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Using *curriculum vitae* to compare some impacts of NSF research grants with research Center funding

Monica Gaughan and Barry Bozeman

While traditional grants remain central in US federal support of academic scientists and engineers, the role of multidisciplinary NSF Centers is growing. Little is known about how funding through these Centers affects scientific output or (as is an NSF aim) increases academic collaboration with industry. This paper tests the use of CVs to examine how Center funding affects researchers' publication rates and their obtaining industry grants.

We find that CVs are indeed usable, but some ways of collecting them work much better than others, and that researchers who obtain Center grants are more likely to obtain grants from industry too, suggesting that this NSF aim is being met. We do not find that Centers improve publication rates.

Monica Gaughan and Barry Bozeman are both at the Research Value Mapping Program, School of Public Policy, Georgia Tech, Atlanta, GA 30332, USA; Monica Gaughan tel: +1 404 385 2800; email: monica.gaughan@pubpolicy.gatech.edu; Barry Bozeman tel: +1 404 894 0093; email: barry.bozeman@pubpolicy.gatech.edu

TWO OF THE POSSIBLY most important public policy factors shaping US science and engineering remain poorly understood and little researched. One of these is the shift from peer-reviewed, investigator-initiated federal grants funding to block funding of Centers. This phenomenon became important only about 15 years ago and the policies and institutional arrangements accompanying it are still very much in flux. Second, there is a dearth of studies of the impacts of research grants upon the careers and productivity of scientists and engineers in the USA. This study proposes a data source — the academic curriculum vita — that can be used to help evaluate the impact of grant sources and Center funding on industrial collaboration and productivity.

Generally, grants are viewed as an unleavened blessing, both for the scientist and for their institution. Occasionally, there is musing about the impact of grants on teaching, particularly the displacement of teaching by sponsored research (Clark, 1987). But most scientists are voting with their grant submissions and most institutions, especially universities, have come to view grants as income (Stahler and Tasch, 1992) and indirect costs as profit. It is only in marginalized research enterprises, including much of the social sciences, that anyone today deliberates much about such issues as the deflection of research agendas and external control of inquiry (e.g. Useem, 1976) . In the physical and natural sciences the anecdotal evidence is that self-reflection is nowadays largely confined to complaints about increased bureaucratic red tape and burdensome procedures of research administration.

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Our study examines jointly grants impacts and the move from decentralized peer-reviewed grants to science Centers. We focus on more than 1,000 scientists and engineers employed at university-based science and engineering Centers, using an unusual form of data, scientists' and engineers' curriculum vitae (CVs). While the very currency of career mobility, the CV has not often been employed as a source of data (see Dietz *et al*, 2000), but it is a rich source of time series data about matters central to scientific careers. The CV data provide insight about who does and does not receive grants of various types, and gives some information on how involvement in an interdisciplinary Center affects industrial ties and scholarly productivity.

Given the focus on science and engineering Centers, many of which were explicitly developed to promote cooperative research with industry, we are particularly interested in relationships to industrial funding and careers in industry. We also seek to compare those who receive Centers funding for their individual research with those who receive external funds from peer-reviewed federal research programs. Does one type of funding result in greater productivity, as measured by publications, or by greater industrial ties? Before considering these questions, we present an overview of the recent history and status of grants funding as well as the state of knowledge about the impacts of grants funding in the USA. We then turn to a description and analysis of the changing institutional context of academic science and engineering.

Research grants and their impacts

The federal research grant originated not long after the beginning of the United States. The Lewis and Clark expedition was based on a grant, authorized by Congress at the behest of President Thomas Jefferson (Cohen, 1995). An early draft of the Constitution included provisions for federal payments of awards to successful scientists and inventors (Farrand, 1911). But it was not until the mid-nineteenth century that serious thought was given to providing research grants to universities and university scientists and engineers. In the 1840s, Harvard and Yale began institutionalizing scientific research and education and used private philanthropy to attract scientific faculty. The Morrill Act of 1862 provided land grants and funds to the states and proved a powerful force for developing agricultural research and engineering programs.

While research grants have a long history in the USA, the modern university research grant originated in the 1950s. The National Science Foundation Act and the ensuing National Science Foundation established the template for the university grant. While the Defense Department and the Atomic Energy Commission already had important grants programs in place, it was the NSF grant system that would dominate academic research for years, in part because the NSF was created to support and nurture university research. The NSF system entailed providing awards to universities, as agents for the individual faculty who formulated grant proposals and who served as principal investigators. It was expected that the research initiative would come from the individual scientist who would write a brief description of their research idea; that idea would, in turn, be reviewed by scientific peers and if meritorious, funding would be provided through the university. The grant would typically allow the professor (rarely a postdoctoral researcher or graduate student) to obtain 'released time' from teaching, money for small-scale equipment and laboratory expenses, travel, support of graduate student research assistants and, to the delight of universities, reimbursement for 'indirect costs' — the mundane support infrastructure of the sciences, including everything from heating, air conditioning and building maintenance to research accounting and administration.

This system is still in place, not much altered, but others have been built upon it (as we discuss in the next section). In 1955, the total US university expenditures on research and development (R&D) were $590 million, of which only $180 million were from federal sources and only $20 million from the National Science Foundation, at that time the only agency with a mission to provide research grants, on a competitive peer-reviewed basis, to university scientists (Reagan, 1969, page 322). Thirty years later, the amount of federal obligations for university research would eclipse early support levels, with $12.3 billion (in constant dollars) federal support for academic R&D (National Science Board, 2000). By this time the National Institutes of Health would surpass the level of support provided by the National Science Foundation.

Grants have become such an integral part of university research that it is easy to think of grants systems and scientific research as essentially one and the same. Perhaps this accounts for the fact that so little attention has been given to the impacts of grants on researchers' productivity and careers. To be sure, there is an interest in grants, and studies have focused on the equity of the grants decision-making process (e.g. Walsh, 1975; Cole and Cole, 1973), the perceived deflection of funding from peer-reviewed programs to earmarking (e.g. Savage,

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1999), the dispersion of funds for academic science (Geiger and Feller, 1995), and the organizational culture of universities (Chubin and Hackett, 1990). Since the beginning of modern scientific grants, there has been a great deal of interest in the social and economic results of grants funding. But we have little systematic information about the impacts of grants acquisition on the careers and rewards of scientists and engineers acquiring them.

Liebert (1976) provided one of the few studies of the impacts of grants on researchers' productivity. In a study based on a sub-sample (n = 4,947) of the American Council on Education (ACE) survey of university professors, he found that grants were, indeed, associated with career article production and that there were differences of impact according to funding agency. He found that grant awards were predicted by very few of the variables in his model, with article production and field having important effects, but little else. His findings pertained only to getting grants, not the size of the award. Liebert (1976, page 673) concludes that since grants are widely distributed and have little bias according to field,

> such a system is not likely to provoke charges of inequity or injustice. This, indeed, may be one of the principal functions of a broad-based competition having many winners.

The view of science as distributive politics (Schooler, 1971) is very much in line with the immediate postwar science policy notion that every competent scientist should as a matter of course be awarded research grants (Greenberg, 1968) — an idea that proved impractical in later years. The 'every scientist a king' concept of distributive science policy has been most severely tested with the shift of resources from investigator-initiated 'little science' to Center-focused 'big science'.

The changing institutional context of science

From its humble beginnings, the National Science Foundation was by 1985 contributing more than $1 billion to university research, about one-sixth of the total of more than $6.5 billion of federal obligations for academic research and development (National Science Board, 2000). 1985 is a benchmark because that is the year in which the National Science Foundation announced its awards for six Engineering Research Centers. While now well accepted, the move to create the ERCs and, later, the NSF Science and Technology Centers, was at the time quite controversial. One element of the controversy was that it would compromise the system of decentralized, investigator-initiated, peer-reviewed grants upon which the National Science Foundation, and much of its political mythology, originally had been based.

The origins of Center-focused research at the National Science Foundation relate to the perceived 'competitiveness crisis' of the early 1980s: when the US economy was slumping, Japan was viewed as a primary economic competitor and was perceived as having a competitive advantage based on their ability to organize for cooperative research. Man and time were aligned as President Reagan appointed Erich Bloch director of the National Science Foundation, charging Bloch to shake up the NSF by bringing it four square into the nation's economic productivity equation. Bloch, the first engineer to direct the NSF, had spent most of his career in industry and was not acculturated into the norms and rituals of academic science and, while not an enemy of fundamental science, was not one to make sharp distinctions between 'pure' and 'applied' science (Bloch, 1986).

When Bloch came to the NSF, the Engineering Directorate was a stepchild of the Foundation, added several years after the creation of the NSF and receiving budgets that were a small fraction of those for the discipline-based physical and natural sciences. The program announcement for the creation of university-based Engineering Research Centers created quite a stir in the academic science and engineering communities. While the amount of money to be devoted to the ERCs was miniscule compared to the budget of the NSF (and was, indeed, a relatively small fraction of the Engineering Directorate's budget), the idea of making block grant awards to institutions was anathema to those who Daniel Greenberg (2001, page 380) refers to as the 'Bush worshipers', those who embrace the basic research myth of Vannevar Bush, the Roosevelt-Truman science advisor who set up the conceptual framework for the National Science Foundation. The Bush worshipers continued as Bloch's nemesis, so much so that in his farewell statement to the Senate Committee overseeing the NSF, Bloch felt compelled to observe that the NSF mission

> ties NSF to the broader needs of the nation … this interpretation may rankle those who view NSF's role as solely to advocate one approach to academic research in only a specific set of fields. But NSF is not the captive of individual investigators. (Greenberg, 2001, pages 368–369)

During the decade of the 1990s, the NSF investment in Centers was solidified and institutionalized. The NSF strategic plan for fiscal years 1989–1993 endorsed the continued allocation of resources to Centers, with no guarantee that small, investigator-initiated grants would receive as large a proportion of NSF funds as they had in the past. Increasingly, the strategy pioneered in the creation of the ERCs was brought to other directorates and scientific fields.

Presently, a long list of Centers is supported by the NSF, all established by procedures begun with the ERCs: program solicitations for science or engineering-focused Centers, submissions by universities and teams of universities, sometimes with industry partners, and selected by panels of external scientists and engineers. In FY2000, total annual funding for each of the ERCs ranged from \$3.1 to \$19.4 million, with NSF's contribution ranging from \$2.0 to \$2.9 million per year, averaging \$2.5 million per year (National Science Foundation, 2000). At the end of their support cycle, the NSF 'sunsets' the ERCs, requiring that they be self-sustaining, which about half seem to meet.

According to the National Science Foundation (2000), the ERC mission has three main elements: Cross-disciplinary and Systems-oriented Research, which focuses on global competitiveness; Education and Outreach, which links graduate education and industrial partnership; and Industrial Collaboration and Technology Transfer, which develops partnership between academe and industry. The current focus of the ERCs is in four program areas: bioengineering; product design and manufacture; earthquake engineering; and microelectronic systems and information technology. Examples of ERCs include: Montana State University Center for Biofilm Engineering; Duke University-led ERC for Emerging Cardiovascular Technologies; and University of California–Berkeley-led Pacific Earthquake Engineering Research Center (see also National Academy of Sciences, 1986; National Academy of Engineering, 1983).

The NSF Science and Technology Centers (STCs) were begun in 1989, also during Erich Bloch's tenure. During 1996–1997, the National Science Board affirmed its commitment to the STC concept, which had by that time grown to 24 Centers and a \$60 million NSF funding commitment. In some respects, the STCs were even more controversial than the ERCs since they explicitly involved science rather than the traditionally more applied, industrially oriented engineering disciplines (Kaiser, 1996). As a result of controversy, including continued criticism of mainstream disciplinary science, the STCs were the subject of numerous reviews, including ones conducted by the National Academy of Public Administration, the NSF inspector general, various consulting firms and the General Accounting Office. But the program withstood skepticism and oversight scrutiny and has become a major vehicle for NSF funding. The Centers can receive funding for 11 years and then must be self-sustaining. Since 1996, seven or eight new STCs have been established each year. Some examples of STCs include: the Center for Biological Timing, University of Virginia; Center for Light Microscope Imaging and Biotechnology, Carnegie Mellon University; the Center for Clouds, Chemistry, and Climate, University of Chicago; and the Center for Superconductivity, University of Illinois, Urbana–Champaign.

This discussion has focused on the new Center-based structures of the National Science Foundation, in part because the data reported here are from NSF Centers, but also because the NSF has pioneered the university Centers approach, at least in the United States. Furthermore, Centers facilitate the development of theoretically relevant knowledge value alliances, rather than focusing exclusively on a project-based evaluation focus (Rogers and Bozeman, 2001). Nevertheless, it is important to note that the National Institutes of Health have increasingly begun to use science Centers as funding vehicles (albeit ones different in structure than those of the NSF) and that the Department of Energy has long had Center-based structures linking universities with government laboratories (e.g. Ames Energy Laboratory, Lawrence Berkeley National Laboratory). The peer-reviewed, individual investigator-initiated, 'small science' grant is certainly not a thing of the past, but clearly the business of science is getting done in new ways, possibly with far-reaching implications. While there is knowledge of the history of this change and the personalities and their influence, there has as yet has been little attempt to apply perspectives from social science theory. We do not attempt to develop such a theory here; rather, we develop a model that helps one to evaluate the impact of institutional change on the individual scientists and engineers. How have their entrepreneurial behavior, productivity and career paths been affected by their affiliation with science and engineering Centers?

Impacts on Center-affiliated scientists

We assume that institutional change in science funding will directly affect scientists' work and careers and that to the extent that much broader forces ('competitiveness', globalization, change of Presidential administrations) affect scientists, those changes are mediated by the institutions of the proximate environment, the environment experienced in the scientist's professional and work routines. This is exactly what we expect happens in the shift from grants-based funding to Centers-based funding: political and economic pressures dictate institutional changes; these changes, in turn, affect scientists' career trajectories, as well as the composition, productivity and range of impacts of scientists' work.

Research questions

Our data allow us to examine empirically the differences in professional characteristics between grant awardees and Center grantees with scientists who have not been awarded investigator-initiated grants or Center grants. We are also able to test causal models to see what impact investigator-initiated and Center grants have on scientists' professional behavior. We explore two primary questions. First, given that a stated objective of the Centers is to increase ties with industry, does Center-based grantsmanship predict greater involvement with industry? Second, how do investigator-initiated and Center-based grants affect the primary measure of individual academic success, the publication productivity rate?

Data sources

The primary data used in this analysis come from the *curriculum vitae* of 1,041 PhD level scientists and engineers who are not currently in a postdoctoral position. Our target population was scientific researchers working in multidisciplinary work groups or research areas. We were particularly interested in biotechnology, biochemistry, bioengineering, and microelectronics because of the linkages between academia and industry in these fields that are matters of increasing policy interest. In our sampling strategy, we particularly focused on university-based multidisciplinary science Centers funded by the National Science Foundation.

Clearly, a limitation of this approach was the sampling being restricted to scientists and engineers working in NSF multidisciplinary Centers, and excluding those in Centers funded by NIH, Energy, and Defense. Since NSF is the agency whose mission is exclusively to support academic universities, we believe that this is an important approach to understanding Center-based career behavior. Nevertheless, future research should expand the sampling frame to include other types of federally-funded multidisciplinary Centers.

The *curriculum vitae* is a rarely used tool in science policy research. This study is part of a larger effort to understand how and in what ways this important source of rich career information can be used to understand scientific careers and collaborations. The reader is likely to understand that the CV is a comprehensive source of information about academics. For our purposes, we assume it provides complete and accurate information about the researchers' graduate education, academic and professional positions, publication productivity and grant success. No doubt some will contain misprints, omissions or even downright lies, but we do have not the extensive resources that would enable us to check out each CV we used. We assume such errors would not substantially affect our results.

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Due to the applied nature of the research we did not entertain the possibility of a random sample of Centers. Moreover, given that one of our primary objectives was simply to test the feasibility of using CVs as a research instrument, we were as concerned about the ability to develop adequate responses as with the external generalizability of the study. We are currently in the process of developing a fully representative data base — a random probability sample drawn from the population of academic scientists and engineers. The procedures for this preliminary study were, by necessity, more of the patchwork design model. In a companion paper (Dietz *et al*, 2000) the sampling process is treated in detail, but is summarized here.

There were two stages to the sampling process, a 'test run' and a 'main run'. The test run was chiefly to determine the practicality of using CVs to study the careers of scientists and engineers. For this purpose, four data collection approaches were used: an NSF database search, an industry search, an Internet search, and a collection of CVs from a multi-institutional, microelectronics research Center headquartered at the Georgia Institute of Technology (where we were conducting an intensive 'base case' case study, seeking to learn as much as possible about linking CV methods to more conventional research assessment approaches).

We purposely limited our collection to the broad fields of biotechnology (and related fields such as biochemistry and bioengineering) and microelectronics-related areas to make the task a manageable one. The goal was to obtain an expected sample of 300 to 400 CVs from researchers with diverse backgrounds, working in diverse research contexts.

We expected that these methods would not only ensure that most, if not all, of the methodological potential problems would surface (at least in these fields), but also that they would provide an opportunity to test various data analysis methods, including descriptive statistics, OLS regression and event history analysis. Thus, CVs were not collected to be fully representative of any particular group, but to allow us to develop and test coding procedures and data analysis approaches and to evaluate various methods of obtaining CVs.

In more detail: for the NSF, industry, and research Center collections in this test run, an email message was sent directly to potential respondents who were asked to submit a full CV via email. In contrast, for the Internet search, various search engines and search phrases were tested to identify a subgroup of web-posted CVs. Fifty CVs were thus solicited from industry scientists and engineers, 200 from NSF-funded academic researchers, 100 from the web (we stopped when we got to these round numbers; this was only a test run), and all faculty and graduate students affiliated with the multi-institutional research Center and its primary research program (210).

The contact details of a further 200 researchers funded by NSF's biotechnology program and working at US institutions were obtained from the NSF awards database. This source has the main advantage of identifying a group of active researchers (in any given field(s)) whose email addresses are provided by NSF. An email was sent inviting the 200 researchers to submit their full CV. Approximately 20% of the email addresses taken from the database were erroneous or obsolete. The researchers attempted to obtain a current address for all the undelivered emails using institutional directories via the worldwide web. No follow-up was done on the non-respondents. Fifty-five CVs resulted. Four respondents formally refused and one claimed not to have been funded by NSF. The effective response rate was approximately 28%.

Prior to conducting the industry search, the *Science Citation Index* (SCI) was explored for the years 1995–1999 using the key word 'biotechnology'. Over 3,100 titles were returned. Because searching each title for industry affiliation would have required extensive time and would not necessarily have yielded useful results, we opted to identify five journals that were likely to draw readers and authors from industry. Two of these were not available on the SCI and were substituted by two additional journals. Fifty-nine email notes were mailed and 19 responses with useable CVs were received — a response rate of approximately 32%. Based on their email addresses, 13 of the industry recipients did not reside in the USA, seven appeared to work in government agencies (which we considered non-academic for our purposes), and two worked with university-affiliated hospitals.

Our third group of CVs in this test run was acquired via a passive search over the Internet using popular web search engines. This approach has several advantages: it is non-intrusive, it utilizes CVs already available in the public domain, it is cost-effective, and there is virtually no wait time. On the other hand, two major disadvantages were identified: the sample includes only people who posted their CV on the web, and web-posted CVs tended to lack detail.

Web searches were conducted on ten different search engines. The initial results using standard keywords (e.g. *curriculum vitae*) were disappointing since these search engines turned up too many irrelevant web pages such as job search lists, academic newsletters, job announcements or résumé-writing guide pages — 'noise'. Advanced search features were used to reduce the noise level dramatically. Ninety-four CVs were retrieved from the web.

Our fourth test approach to CV collection was through a pilot study we conducted of the Micro-elec-tronics Research Center (MIRC) at the Georgia Institute of Technology and its major multi-institutional collaborative research program, the Interconnect Focus Center (IFC). We sought to collect all of the CVs of researchers and graduate students affiliated with MIRC (146 people) as well as researchers affiliated with the IFC (64 people). Like the NSF and industry targeted collections, we sent email messages to the Center's 64 affiliates asking them to submit their CVs. Two follow-up emails were sent to non-respondents. Our overall response rate was 41% for MIRC (52% for faculty and 37% for graduate students) and 73% for the IFC component.

The main run

After learning from this initial, methodologically driven approach, we developed our main sample. The 'main run' started in October 1999. After the practice run, the team set up a different strategy to collect the data. The team contacted 13 NSF Centers to obtain the scientists and engineers list. These Centers were chosen either because we had conducted intensive on-site interviews (which we planned to use as ancillary data) or at program managers' behest. They do not represent a random sample of all NSF Centers; in particular they are biased in favor of ones that have been in existence for at least three years.

After obtaining the lists, the team visited the Centers for interviewing potential respondents and personnel administrators/directors. But this direct visit and interview were not so effective, especially compared to the cost and time.

After considering the several options, the team made a decision to use the NSF Center lists for the basic data source. The NSF website included all of the Centers, which also provided each Center homepage. (NSF Centers were divided into four main categories such as: ERCs — Engineering Research Centers, I/UCRCs — The Industry/University Cooperative Research Centers, S/IUCRCs — State/ Industry Cooperative Research Centers, and STCs — Science and Technology Centers.) Each homepage had the faculty list with the basic information, such as the email address, telephone number, affiliation and mail address. All members from the faculty list were chosen as potential respondents, to whom we sent emails to ask for CVs.

The follow-up emails were sent twice unless there was a response. In the main run, we sent the request emails to 3,799 people and we received 1,106 CVs from them (the response rate is 29 %). Therefore, the total number of obtained CVs from the practice and main run is 1,384, with 32% as the overall response rate.

The current study is based on 1,041 scientists and engineers who are not currently in postdoctoral positions, and not working on dissertations. This is unlikely to influence the main effects of interest — grants — since it is uncommon for researchers to obtain them prior to completing these professional milestones. In another paper, we demonstrate that the methodology we used to code the CVs is reliable (Dietz *et al*, 2000).

Sample characteristics

In Table 1, we present univariate and bivariate statistics of the characteristics of our 1,041 sample of researchers. The first column shows the attributes of the whole sample, and the second stratifies them into those who have ever had a grant (grant) and those who have not (none). These researchers are predominantly male, who do not differ from women in their propensity to be awarded grants (Corley, Bozeman, and Gaughan, forthcoming).

Almost one-third of the sample has completed a postdoctoral assignment, and two-thirds published prior to completing their PhD. These early career characteristics do not differentiate those who have had grants from those who have not.

Consistent with our study design that used Centers as our sampling universe, those holding PhDs in engineering and the biological sciences are most likely to be represented in our study, comprising 61% of the respondents. Their representation among grantees is equal to their representation in the larger sample. By contrast, chemists, physicists and other researchers are less likely to be awarded grants, and computer scientists, mathematicians and social scientists are more likely to be grantees.

To evaluate the dynamics of employment experience, we constructed several variables to tap different aspects of a scientific career. The variable 'academic' represents researchers who have ever held any traditional academic position. 'Traditional trajectory' represents those following the assistant to associate to full professor career path with no skips or interruptions. The majority of our researchers have participated in some aspect of the academic labor market, but note that grantees are much more likely to be pursuing this behavior. For example, four-fifths of our grantees are on traditional academic trajectories, while only half of non-grantees are.

Table 1: Training and Professional Experiences of Sample Scientists

	Sample	Grant	None	Sig
Sample Size	1,041	436	605	
Male	88%	88%	87%	ns
Training experiences				
Postdoctoral study	28%	28%	28%	ns
Publish b/f PhD	62%	65%	59%	ns
Field				
Engineering	44%	47%	42%	ns
Chemistry	9%	6%	10%	*
Physics	8%	6%	11%	**
Biological science	17%	17%	17%	ns
Computer/math	6%	8%	4%	**
Other science	6%	4%	7%	ns
Social science	5%	8%	3%	***
Other	5%	4%	5%	ns
Employment experience				
Academic	83%	96%	75%	***
Traditional trajectory	63%	80%	50%	***
Any non academic	56%	57%	55%	ns
Private industry	48%	49%	47%	ns
Government	17%	19%	15%	ns
Role complexity	2.68	2.93	2.5	***
Professional Productivity				
Total no. of pubs	66	70	63	ns
Annual rate of pub	3.78	4.01	3.62	ns

Note: *** p < .001; ** p < .01; * p < .05

Despite this, grantees and non-grantees are equally likely to have had non-academic work experiences. Overall, almost half of all our sample have worked in private industry, and one-fifth have worked for government.

Grantees differ from non-grantees in their propensity to engage in traditional academic careers, but not in their involvement in other sectors. This is captured in the 'role complexity' variable, which taps the number of different kinds of employment sector roles our researchers have engaged in over the course of their career. Grantees have more complex careers than non-grantees in terms of the number of sectors of the labor market they participate in, and in the number of distinct roles they assume within them.

Finally, we look at the productivity of these scientists and engineers. Those in this sample have been very productive, authoring or co-authoring on average 66 published articles in their careers-so-far, or an average annual rate of almost four articles per year. Somewhat surprisingly, we find that grantees and non-grantees do not differ in this critical component of academic success, a pattern we explore in greater detail later in the analysis.

In Table 1, we demonstrated that grantees and non-grantees differ significantly in some important ways, and not at all in others. In Table 2, we focus specifically on the grantees to explore the dynamics of their grant-seeking and -winning. We further stratify the analysis to compare the 177 grantees who have been awarded Engineering and Resource or Science and Technology Center grants, and the 259 grantees who have not. We examined the precocity of grant winners and found that only 6% were awarded a grant before earning the PhD. Furthermore, the first award of any kind is made an average of five years after the completion of the PhD. Note, however, that the Center grantees receive grants more than a year earlier in their career than the other grantees. The amounts of these first awards do not differ significantly, however. The average first grant is $400,000, and the median first grant is $65,000.

There is quite a marked difference in the overall number of grants that our Center grantees get over the life of their careers: they are awarded 21 grants in their career so far, compared to only 13 of non-Center grantees. Although Center grantees total almost US$8.5 million in grant activity over the course of their careers, their annual average grant amount is similar to that of non-Center grantees.

Table 2. Grant histories of award-winning scientists

	Grantees	ERC/SIC	None	Sig
Sample Size	436	177	259	
Precocity				
Grant b/f PhD	6%	6%	6%	ns
First Awards				
Years to first $	4.99	4.21	5.53	*
Mean first grant	$399,209	$449,381	$359,454	ns
Median first grant	$65,000	$64,950	$65,000	ns
Lifetime				
Number of grants	16.55	21.24	13.34	***
Lifetime all grants	$6,571,095	$8,478,839	$5,170,916	***
Grant per year	$437,753	$463,721	$358,075	ns
Grant Sources				
Source diversity	3.84	4.73	3.23	***
ERCSRC	41%	--	--	
Energy	20%	23%	18%	ns
NIH	23%	14%	30%	***
Other NSF	59%	49%	66%	***
DOD/NASA	36%	51%	26%	***
Other government	57%	68%	49%	***
Private industry	63%	76%	54%	***
Foundation	43%	47%	39%	+
Other	42%	46%	40%	ns

Note: *** p < .001; ** p < .01; * p < .05; + p < .10

The ERC and STC Center grants are only one of a diverse pool of possible grant sources that scientists depend on to fund their work. Although 41% of these researchers have been awarded a Center grant, the average scientist relies on four different sources of funding. In this sample, almost two-thirds have been awarded private industry grants, and over half have other NSF funding or other government funding. What stands out in the comparison between Center grantees and others is the grant diversification behavior that is employed. Center grantees tend to receive Department of Defense, NASA, private industry and other government sources of funds. By contrast, the non-Center grantees receive funding relatively more often from NIH and other NSF sources.

These two groups of scientists are equally likely to seek finding from the Department of Energy and all other sources. Center grantees are slightly more likely to obtain foundation funding.

Table 3. Training and professional experiences of award-winning scientists

	Grantees	ERC/SI C	None	Sig
Sample Size	436	177	259	
Male	88%	92%	86%	+
Training Experiences				
Postdoctoral Study	28%	23%	32%	*
Publish b/f PhD	65%	66%	64%	ns
Field				
Engineering	47%	55%	41%	***
Chemistry	6%	7%	6%	ns
Physics	6%	5%	6%	ns
Biological Science	17%	7%	25%	***
Computer/Math	8%	12%	5%	**
Other Science	4%	4%	5%	ns
Social Science	8%	5%	10%	+
Other	4%	5%	2%	ns
Employment Experience				
Academic	96%	97%	95%	ns
Traditional Trajectory	80%	78%	81%	ns
Any Nonacademic	57%	59%	55%	ns
Private Industry	49%	51%	47%	ns
Government	19%	20%	19%	ns
Role Complexity	2.93	2.97	3.15	ns
Professional Productivity				
Total # of Pubs	70	71	67	ns
Annual Rate of Pub	4.01	4.16	3.79	ns

Note: *** p < .001; ** p < .01; * p < .05; + p < .10

The previous analysis helps to elucidate the dynamics of funding and grant-seeking behavior for grantees. In Table 3, we assess the extent to which Center grantees differ from non-Center grantees in their professional behavior. Center grantees are somewhat more likely to be male than other grantees, and are significantly less likely to have pursued postdoctoral study. Each group is equally likely to publish before earning the PhD. As would be expected from our sample selection criteria, the Center grantees tend to be engineers, computer scientists and mathematicians. Non-Center grantees tend to be trained in the biological sciences. Recall that scientists with grant awards and those without differed significantly in their employment experiences (Table 1). Such is not the case between the Center grantees and non-Center grantees: each group pursues similar career trajectories. They also produce similar levels of publications at both the career and annual levels.

In this sample, what stands out in the comparison between Center grantees and others is the grant diversification behavior that is employed.

Multivariate analyses

Clearly, a limitation of the first three tables is our reliance on univariate and bivariate statistics to explore the career and grant-seeking behavior among these scientists. In the next two analyses, we introduce multivariate analyses to explore some of the causal mechanisms that may be at work to explain the observed patterns.

In the first such analysis, we use maximum likelihood logistic regression to evaluate the apparent relationship between ERC and STC Center grants and obtaining grants from private industry. In the second analysis, we use ordinary least squares regression to regress annual publication productivity on various grant activities.

In Table 4, we explore how grant-winning behavior affects the likelihood of obtaining an industry grant. The dependent variable is whether or not a scientist has ever been awarded a grant from private industry, and the analytic technique is maximum likelihood logistic regression. The Table presents the log-odd coefficients and their standard errors. Here, however, we will rely on the intuitively more appealing risk-ratios, which are obtained by exponentiating the log-odds coefficient. We pursue a nested strategy, beginning with the impact of an ERC/STC Center grant (Model 1), then evaluating other grant dynamics (Models 2–4), the possible confounding effect of having had an industry job (Model 5), and finally the possible impact of publication rates (Model 6).

Looking across all models, we see that having an ERC/STC Center grant significantly affects the likelihood that a scientist will be awarded an industry grant. Indeed, even in the most conservative model, scientists with Center grants are 1.9 times as likely to obtain an industry grant. In Model 3, we find that a significant effect for other grant sources in Model 2 is serving as a proxy for the number of lifetime grants. Each additional career grant improves the likelihood of obtaining an industry grant by 8%.

A possible threat to our inferences is the possibility that scientists who have had private industry jobs are better able to obtain private industry grants. Going by our data, this is indeed the case (Model 5), with those with such experience being 1.9 times as likely to obtain such a grant. Note, however, that the equally large impact of the ERC/STC Center grants remains. These factors serve as independent, direct effects on the likelihood of obtaining an industry grant, and there are no interactive effects (not shown).

Model 6, which is the only model that does not significantly improve the fit of the model using a chi square test, shows that publication productivity has no impact on the likelihood of obtaining an industry grant.

In Table 5, we use ordinary least squares regression analysis to predict annual publication productivity rates among the grant-earning scientists. For our baseline model, we control for being male, which is a well-known predictor of publication productivity. Until we control for lifetime grant volume in Model 5, being male is a significant predictor of publication productivity.

Although having an ERC/STC Center grant has an impact on getting industry grants, it has no impact on publication productivity. By contrast, having another type of government or foundation grant does

Table 4. Predicting the likelihood of obtaining an industry grant
Maximum likelihood log-odds coefficients

n = 436

Model	1	2	3	4	5	6
ERC/STC	**0.99** (0.22)	**0.94** (.22)	**0.6** (.24)	**0.64** (.24)	**0.66** (.24)	**0.65** (.24)
Other source		**0.28** (.08)	-0.11 (.10)	-0.1 (.10)	-0.09 (.10)	-0.09 (.10)
Number of grants			**0.08** (.01)	**0.08** (.01)	**0.08** (.01)	**0.08** (.01)
Avg. annual award				-2E-07 (1E-7)	-2E-07 (1E-07)	-2E-07 (1E-07)
Ever industry job					**0.66** (.22)	**0.66** (.22)
Avg. annual pubs						0.03 (.05)
Intercept	0.18 (.13)	-0.56 (.24)	-0.53 (.25)	-0.45 (.25)	-0.76 (.27)	-0.84 (.30)
- 2 Log likelihood	22.21	36.09	83.99	87.83	96.59	94.97
d.f.	1	2	3	4	5	6

Notes: Standard errors are shown in parentheses.
Coefficients significant at $p < .05$ or better are shown in bold.
An interaction of ERC/STC with industry job is not significant.

Table 5. Predicting publication productivity: average annual publication rate

n=436

Model	1	2	3	4	5	6	7
Male	**1** (.43)	**0.96** (.43)	**0.82** (.42)	**0.82** (.42)	0.68 (.41)	0.68 (.41)	0.69 (.41)
ERC/STC		0.31 (.28)	0.17 (.27)	0.07 (.27)	-0.1 (.27)	-0.1 (.28)	-0.1 (.28)
Other source			**0.51** (.09)	**0.48** (.10)	**0.28** (.11)	**0.28** (.11)	**0.28** (.11)
Private grant				0.45 (.28)	0.17 (.29)	0.17 (.29)	0.18 (.29)
Number of grants					**0.04** (.01)	**0.04** (.01)	**0.03** (.01)
Avg. annual award						-1.5E-8 (1E-6)	-1.3E-8 (1E-6)
Ever industry job							-0.06 (.26)
Intercept	3.05 (.40)	2.96 (.41)	1.72 (.46)	1.55 (.47)	1.85 (.47)	1.85 (.47)	1.87 (.48)
Adj R2	0.01	0.01	0.07	0.07	0.10	0.10	0.10

Notes: Standard errors are shown in parentheses.
Coefficients significant at $p < .05$ or better are shown in bold.

improve publication productivity (Model 3). Having a private grant, like having a Center grant, does not improve productivity. In Model 5, we control for the number of grants, and find that grant volume improves productivity. Note the attenuation of the other grant source variable. Most interesting is that the number of grants erases the significant gender effect on publication productivity.

Overall, the models are fairly poorly performing in their ability to explain productivity. Being male explains about 1% of the variability in productivity, having non-Center and non-industry grants explains an additional 6% of the variability, and controlling for the number of grants adds an additional 3% of predictive power. Nevertheless, this analysis demonstrates that grant activity is an important component of publication productivity.

Conclusions

We have already noted that univariate and bivariate analyses can only help us to identify patterns of association, and do not establish causal relationships. In these last two analytic models, we have attempted to control for other effects in an attempt to understand better the impact of grant-winning activities on productivity and industrial collaboration. We do not claim to have established complete models. Studies of scientific productivity (e.g. Long, 1981) have included a variety of variables — e.g. wage data, social status, network linkages — not available from the unobtrusive source of our data, the CV. Just as important, our measure of productivity focused on publications, certainly important for scientists, but not on commercial activities, generally important for Center-based scientists.

We feel safe in concluding that Center-based grants and conventional investigator-initiated grants have different impacts, at least in respect to scientific productivity and industrial engagement of Center-affiliated scientists. But the question remains as to whether Center-based grants redirect the activities of scientists or whether Center-based scientists are affiliated with Centers *because* their research interests and activities differ from other scientists. As we develop data from a more general sample of scientists and engineers, answers to the questions about the impacts of institutional changes in funding will become more complete.

In the meantime, we can at least affirm that the creation of university-based science and engineering Centers does, indeed, seem to have led to a different set of industrial and academic productivity outcomes. Furthermore, these basic processes can be detected using a readily available and unobtrusive source of data, an important consideration in research program evaluation.

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