quantified with a rank percentile score. Blue/pink lines represent the regression coefficients and associated 95% CIs for men/women. For men, only centrality in school-wide network predicts job-placement ranking. For women, centrality and the interaction between communication equality and gender homophily predict job-placement rankings.
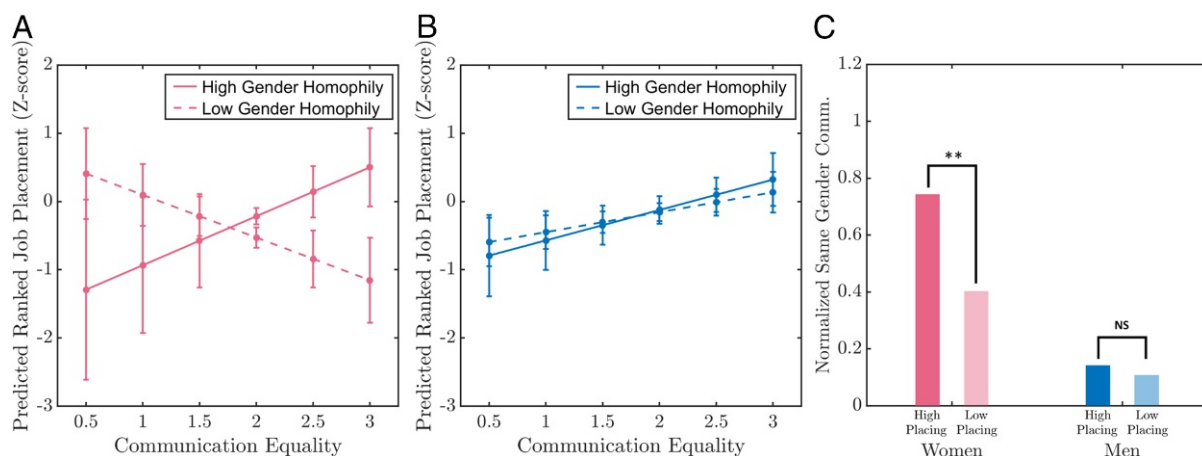
Fig. 2. Gender homophily and communication patterns predict women's, but not men's, job placements. Margins plots are estimated from coefficients reported in Fig. 1. Solid lines represent students whose networks have more same-gender contacts than expected by chance (i.e., same-gender "dominated" networks) and vice versa for dashed lines. *A* indicates that women have higher-ranked placements when they have female-dominated networks and communicate relatively evenly with the contacts in their network and vice versa for low-placing women. *C* demonstrates that high-placing women also have relatively stronger ties with the women in their network than do low-placing women (bar height is normalized for each group). *B* and *C* indicate that high- and low-placing men show no differences in their gender and communication patterns. See *SI Appendix*, section 5.2 for computational details. NS, not significant; **$P < 0.01$.

job-rank placement. Fig. 2 *A* and *B* presents the margin plots with 95% CI of women's and men's predicted placement level (Z score) for the interaction between communication equality and gender homophily based on a split at the median level of the gender homophily. The figures indicate that communication patterns and gender compositions significantly predict women's placement level, but not men's, although we cannot reject the null hypothesis that the corresponding coefficients are similar for both groups (*SI Appendix*, section 5.1.1). For women, the significant interaction indicates that women place higher the more women-dominated their network is (solid line) and the more they communicate relatively evenly with their contacts.

Fig. 2*C* further indicates that high-placing women have relatively stronger relationships with the women in their network than do low-placing women. Seventy-seven percent of high-placing women have an inner circle of strong ties to two or three women who communicate intensely with one another. By contrast, low-placing women have a male-dominated network and relatively weak ties with the women in their network. The regression estimate of the impact of these network differences for women's placement implies that woman with a network centrality in the top quartile and a female-dominated inner circle have an expected job placement level that is 2.5 times greater than a woman with low centrality and a male-dominated inner circle.

The positive link for high-placing women between their inner circle and leadership attainment is striking. Cliquish, homogeneous networks normally hurt job-search and promotion opportunities (29, 33, 46). In this context, how does an inner circle benefit high-placing women? One possible account is that while the inner circle is made up of a small cluster of tightly interlinked women, each woman simultaneously has nonoverlapping third-party contacts; the former provide gender-specific private information and support, while the latter provide job-market information scattered among separate contacts in the larger school network. To explore this hypothesis, we counted the number of uniquely new contacts added with each inner-circle contact at the time the relationship formed (Fig. 3 *A* and *B*). Consistent with our hypothesis, Fig. 3*C* demonstrates that each new inner-circle contact of a high-placing woman, although cliquishly connected, provides connections to an unusually large number

of new contacts that were unreachable through her previous contacts. By contrast, the strong-contacts of low-performing women and all men lack this network duality—they provide redundant paths to contacts already reachable via their current network connections. Specifically, each inner-circle contact of high-placing women puts them in reach of (i.e., fewer hops away from) nearly twice as many new contacts as that of either low-placing women or all men ($P < 0.01$).

Quasi-experimental Causal Inferences. The above results demonstrate robust correlations between a student's graduate-school social network and his or her ranked leadership-job placement. In observational data, unobserved individual differences could account for both variations in students' social networks and ranked placement. An experiment could account for unobserved differences; however, an experiment is impossible because students' careers may be unintentionally harmed (23). As an alternative, we used a quasi-experimental design (QED) that implemented IV regression and CEM to test for causal inference. Both methods support a causal inference between social networks and ranked job placement.

Our QED exploits exogenous variation in students' chances of forming inner circles to implement an IV estimator for our inner circle. The QED had the following design based on prior studies conducted in similar educational settings (47, 48). Before classes began, all incoming students were randomly assigned to one of nine roughly equivalently sized "home sections." Randomized assignment to a home section equalized student characteristics across home sections on all observable characteristics, including gender, nationality, entrance-examination scores, years of work experience, GPA, and industry background. For example, if women made up 25% of the entire incoming class, each home section had ∼25% women students in it, who were drawn randomly from the full set of women in the incoming class. *SI Appendix*, Fig. S1 verifies that home sections had no observable differences per the randomization.

Because students take their first-quarter classes exclusively with their home-section-mates, most students initially form a network that includes contacts predominantly from their home section rather than from their nonhome sections. Beginning with second-quarter classes, students are differentially exposed, depending on the classes to which they are assigned, to male
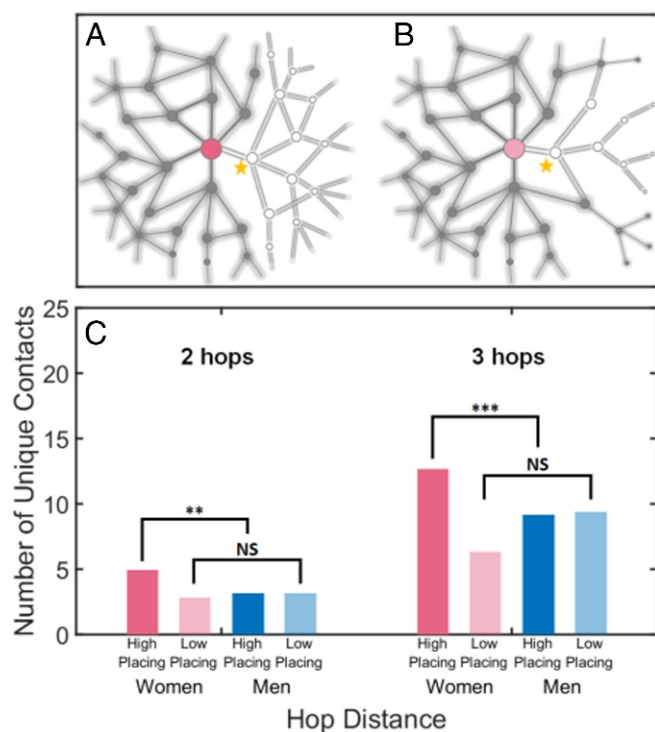
Fig. 3. High-placing women have an inner circle in their networks that distinguishes them from low-placing women. *A* highlights the functions of the inner circle of high-placing women. An inner-circle contact provides a high-placing woman with access to diverse sets of contacts by connecting her to an usually large number of new, nonoverlapping contacts that would be unreachable through contacts already in her network. *B* shows that, on average, low-placing women lack this inner circle. The strongest contacts in a low-placing woman's network connect her to overlapping contacts. *C* quantifies the average number of unique contacts reached through friends-of-friends in the networks of high- and low-placing men and women. Two "hops" is equivalent to friends-of-friends, while three hops is equivalent to friends-of-friends-of-friends. High-placing women have significantly better reach to diverse, nonoverlapping contacts than low-placing women (see *SI Appendix*, section 5.3, Figs. S6 and S7 for additional tests). **P < 0.01; ***P < 0.001; NS, not significant.

and female students from outside their home section. The level of exposure a student has to nonhome-section students depends on an auction system that assigns students to classes. As part of the class-auction system, students bid for classes they want, but bidding outcomes are unpredictable, and students end up being assigned, in varying degrees, to classes they did not choose to be part of, and in those classes, meet new students from other home sections that they did not expect to meet.

These procedures create random variation in a student's exposure to nonhome-section male and female students, and these nonhome-section classmates are likely to have connections that don't overlap with the student's current connections. This random variation is used to create an IV that can be used to predict the likelihood of having a network with an inner circle. In IV regression, causal inferences are supported when a valid instrument correlates with the explanatory variable, but not with other determinants of the dependent variable. Here, our explanatory variable is the "inner circle" (measured as Communication Equality × Gender Homophily), and our instrument is the degree of exposure a student has to same-gender classmates from their nonhome sections. Our reasoning behind this instrument is that the inner circle of high-placing women has high clustering among her same-gender contacts and high diver-

sity of third-party contacts. High clustering is more likely when a student is put into classes that have relatively high numbers of same-gender classmates. High diversity is more likely if those same-gender contacts have nonoverlapping connections. While we cannot directly test the exclusion restriction that our instrument is unrelated to the dependent variable through a channel other than our explanatory variable (i.e., the inner circle), we stress that our IV derives from a quasi-random assignment procedure that is beyond a student's control.

Fig. 4 presents the results of the two-stage least-squares (2SLS) regression analysis. The results support our regression findings (Fig. 1). Looking at the link between a student's exposure level to same-gender contacts from other sections and having an inner circle, Fig. 4 indicates a significant first-stage relationship between our IV and explanatory variable for both women ($P = 0.002$) and men ($P = 0.004$), a finding consistent with expectations. Fig. 4 reports the link between job placement and a student's inner circle based on the first-stage fitted values of the inner circle. These 2SLS estimates indicate that having an inner circle strongly and positively predicts women's ranked job placement ($P = 0.026$). By contrast, the 2SLS estimates indicate that an inner circle has a null effect on men's ranked job placement ($P = 0.670$). A CEM also confirmed the IV regression results (49, 50) (see *SI Appendix*, section 4 for details).

Discussion

Leadership positions are increasingly filled by graduates of programs that prepare leaders with the skills needed to be directly hired into positions of leadership. Our study used a quasi-experiment to isolate and test for causal inference in leadership attainment based on human and social capital variables. We found that a graduate-school network predicts placement in leadership positions for male and female students alike, but high-placing women have distinctive networks. High-placing women tend to have an inner circle of contacts who are cliquish in terms of gender, yet diverse in terms of having contacts whose contacts are nonoverlapping. IV regression and CEM analysis further support the causal inference that high-placing women have a

Panel A: 2SLS Estimate of Ranked Job Placement
(Dependent variable is ranked job placement in leadership positions)

	2SLS (Women)	2SLS (Men)
Inner Circle	0.241*	-0.0806
(Communication Equality × Gender Homophily)	(0.108)	(0.189)
Controls	Y	Y

Panel B: First-stage Regressions
(Dependent variable is inner circle — Communication Equality × Gender Homophily)

	OLS (Women)	OLS (Men)
% exposure to the same gender classmates	36.997**	6.440**
from different sections (Instrumental Variable)	(11.676)	(2.226)
Controls	Y	Y
First-stage F statistic	10.04	8.37
Number of Observations	186	542

*, $p < 0.05$; **, $p < 0.01$

Fig. 4. IV regression of leadership-job placement on women's and men's inner circles. *B* reports estimates of the first-stage regression, where a student's observed inner circle is regressed on the instrumental variable explained in the text. *A* reports 2SLS estimates of leadership-job placement on the fitted values of inner circle from the first-stage regression. We observe that leadership-job placement is significantly associated with the inner circle of women only. All regressions include the controls described in Fig. 1. The first-stage F statistic indicates that weak instrument pathologies are unlikely to be a concern (36). OLS, ordinary least squares. *$P < 0.05$; **$P < 0.01$.

distinctive inner-circle network that predicts their placement level in a leadership position.

Theoretically, the association between an inner circle and job placement both supports and challenges current thinking. Research on women in leadership has argued that getting leadership positions on par with men is not dependent on working harder, but working smarter (51). One interpretation of our findings is that working smarter means having a network that addresses the dual concerns of women leaders—simultaneous access to public information and private, gender-specific information (51). We find that the high-placing women have this kind of network duality, but low-placing women have networks that resemble men's networks—they have high network centrality, but not an inner circle.

Unlike prior work on social networks and job attainment, we find that cliquish networks are not associated with poor job placement. Prior work has found that network relationships based on homophily and high clustering, where friends of friends are friends of each other, work against professional success by putting job seekers in echo chambers that lack the informational breath and diversity that supports a successful job search. By contrast, we find that women leaders who have an inner circle of high clustering and high diversity, they appear to reconcile the dual employment challenges that women have to face in male-dominated jobs. In male-dominated settings, women need to gain trustworthy, gender-relevant information about job cultures and social support and wide access to diverse public job-market information. For male graduates, placement depends only on their network centrality—which provides a high level of public job information. Thus, the processes identified in this study—a first examination of women's placement from graduate school directly into leadership positions, reveal patterns that may help women's and men's attainment of influential leadership positions in all jobs.

Another implication for network theory posed by our work concerns network formation. Preferential attachment theory argues that strategically oriented persons should connect to the best-connected persons. However, for women's job attainment in leadership positions, the best choice is not simply to connect to the best-connected person. Such a process is likely to raise a student's centrality but fail to create an inner circle, which doesn't focus on contacts who have lots of connections but contacts who have nonoverlapping connections.

Areas of future research concern whether women directly attaining leadership positions out of graduate school continue to develop special networks that benefit the firm, their career success, and the success of the personnel they manage. Studies show that when women work with a higher percentage of female supervisors, they report more gender equality (9); family and organizational support (12); and smaller gender pay gaps (13). Yet some research finds that when women view women leaders as threats to power, the presence of women leaders can backfire, particularly in firms with relatively low proportions of senior women (10). Thus, one hypothesis is that graduate-school networks may increase the proportions of senior women in firms and expose aspiring women leaders to each other, reducing expectations of threat. Another area of future research focuses on two theoretical explanations for the impact of networks on job-search information and social support. In our analysis, unfortunately, we do not have data that allow us to definitively say in what relative proportion social support and information are active in women's networks or how they possibly interact with one another. While our measures focused on communication volume in our networks, leaning our explanation of the findings toward the role of information in networks, more research is needed on the role of social support.

Susan Finley launched her career at the Jet Propulsion Laboratory in 1958. Her career success is partly attributed to an inner circle of women contacts that formed in college, expanded at NASA, and was instrumental in providing information and social support beneficial to her leadership success. Today, she is involved in developing the software that will land the first women and men on Mars.

Materials and Methods

Data. Our data came from a top-ranked business school in the United States. The data include all 4.55 million email messages sent by students from two classes. During this time window, the host institution verified that students almost exclusively used the school's email service rather than personal email accounts to communicate with each other. Individual attribute data on undergraduate major, entrance examination scores, gender, and so on, as well as student performance (GPA, industry placement, and job-rank placement, etc.) came directly from the programs registrar records and student transcripts. See *SI Appendix*, sections 1 and 2 for additional details. All data in the study were anonymized by a third party before being analyzed. Northwestern University Institutional Review Board approved this study (no. STU00002048).

Measures. Ranked job-placement and network variables were defined in the text (see *SI Appendix*, section 2 for details). Control variables for individual student characteristics were collected directly from students' official transcripts. Detailed information on control variables and interactions among variables can be found in *SI Appendix*, sections 2 and 5.1.

Methods. To address whether the observed network features could be explained by chance interactions, we constructed 10,000 surrogate networks where the degree centrality sequence (52) of the actual network is preserved and links are placed at random (44, 52) (see *SI Appendix*, section 3 for details).

1. Holt N (2016) *Rise of the Rocket Girls: The Women Who Propelled Us, from Missiles to the Moon to Mars* (Little, Brown, New York).
2. Beaman L, Chattopadhyay R, Duflo E, Pande R, Topalova P (2009) Powerful women: Does exposure reduce bias? *Q J Econ* 124:1497–1540.
3. Beede D, et al. (2011) *Women in STEM: A Gender Gap to Innovation, Economics and Statistics Administration Issue Brief 04–11* (US Department of Commerce, Washington, DC).
4. Matsa DA, Miller AR (2011) Chipping away at the glass ceiling: Gender spillovers in corporate leadership. *Am Econ Rev* 101:635–639.
5. Hultin M, Szulkin R (1999) Wages and unequal access to organizational power: An empirical test of gender discrimination. *Administrative Sci Q* 44:453–472.
6. Sandberg S (2013) *Lean in: Women, Work, and the Will to Lead* (Random House, New York).
7. Etkowitz H, Kemelgor C, Uzzi B (2000) *The Advancement of Women in Science and Technology* (Athena Unbound, Cambridge, UK).
8. Etzkowitz H, Kemelgor C, Neuschatz M, Uzzi B, Alonzo J (1994) The paradox of critical mass for women in science. *Science* 266:51–54.
9. Alison MK, Cannings K, Goldberg CB (2010) Asymmetrical demography effects on psychological climate for gender diversity: Differential effects of leader gender and work unit gender composition among Swedish doctors. *Hum Relat* 63:1661–1685.
10. Ely RJ (1995) The power in demography: Women's social constructions of gender identity at work. *Acad Management J* 38:589–634.
11. Webster C, Grusky O, Podus D, Young A (1999) Team leadership: Network differences in women's and men's instrumental and expressive relations. *Adm Policy Ment Health Ment Health Serv Res* 26:169–190.
12. Foley S, Linnehan F, Greenhaus JH, Weer CH (2006) The impact of gender similarity, racial similarity, and work culture on family-supportive supervision. *Group Organ Management* 31:420–441.
13. Shin T (2012) The gender gap in executive compensation: The role of female directors and chief executive officers. *Ann Am Acad Polit Social Sci* 639:258–278.
14. Cohen LE, Broschak JP (2013) Whose jobs are these? The impact of the proportion of female managers on the number of new management jobs filled by women versus men. *Administrative Sci Q* 58:509–541.

SOCIAL SCIENCES

15. Phillips DJ (2005) Organizational genealogies and the persistence of gender inequality: The case of Silicon Valley law firms. *Administrative Sci Q* 50:440–472.

16. Dennehy TC, Dasgupta N (2017) Female peer mentors early in college increase women's positive academic experiences and retention in engineering. *Proc Natl Acad Sci USA* 114:5964–5969.

17. Dasgupta N, Scircle MM, Hunsinger M (2015) Female peers in small work groups enhance women's motivation, verbal participation, and career aspirations in engineering. *Proc Natl Acad Sci USA* 112:4988–4993.

18. Moss-Racusin CA, Dovidio JF, Brescoll VL, Graham MJ, Handelsman J (2012) Science faculty's subtle gender biases favor male students. *Proc Natl Acad Sci USA* 109:16474–16479.

19. Committee on Maximizing the Potential of Women in Academic Science and Engineering (2007) *Beyond Bias and Barriers: Fulfilling the Potential of Women in Academic Science and Engineering* (National Academies Press, Washington, DC).

20. Oliveira DFM, Ma Y, Woodruff T, Uzzi B, Gender gaps in NIH funding and grant leadership at the Big Ten and Ivy League universities, 2006-2017. *J Am Med Assoc*, in press.

21. Belliveau M (2005) Blind ambition? The effects of social networks and institutional sex composition on the job search outcomes of elite coeducational and women's college graduates. *Organ Sci* 16:134–150.

22. Byrne JA (May 31, 2014) *Why the MBA has become the most popular master's degree in the U.S.* Fortune. Available at fortune.com/2014/05/31/mba-popular-masters-degree/. Accessed October 25, 2017.

23. Shue K (2013) Executive networks and firm policies: Evidence from the random assignment of MBA peers. *Rev Financ Stud* 26:1401–1442.

24. Castilla EJ (2011) Bringing managers back in: Managerial influences on workplace inequality. *Am Sociol Rev* 76:667–694.

25. Fernandez RM, Mors ML (2008) Competing for jobs: Labor queues and gender sorting in the hiring process. *Soc Sci Res* 37:1061–1080.

26. Rivera LA (2016) *Pedigree: How Elite Students Get Elite Jobs* (Princeton Univ Press, Princeton).

27. Fernandez RM, Weinberg N (1997) Sifting and sorting: Personal contacts and hiring in a retail bank. *Am Sociol Rev* 62:883–902.

28. Rivera LA (2012) Hiring as cultural matching: The case of elite professional service firms. *Am Sociol Rev* 77:999–1022.

29. Lutter M (2015) Do women suffer from network closure? The moderating effect of social capital on gender inequality in a project-based labor market, 1929 to 2010. *Am Sociol Rev* 80:329–358.

30. Aral S, Van Alstyne M (2011) The diversity-bandwidth trade-off. *Am J Sociol* 117:90–171.

31. Rivera MT, Soderstrom SB, Uzzi B (2010) Dynamics of dyads in social networks: Assortative, relational, and proximity mechanisms. *Annu Rev Sociol* 36:91–115.

32. Uzzi B (1997) Social structure and competition in interfirm networks: The paradox of embeddedness. *Administrative Sci Q* 42:35–67.

33. Granovetter MS (1977) The strength of weak ties. *Social Networks* (Elsevier, Amsterdam), 347–367.

34. Deming DJ (2017) The growing importance of social skills in the labor market. *Q J Econ* 132:1593–1640.

35. Davies NM, Smith GD, Windmeijer F, Martin RM (2013) Issues in the reporting and conduct of instrumental variable studies: A systematic review. *Epidemiology* 24:363–369.

36. Staiger DO, Stock JH (1994) *Instrumental Variables Regression with Weak Instruments.* NBER Technical Working Paper 151 (National Bureau of Economic Research, Cambridge, MA).

37. Finkelstein S (1992) Power in top management teams: Dimensions, measurement, and validation. *Acad Management J* 35:505–538.

38. Mertler CA (2002) Using standardized test data to guide instruction and intervention. *Eric Digest*.

39. Romero DM, Uzzi B, Kleinberg J (2016) Social networks under stress. *Proceedings of the 25th International Conference on World Wide Web* (International World Wide Web Conferences Steering Committee, Geneva), pp 9–20.

40. Kossinets G, Watts DJ (2006) Empirical analysis of an evolving social network. *Science* 311:88–90.

41. Wuchty S, Uzzi B (2011) Human communication dynamics in digital footsteps: A study of the agreement between self-reported ties and email networks. *PLoS One* 6: e26972.

42. Eagle N, Pentland AS, Lazer D (2009) Inferring friendship network structure by using mobile phone data. *Proc Natl Acad Sci USA* 106:15274–15278.

43. Wasserman S, Faust K (1994) *Social Network Analysis: Methods and Applications* (Cambridge Univ Press, Cambridge, UK), Vol 8.

44. Bearman PS, Moody J, Stovel K (2004) Chains of affection: The structure of adolescent romantic and sexual networks. *Am J Sociol* 110:44–91.

45. Brown R, Brown J, Reardon K, Merrill C (2011) Understanding STEM: Current perceptions. *Technology Eng Teacher* 70:5–9.

46. Burt RS (2009) *Structural Holes: The Social Structure of Competition* (Harvard Univ Press, Cambridge, MA).

47. Hoxby C (2000) Peer effects in the classroom: Learning from gender and race variation. NBER Working Paper 7867 (National Bureau of Economic Research, Cambridge, MA).

48. Sacerdote B (2001) Peer effects with random assignment: Results for Dartmouth roommates. *Q J Econ* 116:681–704.

49. Stuart EA (2010) Matching methods for causal inference: A review and a look forward. *Stat Science: A Rev J Inst Math Stat* 25:1–21.

50. Iacus SM, King G, Porro G (2012) Causal inference without balance checking: Coarsened exact matching. *Polit Anal* 20:1–24.

51. Ragins BR, Townsend B, Mattis M (1998) Gender gap in the executive suite: CEOs and female executives report on breaking the glass ceiling. *Acad Management Perspect* 12:28–42.

52. Hakimi SL (1962) On realizability of a set of integers as degrees of the vertices of a linear graph. I. *J Soc Ind Appl Math* 10:496–506.

Yang et al.