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Impacts of grants and contracts on academic researchers' interactions with industry

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Abstract

Based on a representative national sample of 1564 academic researchers, we investigate the impacts of research grants and contracts on the nature and extent of faculty research and technology activities with industry. A particular focus is on understanding the independent contributions of industry and government grant sources on levels of industrial involvement. In addition to examining the source of grants, the study controls for a number of independent factors including: scientific field, research center affiliation, tenure status, and gender. Results suggest independent effects of grants and contracts on industrial activities. Grants and contracts from industry have a significant effect on academic researchers' propensity to work with industry, as measured by an "industrial involvement scale." Federally-sponsored grants also have an impact in increasing work with industry, but a more moderate one. Further, those with more grants and contracts (of each type) have a greater propensity for industrial involvement than those who have such contracts but fewer. This holds even when proxies for productivity and career stage are introduced in regression equations. The analysis also considers whether provision of grants and contracts is best viewed as a predictor of industrial involvement or just another type of industrial involvement using factor analysis and nested multivariate modeling to compare effects.
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1. Introduction

Historically, academic researchers at U.S. universities have relied on government grants, overwhelmingly federal government grants, to support their research. While U.S. industry is perennially the leading sector in both funding and performance of R&D, at no time during the history of the modern U.S. research university (i.e. the university regime created after World War II) has industry provided as much support for *university* research as any of the top five government funding agencies. In 2002, U.S. academic institutions spent an estimated $36 billion, or $33 billion in constant 1996 dollars, on R&D. U.S. industry provided 6.8% of academic R&D funding (National Science Foundation, 2004); this rate has been declining, to 5% of academic R&D funding (National Science Foundation, 2006).[2]

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[2] For those unfamiliar with research funding in the United States, a few simple distinctions are useful. First, money provided to universities from federal research funding agencies such the National Science Foundation or the National Institutes of Health are usually

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Despite the relatively small percentage of university research funding provided by industry, it is often argued that industry funding of U.S. academic research is socially and economically more significant than one would infer just from considering its percentage of the whole (e.g. National Research Council, 2003; Hall et al., 2000; Henderson et al., 1998; Mansfield, 1995). Efforts have been underway for several decades to enhance relations between universities and industry to promote innovation and technology-based economic growth (Powell and Owen-Smith, 1998; Slaughter and Leslie, 1997; Etzkowitz et al., 1998). Policies encouraging industry funding of academic research include R&D tax credits rewarding industry for contributions to academic R&D (Joint Committee on Taxation, 1981; Guenther, 2000). Just as important are the several government-sponsored programs to develop industry–university research and technology partnerships, programs such as the Small Business Administration's Innovation Research program (Audretsch, 1995; Link and Scott, 2000; Audretsch et al., 2002) which often features industry-partners, the Cooperative Research Act (Scott, 1989; Crow and Bozeman, 1998), and the NSF industry–university cooperative research centers program (Gray and Walters, 1998; Hetzner et al., 1989). The Engineering Research Centers program at the NSF was developed expressly to strengthen industry–university bonds (Feller et al., 2002). Perhaps most important, changes in intellectual property law during the 1980s, including most famously the Bayh-Dole Act (Mowery et al., 2001), smoothed the way for university commerce, including patents and licenses.

Despite researchers' attention to a wide variety of factors hypothesized as affecting the formation and also the success or failure of university–industry partnerships (e.g. Gray and Steenhuis, 2003; Behrens and Gray, 2001; Geisler et al., 1991), some fundamental questions remain unanswered. There is surprisingly little work on industry funding of university research, especially when the focus is individual faculty rather than institutions. An important exception is the work by Blumenthal and colleagues (Gluck et al., 1987; Blumenthal et al., 1996, 1997) on university biotechnology faculty and their relations with industry. Our study examines a broad and representative sample of U.S. university faculty and seeks to shed additional light on the impacts of industry funding (and, by comparison, national government grants funding) on university researchers.

Perhaps one reason for limited evidence about the effects of industry funding of university research on industry–university relations is that common sense seems to dictate that this type of funding will strengthen bonds between companies and universities. The implicit logic is that if industry funds academic research, industry–university relations will be stronger, collaborative activities will be enhanced and there will be increased success with respect to innovation, technology development and transfer and, ultimately, economic growth.

Even if one accepts the implicit logic equating industry funding with collaborative effectiveness, fundamental questions remain about such issues as magnitude of effects, shifts in particular types of relationships, and relationships of industry funding to other types of funding, especially federal grants. Moreover, even holding aside these important subsidiary questions, one is perhaps ill-advised to accept uncritically the above logic of the impact of industry funding. In the first place, previous research has shown that common sense expectations about industry–university interactions often do not hold up under the scrutiny of systematic research (e.g. Hetzner et al., 1989; Rosenberg and Nelson, 1994). In the second place, some well known, large-scale industry–university collaborations have not succeeded despite the infusion of industry R&D support (Etzkowitz and Brisolla, 1999; Carayannis and Alexander, 1999). In the third place, it is possible that industry support for specific university R&D may be highly subject to scale effects; that is, it may be the case that percentages or thresholds of industry support make a difference in collaboration effectiveness (Jones, 1995).

provided in one of two manners, either "grants" or "cooperative agreements." Grants are provided on the basis of proposals from university researchers who propose research projects. These are usually made on the basis of peer review decisions. While the individual researchers propose the grants and use the subsequent resources (if successful), the legal agreement is with the university, not the individual researcher. Grants generally do not include formal deliverables and, while sometimes audited, are somewhat flexible with respect to research focus and resources deployment. Cooperative agreements are also made with the universities but are not typically proposed nor controlled by a single investigator. Cooperative agreements are used for large centers such as, the NSF's university-based Engineering Research Centers. Industry rarely provides either grants or cooperative agreements to universities. Most industry funds are provided via contracts and often have quite specific deliverables (government agencies are also very much involved with contracting for universities but not generally for research, except of the most applied, agency-focused sort). Industry also works with individual university researchers on consulting agreements and these are not generally viewed as "university funding" since they typically provide no institutional funds for the university and are made on a bilateral basis with the individual. The only university role in individual consulting is to set policies about the acceptable amount of time devoted to consulting and about conflicts of interest and use of university resoures in consulting. For additional information see Crow and Bozeman (1998).

The primary research focus here is the extent to which academic faculty that are supported by grants and contracts, especially grants and contracts provided by industry, interact with industry and, among those who do interact with industry, *how* they interact. Arguably, industry funding may encourage academic researchers to interact with industry in some ways and not others. Several corollary questions are addressed as well. First, does industry research support contribute more to university–industry collaborative activities than do other types of grants? This is an especially important question in light of the fact that most academic scientists' research is supported by federal grants; industrial support is a comparative rarity. Related, do federal grants enhance or inhibit academic researchers' interactions with industry? Another question considered is whether industry research support is best viewed as a determinant of academic faculty interaction with industry or, rather, just another variety of interaction, one inseparable from other sorts of faculty–industry interactions.

One contribution of this research is simply that it takes a much broader perspective on university faculty interaction with industry than do many other studies by documenting the breadth and prevalence of faculty interactions with industry. There has recently been a prodigious growth of studies of university and university faculty patenting activity (for an overview, see Mowery et al., 2001). This focus on patenting and licensing is understandable given the inherent importance of the topic as well as analytical convenience attendant to output measures. However, it seems clear that universities engage in a wide variety of interactions with industry, many of which do not pertain to patenting and, importantly, studies of industries' goals in university partnerships rarely list patenting and intellectual property development as among the top priorities (e.g. Feller and Roessner, 1995).

The next section reviews research questions and related studies. While the industry–university research partnership literature is now vast, it is reviewed in detail elsewhere (Martin, 2003; Link and Siegel, 2005). Thus, the section below chiefly considers those few studies providing direct evidence of the impacts of research funding on industrial activity of university faculty.

2. Research questions and previous studies

In most instances, a good place to start in the formulation of research questions is previous studies. However, as we see in this section, very few published studies impinge directly on the topic examined here.

2.1. Related studies

Given the explosion of research on industry–university relations, it is surprising how few studies focus on the individual academic researcher as opposed to the organizational or institutional level of analysis. Among these, fewer still examine the effects of grants and contracts.

Benner and Sandstrom (2000) provide one of the fundamental studies of the impacts of grants and contracts, demonstrating in their study of publicly financed research in Sweden the dynamics by which such funding can alter research trajectories. However, the study focuses only on government funding and analyzes organizational-level research agendas rather than individual researchers.

One study especially relevant to the question of the impacts of industry research funding on academic faculty interactions with industry considers Norwegian universities. Gulbrandsen and Smeby (2005) examine questionnaire data for 1697 university professors (all fields, including not only sciences and engineering, but humanities and social sciences) in Norway, about 60% of all professors in that nation. Gulbrandsen and Smeby consider the impact of industrial funding on: (1) whether respondents characterize their research as basic, applied or development; (2) the extent of research collaboration; (3) scientific publishing productivity; and (4) patents and other commercial outputs. The results of their descriptive data as well as logistic regression analysis show that those professors with industrial funding are more likely to describe their research as applied (but not development) and that they are more active collaborators, not only with industry researchers but also with researchers in universities. Those with industry funding report higher publishing levels as well as higher levels of entrepreneurial output, including patents. Interestingly, there is no relationship between level of publishing activity and level of entrepreneurial activity.

While the authors control for a number of variables possibly confounding the relationship between industry funding and the outcomes they examine, their results may be compromised somewhat by (1) more finely grained field effects (they use a five-fold comparison among natural science, humanities, medicine, technology, social sciences); (2) the fact that many respondents who report industrial support have not had support during the past 5 years; and (3) a limited ability to parse the individual researcher's ability and human capital endowments and research support. Nevertheless, the findings are for an impressive sample and are, overall, quite instructive.

A narrow examination of the impact of research funding on academic faculty is provided by Van Looy et al. (2004). They focus intensely on just one university, the Catholic University of Leuven, Belgium, to determine if faculty who have industry contracts publish more or less and whether they have different publishing profiles (applied or basic). They find that entrepreneurial activities and publishing are compatible and, indeed, that engaging in entrepreneurial activity is related to higher publication rates. However, a variety of selection effects are not controlled in the study and, thus, it is not easy to determine if industry funding is causal or a reflection of industry selection of more productive researchers.

Another study similar to the present one in its focus on the impacts of funding sources is Guena's (2001) analysis of the impacts of the "rationale and composition" of university funding (including but not limited to industry and government providers). However, this study, like most studies of university research resources, focuses on the university as unit of analysis. Guena finds that the shift toward increased industry funding has negative, unintended consequences, including a shift toward short term goals and conflicting incentive structures.

Bourke and Butler's (1999) analysis of funding modes and sources in Australian universities is related to the present analysis in some respects, including its focus on the university researcher as the unit of analysis. However, rather than compare industry and government funding sources, the authors compare different modes of government funding. Examining publications data, they show that funding mode is less important than the nature of the academic researcher's position, especially whether full-time, and discipline.

The U.S.-based study closest to the present one in its focus is questionnaire-based study of more than 1200 biotechnology research faculty at 40 U.S. universities. Their findings indicate that faculty with industrial support publish at higher rates, have more patents and are more active in professional activities than those who do not have such support. However, in this study and related ones (e.g. Blumenthal et al., 1997), the authors' chief focus is on faculty openness in communicating research findings that may have commercial value and, thus, they do not probe deeply into the causal mechanics or broader implications of industry contracts or the joint relationships between government grants and industry contracts.

While it is possible that simply knowing whether an individual has an industry or government grant is the key issue, it is also possible that the number of grants may tell more about industry activities than simply knowing that an individual has a grant. However, it is not easy to determine the impacts of the number of grants due to a likely endogeneity problem and due to definitional dependence; those who have more grants and contracts are generally more productive in many respects. Thus, does a researcher engage in more industrial activity because of the availability of resources from grants and contracts? Or does the researcher have more grants and contracts because she is more productive and, thus, more in demand from industry?

2.2. Research questions and hypotheses

From the foregoing review of the literature on impacts of grants and contracts it is perhaps fair to say that many potentially important research questions remain open, including the central research question examined here:

> Central Research Question: What is the relationship, if any, of grants and contracts to academic researchers' propensity to work with industry?

From this central research question let us consider the following hypotheses:

H1. University researchers who have active grants and contracts will be more likely to work with industry.

H2. Among those university researchers who have active grants and contracts, those with industry grants will be more likely to work with industry than will researchers who only have government grants and contracts.

It is, of course, possible that those university scientists with industry grants and contracts are no more likely to work with industry. However, this seems implausible. In the first place, at least some industry grants and contracts either assume or mandate interaction between the researcher and the sponsoring firm. In the second place, even when interaction subsequent to the research itself is not required, it seems likely that industry would in many instances choose to fund persons who are predisposed to develop working relations. Thus, our primary interest here is the extent to which industry funding leads to working with industry and the differences with respect to particular types of interaction (e.g. joint publishing, research exchange, patenting).

The impact of government grants on industry activity seems less obvious. Why would one expect that government grants would relate to industry activity? One reason is simply that those who have government grants, especially multiple ones, are more productive and, thus, in greater demand from industry. But if one controls for number of grants and contracts and tenure status, is there any remaining reason to believe that government grants will result in greater industry activity? Perhaps there is not. In fact, there may be a mild suppression effect. Those having government grants may be less interested in near-term research results of the sort that may be presumed (Harman, 2001) to be of greater interest to industry.

Our analysis includes a number of control variables. In our previous research (e.g. Gaughan and Bozeman, 2002; Bozeman and Corley, 2004) we found it useful and causally relevant to control for gender, institutional affiliation, career status, and discipline when considering the impacts of grants. The reasoning here is that those who have active grants and contracts, whatever the source, are more likely to be senior and more likely to be productive (Gaughan and Bozeman, 2002) and, thus, be more in demand from industry. Similarly, patterns differ from women and men, especially when one is examining industrial support and industrial activity (Carley and Gaughan, 2005). Disciplinary field differences are widely viewed (e.g. Small and Griffith, 1974; Becher, 1994) as important to a range of scholarly activities and to research productivity.

3. Data and descriptive results

3.1. Sample

The data employed here are from the "Research Value Mapping Survey of Academic Researchers," a study by researchers at Georgia Tech's Research Value Mapping Program (RVM) of a representative sample of more than 2000 academic faculty in the sciences and engineering. The project, completed in 2005, is based on a variety of data sources, including mailed questionnaire responses, secondary data about universities and university research centers and data drawn from curricula vitae of the respondents. The present research draws only from the questionnaire data.

The RVM project directors sought to develop a sampling frame that would represent the population of academic researchers working in "Carnegie Extensive" (formerly known as "Research I") universities (see Carnegie, 2000).[3] Using the Carnegie list, we retained universities ($n = 150$) that produced at least one Ph.D. in 2000 in at least one of 13 science and engineering disciplines. Health sciences and economics were excluded from the NSF definition of science and engineering (NSF 2000), and engineering was represented by five of its major specialties. The resulting disciplines include: biology, computer science, mathematics, physics, earth and atmospheric science, chemistry, agriculture, sociology, chemical engineering, civil engineering, electrical engineering, mechanical engineering, and materials engineering.

Having delineated the target population of universities and disciplines, we collected the names of tenure-track faculty in each university by discipline. The list of faculty was obtained from (1) the on-line university catalog or (2) the on-line departmental website. This resulted in a sampling frame of 36, 874 scientists and engineers occupying a tenure-track or tenured faculty position.[4] The target sample was for 200 men and women from each of the 13 disciplines. Because the size of disciplines varies, as does the representation of women in each discipline, the sampling proportions varied from 0.21 (for women in biology) to 1.0 in five disciplines (e.g., the "sample" is actually a census of the women in the discipline). Men's sampling proportions varied from 0.06 in biology to 0.23 in agriculture. The final target sample (accounting for women representing fewer than 200 in the discipline) was 4916.[5]

The questionnaire was administered by mail, focusing in particular on the following domains of faculty activity: funding, collaboration, institutional affiliations,

[3] The Carnegie Classification of Institutions of Higher Education (2000) categorizes the thousands of institutions of higher education in the United States according to their primary mission. The 151 Research Extensive universities award at least 50 doctoral degrees each year. In this sample, we exclude Teacher's College of Columbia University, which is a Research Extensive university, but does not award doctorates in science or engineering fields. The Research Extensive universities are similar to European universities in size, scope of work, and research focus. The Carnegie Classification is currently undergoing revision.

[4] There are several ways to be employed as a professor in U.S. universities. In this study, we focus only on professors who have full-time tenured or tenure-track appointments. A typical tenured professor spent six or seven probationary years to meet the academic requirements for permanent employment by the university. Tenure-track professors are hired under such a probationary contract. These positions are the hardest to get and generally represent the best academic positions in the university. This sampling requirement primarily eliminates professors who are members of the contingent labor force working on short-term contracts (a rapidly growing sector of the academic labor force in the United States), and full-time research scientists without academic responsibilities.

[5] Following Winship and Radbill (1994), we control for gender and tenure status – used to stratify the original sampling frame – in all multivariate models. This approach controls for the basis of selection, and results in unbiased estimates.

career timing and transitions, and distribution of work effort. The questionnaire survey also obtained basic demographic information about the researchers, their research-specific motivations and values, and the perceived benefits derived from their work.

After three waves (initial mailing, reminder post card, second mailing) 1795[6] usable questionnaire were received, for a response rate of 38%. For the population of academic researchers, this response rate is comparatively high and the possibilities for determining response bias are enhanced by the fact that the project researchers were able to compare the resultant sample to known parameters of the population (e.g. scientific fields, gender composition). Furthermore a "wave analysis," correlating all items with each of the three waves of response (wave 1 $n = 1372$, wave 2 $n = 449$, wave 3 $n = 449$), indicated no significant differences in response patterns by either wave or date received, indicating that non-respondents, who are theoretically more like late or third wave respondents, are not significantly different than respondents.

3.2. Descriptive statistics

We present the means and standard deviations of the sample characteristics relevant to this study in Table 1. Reflecting the over-sample of women, half of our respondents are male. In 1995, the actual population parameter for tenured and tenure-track women in Research Extensive universities was 17% (National Research Council, 2001). We control for this sample selection factor in all multivariate models, resulting in unbiased estimates (Winship and Radbill, 1994). In this, the first nationally representative sample estimate of multidisciplinary center affiliation, we find that 40% of researchers affiliate with such centers. A recent study using these data determined that center affiliation does not vary by gender in this population (Carley and Gaughan, 2005). Almost three-quarters of the respondents are tenured, roughly reflecting the proportion of tenured professors in Research Extensive universities. The reason that the over-sample of women does not affect this statistic is that the sample was also selected by rank, which controls for the differential likelihoods of rank by gender. The disciplinary affiliation controls also reflect the structure of the sample design: slightly less than one-tenth of respondents came from each discipline. In this study, we use biology as the reference category in multivariate analysis. After evaluating the effects of collapsing categories, and finding none, 35% of the samples are physical scientists (physics, chemistry, mathematics, and earth and atmospheric science), and 41% of the samples are engineers (civil, chemical, electrical, materials, mechanical).

[6] This percentage reflects the fact that 134 individuals were removed from the 4916 sampling frame due to retirement, death, inadequate addresses or because they were determined not to be faculty researchers.

Table 1
Means and standard deviations of independent controls

Variable	Mean	Standard deviation
Demographic		
Male	0.49	0.5
Career		
Tenured	0.73	0.45
Center affiliated	0.39	0.49
Grants activity		
Any industry grant	0.12	0.32
Number of industry grants	0.15	0.45
Any government	0.76	0.43
Number federal grants	1.17	0.94
Industry involvement scale[a]	1.09	1.46
Disciplinary affiliation		
Biology	0.08	0.27
Physical science	0.35	0.48
Engineering	0.41	0.49
Agriculture	0.08	0.27
Computer science	0.09	0.28

[a] Measurement properties of the industry involvement scale in companion table.

The key dependent variable is industrial activity, which we evaluate in detail in the next section. Our focal independent variables focus on the number of grants from industry and government, respectively. Only 12% of respondents currently have an industry-supported grant or contract. The average for the sample as a whole is 0.15 grants, reflecting the clustering at zero. By contrast, more than three-quarters of respondents currently have a government supported grant or contract; the average number of government grants for the sample respondents is 1.17. This pattern of grant support reflects the dominant one in the United States whereby the majority of research funding for academic scientists comes from the federal and state governments. To elaborate, in 2003, only 5% of expenditures on academic R&D was funded by private industry; by contrast, 62% of research expenditures for academic R&D came from the federal government (National Science Foundation, 2006). As professors in the most elite research universities in the country, the respondents in our study are actually more likely to have industry and government supported grants than professors in other kinds of universities.

3.3. Measurement of the industrial involvement scale

3.3.1. Industrial activities

This work introduces a new way of measuring industrial involvement. Since the industrial involvement scale we introduce serves as the dependent variable, we address measurement issues in detail in this section. The RVM questionnaire asked a branching question, first asking respondents if they had any working relations with private companies during the past 12 months. Over half of respondents, 796 (50.9%) reported that they had some type of industry interaction. These respondents were referred to a check list to indicate the specific types of activities. Since only 12% of respondents get industry funding, but over half engage in industrial interactions distinct from funding, this is initial support for the independence of these factors.

Given the very different nature of these industry interactions, some being much more intensive than others and requiring a much higher commitment of time and energy, it stands to reason that the impacts of grants on the respective activities will vary. For example, no grant or contract is needed simply to provide information about one's research. But presumably a grant or contract would abet work as a co-author or as a partner in patenting. The first column of Table 2 shows the overall levels of involvement by the respondents, and the hypothesized variation among activities. For example, only 3.1% of respondents worked at or owned a company. By contrast, 38.2% had provided research information to a private company.

We find significant differences in industry-related activities by grants status. In the middle columns of Table 2, we compare the 185 researchers with current industry grants with the 1379 researchers who do not have industry funding. Perhaps not surprisingly, those who have industry grants and contracts are more likely to be engaged in each industry activity than respondents who do not have industry grants and contracts. In most cases, the multiplier is 2–3. Those with industry grants are twice as likely to be asked about their research by

Table 2
Measurement construction: indicators of industry involvement test of differences by grant activity and source

Variable	All $n = 1564$ (%)	No industry grants $n = 1379$ (%)	Sig. t-test	Industry grants $n = 185$ (%)	No government grants $n = 379$ (%)	Sig. t-test	Government grants $n = 1185$ (%)
Private company asked for info about research and it was provided	38.2	33.3	***	71.4	29.0	***	40.3
Contacted persons in industry about their research	19.1	15.6	***	48.1	14.8	**	20.9
Served as formal paid consultant to an industrial firm	18.4	15.8	***	35.1	13.3	**	19.7
Helped place graduate students or post-docs in industry jobs	25.3	20.9	***	58.4	17.9	***	27.7
Worked at company at which I am an owner or employee	3.1	2.9	n.s.	6.6	2.4	n.s.	3.6
Worked directly with industry in work that resulted in a patent or copyright	5.2	3.8	***	17.2	3.4	*	6.1
Worked directly with industry in effort to commericalize or transfer technology	16.7	12.9	***	38.9	12.9	*	17.0
Co-authored a paper with industry personnel that was published	15.5	11.4	***	42.2	9.5	***	16.8
Weighted industry involvement scale[a] (mean)	1.09	0.90	***	2.52	0.80	***	1.19

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$.

Note: Levene's F-test indicated that all variances should be treated as unequal; therefore, t-test for equality of means is based on the assumption of unequal variances.

[a] The scale has the following properties: an alpha reliability of 0.78, and normal distribution (skew = 1.3; kurtosis = 0.99).

private industry, to serve as a paid consultant to industry, and to work at or own a company. They are about three times more likely to ask industrial researchers about their research, to have engaged in technology transfer-related research, to have co-authored a paper with industry personnel, and to place students in industry jobs. Those supported by industry grants are four times as likely to have worked with industry on research that yields a patent or copyright.

The last columns of Table 2 compare the industrial activities of those academic researchers who have federal grants and contracts ($n = 1185$) with those who do not ($n = 379$). Those who have government grants are more likely to have industry interactions of all types. However, the percentages for those with government grants are consistently lower than those who have industry grants. Furthermore, the multipliers are consistently smaller than for the difference between those with industry grants and contracts and those without them. Moreover, while the difference between those with federal grants and those without them are significant in every case ($p < 0.05$ for all cases but one), the differences between those with federal grants and the overall sample mean are modest. This, of course, is not entirely unexpected since such a large proportion of persons in this sample have federal grants and contracts. What is perhaps more interesting is that those who do *not* have federal grants and contracts are substantially less likely to be involved in industrial activities of all sorts.

3.3.2. Factor analysis of the measurement model

While these single indicators of industrial activity are a good place to start, the issue of grants and contracts impacts is actually much more complicated than can be shown in such simple univariate and bivariate analyses. To facilitate a richer and at the same time a more parsimonious analysis, a single index of industrial activity is developed here, one that is more appropriate for multivariate analysis than the eight separate items thus far examined. The first issue is to consider whether or not industry funding is simply one component of industrial activity, and not a causal factor. The position taken here is that industry grants and contracts are better viewed as a *predictor* rather than a *component* of industry involvement. One practical rationale for this view is that it provides a more interesting and useful policy perspective. Policy-makers can manipulate grants and contracts awards. Another has to do with the presumed meaning of grants and contracts provision. Doubtless, industrial sources who are providing grants and contracts are not chiefly aiming to stimulate resources for the recipient; rather they are seeking to stimulate other behaviors such as collaboration, information exchange, and technology transfer (for an overview of research supporting this conclusion see Bozeman, 2000). In many cases, grants and contracts have explicit deliverables, further reinforcing the quid pro quo view of funding. Even among those (if there are any such) who provide funding as a sort of overhead investment, there is nonetheless a long-run instrumental motivation.

It makes sense that industry sources of funds have instrumental views for resource funding as do, in all likelihood, the proposers for and recipients of funds, the academic researchers. However, these instrumental views may not be in alignment. Quite possibly, university researchers consider industry funding a somewhat substitutable asset, not much different from other assets such as publications, patents or, generally, the "scientific and technical human capital" that develops from working with industry. Determining the relative value of these two theoretical perspectives (funding as instrumental or funding as embedded) is not an easy matter either theoretically or statistically.

We use multivariate analyses to investigate the causal argumentation in more depth in the next section. Here we present results from factor analysis to validate the theoretical measurement model (Bollen, 1989). Specifically, let us examine the dimensional properties of the specific industry activity variables (the ones shown in Table 2) simultaneously with numbers of industry and government grants and contracts. We employ oblique factor analysis, which imposes minimal force constraints for factor extraction and rotation. Such an analysis results in the dimensional properties closest to those in the original. It is important to note that this analysis is for that sub-sample that has either a government grant or an industry grant. Given that the idea of the analysis was to determine the dimensional loadings of grants and contracts variables, the small percentage of respondents who have neither federal nor industry grants were excluded.

The structure matrix results in one primary dimension, accounting for 34.1% of the variance. Two minor dimensions account for 11.2% and 10.7% of the variance. The coefficients in the dimensions show that the primary factor describes a variety of activities, generally the ones that are quite common among respondents (e.g. responding to requests for papers). The second minor dimension is of interest because it seems to imply more of an "insider dimension," including as it does items related to actually working at the company, patenting and working in technology transfer collaborations. Most important for the purpose of this analysis is that the third dimension includes only one coefficient of any significant magnitude, Total Industry Grants and Contracts.

This is an important outcome because the factor method used was closest to the actual properties of the sample data in the sense that it avoids almost all the artificial constraints usually imposed in factor analysis (i.e. orthogonality, distributed variances through Varimax rotation, unities in the principal diagonal, maximum likelihood extraction). Nonetheless, the factoring properties yielded Total Industry Grants and Contracts as its own dimension. This gives support to the idea that industry grants are best viewed from the instrumental perspective, as a predictor variable of industry activity, rather than just another industry activity in which faculty researchers might engage. It also suggests that the most obvious sort of endogeneity threat, a possible confounding of grants and contracts with industrial activity, may be at most a modest threat.

3.4. Constructing the industry involvement scale

Having determined through factor analysis[7] that industry grants and contracts are conceptually distinct from other industrial activities, we now turn to the scale construction itself. An "industrial involvement scale" was created by examining the percentages for each industrial interaction items and then using the inverse as a weight. To give an example, 15.5% of the sample report having co-authored a paper with someone from industry and, thus, engaging in that activity receives a weight of 84.5. Similarly, 5.2% of the sample report having developed a patent with someone from industry and, thus, engaging in that more uncommon activity receives a weight of 94.8. The weights for all types of activities in which the respondents were engaged were then summed, creating a weighted industrial involvement scale. For the present sample, the industrial involvement scale ranges between 0 and 6.68 with a mean of 1.09. The scale has the following properties: an alpha reliability of 0.78, and normal distribution (skew = 1.3; kurtosis = 0.99). It, therefore, meets the requirements for ordinary least squares (OLS) regression (below).

We could have used a more straightforward scale, simply adding the values of responses on the various indicators of industrial activity. Indeed, doing so makes no difference to our analysis. However, we used the weighted scale because it seems theoretically more important. Standard measurement theory suggests that items "more difficult" (in a behavioral or psychological sense) should receive stronger weight than those "less difficult." Often cumulative (Guttman-type) scales are used to take into account these "item difficulty" properties but our data did not meet the requirements of a cumulative scale (0.90 index of order reproducibility). The weighted scale we used instead retains the theoretical value of providing greater weight to "more difficult" items while not enforcing requirements for ordered symmetry.[8]

4. Findings

We use regression analysis to test the causal hypotheses developed earlier, focusing on the relationships between academic researchers' grants and contracts and their industry involvement. Ordinary least squares analysis is appropriate because the dependent variable, the industrial involvement scale, is continuous and normally distributed. The predictors of primary interest in each model are variables pertaining to academic researchers' industrial and federal government grants and contracts. In every model, we control for gender, tenure status,[9] center affiliation, and disciplinary affiliation[10] in order to account for known or theorized bases of difference in industrial activity by faculty. We pursue a nested strategy to explore the direct and joint effects of industrial and governmental grant funding on industrial involvement. We also test a conservative model that excludes researchers who have industrial grants to investigate the independent impact of governmental grants alone on industrial involvement.

[7] In the interest of space, we do not report the results of this factor analysis. The analysis was undertaken to validate measures rather than to create new measures or test hypotheses. Thus, an oblique solution (Oblimin) was used for this purpose. The result indicated that even with the oblique (i.e. no forced orthogonality) solution that receiving industrial contracts was not part of any of the significant (i.e. one eigenvalue or more) factor dimensions including other industrial activities (the ones comprising the industrial involvement scale) as high magnitude (equal or greater to 0.50) loading variables. This provides a strong test of the independence of industry research support from other industry activities. More information on this analysis, as well as all the resulting tables, is available upon request.

[8] We conceptualize the measurement of the dependent variable on conceptual and theoretical grounds. For the unconvinced, we ran all of the final multivariate models using a simple summed scale of the indicators in Table 2 as the dependent variable. There was no change in the pattern, direction, magnitude, or significance of effects.

[9] Given the possibility that career years might provide explanatory power well beyond that provided by tenure, preliminary models were estimated that included both tenure and career years. For the dependent variable of interest, the industrial involvement scale, career years proved not to be a significant predictor once the variance explained by tenure had been accounted for.

[10] Each model in Table 3 was run using the dummy variables for each field instead of collapsing the disciplinary affiliations as shown. It made no difference in effects, so we report the more parsimonious measurement approach in this analysis.

Table 3
Regression of industry involvement on grants activity: unstandardized coefficients

Independent variable	Industry $n = 1564$ Model 1	Government $n = 1564$ Model 2	Full $n = 1564$ Model 3	Government $n = 1004$ Model 4
Demographic				
Male	0.18** (0.06)	0.20** (0.07)	0.19** (0.06)	0.19* (0.08)
Career trajectory				
Tenured	0.40*** (0.07)	0.39*** (0.80)	0.35*** (0.07)	0.23** (0.09)
Center affiliated	0.39*** (0.07)	0.35*** (0.07)	0.30*** (0.07)	0.31*** (0.08)
Grants activity				
Number of industry grants	0.86*** (0.07)	–	0.85*** (0.07)	–
Number government grants	–	0.26*** (0.04)	0.24*** (0.04)	0.36*** (0.05)
Disciplinary affiliation				
Agriculture	1.04*** (0.16)	1.27*** (0.17)	1.12*** (0.16)	1.04*** (0.21)
Physical science	0.05 (0.13)	0.07 (0.13)	0.05 (0.12)	0.12 (0.15)
Engineering	1.13*** (0.13)	1.26*** (0.13)	1.06*** (0.12)	0.99*** (0.15)
Computer science	0.73*** (0.16)	0.92*** (0.16)	0.71*** (0.16)	0.80*** (0.20)
Intercept	−0.19 (0.13)	−0.44*** (0.14)	−0.38** (0.13)	−0.52* (.17)
Adjusted R^2	0.28	0.24	0.30	0.19

***$p < 0.001$; **$p < 0.01$; *$p < 0.05$.
Standard errors are shown in parentheses.
[a]The results are the same in terms of coefficient direction and level of significance when a simple summed industry involvement variable is used as the dependent variable in this regression.
[b]Biology is the reference category.

4.1. Regression results

Table 3 presents the nested unstandardized OLS regression analyses of the industry involvement scale on industry and government grants, with independent controls. The first model evaluates the independent direct effect of number of industry grants on industry involvement. The independent control variables all show significant effects as hypothesized, a pattern that persists in every model. Specifically, we find that men engage in higher levels of industrial involvement. Further, more experienced tenured faculty are involved with industry to a higher degree, as are faculty affiliated with multidisciplinary science centers. Disciplinary effects are as hypothesized: relative to biologists, those in agriculture, engineering, and computer science are all significantly more involved with industry. Physical scientists follow the same lower involvement pattern as biologists. The most important predictor of industrial involvement, net of the effects of the independent controls, is the number of industry grants. Those with more industry grants have significantly higher levels of industry involvement than those without such funding.

The second model evaluates the independent direct effect of number of government grants on industrial involvement, excluding the number of industry grants from the equation. The pattern, magnitude and significance of the effects of the independent controls remain similar. The number of government grants is also a significant and important indicator of industrial involvement. Note, however, the loss of fit between model 1 and model 2: the industrial grants model performs better in explaining variance (adjusted $R^2 = 0.28$) than the government grants model (adjusted $R^2 = 0.24$).

The last column of Table 3 presents results for a subsample that includes only those ($n = 1004$) who have government grants but no industry grants. This has the effect of developing a somewhat less complex indicator of the effects of government grants (i.e. excluding the 12% who have industry grants removes potentially strong joint effects). As the table shows, the number of government grants and contracts does seem to have some impact on industrial activity and the fact that there are tenure controls indicates that this is perhaps not entirely a function of overall research productivity. The relationship of Total Government Grants and Contracts to the industrial involvement scale is significant ($p > 0.000$) with a beta of 0.20.[11] Interestingly, this represents a modest increase over the beta for the full model in col-

[11] Table 3 reports unstandardized coefficients; we discuss standardized beta coefficients for comparative purposes in this section.

umn 3 (beta = 0.16). This lends support to the idea that government grants make a significant and independent contribution to faculty researchers' industrial activities. Note, however, that this model explains the least amount of variance (adjusted $R^2 = 0.19$), suggesting that it is preferable to include those with industrial grants in the models.

We present the best fitting model (adjusted $R^2 = 0.30$) in column 3. In this full model, we include all researchers and control for numbers of both industry and government grants. The independent controls persist in their effects. The analysis shows that Total Industry Grants and Contracts is the best predictor of respondents' (beta = 0.26) values on the Industry Involvement Scale. Furthermore, Total Government Grants and Contracts is significant but the beta coefficient is smaller (beta = 0.16). It is not surprising that number of industry grants and number of government grants are related to industrial involvement, but the regression results suggest that the relationships are independent ones. They are not artifacts of other correlates such as discipline,[12] research center affiliation or tenure. Most important, grant support provides independent direct influences on industry involvement regardless of source.

5. Implications of empirical findings for hypotheses

The central research question for the paper is "what is the relationship, if any, of grants and contracts to academic researchers' propensity to work with industry?" Every stage of the results suggests strongly that industry grants and contracts are associated with academic researchers' industrial activity. The multiple regression analysis, using the industrial involvement scale as dependent variable, indicated a strong and significant relationship, even controlling for a variety of other independent variables. The full regression model (model 3) similarly shows that having government grants and contracts relates to industrial involvement, but that government grants explain less of the variance (in terms of the contribution to R^2) than does industry grants. Nevertheless, each source of grant provides independent direct effects on industrial involvement.

Let us briefly consider each of the specific hypotheses in terms of the empirical results:

H1. University researchers who have active grants and contracts will be more likely to work with industry.

Consistent with the findings for the central research question, this hypothesis is not disconfirmed.

H2. Among those university researchers who have active grants and contracts, those with industry grants will be more likely to work with industry than will researchers who only have government grants and contracts.

Similarly, this hypothesis cannot be disconfirmed from the evidence presented here.

6. Conclusions

The central conclusion of this paper is a straightforward one: that academic researchers who have research grants and contracts work more extensively with industry than those without grants or contracts. Furthermore, the few scientists who have industry contracts (12%) interact with industry to a greater degree than those who are exclusively funded by governments. Further, having more grants generally increases the level of industrial engagement. These effects appear to be independent and not entirely a function of seniority. While these results are perhaps not surprising, they are, in a way, reassuring. A great many companies and industrial consortia have invested research dollars in universities and it appears that these dollars have been well leveraged, increasing a wide range of university-industry interactions.

Understanding that grants and contracts tend to increase industrial involvement among university researchers is a general finding that includes with it several interesting caveats. The data show quite significant field effects with some disciplines being quite likely to work with industry and others showing virtually no industrial involvement. There are career stage effects with most of those actively engaged with industry being tenured and more senior researchers, perhaps indicating that tenure criteria provide limited reward for industrial involvement.[13]

There are important questions not addressed in this study. For example, what are the "portfolio effects" of various combinations of industry and university grants

[12] We ran the final model again with individual interaction terms for disciplinary affiliation by industrial involvement. We found no significant effects of any interaction term, and no improvement in model fit, suggesting that the disciplinary affiliation effects on industry involvement are direct.

[13] It is possible that tenure is confounded to some degree with grants acquisition. While academic departments and institutions vary considerably in the extent to which they include grants acquisitions as a tenure criterion, some do.

and what are the interaction effects between the two? Answering these questions requires an even larger sample than employed here. To what extent does magnitude of grants affect various types of industry involvement? Answering this question awaits the coding of data on the actual size of active grants. Most important, the study focuses on industrial involvement, not specifically on industrial effectiveness. While it is difficult to study effectiveness using aggregate data, it is possible at least to attend more fully to such outputs as patents and publications and the effects of industry grants on these. Finally, an important limitation is that this is a cross-sectional study. Among the several constraints imposed by this limitation is the inability to consider the cumulative effects of various funding types.

The implications of these results for policy are not clear-cut but suggestive. In the first place, companies investing in university research seem to be succeeding in commanding the attention of academic researchers, not always easy in the absence of research support. Indeed, the percentages of academic researchers involved to some degree or another in industrial relationships is noteworthy. Even discounting the most passive activities, such as sending along research requested, or the most traditional activities, such as placing students, the percentage engaged actively in collaborations for publication, patents and technology transfer is significant. Moreover, one can speculate that provision of grants and contracts seeds this activity even among those who do not have active grants and contracts. The very idea that industry is a possible source of research support is not one that would have occurred to many academics 20 years ago.

An issue for government policy makers, and one not really answered here, are the complementarities between industrially-sponsored research, research with industry-centered foci but more traditional funding sources, and more traditional research and technical activities. If university researchers are, indeed, responsive to fitting their research agendas to industrial agendas, what of consequence is lost? One of the most common alleged losses is a focus on education, but our companion research (Lin and Bozeman, 2006) seems to suggest these impacts have been widely exaggerated and, indeed, that there exist many salutary effects of industrial ties on education. However, what about undirected or basic research? There seems relatively little need for concern on this account as well. The data show vast differences in the degree of industrial involvement among the disciplines, with the agriculture, engineering and computer sciences fields leading the way. There are much lower rates of industrial interaction among the disciplines traditionally associated with basic research, such as physics and chemistry, and among math respondents, there is almost no industrial interaction. If there is a concern that industry will "take over" the academic research agenda, the concern at this point should be focused on engineering. However, many of the policies of the late 1970s and early 1980s, policies such as establishing the NSF Engineering Research Centers, were aimed directly at making engineering more responsive to industry. Whether or not because of these programs, this responsiveness does seem to have occurred.

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