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How do men and women differ in research collaborations? An analysis of the collaborative motives and strategies of academic researchers☆

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ABSTRACT

Do men and women academic faculty vary in their research collaboration patterns and strategies? This straightforward question does not lend itself to a straightforward answer. A great many sex-correlated variables could possibly mitigate the relationship of sex and collaboration. If one finds sex-correlated differences in the number of collaborators, can one infer that there is something intrinsic to men's and women's work strategies and preferences? Or would such differences owe instead to women's and men's different positions in work structures and hierarchies? The focus here is on two sets of research collaboration variables, numbers of collaborators and the collaboration strategies employed. The study uses questionnaire data from the U.S. National Survey of Academic Scientists ($n = 1714$) and tests several hypotheses about collaboration numbers and strategies. Regression results indicate, counter to the core hypotheses and almost all published literature, that in a properly specified model, one taking into account such factors as tenure, discipline, family status and doctoral cohort, women actually have somewhat more collaborators on average than do men. For both men and women, those with more industrial interactions and those affiliated with university research centers have more collaborators. Men and women differ in their collaborator choice strategies. Men are more likely to be oriented to "instrumental," and "experience" strategies, while both men and women are motivated by "mentoring" strategies. Regression analyses show that for both men and women, having a coherent collaborator choice strategy predicts the number of collaborators.

1. Introduction

Do men and women academic faculty vary in their research collaboration patterns and strategies? This straightforward question has received surprisingly little attention (Fox and Faver, 1984; Kyvik and Teigen, 1996; Lee and Bozeman, 2005). It deserves more. Evidence about sex-based differences in collaboration may well impinge on a variety of crucial issues in research and education, including team-building effectiveness but also such secondary effects as educational attainment, representativeness of the scientific workforce, recruitment and retention of scientific and technical human capital, and perhaps even the quality of the research itself.

While it is easy enough to frame the question of possible sex-based differences in research collaboration, obtaining a confidence-inspiring answer to the question proves less simple. Perhaps sex-correlated variables mitigate the effect of sex on collaboration. If one finds sex-correlated differences in, say, the number of collaborators, can one infer that there is something intrinsic to men's and women's work patterns? Or has one simply failed to properly specify the comparative model (Western, 1998)? Abundant research shows that men and women differ in situational factors that could be presumed to relate to collaboration patterns. For example, compared to men, academic women have lower marriage and partnering rates (Probert, 2005) and research shows (Xie and Shauman, 1998; Toutkoushian and Bellas, 1999; Perna, 2001; Lee and Bozeman, 2005) that single academics, both men and women, tend to be less productive in terms of research publication (and perhaps collaborate less). When academics have children at home, women tend to have greater child rearing responsibilities, even when both spouses are academic faculty (Hamovitch and Morgenstern, 1977). Men and women have different degrees of geographic and job mobility (Rosenfeld and Jones, 1987). In some

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cases situational and structural factors interact, as when negative academic department norms or expectations interfere with family obligations (Fox, 2010) and, in turn, differentially affect women's research.

Structural factors may also factor in significantly in how scientists collaborator. One factor possibly accounting for differences in men's and women's collaboration is academic mentoring. Studies have shown that academic women, both graduate students and faculty, tend to differ from men with respect to mentoring experiences (Dreher and Ash, 1990; Green and Bauer, 1995; Tenenbaum et al., 2001). Academic women are less likely to have mentors and the nature of women's mentoring differs from men's (Sands et al., 1991; Sambunjak et al., 2006; Kiopa et al., 2009). Many academic researchers learn from their mentoring relationships how to collaborate and how to interpret social dynamics of collaborations (Bozeman and Corley, 2004; Mayer et al., 2008). The complexity of sex-based differences in collaboration mounts when one considers the many non-work issues that may tend to impinge on collaboration (Hunter and Leahey, 2010) or that women are more often the "trailing spouse" (Harvey, 1998; Bailey and Cooke, 1998; Shauman and Noonan, 2007).

Developing a properly specified model of differences between men's and women's collaboration provides a number of benefits. In the first place, such a model permits one to focus on the valid, non-spurious sex-based collaboration differences between men and women, providing a better prospect for understanding and enhancing career development and success. Perhaps just as important, however, is developing a fuller understanding of structural factors mitigating men's and women's collaboration. Even if one were to find, with a properly specified model, that women and men do not differ greatly in their collaboration patterns, the mitigating factors (the intervening variables) are themselves of interest. Thus, if one were to find, for example, that age and cohort interactions have stronger effects on collaboration than do differences in the sex of collaborators, then it is perhaps possible to develop policies addressing differences in power and resource dynamics without muddying the water by treating these as inherently related to sex or gender. Likewise, were one to find that, say, women's lesser degree of affiliation with interdisciplinary research centers explained much of the variation between men's and women's collaboration patterns, then such affiliations could be viewed as policy levers related to career success. In short, situational differences, structural, and climate-related contextual issues have great import; a properly specified model is required to sort out these causal differences.

Studies of research collaboration have examined a wide variety of factors and dynamics of collaboration (Shrum et al., 2007), but most studies of individual level (researcher-to-researcher) collaboration examine one of two general constructions of collaboration. Some studies (e.g. Heffner, 1981; Vinkler, 1993; Wagner, 2005; Heinze and Bauer, 2007; Mattsson et al., 2008) focus on discretely measured co-authorships and factors pertaining to those authorships (e.g. author order, number of authors). These studies have proven quite useful in many respects and have the advantage of being amenable to use of standard, unobtrusive data, especially as developed in Web of Science and similar data repositories. The current study follows in the second of two major traditions (e.g. Katz and Martin, 1997; Melin, 2000; Boardman and Corley, 2008) in which researchers are asked to report on their collaborations. While this has the obvious disadvantage of possible instrument bias, it has several advantages (outlined in detail in Bozeman and Corley, 2004). In particular, reports of collaboration have the advantage of recognizing contributions of persons who may not have co-author status but who made important contributions. Similarly, self-reported collaboration diminishes problems related to the "ghost authors" increasingly evident in co-authoring (Rennie et al., 1997; Mowatt et al., 2002; Wager, 2007).

In this paper, we contribute to the literature on research collaboration by studying how situational, structural and climate-related institutional factors contribute to the collaboration patterns and strategies of research university professors in the United States. We examine the determinants of volume of collaborations, as well as how collaboration strategy preferences affect the volume of such collaborations. We find that situational factors related to collaborations tend to have modest effects on the volume of collaborations, while structural effects such as tenure status and discipline have strong positive effects on collaboration volume. Institutional affiliations that tend to improve collaborative climates – such as multidisciplinary science centers – also increase collaborations. We extend understanding of these phenomena by further inquiring how collaboration strategies affect collaboration volume. In all analyses, we evaluate the extent to which men's and women's collaboration volume and strategies may vary, finding both similarities and differences.

2. Hypotheses

The key issue for the current study is whether (and, if so, in what ways) male and female academic faculty members differ in their research collaboration patterns. In addition to the discrete indicators of numbers of collaborators, the study examines the collaboration strategies researchers report. A previous study with a more limited sample (Bozeman and Corley, 2004) found differences in men's and women's collaboration strategies; the present study delves more deeply into these possible differences.

2.1. Hypotheses about number of collaborators

While there has not been a great deal of research focusing on researchers' numbers of collaborators and even less comparing men's and women's numbers of collaborators, published studies (e.g. Cole and Zuckerman, 1984; Bozeman and Corley, 2004; Lee and Bozeman, 2005) agree that men in general have more research collaborations than women. No previous study has employed a broad-based representative sample, but in light of the available evidence let us propose the following core hypothesis:

Hypothesis 1.0. Men and women faculty researchers differ significantly in their number of collaborations.[1] Men will (*ceteris paribus*) tend to have more collaborators than will women.

Despite the preponderance of evidence, the hypothesis remains worthy of test, and not only because there are so few relevant studies. In different ways, the few previous studies directly relevant to the topic all have limitations. Perhaps most important, previous samples have been either unsystematic or narrowly representative. The current data set differs from previous ones – it is more representative than others and it includes numbers of women sufficient to make inferences about male–female differences. Women represent a larger proportion of academic faculty than they did even 10 years ago and the trend is for increasing representation of women (National Science Foundation, 2009). According to the most recent

[1] Detailed information about this variable and the others employed in the study is provided in Table 1 along with descriptive statistics. For present purposes it is useful to note that the number of collaborations was derived from a the following questionnaire item: "For the past *twelve months*, please tell us the approximate number of people in each of the following categories with whom you have had research collaborations." The categories included male university faculty, female university faculty, male graduate students, female graduate students and other. The dependent variable "number of collaborations" is the total for all categories.

data (Bell, 2010), in 2009 U.S. women, for the first time in history, received more (50.4%) research doctoral degrees than did men.

The greater incidence of women among academic researchers may increase the supply of women as potential collaborators. Since most researchers tend to concentrate collaborations on those in their own laboratory, research group or academic department, the prevalence of women presents women with the possibility of proximate collaborations with women (Boardman and Corley, 2008). In sum, it is no longer patent that women have fewer collaborators than men. We have already noted that men and women tend to inhabit different sex-based family situations that may affect collaboration patterns. These include academic women's lower marriage rates (Probert, 2005), lower geographic and job mobility related to marriage (Rosenfeld and Jones, 1987), and more significant childcare responsibilities (Hamovitch and Morgenstern, 1977). Therefore, we test the following:

Hypothesis 1.1. Men and women faculty researchers differ significantly in their number of collaborations and these differences will in part relate to family status, including marital status and number of children at home).

In addition to situational factors, a compelling set of studies (e.g. Kanter, 1976; Miller et al., 1979; Lefkowitz, 1994; Ely and Padavic, 2007), ones we can place in the sex-spurious category, argue that any observed differences in men's and women's work behaviors are artifactual, owing to the different places men and women, respectively, find themselves in organization structures and hierarchies. Some particularly relevant studies of this type focus on scientific productivity or collaboration (Fox, 1991, 2010; Xie and Shauman, 1998). According to the structural context perspective, if one compares men and women working within similar structures and hierarchies those differences vanish. Therefore, we test the following:

Hypothesis 1.2. Men and women faculty researchers differ significantly in their number of collaborations and these differences will in part relate to tenure status, professional age, and discipline.

Prior research has shown that departmental climates – such as discussion about scientific matters, networking behavior, and mentoring practices – predict a variety of scientific behavior (Fox, 2010; Fox and Mohabatra, 2007; Quinlan and Akerlind, 2000). Our data do not allow us to test departmental climate directly, but we are able to examine the impacts of institutional structures that have been demonstrated to create more gender-egalitarian scientific contexts. For example, interdisciplinary research and interdisciplinary institutions have altered the collaborative landscape in ways that tend to facilitate women's productivity relative to exclusively department-based scientific work (e.g. Corley and Gaughan, 2005; Boardman and Corley, 2008; Gaughan and Ponomariov, 2008; Gaughan and Corley, 2010). Therefore, we test the following:

Hypothesis 1.3. Men and women faculty researchers differ significantly in their number of collaborations and these differences will in part relate to affiliation with a university research center and industrial involvement.

In some respects, the actual number of collaborators for men and women is less important than understanding factors that may impinge on collaboration patterns. What factors mitigate men's and women's numbers of collaborators? To be sure, we can expect that some factors will affect collaboration with little difference in effects on men and women. But other factors (expressed as intervening variables in the hypotheses below) may have stronger effects on one or the other sex and, thus, are included in the core model of collaboration.

2.2. Hypotheses about collaboration strategy

Another set of hypotheses pertains to researchers' collaboration strategies, a topic not often addressed in the empirical literature (exceptions include Melin, 2000; Laudel, 2001; Birnholtz, 2007; Leahey and Reikowsky, 2008). Earlier work on a more limited sample (Bozeman and Corley, 2004) demonstrated that collaboration strategies include "Instrumental" (concerned with immediate work factors, including assignment of credit), "Experience" (previous experience collaborating), "Nationalist" (wishing collaborators from one's own nation or shared language) and "Mentoring" (desire to help graduate students and junior faculty).

There are several reasons to believe that women and men may differ in their collaboration strategies. To a large extent, strategies for choosing collaborators are likely entangled with a variety of relevant factors on which men and women differ. For example, women in our representative sample (and the population of U.S. academics) tend to be younger and they are less likely to be tenured. Younger, untenured faculty may well be more instrumental aims and may be less interested or at least less involved in serving as a mentor. Any observed relation with sex may be attenuated by age and career experience differences (i.e. sex-spurious); but if we control for such mitigating factors, is there still reason to expect different collaboration strategies? Quite possibly these differences could be carried over to research collaboration strategies and criteria for collaborator choice (Melin, 2000). For example, one study (e.g. Huberman et al., 2004) shows that in each of several nations, men are more likely to value status for its own sake (apart from its instrumental value). This could perhaps lead men to give greater emphasis than women to the scientific reputation of the research collaborator. The fact that women tend to have different levels and types of network ties could also affect collaboration strategies (Welch and Melkers, 2008). Therefore we hypothesize:

Hypothesis 2.0. Men and women faculty researchers differ significantly in their strategy for choosing collaborators. Specifically, women will tend more than men to adopt an "Instrumental" strategy and an "Experience" strategy; men will be more likely than women to adopt a "Mentoring" strategy." No difference will be observed with respect to a "Nationalist" strategy.

While there is no literature to guide our hypothesis of no nationalist strategy differences, we posit that there is no particular reason to expect that gender would affect preferences for native language use or preference for a collaborator from one's country of origin.

3. Methodological approach

3.1. Data collection

The data employed here are from the NSF-funded Survey of Academic Researchers (SAR) conducted in 2004–2005. The purpose of the survey was to study a variety of aspects of faculty work and attitudes in universities, focusing in particular on industrial activities and research center affiliations. Our initial target population was tenured and tenure track faculty members in Carnegie (2000) research extensive universities, Historically Black Colleges and Universities (HBCU) and universities designated as Experimental Program to Stimulate Competitive Research (EPSCoR). Sampling frames were constructed from university catalogs in the following National Science Foundation STEM disciplines: biology, computer science, mathematics, chemistry, physics, earth and atmospheric sciences, agriculture and sociology. In addition, samples were drawn from five sub-disciplines of engineering: chemical, civil, electrical, materials, and mechanical.

Women were over-sampled from all disciplines. This was done to make sure that sufficient numbers of women appeared in the sample and, specifically, to ensure that women from every discipline would be represented, even those (e.g. computer science, electrical engineering) where women are found in quite small numbers. Furthermore, stratification by sex replicates the tenure and rank distribution of fields, as women are likely to be at earlier career ages. The result of this stratification, of course, is that variables strongly correlated with sex may lead to spurious inference about co-varying variables. In other studies (Link et al., 2008; Gaughan and Corley, 2010; Bozeman and Gaughan, 2011) we have used weights to adjust for sample design. In the previous studies where we used weights we found negligible differences between a weighting strategy and controlling for gender. We do not use weights here because sex is the variable of primary predictive interest and is viewed as endogenous in models (see Winship and Radbill, 1994).

3.2. Respondents

The survey was sent to 5916 targets, yielding 2086 respondents after three waves of administration. The current study uses a sub-sample of the initial survey, eliminating the HBCU and EPSCOR respondents as well as the sociology discipline. These HBCU and EPSCOR respondents have been eliminated here because (1) previous studies (e.g. Link et al., 2008) using these data have shown that the composition of work for persons at persons at HBCU and EPSCOR universities is quite different from those at Carnegie Extensive universities, suggesting that collaboration has different meanings and intensities; (2) many HBCU and EPSCOR universities do not have doctoral programs and, thus, a major element of the collaborations examined here, collaborations with students, is not possible at some of these universities. The sociologists have been eliminated because many of the determinants of collaboration examined here are not as relevant for sociologists, including affiliation with university research centers and, especially, industrial involvement. Relatively few sociologists in these data are affiliated with university research centers and almost none of the sociologists report industrial involvement.

Adjusting for deceased and retired targets, the effective response rate for the current sub-sample of Carnegie Extensive faculty is 39.5%. For this group we have found no response bias based on discipline or rank. This particular analysis includes 1714 respondents. Missing data is a very small percentage (less than .1% of all observations) and appear to be at random in sensitivity analyses.

3.3. Measurement

The Appendix shows how survey items were developed to represent key constructs. All measures are based on self-report except for center affiliation, which was verified using unobtrusive means. In this section, we discuss measures that represent complex measurement design (i.e., the measure is not a simple indicators like whether or not a person is tenured). There are two constructs that meet this characteristic: The industrial involvement index and the collaboration strategies variables.

Respondents were asked, “have you had any working relations with private companies during the past 12 months?” This question was followed by a series of possible interactions, such as co-authoring with industrial researchers, placing graduate students in industrial research, paid consulting, and owning or managing a start-up or spin-off company. The industrial involvement index is constructed by adding the percentage of the reciprocal to weight for rare behaviors (Bozeman and Gaughan, 2007 or Gaughan and Corley, 2010).

The construction of collaboration strategy measures follows instrumentation developed in a previous study of a different population (Bozeman and Corley, 2004). Respondents were asked to rate, according to a 5-point Likert-type scale, each of several possible reasons for collaborating. Some of these included collaborators' complementary skills, practices for assigning publishing credit, experience with previous collaborations, collaborators' scientific reputation, and a desire to help graduate students or colleagues. The full set of choices is provided in the Appendix A.

It is useful to understand the underlying dimensional properties of the various collaborator strategy variables and, if appropriate, to reduce according to coalescing variables. This was accomplished by a factor analysis, specifically a principal components analysis with a Varimax rotation (with Kaiser Normalization) of factor dimensions, and extraction of factors at the 1.0 or greater eigenvalue level. This resulted in four dimensions and, as is customary, they are named according to the variables loading to the extent of $\pm.50$ or greater. Table 1 provides the results of the factor analysis; the dimensions are labeled “Instrumental,” “Experience,” “Nationalist,” and Mentoring.” To facilitate the use of the four dimensions in regression models, factor scores were calculated relating the cases (respondents) to the respective dimensions.

4. Analysis

4.1. Descriptive results

Means and standard deviations for total number of collaborators, by sex and status, are given in Table 2. The table shows that, contrary to the findings of most previous studies, women actually have a larger number of collaborators (though not statistically significant). Indeed, the only statistically significant difference in the sex composition of collaboration pairs is that male faculty collaborate with a greater number of male graduate students.

While the differences in number of collaborators are slight, it is noteworthy because almost all previous studies have found that women tend to have fewer collaborators. Possibly this is because previous studies were not as fully representative, but it is also possible that collaboration patterns have changed in recent years. We explore this possibility in the statistical models presented below.

4.2. Results for statistical tests of hypotheses

We begin with the models developed for analysis of Hypotheses 1.0–1.3, dealing with the number and composition of collaborators. We have already seen from the descriptive tables that men and women do not differ greatly in their number of collaborators and, somewhat surprisingly, that women may tend to have more collaborators. However, by introducing a model that seems to account for some of the characteristic structural and individual differences between men and women it is possible that the result could be different.

4.2.1. Findings for number of collaborators

Table 3 provides results for a negative binomial regression. The dependent variable is a count variable, implying that the standard errors may be distributed so that OLS may provide a biased estimate. Negative binomial regression (NBR) is preferred to Poisson regression because of the degree of dispersion in the dependent variable and NBR is applicable because of the small number of zero observations for the dependent variable. Much like OLS, the coefficients for NBR can be interpreted as units of change in the predictor variable estimating a unit of change in the dependent variable, holding all other variables in the model constant. However, in NBR the focus is on unit of change in the logs of expected

Table 1
Factor analysis for collaboration strategies.

Collaboration criterion variable	Factors			
	Instrumental	Experience	Nationalist	Mentoring
Complementary skills	0.15	0.77	−0.1	−0.06
Practices for credit assignment	0.67	0.06	0.18	−0.02
Fluent in my language	0.14	0.01	0.72	0.01
Help out graduate students	0.15	0.05	0.002	0.77
Help junior colleagues	0.05	0.1	0.06	0.80
Quality of previous collaboration	0.13	0.65	0.04	0.22
From the same country	0.11	−0.08	0.78	−0.04
Strong scientific reputation	0.18	0.58	0.11	0.04
Ability to stick to a schedule	0.81	0.16	0.11	0.08
Time known	0.02	0.27	0.41	0.22
Work ethic	0.74	0.27	−0.04	0.17
Fun or entertaining	−0.23	0.37	0.38	0.35

Table 2
Means for total number and type of collaborators.

	Men	S.D.	Sig.	Women	S.D.
Total number of collaborators	11.54	18.27	n.s.	11.84	10
Characteristic of collaborators					
Female Faculty Members	1.15	3.74	n.s.	1.34	1.71
Male Faculty Members	4.41	7.06	n.s.	4.4	4.91
Female Graduate Students	1.36	3.39	n.s.	1.58	1.86
Male Graduate Students	3.16	5.6	*	2.67	3.1
Other Collaborators	1.88	8.08	n.s.	1.85	4.14

$n = 1714$
(Male: 826; female: 888)

Independent samples t-test: $^{*}p < 0.05$

counts of the dependent variable, holding all other predictor variables in the model constant. In this case the alpha test is an estimate of a dispersion parameter, especially important in the case of count variables inasmuch as it indicates the fit of the model. We observed a low alpha, indicating a low (i.e. acceptable) degree of dispersion.

Table 3
Negative binomial model for number of collaborators.

Independent Variable	Coefficient	S.E.	Sig.
Demographic			
Male	−0.08	0.04	*
Non Hispanic White	0.05	0.05	
Native born citizen	−0.01	0.04	
Situational			
Married	0.07	0.05	
Number of children at home	−0.03	0.02	
Structural			
Professional age	−0.01	0.002	***
Ever tenured	0.14	0.05	**
Discipline[a]			
Life science	−0.17	0.05	**
Math/computer science	−0.14	0.06	*
Engineering	−0.1	0.04	*
Hours worked per week	0.01	0.001	***
Hours teaching undergraduates	−0.01	0.002	***
Number of active grants	0.34	0.06	***
Climate			
Center affiliate	0.19	0.04	***
Industrial involvement	0.1	0.01	***
Constant	1.98	0.11	***
Delta	4.3	0.2	

[a] Reference category is physical science.
* Significant at .05 level.
** Significant at .01 level.
*** Significant at .001 level.

The model provided in Table 3 tests all the relationships stipulated in hypothesis set one. Thus, the results are reviewed according to the hypotheses. However, we begin by noting that in a more fully specified model, men continue to have fewer collaborators, against the prediction of the hypothesis and counter to most research on the topic. We can see from the coefficient (−0.08) that the relationship of sex to collaboration is one of considerable statistical importance, though it is not the most powerful predictor in the model.

Hypothesis 1.1 focused chiefly on situational variables related to family status. We find that neither marriage nor number of children living at home is a predictor of number of collaborators. Testing an interaction between sex and these two situational variables, there is no difference between men and women in the negative impact of children living at home.

Hypothesis 1.2 considers the effects of career factors, including whether the respondent is tenured, respondent's professional age, discipline, working hours, and grant funding, all factors that could be expected to moderate effects of sex on collaboration. The results show that tenure has a significant positive effect: Those who are tenured tend to have more collaborators. However, professional age has a negative relationship with number of collaborators. An examination plotting age and collaborators (not reported here but available from the authors) showed that the relationship is curvilinear with a sharp drop after the 85th percentile of age and a peak at the 60th percentile. Compared to physical scientists, who tend to work in large teams, life scientists, mathematicians and engineers collaborate with significantly few people. Those working more hours have significantly more collaborators, while number of hours teaching undergraduates has a significant negative impact. Finally, having an active grant also positively affects number of collaborators. We tested sex interactions with each of these variables (interactions entered one at a time), and found no differences in these patterns between men and women. We see from Table 3 that the variables identified in Hypothesis 1.3 have a significant effect on collaboration. In the sample, 29.4% of the respondent reported an affiliation with a multidisciplinary university research center, defined as having five or more faculty and postdoctoral researchers and including participants from more than on discipline and more than one academic department. There is a strong and significant relationship between being affiliated with a research center and having more collaborators; however, the hypothesis that this finding would diminish when taking into account industrial activity of respondents is disconfirmed. Industrial activity, as measured by the Industrial Involvement Scale, has strong, significant effects on number of collaborators. Thus, *both* those who are center-affiliated and involved with industry are likely to have significantly more collaborators. This finding is perhaps not so surprising inasmuch as previous research on centers shows that a large percentage, nearly a majority, reports no significant industrial activity (Bozeman and Boardman, in press; Lin and Bozeman, 2006). Sensitivity tests of the interaction of sex with the organizational climate variables indicated no differences in this pattern between men and women.

To summarize, the model evaluating the impacts of demographic, situational, structural, and climate factors performs well in explaining number of research collaborators. Men have significantly fewer collaborators when controlling for other factors, a finding not previously observed, and contrary to our hypotheses. Although the direct effects of situational, structural and climate variables operate as expected, we found no differences in the pattern of these effects between men and women.

4.2.2. *Findings for collaboration strategy*

Hypothesis 2.0, based in part on previous research (Bozeman and Corley, 2004), suggested that men and women would tend to employ somewhat different collaboration strategies, specifically that women would tend to employ "Instrumental" and "Experience" strategies whereas men would be more likely to employ "Mentoring" strategies. Hypothesis 2.1 indicated that a "Mentoring" strategy would be associated with a larger number of collaborators whereas an "Instrumental" strategy would be associated with a smaller number of collaborators.

In Table 4, we re-specify the model presented in Table 3 by adding the collaboration strategy measures; we further divide the analysis between men and women so that direct comparisons can be made. We find that mentoring strategies are associated with a greater number of collaborators for both men and women. However, we also find that the mentoring strategy is the only one that increases the number of collaborators for women. By contrast, men's collaborators are also increased by instrumental and experience-based strategies. It should be noted that these positive findings for men (and non-findings for women) occur only when controlling for being a grant-active researcher. In other words, having an active grant tends to increase men's collaboration strategies, but to reduce women's collaboration strategies. A nationalist strategy has no effect on either men or women, consistent with our hypothesis.

In other respects, the model performs as in Table 3, except that the negative effect of the disciplinary variables is attenuated for women, becoming insignificant for female engineers, mathematicians and computer scientists. This suggests that disciplinary field does not have as strong an effect on women's collaboration patterns as it does on men's. Hours worked per week and hours teaching undergraduates are not significant for the men, but note the small and functionally identical coefficients for the women. We continue to find no evidence that situational factors related to family status have any effect on either men or women, and structural predictors are week. Climate variables associated with being a mul-

Table 4
Negative binomial model for number of collaborators, by sex.

Independent variable	Men			Women		
	Coefficient	S.E.	Sig.	Coefficient	S.E.	Sig.
Demographic						
Non Hispanic White	0.01			0.1	0.07	
Native born citizen	0.02			−0.02	0.05	
Situational						
Married	−0.03	0.1		0.05	0.06	
Number of children at home	−0.03	0.02		−0.02	0.02	
Structural						
Professional age	−0.01	0.003	**	−0.01	0.003	*
Ever tenured	0.03	0.08		0.1	0.06	
Discipline[a]						
Life science	−0.2	0.08	*	−0.16	0.07	*
Math/computer science	*−0.20*	*0.09*	*	*−0.08*	*0.07*	
Engineering	*−0.20*	*0.07*	**	*−0.06*	*0.06*	
Hours worked per week	*0.003*	*0.002*		*0.003*	*0.002*	*
Hours teaching undergraduates	*−0.01*	*0.004*		*−0.01*	*0.003*	***
Has an active grants	0.4	0.08	***	0.23	0.08	**
Climate						
Center affiliate	0.21	0.06	***	0.15	0.05	***
Industrial involvement	0.09	0.02	***	0.08	0.02	***
Collaboration strategy						
Instrumental	*0.06*	*0.03*	*	*0.04*	*0.02*	
Experience	*0.08*	*0.03*	**	*0.04*	*0.03*	
Nationalist	−0.03	0.03		−0.01	0.02	
Mentoring	0.09	0.03	***	0.09	0.02	***
Constant	2.15	0.18	***	2.11	0.15	***
Delta	5.09	0.34		3.25	0.23	

[a] Reference category is physical science.
* Significant at .05 level.
** Significant at .01 level.
*** Significant at .001 level.

tidisciplinary center affiliate and working with industry continue to be strong predictors of number of collaborators for both men and women.

5. Limitations and further research

Our study focuses on a nationally representative sample of STEM researchers in research extensive universities in the United States. This is a large and important group in the production of academic science and engineering research and education. Nevertheless, our findings may not extend to the collaboration behavior of social science, humanities and professional faculty. Similarly, our findings may not extend to the many other types of universities in the United States. Our findings may be instructive in understanding the collaborative behavior of scientists and engineers in research universities in some Western European countries, although rapid institutional changes in Europe may make direct comparisons of faculty collaborative behavior more limited, at least in the short-term.

An additional methodological limitation of this study is our inability to look at departmental-level factors that may affect collaboration behavior. Propinquity is an important determinant of social intercourse of all kinds, but the survey did not include questions that would capture that dimension of the collaborative relationship. Although departmental norms and climate are theoretically relevant to understanding collaborative behavior, we simply did not collect data in such a way that would allow inquiry into those determinants.

The study is limited by its lack of individual performance indicators, such as publications and patents. The authors' previous studies (especially Lee and Bozeman, 2005; Gaughan and Ponomariov, 2008) have investigated relationships between collaboration and performance but that is not a focus here and, thus, a limitation.

Finally, we note that academic leadership positions may well mitigate our findings. We do not have data on academic leadership but it is quite possible that leadership relates to research collaboration patterns and in many fields men are more likely to occupy academic leadership positions, due in part to increased social capital and higher intensity of network involvement.

Future research seeks to address some of these shortcomings, but is in the early stages for the co-authors. Bozeman is undertaking a study of collaborators that takes the scientific product as the level of analysis, surveying and interviewing the co-authors involved in that scientific production. Gaughan is studying a population of doctoral students over time to examine how they have been distributed into the national innovation system; this approach will expand our current understanding of collaborative behavior beyond the research extensive universities. Each of these current projects incorporates measures of departmental and local climates much more effectively than the data on which the present study is based.

6. Conclusions

The study began with the expectation that men and women researchers would differ significantly in their research collaborations and strategies. The limited number of previous studies (including the author's own (Bozeman and Corley, 2004; Lee and Bozeman, 2005)) comparing men's and women's collaboration consistently found systematic differences. The driving issue, then, was whether these differences were valid ones or the result of limited data and underspecified models. That is, would the "sex-based" or "sex-spurious" general explanation seem more potent?

The most important finding from the study is that, contrary to expectations, men and women differ relatively little with respect to research collaborations and, surprisingly, women have somewhat more collaborators, especially when controlling for structural and climate factors. In some respects, men and women share common predictors of collaboration. The most consistent positive effects operate through being grant active, affiliating with a multidisciplinary center, and through industrial involvement. Those following a mentoring strategy tend to have a greater number of collaborators. Men and women scientists also share non-predictors of collaboration: demographic and situational variables fail to predict the number of research collaborators, and neither is affected by a nationalist strategy. We find that men experience gains in the number of collaborators via three collaboration strategies: Instrumental, experience and mentoring. By contrast, women's mentoring strategies are the only ones that predict the number of research collaborators.

Our research suggests two important policy implications. First, much attention has been focused on creating more equitable policy structures to ensure that women can more effectively balance work and family responsibilities. Although our data do not allow us to examine how these faculty members are balancing work and family, the consistent finding of no effect of either marriage or dependent children suggests that these may no longer be such significant barriers to collaboration patterns. The case of a gender non-finding may be construed as policy success to the extent that a nation cannot thrive when family responsibilities interfere with work, or when those family responsibilities have disproportionate effects on one demographic group of people. Our findings suggest that the decades-long policy focus on reducing family-related barriers to women's participation in scientific work may well be paying off.

Also for several decades, the US federal government has created incentives for university scientists to develop new behaviors and institutions to facilitate their work. Specifically, national policy makers have been eager to facilitate the growth of the national innovation system by creating incentives for engagement by universities with industrial partners. The science funding agencies have created numerous incentives for the creation of multidisciplinary science research centers to facilitate industrial involvement and innovative collaborative partnerships. One of the key motivating ideas behind this federal support is that fostering linkages between sectors (such as universities and industry), and among multi-disciplinary collaborators (such as in multidisciplinary research centers), will enhance research creativity and productivity. Although we do not examine productivity directly in this work, we do study the determinants of one input into the productivity explanation: that of collaboration. As already noted, future research will explore how collaboration patterns affect productivity patterns among scientists and engineers working in the United States.

Appendix A.

See Table A1 .

Table A1
Variables and descriptive statistics.

Variable name and description	Mean	Standard deviation	Notes
Sex (0 = female, 1 = male)	.48	.501	Based on stratified sample ensuring roughly equal numbers of women and men in the sample.
Non-Hispanic white = 1	.81	.397	Respondents who identify only as white, and not indicating Hispanic or mixed race.
Native born U.S. citizen	.70	.458	Respondents were asked to identify their citizenship and visa status. These are native-born US Citizens (as opposed to visa holders, or those who obtained citizenship.
Married	.85	.354	*Item*: "Currently, are you either married or living with a domestic partner?"
Children at home	.83	1.086	*Item*: "Currently, do you have children living with you as part of your family? If so, how many?"
Ever tenured	.70	.452	*Item*: "In what year did you first obtain tenure" [Measured here as a dummy variable, 1 = ever tenure, 0 = never tenured]
Hours worked per week	54.17	13.781	*Item*: "For the most recent full academic term, please indicate the average number of hours per week devoted to each of the activities below." The items were an exhaustive set (see Link et al., 2008 for complete details). The variable is total for all categories (e.g. "teaching undergraduates," "administering grants," paid consulting")
Hours teaching undergraduates	9.91	8.56	See description for hours worked per week above.
Grant active	.83	.374	Dummy variable of whether respondent currently has an active research grant.
Professional age			*Item*: "In what year did you complete your PhD Professional age was calculated from year of PhD to 2005
Center affiliate	.30	.452	*Item*: "Definition: A university research center is a 'research institution that has five or more faculty and postdoctoral researchers and includes participants from more than one discipline and more than one academic department" "Considering the above definition I am not affiliated. . .' or "I am affiliated with a university research center. The name of the center(s) I am affiliated with. . ." *Note*: center affiliation was later validated with analysis of web sites and follow-up telephone calls (see Bozeman and Boardman, in press).
Industrial involvement index	1.07	1.437	This variable is an additive index of the percentage reciprocals for an exhaustive set of possible industrial interactions. For complete details see Bozeman and Gaughan (2007)
Discipline dummies: Life sciences; math and computer science; physical sciences; engineering	Dummy Variables 0/1		*Note*: These discipline dummies are created from data in which the major disciplines were separate. In other studies it was shown that the predictive power was little diminished by the convenience of aggregating disciplines (see for example Gaughan and Corley, 2010).
Number of collaborators	11.7	14.573	Constructed from this *Item*: "For the past twelve months, please tell us the approximate number of people in each of the following categories: male university faculty, female university faculty, male graduate students, female graduate students, others." The variable is the sum of these.
Collaboration strategy Indicators:			The factor analysis is explained elsewhere in the paper, but the item upon which it is based: "If we define research collaboration as 'working closely with others to produce new scientific knowledge or technology,' how important are each of the following factors in your decisions to collaborate?" Responses were to the scale "very important" (4), "somewhat important" (3), somewhat unimportant" (2) and not important" (1). The items are given in the column with the means.
"Length of time I have known the person"	2.59	.815	
"Interest in helping junior colleagues"	2.71	.859	
"Desire to work with researchers who have strong scientific reputations"	3.09	.864	
"Desire to work with researchers whose work skills and knowledge complement my own"	3.77	.486	
"Quality of my previous collaborations with the person"	3.66	.590	
"Interest in helping graduate students"	3.15	.833	

Table A1 (*Continued*)

Variable name and description	Mean	Standard deviation	Notes
"The extent to which working with the individual is fun or entertaining"	2.78	.927	
"Desire that the collaborator be highly fluent in my native language"	2.00	.937	
"Desire to work with researchers from the same country of origin"	1.32	.562	
"The collaborator should have a strong work ethic"	3.51	.662	
"The ability of the collaborator to stick to a schedule"	3.51	.723	
"Practices for assigning credit"	2.47	.953	

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