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Academic outcomes among principal investigators, co-principal investigators, and non-PI researchers

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Abstract Faculty at research universities are evaluated on a number of productivity measures including their ability to conduct research, teach, and engage in service. Research outcomes include publishing research results and acquiring grants and contracts to conduct additional research. While it is assumed that researchers who are awarded grants are more likely to publish research results, there is little research investigating the ways in which grants affect outcomes or how principal investigators differ from researchers who do not hold research grants or those who are co-principal investigators. This research seeks to understand if principal investigators are more or less productive than co-principal investigators and those who do not have grants, and if so, what explains that variation in productivity. It also examines whether women PIs are more or less productive than men PIs. This research uses longitudinal data drawn from an NSF funded survey of academic scientists in Carnegie-designated Research I universities in six fields: biology, chemistry, computer science, earth and atmospheric sciences, electrical engineering, and physics. From this national random sample of men and women scientists and engineers we investigate whether there is variation in the production of outcomes (e.g. publications, teaching, and training graduate students) among PIs, co-PIs, and other researchers. Findings show that productivity and outcomes vary significantly for PIs, co-PIs and by sex.

Keywords Principal Investigators · Co-Principal Investigators · Academic outcomes · Universities · Academic productivity · Publications

JEL Classification O30 · O32 · I23 · O34 · O38

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1 Introduction

Productivity outcomes in research universities in the United States have long been organized into three categories: research, teaching, and service. Faculty at research universities are evaluated and promoted on these three outcomes. While grant-getting activities bring resources to faculty and departments and have the potential to increase research, teaching, and service outcomes, it is also possible that grant-getting pulls faculty away from these other activities. This research seeks to investigate the ways in which grant-getting affects outcomes, or how principal investigators and co-principal investigators differ from researchers who do not hold research grants.

Research outcomes at universities are typically measured by peer-reviewed journal publications, conference presentations and proceedings, book chapters, books, and other forms of publication. Publications are important indicators of science productivity because they indicate dissemination and verification of findings by peers (Price 1963; Merton 1973). Publication metrics include not only publication counts, but also publication quality, which is often measured as citation rates. Research grants are another important indicator of science productivity. Because most grants are awarded through a competitive, peer-review process, universities view grant awards to be endorsements of the quality and value of new research ideas. In addition to bringing in revenue to the university to support research, purchase and maintain research equipment, update facilities, and provide further training of graduate students, grant awards have the potential to advance the reputation of the scientist and the university. The other categories of productivity outcomes—teaching and service—are important albeit often less renown in research universities. Teaching is usually measured as the number and type of courses taught, and assessed using student evaluations of the instructor. Training and mentoring of graduate students are also important, albeit often ignored, activities within the teaching category. Service activities include service to students (e.g. advising and mentoring), department (e.g. committees), campus (e.g. committees and administrative work), community (e.g. media appearances, expert testimonies), and discipline (e.g. leadership in scientific associations).

While there is some evidence that activities across these three categories or roles—research, teaching, and service—are complimentary (Becker 1975; Colbeck 1998; Faia 1980; Marks 1977), others find they are substitutive such that, for example, faculty who focus on research and publishing commit less time to teaching and service (Coser and Coser 1974; Goode 1960; Hu and Gill 2000). Prior work has shown that faculty spend about 20 % of their time on activities that simultaneously accomplish teaching and research goals (Colbeck 1998) and that 22 % of faculty in 4 year institutions attained high productivity in both teaching and research (Fairweather 2002). However, there has been little to no empirical research investigating how different within-category activities affect each other. For example, it is unclear whether grant awards are associated with higher or lower production of journal articles, or whether grant success increases or decreases teaching and graduate student training. In response, this research examines how grant awards advance or hinder publication, teaching and training outputs of academic scientists.

This research empirically tests several basic assumptions about the relationships between grant-getting and other forms of productivity in academic science. Specifically, we investigate whether being a principal investigator or co-principal investigator is related to increased academic outputs, measured as publications, teaching, and supervision of research assistants. We also examine whether the relationships between grant-getting and productivity outputs are similar for men and women. We are particularly interested in the potential differential effects of principal and co-principal investigator roles on different outputs. This paper addresses the following research questions: Do principal and co-principal investigators produce more journal articles than faculty who do not have grants? Does being a principal or co-principal investigator differently affect teaching loads and training of graduate students? Is the productivity of men and women scientists similarly affected by grant awards?

The paper first examines what is known about the activities of principal (PI) and co-principal investigators (co-PI) and demonstrates the motivation for this paper. It then makes use of two theoretical approaches—cumulative advantage and social role theory—to propose hypotheses about the relationships between being a PI or co-PI and publishing journal articles, teaching, and supervising research assistants. Based on prior literature, the paper also formulates a hypothesis to examine whether grant-getting differently affects outcomes for women and men. Hypotheses are tested using survey data collected from scientists at two points in time, 2007 and 2010. The longitudinal nature of the data allows us to examine how having grants in time one affects production outcomes in time two. We conclude with a discussion of the theoretical implications of the findings, as well as for national grant policy and for university management.

2 Principal and co-principal investigators

The conduct of science is increasingly a team-based activity in which multiple investigators collaborate to advance knowledge (Lee and Bozeman 2005; Hackett 1990). Much of this team-based work is funded through federal research grants with team members taking on particular roles such as PI, co-PI, senior researcher, consultant, postdoc, or student. Within this context, PIs and co-PIs are the key personnel that oversee grant money, conduct research, train students, hire research personnel, and carry out numerous decisions that affect the conduct of science. They integrate funder incentives and university regulations in the development of research activities and outputs. For example, a PI might choose to employ undergraduate researchers on a project because federal funders encourage research universities to engage undergraduates in the research process. PIs and co-PIs from different disciplines or institutions may choose to collaborate in response to funder priorities (Abramo et al. 2008), further emphasizing the important role that funded research has on shaping research agendas and collaborative networks. Given the large influence that PIs and co-PIs have over the conduct of and advancement of science, it is increasingly important to understand how these roles matter within the broader work context of academic science and engineering and the production of outcomes.

The distinction between principal and co-principal investigator is not always clear. In 2008, the NSF noted that the "NSF does not infer any distinction in scientific stature among multiple PIs, whether referred to as PI or co-PI. All of the senior personnel are equally responsible for the conduct of the project and submission of the requisite project reports" (NSF 2009, p. 3). However, later in 2011, the NSF distinguished between PIs and Co-PIs as follows: "the individual designated by the grantee and approved by NSF, who will be responsible for the scientific or technical direction of the project. If more than one, the first one listed will have primary responsibility for the project and the submission of reports. All others listed are considered co-PI/PD, and share in the responsibility of the scientific or technical direction of the project" (NSF 2010, Introduction D, 1, h). The NIH also allows for multiple investigators but requires that when multiple PIs are listed on a project they share authority and responsibility for the project and are equally accountable to the funding organization (Source: http://grants.nih.gov/grants/multi_pi/), although it is typically one of the multiple PIs who is ultimately responsible for making sure the project is carried out and for reporting.

While the principal investigator is commonly recognized to be the lead of the research project (Fields and Price 1993; Morahan and Feetwood 2008) or team leader (Hackett 1990), the role of the PI may differ depending upon the project. In some cases the PI may be the actual intellectual leader, in other cases the PI might be the person that the team determines is the most likely to receive the award, based on subjective assessments of prestige, reputation, and qualifications. To enhance the probability of obtaining an award, junior researchers that generate proposal ideas may take a formal role as co-PI or research personnel, while a more experienced or better-known faculty member may serve as the PI. Alternatively, junior, less experienced researchers might take on a PI role to take advantage of set aside funds for new or beginning researchers. For example, the NSF now asks researchers to indicate if the PI is a “beginning investigator”, defined by the NSF as someone who has not held a federally funded award with the exception of doctoral dissertation, postdoctoral fellowship, or research planning grants. Other agencies, including the Office of Naval Research, National Institutes of Health, and the National Institute for Food and Agriculture, offer new and young investigator awards. In these cases, the research team might be responding to the funder’s desire to support new investigators, selecting the less experienced researchers to serve as the PI. In sum, the assignment of the title PI or co-PI might indicate differing roles on a project or be assigned in response to funder priorities or strategies in grant competitions. Despite these possible arrangements, the PI role is widely recognized to be more prominent, more responsible, and more in charge of a funded project than the co-PI role. In general, we assume that a PI is the sole or lead investigator on a scientific project, while co-PIs share responsibility for the intellectual or managerial functions on the scientific project. The PI has primary responsibility for the conduct, completion and reporting on the research outlined in the proposal, while the co-PI has secondary responsibility. The PI is has primary accountability to the granting agency, while the co-PI is primarily accountable to the PI.

3 Linking PI and co-PI status to publications, teaching, and training

In seeking to understand why PIs and co-PIs may produce more or fewer outputs, this paper adopts two theoretical approaches used in prior research to explain productivity outcomes in academic science: cumulative advantage theory and social role theory. Cumulative advantage theory provides an approach to understanding the dynamics of the science production process in which prior accomplishments predict future accomplishment, and scientists that realize early grant success are more likely to attain higher levels of grant success more quickly in their careers (Merton 1973). Social role theory provides a second approach to explain the factors that determine PI and co-PI productivity outcomes (Biddle 1986). The theoretical perspective is applicable in two ways. First, as shown above, PIs and co-PIs undertake different activities and have different expectations and responsibilities associated with them. As a result, the PI and co-PI positions can be considered different roles on funded projects. Second, there are several key roles that academic scientists play related to each of the different outputs of interest in this study—teacher, researcher, and contributor to the academic community. The PI and co-PI positions may result in different types of synergies and conflicts with these different academic roles. Additionally, social role theory and cumulative advantage provide different, yet complementary components of the science production process. One focuses on the complexities of the social context of science activity, while the other recognizes the human capital dimension of scientific capacity development. Together, they provide support for a more comprehensive and nuanced explanation of PI and co-PI production. The two different theoretical approaches are now presented in turn.

First, cumulative advantage posits that success in science is a result of feedback from recognition, resources, and productivity. Structural advantages, such as graduation from a prestigious department, strong research training, and early career mentoring provide initial advantages that lead to access to resources important for the conduct of research. Subsequent research outputs such as publications receive formal and informal feedback that ultimately results in increased future recognition, resources, and productivity, and so on (Bentley and Blackburn 1990; Creswell 1985; Creamer and McGuire 1998; Cole and Zuckerman 1984; Fox 1983).

As scientists are increasingly required to obtain grants at earlier stages of their careers, the value of utilizing cumulative advantage to demonstrate the potential becomes more important. Indeed, Hackett (1990) finds that institutional tenure and promotion requirements increasingly require faculty to obtain external funding. As institutional funding continues to disappear, grant funding is an important source of revenue for scientists to support students and ongoing research and to demonstrate immediate and future potential value to the department and university. In addition to providing funds for conducting research and training students, grant-funded research can expand a scientist's opportunities for gathering data, expanding collaboration networks, and thus increasing productivity. Cumulative advantage theory leads to the expectation that obtaining a PI or co-PI grant represents initial access to resources that would then be transformed into publications, and eventually greater recognition and future resources.

Social role theory explains that behavioral patterns in society are determined by the social positions and expectations that individuals have about themselves and that others have about them. Biddle explains that "…role theory [concerns] a triad of concepts: patterned and characteristic social behaviors, parts or identities that are assumed by social participants, and scripts or expectations for behavior that are understood by all and adhered to by performers." (1986, p. 68). In general, social contexts are thought to form behavioral expectations and the mechanisms by which individuals and groups can demonstrate fulfillment of the expectations. Expectations set, for example, by the organizations, discipline, or profession, result in patterns of behavior that are predictable (Dierdorff and Morgeson 2007).

Social role theory provides the second rationale for understanding how the PIs and co-PIs modify traditional academic role expectations of researcher, mentor, teacher, committee member, and administrator. Faculty have a finite amount of time to allocate to various activities. Prior work has shown that while there is some complementarity across different teaching and research roles, it is limited (Colbeck 1998). Fairweather (2002) finds only a slight "spillover effect" between teaching and research and Ramsden (1994) shows that commitment to teaching at both the individual and department levels lowers research activity. Hu and Gill (2000) find that once faculty members teach more than 11 h per week there begins a strong negative relationship between teaching and research productivity. Similarly, Mitchell and Rebne (1995) find that the first 8 h of weekly teaching has a positive effect on research activity, but more than eight has a negative effect on publication outputs. In general, most research shows some level of role conflict between teaching and research such that a higher level of teaching ultimately leads to reduced research activity.

When scientists and engineers receive grant awards that call for substantial new research activity role conflict can increase because new expectations required to conduct the research require adjustment of time allotted to fulfilling other expectations. One way in which the department and university can alleviate this role conflict is to allow the awardee to substitute research workload for teaching workload. Given the tensions between the roles of teaching and research, it follows that when departments and universities alleviate this tension by allowing faculty to use grant funds to reduce teaching loads or "buy-out" of course teaching, faculty will continue to seek funding for their research activities. While, it is clear that enactment of multiple roles can result in conflicts that reduce productivity, the level of conflict probably varies depending upon the roles considered and the extent to which department and university workload policies address these conflicts.

Prior research has not examined whether being a PI or co-PI is related to productivity. However, we can apply both cumulative advantage and social role theories to develop a model of the expected relationships. In addition, we assume that departments and universities are likely to attempt to maximize production of outputs that enhance their own stature and reputation. Because departments and universities are socially negotiated institutional environments in which some accommodation of workloads and work roles can be made (Colbeck 1998), we would expect that departments and universities will adopt workload policies that further enable grant income and research production (Hackett 1990), and simultaneously reduce role conflict. While we cannot observe department and university policies, we expect that on average PIs and co-PIs will receive reduced teaching loads either because they 'buy-out' of teaching or because of some other negotiated agreement for course release.

H1 Having grants will be associated with higher numbers of publications.

H2 Having grants will be associated with a lower teaching load.

While the role overlap between teaching, research, and administration may be limited, the role overlap between research and training of graduate students may be greater. In academic science and engineering, the increasing dependency upon funded research projects for support of graduate students has resulted in a proliferation of graduate assistantships (Hackett 1990). That said, graduate students might have positive and negative impacts on the productivity of the grantee (Bozeman and Corley 2004; Wood 1990). For example, if mentoring and training duties were high, we would expect a negative impact, at least in the short-run, on awardee productivity (Bozeman and Corley 2004). However, if graduate assistants are strongly motivated and have high capacity and independence, they may increase the productivity of the PI or co-PI, in the same ways that collaborative activity in general can lead to increased productivity (Behrens and Gray 2000; Melin 2000). For example, highly productive graduate research assistants might increase the number of publications co-authored with the project PI and Co-PI. Similarly, support of graduate students might result in increased productivity on research projects, in general.

Although grant funding is likely to increase the hiring of research assistants, there is little research investigating the relationship between working with students and research productivity. Wood (1990) notes that there is a general belief that working students can "enrich the environment through their enthusiasm and new ideas" (p. 90), but there is also an understanding that student researchers might also overburden faculty, especially when those students are unable to carry out independent research or lack motivation. More recently, grant funders such as the NIH and NSF have made working with students an increasingly important component of grant-getting. Grant applications ask applicants to indicate the educational and training outcomes of research proposals, implicitly assuming that funded science will train future scientists. Moreover, recent calls for proposals ask applicants to include undergraduate researchers in their proposals. While no evidence exists tying PI or co-PI awards to hiring research assistants, we expect, given the trends of increasing grant dependence and funders' preference for training students on research grants, the relationship is positive. While it is possible that administrative duties (e.g. running labs, managing grants, overseeing projects) required for managing multiple funded projects may reduce faculty ability to publish research results, we expect that the positive effects of added resources and increased graduate student capacity will outweigh the negative effects of increased administration on productivity. Nevertheless, expectations placed on PIs and co-PIs of grants administration, and the time required to attend to it, create an additional role for scientists. Scientists who develop more effective management capacities and are more able to delegate administrative tasks to other personnel, are likely to realize less role conflict. Although the relationship between working with research assistants (e.g. students) and academic productivity has not been tested empirically, we expect that the shift in priority toward supporting students on funded projects will mean that PIs and co-PIs will have more graduate assistants than non-awardees.

H3 Having grants will be associated with supervising more research assistants.

It is unclear whether or not productivity output will be higher or lower for PIs as compared to co-PIs. As noted earlier, the PI role is consistently described as administrative research leader, while the co-PI is more often considered to be a team member. Hence, it is likely that there are substantial differences in the administrative requirements associated with PI awards, as compared to co-PI awards, where PIs are more responsible for management and reporting. Research indicates that grant success is associated with higher levels of administrative duties (Hackett 1990) and the implications for grant administration on research are likely similar to findings on service load. This additional administrative burden can have strong effects on research productivity and cause role conflict. First, administrative tasks are often less valued in academia. Carr et al. (1993) show that faculty generally prefer to work much more on research and much less on administration than they actually do. Second, additional administrative and service work is negatively related to research activity, because productivity is possibly related to the amount of time devoted to research (Hu and Gill 2000). Additionally, it is likely that administrative roles have a greater level of immediacy associated with them and are therefore prioritized over other roles, such as research productivity (Wood 1990). In sum, the administrative burden associated with managing a grant as a PI might be related to reduced time allocated to research activities such as publishing research results and training students.

On the other hand, it is also possible that PIs, as project leads, may be more likely than co-PIs to employ graduate students due to their higher authority and administrative positions. Additionally, serving as a PI might ensure that the scientist is credited on all outputs associated with the grant, thus increasing co-authorships and publications for the PI. In sum, being a PI may lead to greater productivity due to higher graduate student employment and greater reach on the project; but heavy administrative requirements may mean that the PI spends less time on research activities and publishing. This could leave the co-PI better positioned, with fewer role conflicts, to focus on research outputs.

While there is no research indicating whether the work load and roles on grants will lead PIs and co-PIs to have differing levels of academic outcomes, there is some research investigating the ways in which these two roles are valued in the academy. Faculty evaluations and departmental incentives tend to show that the role of PI is often considered to be more valuable or recognized than the role of co-PI. For example, work by Scheid et al. (2002) shows that a PI award carries the highest relative value of all academic products, while the relative value of a co-PI award holds about two-thirds the relative value of the PI award. A co-PI award has a relative value just below that of a sole author refereed article, making combined value of a co-PI award and a journal article somewhat higher than a PI award. Hence, even in terms of cumulative advantage or local department rewards, a co-PI may be able to receive greater reputational returns than a PI. The loss in prestige and recognition from the 'reduced' co-PI role is made up by the increased production of publications. These types of trade-offs occur within the departmental and university context where incentives, workload policies, norms of social negotiation, and output valuation play out (Colbeck 1998). Because prior work on this is scant and because these workload policies are not easily observed, we offer the following hypotheses:

H4 PI awards will be related to producing more journal publications as compared to co-PI awards.

H5 PI awards will be related to decreased teaching loads as compared to co-PI awards.

H6 PI awards will be related to supervising more graduate assistants as compared to co-PI awards.

Research indicates that academic productivity is related to personal attributes (researcher sex, age, education, etc.), institutional and departmental attributes (characteristics of the institution, size of faculty, technology and instrumental infrastructures available, etc.) and environmental attributes (labor policies, public and private funds available, students available to support the research, etc.). As researchers and science funders have become increasingly concerned about the dearth of women in science, technology, engineering, and mathematics (STEM) fields an increasing amount of research has focused on comparing the productivity rates of men and women. Early research found that after controlling for rank and discipline, gender is not related to research output (Blackburn et al. 1978), however, more recent work argues that because of the structural barriers women face in the academic work place, they often have work loads and outputs that differ from men (Bain and Cummings 2000; Ekzkowitz et al. 2000). For example, women are more likely to have lower ranking positions and are often saddled with more teaching responsibilities than men (August and Waltman 2004). Additionally, women take on more institutional responsibilities, which may contribute to lower research productivity (Olson et al. 1995).

A number of studies have found variation in publication rates by sex (Blackburn and Lawrence 1996; Creamer 1999; Long and Fox 1995; Prpic 2002; Zuckerman et al. 1991). For example, investigating a sample of chemists, Reskin (1978) found that men chemists produce more publications than women, but that women were more influenced than men by having prestigious postdoctoral fellowships, employment in tenure-track university position, and collegial recognition. Fox (2005) investigated productivity of women in academic science, looking at the ways in which marriage and having children are related to women's productivity. Fox concludes that women with preschool children have higher productivity than women without children or with school-age children. She also finds that women's productivity rates vary based on their marital status and type of marriage (e.g. first marriage, marriage to an academic scientist) (2005).

While there is a great deal of research investigating science outcomes and comparing research outcomes of men and women, there is no previous research investigating the ways in which grant-getting differently affects outcomes for men and women academic scientists. Given the previous work finding significant variation in science careers and outcomes for men and women, we propose the following hypothesis:

H7 The relationship between grants and work outcomes will be significantly related to sex.

4 Data and models

This analysis uses data from national surveys of academic scientists and engineers in research intensive universities in the United States collected at two points in time. The surveys collected data on individual background, career experiences, research and teaching responsibilities, productivity, satisfaction, and professional networks. The surveys were implemented online using Sawtooth Software®. Faculty were invited to the survey via traditional mail with a series of personalized email follow-ups. Each of the invitations provided individually assigned user-id and password and directed the individual to the survey website. Overall, the survey took between 30 and 45 min to complete.

The first survey was administered in 2007 to a random sample of 3,667 faculty stratified by sex, rank, and discipline which was drawn from the population of 23,896 academic scientists and engineers in six disciplines in 150 universities that were previously categorized by the Carnegie Classification as Research I universities. Today, these 150 universities would be classified as RU/VH and RU/H, or Research Universities with very high and high research activity, respectively.[1] The population of 23,896 was constructed by manually retrieving information from the web sites of the relevant departments or university directories, and copying the faculty information for assistant, associate, and full professors (all of which indicate rank). The disciplines (biological sciences, chemistry, computer science, earth and atmospheric sciences, electrical engineering, and physics) were selected based on the level of female representation (low, transitioning, and high fields). Of the 1,774 completed surveys, 176 were removed because of ineligible rank, or discipline. Also, 21 partially completed surveys were deemed to have sufficient information (over 95 % of questions answered) and included. The final analysis sample size was 1,598 faculty. The overall response rate of the survey, calculated using the RR2 method of the American Association for Public Opinion Research (AAPOR) was 45.8 %. The weighted response rate was 43 % (AAPOR 2009).

The second survey was conducted in 2010. The purpose of this second survey was to gather longitudinal data from respondents of the 2007 survey. Much of the content of the 2010 survey was identical to that of the first survey, enabling the examination of change in the respondent's network, research activities, and outcomes. The population for the second survey was derived from the 1598 faculty respondents of the 2007 Phase I survey. The final sample size of the 2010 survey was 1498, after eliminating 100 respondents that had invalid email addresses. The overall response rate of the 2010 survey, calculated using the RR2 method of the American Association for Public Opinion Research (AAPOR) was 51 % (weighted response rate was also 51 %). The number of complete responses was 765. Responses were fairly evenly distributed across gender (48 % women) and field (19 % from biology, 19 % from chemistry, 15 % from computer science, 19 % from earth and

[1] The Carnegie Classification distinguishes the 4,400 degree-granting colleges and universities in the United States based on research and degree granting activities. This sample draws from the previous classification which defined Research I universities as granting more than 50 doctoral degrees each year, giving high priority to research, and receiving more than $40 million dollars in federal support annually. As of 2005, the Carnegie Classification has been revised and doctorate-granting universities are now defined as awarding at least 20 doctoral degrees per year and are described as RU/VH: Research Universities (very high research activity) (n = 96); RU/H: Research Universities (high research activity) (n = 103); and DRU: Doctoral/Research Universities (n = 84). The universities used in this sample would now be categorized as RU/VH Research Universities (very high research activity) and RU/H Research Universities (high research activity). (Sources: 2005 Carnegie Classification; National Center for Educations Statistics, IPEDS Fall Enrollment 2004; http://www.carnegiefoundation.org/classifications/index.asp?key=805; http://www.carnegiefoundation.org/about/sub.asp?key=18&subkey=405#1.2).

atmospheric sciences, and 12 % from electrical engineering). The distribution of rank is nearly proportionate to the population (27 % assistant professor, 27 % associate professor).

4.1 Dependent variables

We use three dependent variables to capture faculty outcomes in Time 1 (2005–2007): publications, teaching, and research assistants. **Publications** is a self-reported measure in response to the following questionnaire item: Please indicate how many peer reviewed academic publications (accepted or published) you had in the past two academic years (2005–2007). Response categories are the following categories: 0, 1–2, 3–4, 5–6, 7–9, 10–14, and 15 or more. **Teaching** is the number of courses that the respondent taught or co-taught in past academic year (2005–2006). Teaching is a categorical variable with the following categories: 0, 1, 2, 3, 4, and 5 or more. **Research Assistants** is a categorical variable indicating the number of research assistants that the respondents supervised in past academic year (2005–2006). Response categories are 0, 1, 2, 3, 4, and 5 or more.

After examining the immediate effects between having grants and outcomes, we examine the medium term effects on outcomes in Time 2, 2007–2009. We have two dependent variables for time 2: **PublicationsT2** and **TeachingT2**. **PublicationsT2** is a categorical variable indicating the number of journal publications from 2007 through 2009. **TeachingT2** is a categorical variable indicating the number of courses that the respondent taught or co-taught in past academic year (2008–2009). The response categories in Time 2 are the same as for Time 1.

4.2 Independent variables

The primary independent variables of interest are whether or not the respondents are Principal Investigators (PI), Co-Principal Investigators (co-PIs), and sex. We use four mutually exclusive dummy variables to capture the respondents' status on grants. These four variables were created using responses to the following two questionnaire items: "In the last 2 years of the PI grants you submitted, how many were successful?" and "In the last 2 years of the co-PI grants submitted, how many were successful?" We then created variables for all respondents indicating if they had successfully been awarded grants for which they were a PI or Co-PI. The variable, **PIonly** is coded one if the respondent received at least one grant as a PI between 2005 and 2007. **Co-PIonly** is coded one if the respondent received a co-PI on at least one grant from 2005 to 2007. **BothPIorCo-PI** is coded one if the respondent received PI and co-PI grants from 2005 to 2007. **NeitherPInorCo-PI** is coded one if the respondent did not receive a PI or co-PI grant from 2005 to 2007. In this sample, 404 individuals received grants as PIs during 2005–2007, 122 received grants as co-PIs, 547 received both PI and co-PI grants, and 231 did not receive an award as either PI nor a Co-PI. Sex is measured with a dummy variable, **Female** (=1). As a result of over sampling, there are 731 women (45.7 %) in the sample.

4.3 Controls

Previous research has found that productivity is related to institutional and environmental factors such as discipline and faculty size (Dundar and Lewis 1998), prestige of the academic position and context (Long and McGinnis 1981), and personal factors such as sex, age, and education, scientific collaboration (Fox 1983, 1992a, b; Lee and Bozeman 2005; Reskin 1978). In order to assess the relationships between being a principal investigator or co-principal investigator and academic outcomes, it is important to control for a number of these factors. First, we control for the field of science using the following dummy variables: **Biology, Chemistry, Computer Science, Earth and Atmospheric Science, Electrical Engineering,** and **Physics.**

Since research indicates that affiliation with research centers may be related to productivity (Ponomariov and Boardman 2010), we control for whether or not the respondent has a formal affiliation with a research lab or center. The variable, **Lab Affiliation**, is coded one if the respondent has a formal affiliation with a research lab or center. Approximately one-fifth of the respondents report having a lab or center affiliation.

We also control for seniority and rank with a series of variables.[2] First, we measure time in the career with the continuous variable, **TimeSincePhD**, which ranges from 1 to 54 years with a mean of 18.5 years. Second, we include a dummy variable, **Tenured**, which is coded one if the respondent has tenure; 1105 individuals in the sample have tenure. Because previous research indicates that senior professors are likely to have heavier service loads than junior faculty (Hu and Gill 2000), while women are also more likely to be junior and have higher teaching loads than more senior, men faculty (August and Waltman 2004), it is important to control for rank. Academic rank is measured with three dummy variables for **Assistant Professor** (=1), **Associate Professor** (=1), and **Full Professor** (=1). **Age** is a continuous variable, with a range of 28–82 and mean of 48. Finally, we control for the total dollar amount of grants received by the respondents, since it is possible that an individual is a PI or Co-PI, but does not have a large enough grant to purchase course-buyouts or hire research assistants. We asked respondents to report the total dollar amount of all successful grants for which they are listed as a PI or Co-PI from 2005 to 2007. **TotalGrants 2005–2007** is a continuous variable ranging from 0 to 154 million, with a mean of 1.868 million.

We conduct two sets of OLS regression estimations. The first set of estimations uses the Time 1 dependent variables of publishing, teaching, and the number of research assistants. Because there is some interdependency between teaching, publishing, and working with research assistants, when predicting each dependent variable we include the other two in the model as controls. The second set of estimations regress the Time 2 dependent variables on the independent and control variables, enabling us to investigate causal relationships and not just associations. We conduct these two different estimations, because it is possible that being awarded a grant that was submitted during the 2 years prior to the survey may have both immediate and longer-term effects. Although the near term effects are likely to result in immediate changes in teaching and supervised graduate assistants, we also examine publication outcomes at Time 1. In the medium term, we expect the cumulative effects of receiving a grant to have continuing effects on teaching and publication outcomes. Descriptive statistics for all variables are noted in Table 1.

5 Results

5.1 Comparison of means

Before running the full regression models, we conducted a cross tabulation to investigate differences in outcomes across the four groups of interest in Time 1. Table 2 compares the

[2] Although each of these measures capture rank and seniority and would be expected to be related to age, a multicollinearity test indicates that measures of rank, time since PhD, and age are not multicollinear.

Table 1 Descriptive statistics

	N	Missing	Mean	SD	Min	Max
Time 1 survey data						
Principal investigator (2005–2007)	1,304	294	0.31	0.46	0	1
Co-principal investigator (2005–2007)	1,304	294	0.09	0.29	0	1
Both PI and co-PI (2005–2007)	1,304	294	0.42	0.49	0	1
Neither PI nor co-PI (2005–2007)	1,304	294	0.18	0.38	0	1
Female	1,598	0	0.46	0.50	0	1
Chemistry	1,598	0	0.18	0.38	0	1
EAS	1,598	0	0.16	0.37	0	1
Biology	1,598	0	0.18	0.39	0	1
Physics	1,598	0	0.17	0.38	0	1
Computer Science	1,598	0	0.13	0.34	0	1
Electrical engineering	1,598	0	0.17	0.38	0	1
Formal affiliation with lab or center	1,598	0	0.22	0.42	0	1
Time since PhD awarded	1,591	7	18.51	10.43	1	54
Tenured	1,590	8	0.70	0.46	0	1
Assistant professor	1,598	0	0.27	0.44	0	1
Associate professor	1,598	0	0.28	0.45	0	1
Full professor	1,598	0	0.45	0.50	0	1
Age	1,574	24	48.04	10.07	28	82
Total amount grants 2005–2007	1,363	235	1868760.59	7429000.00	0	154000000
Dependent variables						
Publications	1,588	10	3.82	1.697	1	7
Teaching	1,584	14	3.42	1.121	1	6
Research assistants	1,567	31	3.69	1.774	1	6
PublicationsT2	746	852	3.39	1.231	1	6
TeachingT2	746	852	3.39	1.231	1	6

Table 2 Crosstabulation and means of outcomes for PIs, co-PI, both, and neither, time 1 2005–2007

	Publications		Courses		Research assistants	
	Mean	Pearson χ^2	Mean	Pearson χ^2	Mean	Pearson χ^2
Principal investigator	3.90 (0.032)	69.80***	3.42 (0.020)	140.88***	3.59 (0.031)	394.65***
Co-principal investigator	3.52 (0.064)	72.77***	3.58 (0.049)	40.05***	3.19 (0.066)	91.17***
Both PI and co-PI	4.39 (0.030)	479.77***	3.37 (0.020)	108.04***	4.26 (0.030)	691.59***
Neither PI nor co-PI	3.13 (0.039)	461.47***	3.63 (0.032)	74.67***	2.80 (0.045)	654.68***

Mean (SE of mean)

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

mean responses for PIs, co-PIs, respondents who are both PIs and co-PIs, and those who are neither. Looking at publications, we see that those who received grants as both PI and co-PI report a mean response of 4.39, where 4 indicates 5–6 publications per year and 5 is 7–9 publications per year. Those with no grants report the lowest mean of total publications. Those who are both PIs and co-PIs report the highest mean of supervising research assistants, with a mean of 4.26, while those who are neither PIs nor co-PIs report supervising an average of 2.8 research assistants. When we look at teaching loads, we see that respondents who have no grants report the highest mean teaching load (3.63), followed by PIs (3.58), and then co-PIs (3.42). Respondents who are both PIs and co-PIs report the lowest mean teaching load (3.37).

The differences in means and responses for each of the four groups and the three outcome variables, publications, teaching, and research assistants are statistically significant. The Chi square indicates that the variance is significant at the 0.000 level for all of the groups. In sum, the differences in mean production of publications, mean teaching loads, and the mean number of research assistants supervised are significantly different for PIs, co-PIs, those who are both PIs and co-PIs, and those who did not receive grants.

5.2 Regressions for time 1

Table 3 presents the results of the regression analyses predicting publications, teaching, and research assistants in Time 1 for principal investigators, co-principal investigators, and those who are both PIs and co-PIs. We see that when controlling for gender, field of science, lab affiliation, rank, age, and amount of grant awards, outcomes vary significantly between those who have grants and those who do not. Specifically, we find strong support for the first hypothesis that having grants is associated with higher numbers of publications. PIs, co-PIs, and respondents who are both report significantly more publications than those who do not have grants. We also find support for the second hypothesis that having grants is associated with a lower teaching load, though this relationship only holds for those who are PIs and both PIs and co-PIs. We do not find a significant relationship between being a co-PI and having a reduced teaching load. Similarly, we find partial support for H3: Having grants will be associated with supervising more research assistants. Faculty who are PIs or who are both PIs and co-PIs supervise significantly more research assistants than those who do not have grants. However, receiving a co-PI grant does not affect the number of supervised research assistants reported by respondents.

Having found support for the first three hypotheses which predicted relationships between having grants and increased publications, reduced teaching loads, and increased supervision of research assistants, we now turn to the second set of hypotheses which addressed differences between PIs and co-PIs. First, we see that Principal Investigators, compared to those who received no grants, produce more publications, supervise more research assistants, and teach fewer courses in Time 1. The direction of these relationships hold for faculty who are both PIs and co-PIs on grants from 2005 to 2007, but the magnitude of difference is stronger for those who are both PIs and co-PIs as compared to those who are PIs alone. Thus, faculty who are both PIs and co-PIs have higher near-term production of publications, lighter teaching loads, and supervise more research assistants than those who are PIs alone.

Interestingly, we see that outcomes are slightly different for co-principal investigators. Co-PIs produce significantly more publications than those who do not have grants, but do not significantly vary in the other two outcomes (teaching and research assistants). Co-PIs, compared to those with no grants, produce significantly more publications, but this

Table 3 Grant getting and academic work outcomes, time 1 2005–2007

	Publications		Teaching		Research assistants	
	B	SE	B	SE	B	SE
Constant	6.221	0.225	1.741	0.171	2.487	0.237
Principal investigator (2005–2007)	0.244	0.056***	−0.141	0.041***	0.594	0.056***
Co-PI (2005–2007)	0.251	0.079***	0.031	0.057	0.088	0.079
Both PI and co-PI (2005–2007)	0.593	0.056***	−0.193	0.041***	1.018	0.056***
Female	−0.246	0.054***	−0.177	0.039***	0.204	0.054***
Chemistry	0.304	0.059***	0.146	0.043***	0.949	0.059***
EAS	−0.923	0.061***	0.216	0.045***	0.740	0.062***
Biology	0.227	0.062***	0.517	0.045***	−0.239	0.062***
Computer Science	−0.169	0.062**	0.560	0.045***	0.862	0.062***
Electrical Engineering	0.660	0.056***	0.206	0.041***	−0.020	0.057
Affiliation with lab or center	0.389	0.042***	0.010	0.031	0.480	0.042***
Time since PhD awarded	−0.012	0.006*	0.001	0.004	−0.042	0.006***
Tenured	−0.162	0.104	0.512	0.076***	−0.066	0.105
Assistant professor	−1.780	0.120***	0.675	0.088***	−0.550	0.122***
Associate professor	−0.911	0.052***	0.585	0.038***	−0.190	0.054***
Age	−0.042	0.006***	0.020	0.004***	0.003	0.006
Amount grants received 2005–2007	0.000	0.000***	0.000	0.000***	0.000	0.000***
Publications	–	–	−0.045	0.009***	0.188	0.012***
Teaching	−0.085	0.016***	–	–	0.059	0.016***
Research assistants	0.185	0.011***	0.031	0.008***	–	–
R^2	0.273		0.110		0.272	
Adjusted R^2	0.272		0.108		0.271	

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Rank: reference category is full professor

Field of science: reference category is physics

production is lower than that of PIs. We find support for H4 that PI awards are related to producing more journal articles than co-PI awards. We also find support for H5 and H6, which predicted, respectively, that PIs would have lower leaching loads and supervise more research assistants than co-PIs.

The results presented in Table 3 indicate the ways in which sex is related to the three outcomes in Time 1. Women produce significantly fewer journal publications, teach significantly fewer courses, and supervise significantly more research assistants than men. Because we are interested in understanding the ways in which grant getting is related to outcomes and how those relationships might differ for men and women, we split the sample by sex and ran separate models for men and women. Table 4 presents the results for those models and shows how the independent variables in the models differently affect outcomes for men and women.

Table 4 indicates support for our seventh hypothesis that the relationships between grant getting and outcomes (publishing, teaching, and supervising research assistants) are significantly related to sex. For example, we see that the relationships between grant getting and outcomes significantly vary for men and women in Time 1. For women there is

Table 4 Grant getting and academic work outcomes for men and women, time 1 2005–2007

	Publications				Teaching				Research assistants			
	Women		Men		Women		Men		Women		Men	
	B	SE	B	SE	B	SE	B	SE	B	SE	B	SE
Constant	4.876	0.469	5.906	0.238	2.480	0.381	1.744	0.186	5.214	0.645	2.236	0.256
Principal Investigator (2005–2007)	−0.119	0.143	0.293	0.061***	0.005	0.112	−0.158	0.044***	0.558	0.158***	0.595	0.060***
Co-PI (2005–2007)	−0.308	0.185	0.349	0.086***	0.291	0.145*	−0.016	0.062	0.055	0.207	0.080	0.086
Both PI and co-PI (2005–2007)	0.360	0.145**	0.623	0.061***	0.239	0.114*	−0.254	0.044***	0.818	0.160***	1.056	0.060***
Chemistry	0.281	0.144*	−0.346	0.063***	0.412	0.113***	0.098	0.047*	0.810	0.159***	0.980	0.064***
EAS	−0.637	0.155***	−1.614	0.066***	0.457	0.122***	0.185	0.049***	1.006	0.171***	0.710	0.067***
Biology	0.008	0.139	−0.375	0.067***	0.516	0.108***	0.504	0.049***	−0.303	0.155*	−0.221	0.068***
Computer Science	−0.135	0.177	−0.667	0.061***	0.626	0.137***	0.536	0.048***	0.503	0.197*	0.885	0.066***
Electrical Engineering	0.736	0.152***	−0.833	0.065***	0.086	0.121	0.209	0.044***	0.134	0.172	−0.031	0.061
Affiliation with lab or center	0.102	0.112	0.430	0.045***	−0.183	0.088*	0.028	0.033	0.388	0.124**	0.490	0.045***
Time since PhD awarded	−0.009	0.015	−0.010	0.006	−0.001	0.012	0.003	0.004	−0.015	0.017	−0.048	0.006***
Tenured	−0.167	0.193	−0.142	0.121	0.390	0.151**	0.540	0.087***	0.604	0.215**	−0.276	0.120**
Assistant Professor	1.270	0.198***	−0.769	0.123***	−0.159	0.158	0.681	0.100***	−0.603	0.291*	−0.663	0.138***
Associate Professor	1.904	0.254***	0.950	0.056***	−0.567	0.204***	0.611	0.041***	−0.443	0.163**	−0.178	0.057**
Age	−0.046	0.013***	−0.045	0.006***	0.023	0.010**	0.018	0.004***	−0.047	0.015***	0.011	0.006
Amount grants received 2005–2007	0.000	0.000**	0.000	0.000***	0.000	0.000**	0.000	0.000***	0.000	0.000	0.000	0.000***
Publications	–	–	–	–	−0.088	0.026***	−0.040	0.009***	0.141	0.037***	0.189	0.012***
Teaching	−0.143	0.042***	−0.077	0.017***	–	–	–	–	−0.142	0.047**	0.089	0.017***
Research assistants	0.113	0.030***	0.191	0.012***	−0.070	0.023**	0.047	0.009***	–	–	–	–
R^2	0.290		0.274		0.135		0.112		0.256		0.284	
Adjusted R^2	0.276		0.272		0.118		0.110		0.241		0.282	

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Rank: reference category is full professor

Field of science: reference category is physics no significant relationship between being a PI and publishing, but for men, being a PI is significantly related to increased publishing outcomes. We also see that among co-PIs, publishing outcomes vary for men and women. There is no significant relationship between being co-PI and publishing outcomes for women, whereas men co-PIs report significantly more publications as compared to men with no grants. Receiving both PI and co-PI grants is related to a significant increase in publishing outcomes for men and for women.

When we consider teaching outcomes in Time 1, we see men who are PIs and men who are both PIs and co-PIs report lower teaching loads than men who do not have grants. In contrast, being a PI, for women, is not significantly related to teaching loads. Rather, women who are co-PIs or both co-PIs and PIs report higher teaching loads than women who do not have grants. Thus, grant getting for women is either not related to near term teaching loads or actually increases teaching loads, while grant getting has the reverse effect for men.

Finally, we see that the relationships between grant getting and supporting research assistants in Time 1 are consistent for men and women, though the magnitude of the relationships differ. Both men and women PIs report supervising significantly more research assistants than those who do not have grants. Additionally, those who receive both PI and co-PI awards report supervising significantly more research assistants. The relationship between receiving both PI and co-PI awards and having research assistants is stronger for men than women. There is no significant relationship between being a co-PI and supervising research assistants. This might be explained by the fact that PIs generally have the authority to hire students.

The analyses presented in Tables 3 and 4 present strong evidence that grant-getting is related to near-term work outcomes for academic faculty. Specifically, we find support for H1, and find that having grants is significantly associated with increased publication rates. This relationship holds for men, but as noted in Table 4, there is a negative relationship between being a co-PI and publication productivity for women. We find strong support for H2, having grants is associated with lower teaching rates. Though again, we find this is consistently true for men, but women co-PIs report increased teaching loads. Finally, we find support for H3 and conclude that being a PI (or both a PI and co-PI) is positively related to supervising more research assistants. While these findings are useful, they are limited by the cross-sectional nature of the data. Thus, we turn to the results of the longitudinal analysis, presented in Tables 5 and 6.

5.3 Regressions for time 2

Table 5 shows the results for predicting publications and teaching loads for faculty in Time 2. Again, we find strong support for both H1 and H2. Having grants, as compared to not having grants, significantly increases publishing for academic faculty and significantly decreases teaching loads. The relationship between having grants and increased publishing is strongest for faculty who are co-PIs, followed by those who are co-PIs and PIs, and then faculty who are Principal Investigators alone. It appears that having a co-PI role might be more advantageous for producing publications. The relationship between grant getting and teaching loads also varies across PIs, co-PIs, and those who are both PIs and co-PIs. Faculty who are both PIs and co-PIs report the largest reductions in teaching loads, followed by PIs, and then co-PIs.

Overall, we see that grant getting provides the resources and support to enable faculty to increase journal productivity and relieve them of teaching. Taken together, the variation in magnitude of relationships for PIs, co-PIs, and faculty who are both PIs and co-PIs, it seems that for co-PIs grants offer additional support and resources for increased

Table 5 Grant getting and academic work outcomes, time 2 (2007–2009)

	Publications (2007–2009)		Teaching (2007–2009)	
	B	SE	B	SE
Constant	2.015	0.266	1.008	0.230
Principal investigator (2005–2007)	0.214	0.064***	−0.280	0.059***
Co-PI (2005–2007)	0.434	0.085***	−0.199	0.079*
Both PI and Co-PI (2005–2007)	0.421	0.064***	−0.284	0.058***
Female	0.146	0.056**	−0.159	0.052**
Chemistry	0.051	0.063	−0.226	0.059***
EAS	−0.421	0.072***	−0.264	0.065***
Biology	0.135	0.068*	0.217	0.064**
Computer Science	−0.418	0.069***	−0.021	0.065
Electrical Engineering	−0.171	0.067**	−0.115	0.062
Formal affiliation with lab or center	0.166	0.047***	0.209	0.043***
Time since PhD awarded	0.013	0.006**	−0.033	0.005***
Tenured	0.263	0.114**	−0.200	0.105
Assistant professor	0.417	0.133***	0.075	0.122
Associate professor	0.051	0.057	0.141	0.052**
Age	−0.032	0.006***	0.034	0.006***
Amount grants received 2005–2007	0.000	0.000***	0.000	0.000**
Journals T1 (2005–2007)	0.714	0.013***		
Teaching T1 (2005–2007)			0.496	0.017***
R^2	0.572		0.284	
Adjusted R^2	0.570		0.281	

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Rank: reference category is full professor

Field of science: reference category is physics

publication production, while for PIs grant funding provides additional support for course buy-outs.

Similar to the analysis of men and women presented in Time 1, estimations show that grant getting the effects on work outcomes in Time 2 vary for men and women respondents. Table 6 shows the causal relationships between grant getting and publishing rates and teaching loads for women and men faculty. Importantly, we see that at Time 2 the relationships between grant getting and publishing for women change from Time 1. In Time 2, having grants is a consistent significant, positive predictor for publishing for women. Also, women faculty who are both PIs and co-PIs report the highest publishing outcomes, followed by co-PIs, and then PIs (note that in Time 1, the relationship between women co-PIs and publishing was negative and the relationship between women PIs and publishing was not significant). The literature has found that women tend to produce less than men (Etzkowitz 2002), which is confirmed in our Time 1 results. Perhaps, receiving a grant provides the needed capacity to increase production levels; women may realize higher cumulative benefits than men as a result of receiving grant awards. Additionally, the magnitude of the relationship between grant-getting and publishing outcomes for women is larger than for men. In fact, the constant and in some cases the Beta coefficients for women

Table 6 Grant getting and academic work outcomes for men and women, time 2 (2007–2009)

	Publications (2007–2009)				Teaching (2007–2009)			
	Women		Men		Women		Men	
	B	SE	B	SE	B	SE	B	SE
Constant	3.869	0.552	1.590	0.287	1.096	0.489	1.020	0.246
Principal investigator (2005–2007)	0.509	0.167**	0.147	0.069*	−0.467	0.154**	−0.243	0.063***
Co-PI (2005–2007)	0.623	0.226**	0.397	0.092***	0.163	0.210	−0.232	0.085**
Both PI and Co-PI (2005–2007)	0.724	0.164***	0.360	0.069***	−0.580	0.151***	−0.229	0.062***
Chemistry	−0.076	0.154	−0.460	0.076***	−0.042	0.144	0.010	0.067
EAS	−0.669	0.190***	0.115	0.073	−0.482	0.172**	0.560	0.067***
Biology	−0.292	0.163	−0.082	0.070	−0.200	0.153	0.253	0.064***
Computer Science	−0.619	0.222**	−0.503	0.070***	0.290	0.207	0.228	0.065***
Electrical Engineering	−0.019	0.181	−0.259	0.068***	−0.092	0.168	0.134	0.062*
Affiliation with lab or center	0.136	0.126	0.155	0.051**	−0.112	0.119	0.271	0.046***
Time since PhD awarded	0.011	0.019	0.010	0.006	−0.030	0.017	−0.032	0.006***
Tenured	−0.529	0.230*	0.532	0.132***	0.434	0.214*	−0.503	0.121***
Assistant professor	0.087	0.248	0.693	0.152***	−0.504	0.222*	−0.200	0.139
Associate professor	0.768	0.309*	0.162	0.061**	−0.667	0.274**	0.115	0.055*
Age	−0.061	0.016***	−0.026	0.007***	0.045	0.015**	0.032	0.006***
Amount grants received 2005–2007	0.000	0.000	0.000	0.000***	0.000	0.000	0.000	0.000**
Journals T1 (2005–2007)	0.674	0.038***						
Teaching T1(2005–2007)			0.724	0.014***	0.361	0.047***	0.523	0.018***
R^2	0.542		0.587		0.218		0.315	
Adjusted R^2	0.527		0.584		0.192		0.311	

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Rank: reference category is full professor

Field of science: reference category is physics are nearly twice that of the model predicting publishing outcomes for men. In sum, we see that having grants results in clear positive publishing outcomes for women scientists, as compared to not having grants.

When we look at teaching loads in Time 2, we see that having grants is a significant predictor of having a reduced teaching load for both men and women. Women who are PIs and women who are both PIs and co-PIs have significantly lower teaching loads as compared to those who do not have grants. However, for women there is not a significant relationship between being a co-PI and teaching loads; for men, having any role on a grant (PI, Co-PI, or both) results in a reduced teaching load.

In sum, grants play an important role in increasing work outcomes for women, especially when looking at the downstream or cumulative benefits. In fact, being a PI or a co-PI increases publishing outcomes for women. However, when we consider the limited amount of time faculty have to dedicate to publishing, managing grants, overseeing students, and teaching, it is important to note that for women, being a PI (or both PI and co-PI) reduces teaching loads, but being a co-PI alone does not significantly reduce teaching loads.

6 Concluding discussion

This research is a first step at understanding the effects of grant getting on faculty outcomes. Moreover, this is the first study to look at how grant-getting differently affects outcomes for faculty in different roles: PIs, co-PIs, and those who are both PIs and co-PIs. Overall, we find that having grants is significantly related to increased research outcomes for academic faculty in STEM fields at research universities. Faculty who receive grants, either as PIs or co-PIs, produce significantly more journal publications and supervise more research assistants than those who do not have grants. We also find that there are distinctions between roles on grants; principal investigators report significantly different outcomes than co-Principal Investigators.

Before discussing the policy implications of these findings, it is important to note the limitations of this study. First, this study relies on self-reported survey data. All outcomes (e.g. publication production, teaching loads, and supervising research assistants) are self-reported and subject to respondent recall. Second, this research is limited to faculty working at research intensive universities in six fields of science: non-medical biology, chemistry, computer science, earth and atmospheric sciences, electrical engineering, and physics. Therefore, care should be taken when generalizing these results to faculty at other types of universities, faculty in other STEM fields, and faculty in the humanities and social sciences. Finally, as with all social science research, there are concerns about the direction of causality. It is possible that the relationships we find in the first set of regressions are picking up associations between grant getting and outcomes, not causal relationships. However, our use of data from two time periods does enable us to more firmly establish the causal relationships between our dependent and independent variables.

Despite the limitations of this research, the findings are important for faculty researchers, universities, and policy-makers. This research produces three overall important findings: (1) having grants is associated with increased academic outcomes, (2) PIs and co-PIs have distinct outcomes from grants, and (3) grant-getting differently affects outcomes for men and women scientists. The findings also tend to further support and define the theory underlying the study.

First, we find that having grants (e.g. being a co-PI or PI) is related to increased faculty outcomes. Implying that the university push to increase faculty grant-getting is not only fiscally beneficial to the university, but produces more outcomes for the public through more publications, increased research outcomes, and more students trained through research activities. This finding is supportive of cumulative advantage theory such that resources received at one point in time enable increased productivity at a second point in time. Academic scientists that receive grant awards as PIs or co-PIs, are able to convert the financial resources into demonstrable increases in knowledge output and research capacity. Universities that encourage and facilitate faculty grant getting should reap the benefits of increased publication rates and funding for and supervision of research assistants. We also see that grant-getting enables some level of substitution when it comes to balancing the roles of conducting research, publishing, and teaching, with grant-getting being associated with reduced teaching loads. Thus, while getting grants increases some outcomes, it draws faculty away from teaching, which is an important priority for universities.

Second, we find that the roles of principal investigators and co-principal investigators are significantly distinct in the production of outcomes. In general, principal investigators publish more, teach less, and supervise more research assistants than co-principal investigators. As the primary administrator on the grant, PIs appear to take more responsibility for supervising research assistants and benefit more from course releases. However, co-PIs still report increased publications and reduced teaching loads in comparison to those who do not have grants. From a theoretical perspective, these findings provide support for role theory in which PI and co-PI perceive and act upon different expectations within the academic environment. PIs shift the balance of teaching, research and training toward a new equilibrium in which administrative and training activities increase and teaching activities decrease. It is possible to conclude that PI funding results in a shift in the equilibrium from one in which the PI must balance the two primary, often conflicting roles of knowledge production and knowledge dissemination (Romainville 1996) to one in which the PI is able to build a research enterprise that fosters integrated research and training. Hence the PI position is a valid means by which scientists can reduce the role conflict. While co-PIs also appear to shift away from a teaching role, but not to the extent that PIs do. For the future, it is possible that the new emphasis on team science (e.g. collaborative research among PIs, co-PIs, and others) might enable universities to encourage organizing research that simultaneously reaps the benefits from research funding but maintains important teaching resources. Future research should seek to discover the nuances between PI and co-PI roles on grants and how those roles are more directly related to work outcomes.

Third, we find that the relationships between having grants and productivity vary significantly by sex. Even more important, we see that for women being a PI or co-PI is associated with some negative near term outcomes, but that over the longer term grant awards show cumulative benefits. Concerning the analysis of Time 1 outcomes, there is no significant relationship between receiving a PI award and publishing and teaching outcomes for women. There is a positive relationship for women between being a co-PI and teaching in Time 1. It is possible that the Time 1 results show that women are less likely to have established the publication returns and teaching reductions when they receive the grants. Possibly this is because the population of women in most fields of science and engineering studied here is more junior compared men. Nevertheless, the findings indicate that men have, on average, less role conflict (e.g. teach less) when grants are received, and hence are more likely than women to have established more cumulative advantage at the point when grant proposals are submitted. However, the Time 2 findings show women award recipients (PI or co-PI) generally produce more publications and teach fewer classes, and that these results are similar to the findings for men. As a result, once women are able to receive grant funding, they are able to convert the resources into productive outputs at even higher rates than men. They are also able to rapidly adjust the balance of teaching and research and position themselves with a similar level of advantage as men. Hence, once an award is received, the downstream benefits cumulate as fast for women as they do for men. These results tend to indicate that grant award policies targeting first awards to women are critical for enabling women to balance traditional academic roles of teaching, research and service in the same way as men and thereby establish equivalent levels of cumulative advantage. These policies may be most important and effective early in women's careers.

Additionally, the findings may indicate that social roles are stickier for women than for men. Whereas men are able to more quickly benefit from grant awards, in terms of lower teaching loads, more graduate assistants, and ultimately more publications, women are less able to obtain course releases and, perhaps, find it more difficult to quickly hire graduate students. It is possible that roles are more easily negotiated in universities for men than for women, which results in slower departmental or institutional response times for women to receive the award benefits. While over time women are still able to capitalize on the awards received, it is possible that the stickiness of social roles for women reduces the speed with which they are able to attain cumulative advantages.

Overall, these findings have important policy implications for research universities and research funders. First, we see that being a PI or co-PI on a grant can significantly increase research outcomes such as publications and the training of students, which are important for faculty and universities. However, at the same time, having a grant also takes faculty away from teaching, which is an important component of university activities. As faculty researchers continue to rely on government funding for grants and seek opportunities to work as PIs or co-PIs on research projects, universities will need to develop policies and practices to ensure that they maintain the capacity to employ talented, experienced teachers. Second, our findings point to the important role that grants play in advancing research productivity at universities, for both men and women. Policies that encourage new investigators and investigators from underrepresented groups to apply for grants as PIs or co-PIs are important for ensuring that these investigators have the resources to increase research outcomes.

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